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Catalogue-based spatio-temporal analysis and evaluation of seismic scenarios in the Talysh zone (Azerbaijan)

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In this paper, we simulate ground motion shaking of the Talysh zone based on the hybrid stochastic-deterministic approach using catalogue-based spatiotemporal analysis for 1970—2019 from the various local and international sources and the fault source pattern. Data for a homogenous and reliable catalogue are obtained from the International Seismological Center (ISC), European Mediterranean Seismological Center, National Earthquake Information Center, and Republican Center of Seismological Survey at the Azerbaijan National Academy of Science. To evaluate the ground shaking and to characterize its spatial variability, an intensity map was plotted depending on the selected seven active faults and lineaments tracing in the Talysh zone, considering the location, size and length of faults, using empirical relations between magnitude and intensity. The mapping results are presented in terms of intensity distribution. The plotted map shows that shakings with an intensity of VII are observed mainly in the central and western parts of the zone and are predicted to be the highest in the study area. The ground shaking with an intensity VI covers most of the Talysh zone. The magnitude computation results show that a maximum earthquake with M_w=6.2 can be generated by the West Caspian fault.

This study applied various seismic input parameters and different approaches to give the basic information to evaluate the range of intensity distribution in seismic scenarios. The results will contribute to implementing more solid analyses for advancing earthquake countermeasure plans and seismic hazard analysis.

Key words: Talysh zone, Caspian basin, earthquake, seismic activity, fault length, focal mechanism, seismic hazard.

Introduction. The territory of Azerbaijan is one of the most seismically active regions of the Caucasus. The entire territory is divided into the following seismically very active areas: Guba-Khachmaz, Eastern Caucasus, Kur depression, the eastern part of the Lesser Caucasus, Caspian Sea, and Talysh zone.

Talysh zone stretches to 38°54′N northern latitude and 48°35′E eastern longitude and spreads to the north through the Alborz mountains of Iran. The study area is located in the southernmost part of Azerbaijan at the border with Iran (Fig. 1). The total area covers 3960 km^2 [The State…, 2009; Heiss, 2010].

Geologically, the area is composed of several geologic formations ranging in time from the Cretaceous to Miocene periods, and lithologically, it is composed of shale, fine sandstone, and fragments of various fully crystalline grains of picritesand different types of clays. The Caspian coastal part of Talysh zone is characterized by the presence of carbonate, shaly clays and sandstones.

The seismicity of the Talysh zone, which is also one of the touristic regions of Azerbaijan, is characterized by a complex pattern of seis-

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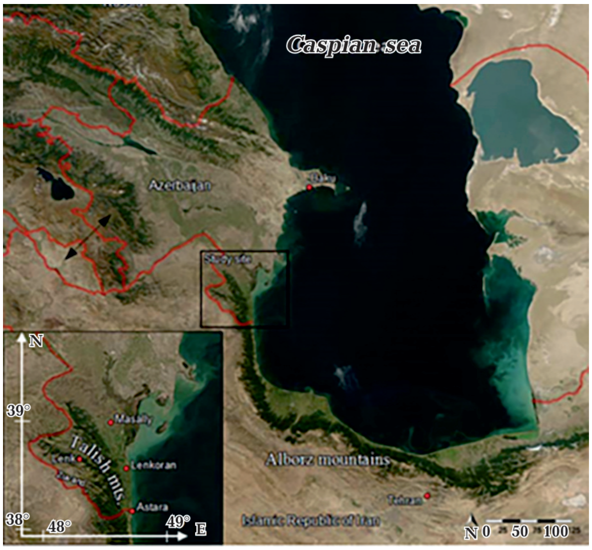

Fig. 1. Satellite image of Talysh zone in quadrangle on the Azerbaijan territory [NASA, 2004; Heiss, 2010].

mic events. Therefore, to study the current seismic regime and situation of the zone, it is necessary to perform earthquake hazard research of the territory.

In the present study, earthquake hazard was evaluated using elements of stochastic-deterministic seismic hazard analysis. Deterministic seismic hazard analysis (DSHA) is believed to be a wide contribution to earthquake hazard assessment [Krinitzsky, 1995; Romeo, Prestininzi, 2000; Klügel, 2008; Mourabit et al., 2014; Puri, Jain, 2016; Babayev et al., 2019; Afsari et al., 2022].

This research required detailed knowledge about the parameters of the active faults and lineaments and associated seismicity of the area. Analysis of lineaments and faults helps in understanding the seismotectonic activity of the studied area. A literature review, study of the existing associated maps, ground reconnaissance study, and analysis of the earthquake catalogs of local and international sources were used in this study to identify the area's seismic generation.

