FEATURES OF THE DISTRIBUTION OF SWARM SEISMIC EVENTS AND EARTHQUAKES WITH M≥4 IN THE SHAMAKHI-ISMAYILLI ZONE IN 2003-2019

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Introduction

The state of the geological environment is associated with its complex structural-tectonic structure. There is an accumulation of elastic energy in large structural elements of the medium and its periodic discharge through earthquakes. Energy is discharged into the surrounding space as a result of the destruction of the material of the earth's crust, i.e., a strong event, in those places where tectonic stresses reach the limit. It is often followed by aftershocks - aftershocks, which are a reflection of the relaxation processes of the medium in the region of the source of a strong earthquake [Arefyev, 2002]. However, the discharge of geodynamic stresses can also occur without the occurrence of the main shock with a sudden significant change in the stress state of the environment, through a swarm of earthquakes. This is a special type of manifestation of seismic activity, when a large number of earthquakes occur in a limited area in a short time. In contrast to earthquakes with aftershocks, when the remaining energy is released after the main rupture, the main shock, swarm sequences do not always have a main event and a characteristic decay of event energy in time (Slavina et al., 2010). They occur both in areas where strong earthquakes have occurred, and in areas where there have been no strong earthquakes. Earthquake swarms are known in various regions of Azerbaijan: in the Caspian Sea in 2000, in Gandja zone in 2001, in Sheki zone in 2004, in the Kura depression in 2011, in the north-west of the republic in Gazakh zone in 2014.

Formulation of the goal

The opening of new digital stations made it possible to register weak seismicity and obtain sufficiently complete seismological material. The presence of such material served as a database for studying the dynamics of seismic activity in the Shamakhi-Ismayilli zone, which is one of the seismically active zones of Azerbaijan.

Observations show that seismic processes are occurring in the Shamakhi-Ismayilli zone at the present stage, including relatively strong earthquakes with Ml≥4 (felt in the epicenter with an intensity of 5-6 points), which are accompanied by numerous aftershocks. At the same time, this is an area of constant stress discharge. A large number of earthquakes occur here, including swarms of earthquakes. It is of interest to reveal the features of the distribution in space and time of the aftershock and swarm sequences of earthquakes, as well as to consider the stress state of the territory under consideration.

The discussion of the results

From the regional catalog of earthquakes for the period 2003-2019 a group of earthquakes with close values of the coordinates of epicenters, compact in area, was distinguished. The sampling was carried out for events with M≥2.5.

For each group of earthquakes, a graph of the distribution of events by magnitude versus time was plotted. The shape of the graph was used to check whether events belong to one or another type. As an example, the distribution graphs of the aftershocks of the earthquake on June 3, 2015 with M=4.6 (Fig. 1.a) and the swarm sequence in 2013 (Fig. 1.b) are given. As can be seen from the graphs, the aftershock sequence is characterized by a hyperbolic form of the attenuation of the energy of the seismic process (F.Omori), while for swarms, this regularity is not observed, they are characterized by a weak attenuation of the energy in time [Slavina, 2010]. To determine the preferential depth of hypocenters, the depth distributions of events were constructed for both swarms and aftershocks. As can be seen from Figure 1a in 2015, the main shock occurred at a depth of 4 km, then, after some deepening, the depths stabilized and varied within 5–15 km. The prevailing depths are 10 km. On Figure 1b for swarms for 2013, they vary within 5–20 km. There are no dominant depths. The same picture is observed for other swarms.

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