The purpose of the current research is to assess the recent seismic situation of the Talysh zone through analysis of the macroseismic data in catalogue, to plot the inten-

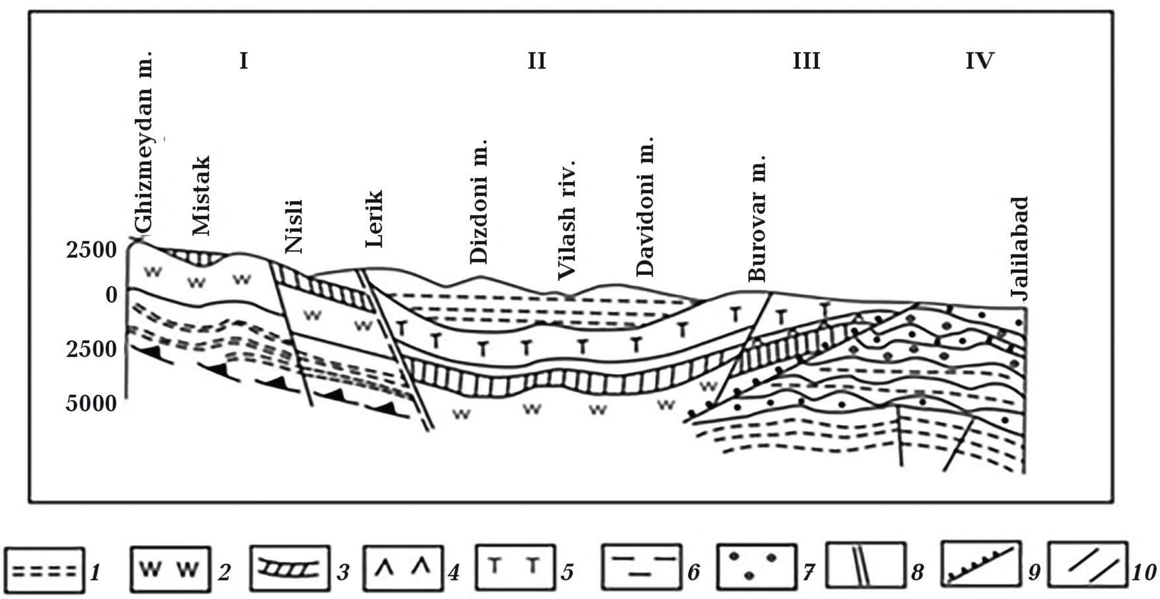

Fig. 2. Gizyurdu-profile on the Jalilabad line. Scale: horizontal 1:500 000 vertical 1:250 000: *1* — Paleocene—Lower Eocene (Astara strata) limestone and tufogen complex, *2* — Middle Eocene (Cosmolyon strata) volcanogens, *3* —Middle Eocene (Nisli strata) tuffs and tuffites, *4* — Upper Eocene (Peshtasar strata) volcanogenic derivatives, *5* — Upper Eocene (Arkivan strata) sedimentary tufogen sediments, *6* — Oligocene—Bottom Miocene (Maikop strata) clayey-sandy sediments, *7* — Middle-Upper Miocene-alternation of clays and sands, *8* — Avash-Hyrkan-seismogenic fault, *9* — regional Erkivan uplift, *10* — other landslides.

sity map by considering the sources of seismic activity, such as faults and lineaments, in order to determine the maximum credible earthquake.

Tectonics and geological setting. The main tectonic regime of the Talysh zone is very complex and is dominated by a structures and dynamics. Talysh folded megazone is located on the northern side of the Lesser Caucasus-Elbursian folded system, separated from the structures of the Lesser Caucasus by the transverse Lower Araz trough. Within Azerbaijan, the megazone is represented by its northeastern wing, and the southwestern wing is a part of the Garadagh zone of Northern Iran, where the volcanogenic-sedimentary formations of the Paleogene are overlapped by the Mio-Pliocene volcanogenic complexes of the Savalan volcano [Khain, Alizade, 2005].

The Erkivan uplift (Fig. 2) is a seismically active fault, along which deposits of tufogenic origin of the Burovar anticline zone underlie the tectonic cover of the Miocene clay complex on the southern flank of the Jalilabad syncline zone. A single Talysh uplift is bordered in the west by the Lower Araz and in the east by the South Caspian depressions [Rustamov, 2019].

One of the other seismogenic faults is Avash-Hyrkan, a giant fault discovered in the Talysh zone. Its vertical amplitude ranges from 5—7 km and is directed to the north at 60—70° [Khain, Alizade, 2005].

The main mass of the rock is fully crystalline and consists of clinopyroxene grains [Azizbekov et al., 1972]. The composition of the megazone has sixty structural floors corresponding to the precollisional (Cretaceous-Eocene) and collisional (Oligocene-Miocene) periods of development of the region:Cretaceous, with carbonate formation; Paleocene, with tuff-sedimentary formation; Eocene, with volcanogenic alkaline-basalt and intrusive subalkaline-ultramafic formations, and for collisional — two floors: Oligocene—Early Miocene, with terrigenous marine molasse formation and Late Miocene—Pliocene, with continental molasse formation [Khain et al., 2005].

According to the geomorphology of the zone, three high-altitude zones are allocated on the territory of the mountainous Talysh [Khain et al., 2005]:

– Middle mountainous zone (absolute elevation of relief 900—2400 m);

– Low mountainous zone (absolute elevation of the relief 400—900 m);

– Foothill sloping plain zone (absolute elevation of relief 200—400 m).

In the Talysh zone, the sedimentary formations (Fig. 3) of the Oligocene transgressively overlie the Eocene volcanic-sedimentary complex. They contribute to the structure of the Lerik-Yardymly, Buravar, and Jalilabad zones. According to [Alizadeh et al., 2008], the lower parts of Oligocene (Tilakend and Pirembel suites) are represented by carbonate and shaly clays and sandstone with Nummulites, Globigerina officinalis, Rotalia Mexicana Nutt. The Upper Oligocene deposits (the Shishnavar suite) are represented by thin layered shaly clays alternating with sandstone with a powder coating of jarosite. Between the basins of the Vilashchay and Bolgarchay rivers, an increased presence of foraminiferas in rocks, small fragments of bones and scales were observed. The total thickness of these deposits varies from 670 to 2400 m [Bagmanov, 1963; Azizbekov et al., 1972; Khalilov, 1978; Alizadeh et al., 2008].

Within the Talysh mountains, Paleogene deposits are widely represented in the Astara zone's structure and appear in the Middle and Upper Eocene carbonate facies. Neogene deposits are represented by Upper Paleocene-Miocene pyroclasts of porphyritic trachyandesite-basalts and leucite trachyandesites (Peshtasar suite — 900—1000 m), which change above to tuffs, tuff-sandstone, tuff-siltstones and shales (Arkivan suite — up to 1000 m) in the Lerik-Yardymly and Buravar zones, while Masally and western part of Lankaranare characterizing with Holocene (contemporary) deposits (Fig. 4) [Azizbekov et al., 1972].

Seismicity. Talysh zone is one of the seismogenic zones of Azerbaijan. The Talysh zone, the southeastern extension of the Lesser Caucasus, is characterized by fairly high seismic activity. The depth of weak

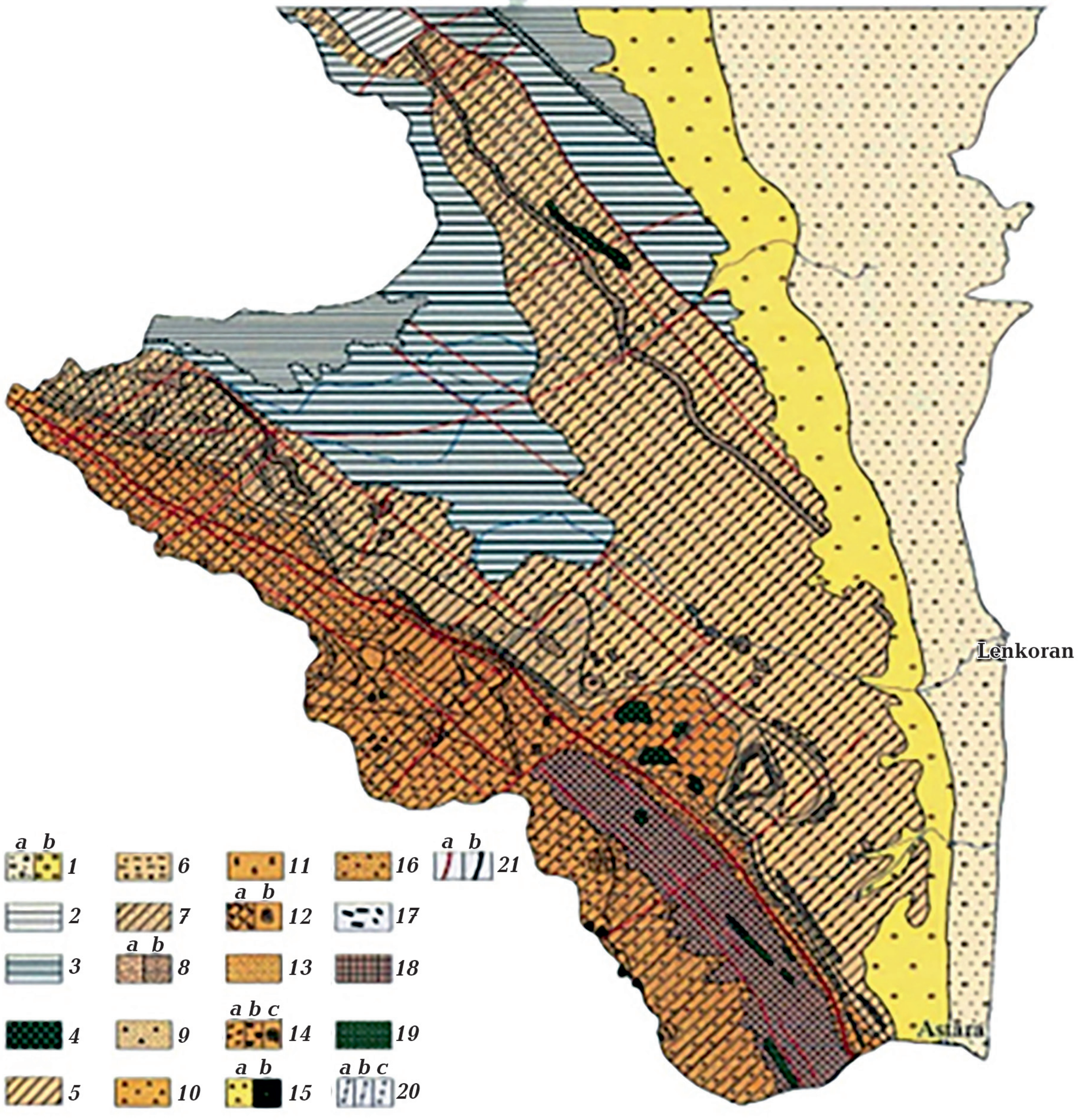

Fig. 3. Structural-formation map of Talysh zone: *1* — Quaternary sediments (*a* — Holocene sediments, *b* — Pleistocene sediments); *2* — Upper Cretaceous sediments(Middle and Upper Pliocene); *3* — Lower Cretaceous sediments (Oligocene and Upper Miocene); *4* — subalkaline ultrabasic formation (Upper Eocene—Lower Oligocene); *Eocene trachybasalt-trachyandezibasalt-phonolite formation*: *5* — trachybasalt-trachyandezibasalt (latite)-phonolite complex (Upper Eocene); *6* — layer of tuffaceous sandstones; *7* — leucitic phonolite layer; *8* — subalkaline trachybasalts, layer of trachydolerites (*a* — lava, pyroclastic facies, *b* — subvolcanic facies); *9* — plagioporphyric trachyandezibasalt layer; *10* — absarocite-shoshonite-alkaline basalt complex (Lower-Middle Eocene); *11* — layer of sedimentary sandstones with flysch tuff; *12* — alkaline basalts layer (*a* — lava, pyroclastic facies, *b* — subvolcanic facies); *13* — layer of tuffaceous sedimentary sandstones; *14* — layer of absarocites and leucite tephrites (*a* — lava, pyroclastic facies, *b* — subvolcanic facies, b_1 — subvolcanic gabbro-techenites); *15* — layer of trachybasalts; *16* — layer of trachyandezibasalt tuffs; *17* — dikes of trachybasalt, leucite tephrites and absarocites; *18* — layer of flysch-tuffaceous sandstones (Paleocene); *19* — limestone layer (Upper Cretaceous); *20* — fractures bordering structural floors (*a* — Eocene age, *b* — Oligocene age, *c* — Miocene age); *21* — magma-carrying and emplacement faults (*a* — connecting, *b* — separating).

earthquakes reaches 25—30 km. Alongside the Avash-Hyrkan uplift, strong earthquakes (Fig. 5) periodically occurred on the uplift zones: 24.05.1861 (*M*=6.2), 22.03.1879

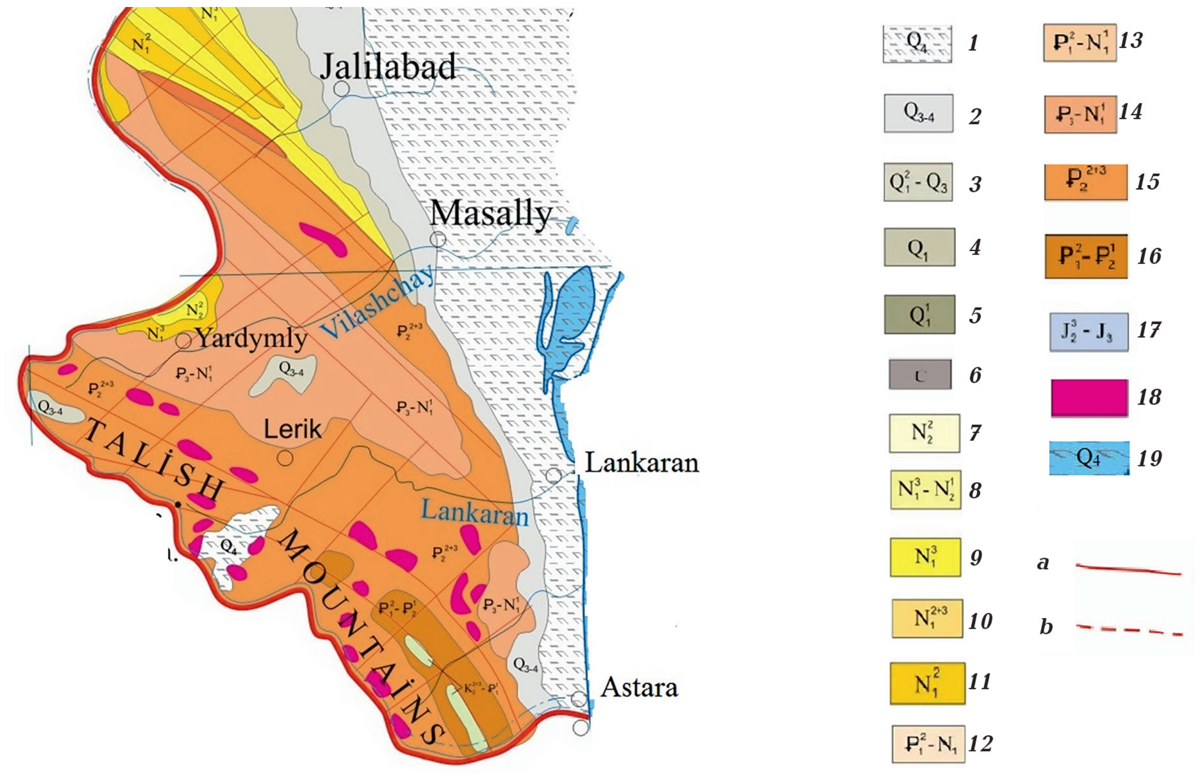

Fig. 4. Geology map of Talysh zone: *1* — Holocene (contemporary deposits), *2* — Upper Pleistocene and Holocene, *3* — Pleistocene, inseparated, *4* — Eopleistocene and Lower Pleistocene, *5* — Eopleistocene, *6* — Carboniferous System, *7* — Upper Pliocene, *8* — Upper Miocene and Lower Pliocene, *9* — Upper Miocene, *10* — Middle and Upper Miocene, *11* — Middle Miocene, *12* — Upper Paleocene — Miocene, *13* — Upper Paleocene — Lower Miocene, *14* — Oligocene and Lower Miocene, *15* — Middle and Upper Eocene, *16* — Paleocene and Lower Eocene, *17* — upper part of Middle Jurassic (Callovian) and Upper Jurassic, *18* — Paleogene, *19* — Holocene (adjacent water area of the Caspian Sea: *a* — authentic, *b* — supposed).

(M_l=6.5), 04.12.1910 (M_l=5.4), 19.02.1924 (M_l=6.6), 12.04.1983 (M=4.6), 25.09.1984 (M=4.7), 27.01.1986 (M=5.4) [Kondorskaya, Shebalin, 1977; Sultanova, 1986; Babayev, Agayeva, 2021]. They are felt in the cities of Lerik, Lankaran, and Yardimli. This uplift is located between the auxiliary syncline and the watershed anticline zones (see Fig. 2).

In this research, it was necessary to prepare homogenous and reliable earthquake catalog to combine the available data on seismic events from various sources. This catalog contains all the available historical and instrumental earthquakes from many different sources, including local data. In this study, the historical data are compiled from published data [Kondorskaya, Shebalin, 1977; Agamirzoev, 1979; Sultanova, 1986; Telesca et al., 2017; Babayev, Agayeva, 2021; Yetirmishli et al., 2022].These data are also compiled from many different sources: International Seismological Center (ISC) online bulletin (http://

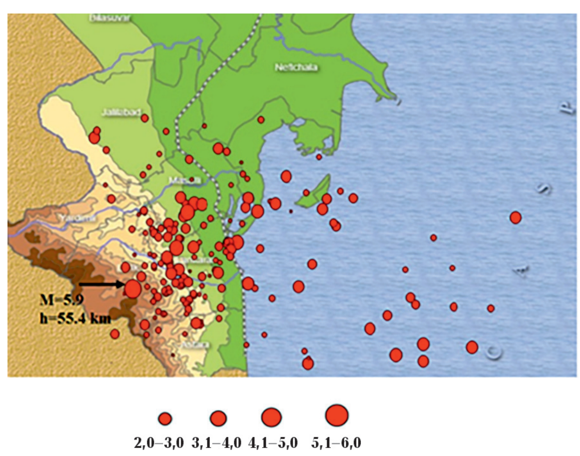

Fig. 5. Distribution of earthquakes in Talysh for 1970—2019.

www. isc.ac.uk/), IRIS, European Mediterranean Seismological Center (EMSC) (http://www.emsc-csem.org), National Earthquake Information Center (NEIC) online bulletin (http://earthquake.usgs.gov/earthquakes/), Republican Center of Seismic Survey of Azerbaijan.

A strong earthquake in Lerik (M=5.9) (see Fig. 5, with arrow pointer) with a h=55 km depth, occurred on 05.07.1998. Many residential buildings were destroyed and damaged.

Applying the data from the compiled homogeneous catalogue, the earthquake depths were analyzed and respective depth distribution map of the Talysh zone was plotted for the period 1970—2019 (Fig. 6).

According to Fig. 6, it can be seen that earthquakes with a higher depth are concentrated mainly in the central part of the Talysh zone — Lankaran, Lerik, and Masalli (up to 70 km) and in the southwestern part of the Caspian Sea (up to 55 km).

Also, to understand the annual quantitative seismic background of the Talysh zone, a dependency graph of the number of seismic events over time was plotted (Fig. 7).

Based on the graph of the distribution of earthquake numbers over the years, it can be indicated that during the studied period, the largest number of earthquakes occurred in 2014 (33 events) with a magnitude range of 2.5<M<4.5.

Fig. 8 illustrates the fault plane solutions of relatively large earthquakes which were

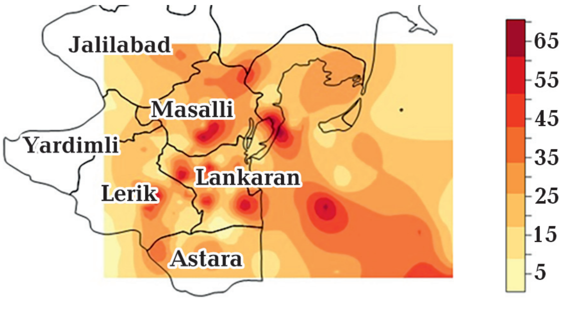

Fig. 6. Earthquake depth distribution map.

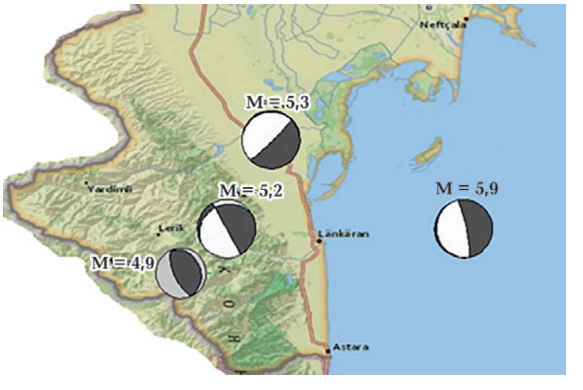

Fig. 8. Map of focal mechanisms of comparatively stronger earthquakes in the territory of Talysh.

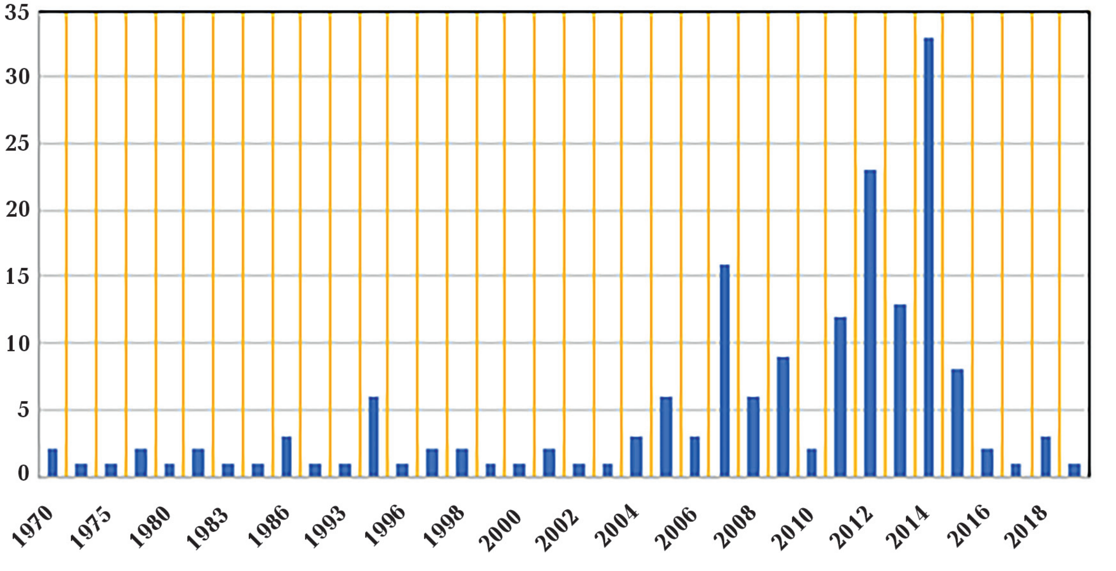

Fig. 7. The graph of the distribution of the number of earthquakes by year. The vertical axis shows the number of earthquakes.

included in different seismic sources. Focal mechanism data were obtained from the Global Centroid-Moment-Tensor (CMT) Project website (http://www.globalcmt.org) [Babayev et al., 2021]. A map of the focal mechanisms of strong earthquakes was plotted using the ArcGIS program. Most of the studied area is subject to compression, while strike-slip faults were noted in the area of Lerik and Yardymly.

Three main types of focal mechanism have been identified for the Talysh zone: thrust fault (36 %), strike-slip faults (34 %) and normal faults (30 %) [Kazimova, Kazimov, 2020].

According to the map, the focal mechanism of an earthquake with a larger magnitude (M=5.9) is concentrated in the adjacent water area of the Caspian Sea, while the focal mechanism of a magnitude 4.9 earthquake is located in a zone of higher intensity at VII.

Methodology. Seismic hazard analysis has been carried out in this study using a stochastic-deterministic approach [Zhuang et al., 2011; Hainzl et al., 2013]. Deterministic seismic hazard assessment allows identifying the maximum credible earthquake that will affect a site. This earthquake type is the largest earthquake that appears possible along a recognized fault under the presently known tectonic activity [Tibaldi et al., 2020].

In the present study, a seismotectonic map in terms of intensity value has been prepared using Surfer version 16.0 package. The length of each fault and lineament (Fig. 9) was calculated by applying ArcGIS 10.7 software [ESRI, 2018]. Seismotectonic details of the study area have been collected in about a 100 km radius around the Talysh zone. They include faults and lineaments with length. The rupture length of the faults and lineaments was taken as one-third of the fault length [Babayev et al., 2020] according to [Baghbani et al., 2016].

The magnitude of the maximum earthquake of the seismogenic structure was determined by fault length based on the correlation ratio of Shebalin [Kuliyev, 1977; Babayev, 2004]:

$$1.4 + 1.8\,\mathrm{Lg}\,h \le M \le 2\,\mathrm{Lg}\,L + 2.0\,, \qquad (1)$$

where h — depth (km), M — magnitude, L — length of the seismogenic structure (km).

Calculations of the maximum magnitude for highly seismogenic zones should be made according to the right limit (1) to estimate the magnitude for earthquakes located in the shallow and intermediate depth of seismic sources [Kuliyev, 1977; Babayev, 2004].

The intensity of the seismic effect of the maximum earthquake of the Talyshseismogenic zone was calculated using the macroseismic field equation. The macroseismic field equation for mountainous regions in the Talysh zone is given in (2) [Kuliyev, 1977; Babayev, 2004].

$$J_0 = 1.5M - 3.3\,\mathrm{Lg}\,h + 2.7\,. \qquad (2)$$

In total, there were seven fault and lineament parts in the study area. The length of the faults and lineaments in the study area and the estimated magnitude and intensity based on empirical relations (1, 2) are shown in Table.

Table. Computed intensity and maximum magnitude of the earthquake effect of the seismogenic zone

Number	L, km	M	h, km	J_0
1	72	5,7	45	6
2	70	5,7	55	5
3	20	4,6	43	4
4	49	5,4	19	7
5	30	5,0	10	7
6	42	5,2	28	6
7	120	6,2	46	6

As a result of the application of the respective equations (1) and (2), it was calculated that the Talysh fault is capable of generating earthquakes with a maximum magnitude M_{max}=5.7 and intensity J_0=6.0; the Pre-Talysh fault with a maximum magnitude M_{max}=5.7 and intensity J_0=5.0; the Astara fault with a maximum magnitude M_{max}=4.6, intensity J_0=4.0; the Yardymli fault — M_{max}=5.4, intensity J_0=7.0; the Bilasuvar fault — M_{max}=5.0, intensity J_0=7.0; the Akhvai fault — M_{max}=5.2, intensity J_0=6.0 and the West Caspian fault

Fig. 9. Fault tectonics of the studied zone. Faults: 1—1— Talysh, 2—2 — Pre Talysh, 3—3 — Astara, 4—4 — Yardymli, 5—5 — Bilasuvar, 6—6 — Akhvay, 7—7 — West Caspian.

generates earthquakes with a maximum magnitude $M_{\max}$=6.2, intensity J_0=6.0. The expected maximum intensity shakings on the Talysh zone were mapped in Fig. 10.

Fig. 10 indicates that the simulated ground motion shaking has large variability. The map shows that shakings with an intensity of VII are observed mainly in the territory of the city of Lerik, stretching from northwest to southeast and in the northwestern part of the zone, in the Jalilabad and Yardimli regions. Ground shaking with an intensity VI cover (higher scattering) almost 70 % of the territory of the Talysh zone. In the research field, there is also shaking intensity with V, which falls on the western part of the city of Lankaran and the eastern part of the city of Yardymly. Based on the plotted intensity map, the northern part of

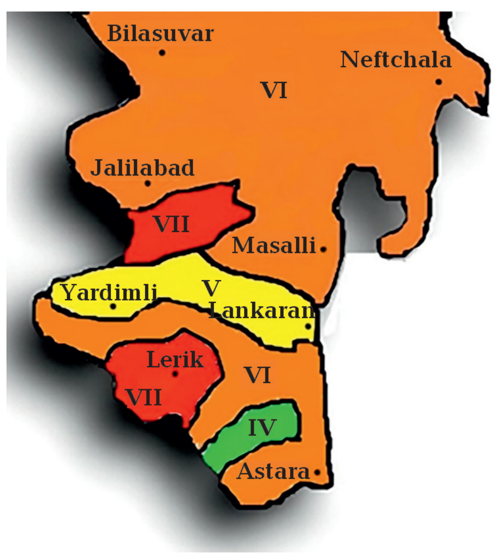

Fig. 10. Intensity map of expected maximum shakings of the Talysh zone.

the city of Astara is characterized by a shaking intensity of IV.

The seismotectonic source mapping results show that the Talysh zone is a moderately active seismic region on a wider scale with some spot areas of intensity of VII. The seismic hazard of the Talysh zone is mainly caused by earthquakes along the Talysh and Pre-Talysh faults.

Conclusion. The main aim of this study was to highlight the level of seismic activity in the Talysh zone of Azerbaijan, which lies in the country's vital strategic and geographic location. Two methods have been applied for the current research: catalogue-based spatiotemporal analysis and evaluation of seismic scenarios through the prediction of ground motion in intensity values due to the fault patterns, adopting that as a seismotectonic map. Regional and seismological studies for the Talysh zone are performed by considering faults, lineaments existing in a radius of 100 km, and past earthquake events in the area. Catalogue-based spatiotemporal analysis was carried out to identify the earthquake depth distribution and analyze the trends of the focal mechanism of the strong earthquakes that occurred all over the Talysh zone. The intensity map of the studied zone characterizing seismotectonic activity illustrates an unusual nature. There is the integration of four, five and seven zones in the total six intensity zone, which is 70—75 % of the entire territory. It should be noted that based on the intensity data, it can be argued that for the Talysh zone, the highest hazard is posed by seismic events that occurred on the territory of Lerik and the Jalilabad-Masally zone.

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Просторово-часовий аналіз каталогів землетрусів та оцінювання сейсмічних сценаріїв у Талиській зоні (Азербайджан)

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У статті струс ґрунту Талиської зони змодельовано на підставі гібридного стохастично-детермінованого підходу з використанням просторово-часового аналізу каталогів землетрусів різних місцевих і міжнародних джерел за період 1970—2019 рр., а також комплексу даних щодо розломних структур. Дані для єдиного зведеного каталогу отримані з Міжнародного сейсмологічного центру (ISC), Європейського середземноморського сейсмологічного центру, Національного інформаційного центру про землетруси та Республіканського центру Сейсмологічної служби Національної академії наук Азербайджану. Для оцінювання струшування ґрунту та характеристики його просторового розподілу побудовано карту сейсмічної інтенсивності за даними обраних семи активних розломів і лінеаментів, що простежуються у Талиській зоні, з урахуванням їх розташування, розміру та протяжності і використанням емпіричних співвідношень між магнітудою та інтенсивністю. За міру оцінювання сценаріїв землетрусів обрано сейсмічну інтенсивність. Побудована карта показує, що струшування ґрунту з інтенсивністю VII спостерігаються переважно в центральній та західній частинах зони і, за прогнозами, є найвищими в досліджуваному районі. Струшування ґрунту з інтенсивністю VI охоплює більшу частину Талиської зони. Згідно з результатами розрахунку максимально можливої магнітуди, максимальний землетрус із магнітудою M_w=6,2 може бути викликаний активністю Західнокаспійського розлому. Дослідження виконано із застосуванням різних базових вихідних сейсмічних параметрів та підходів з метою оцінювання розподілу інтенсивності за сейсмічними сценаріями. Отримані результати сприятимуть більш детальному аналізу для розробки планів запобігання наслідків землетрусів та аналізу сейсмічної небезпеки.

Ключові слова: Талиська зона, Каспійський басейн, землетрус, сейсмічна активність, довжина розлому, механізм вогнища, сейсмічна небезпека.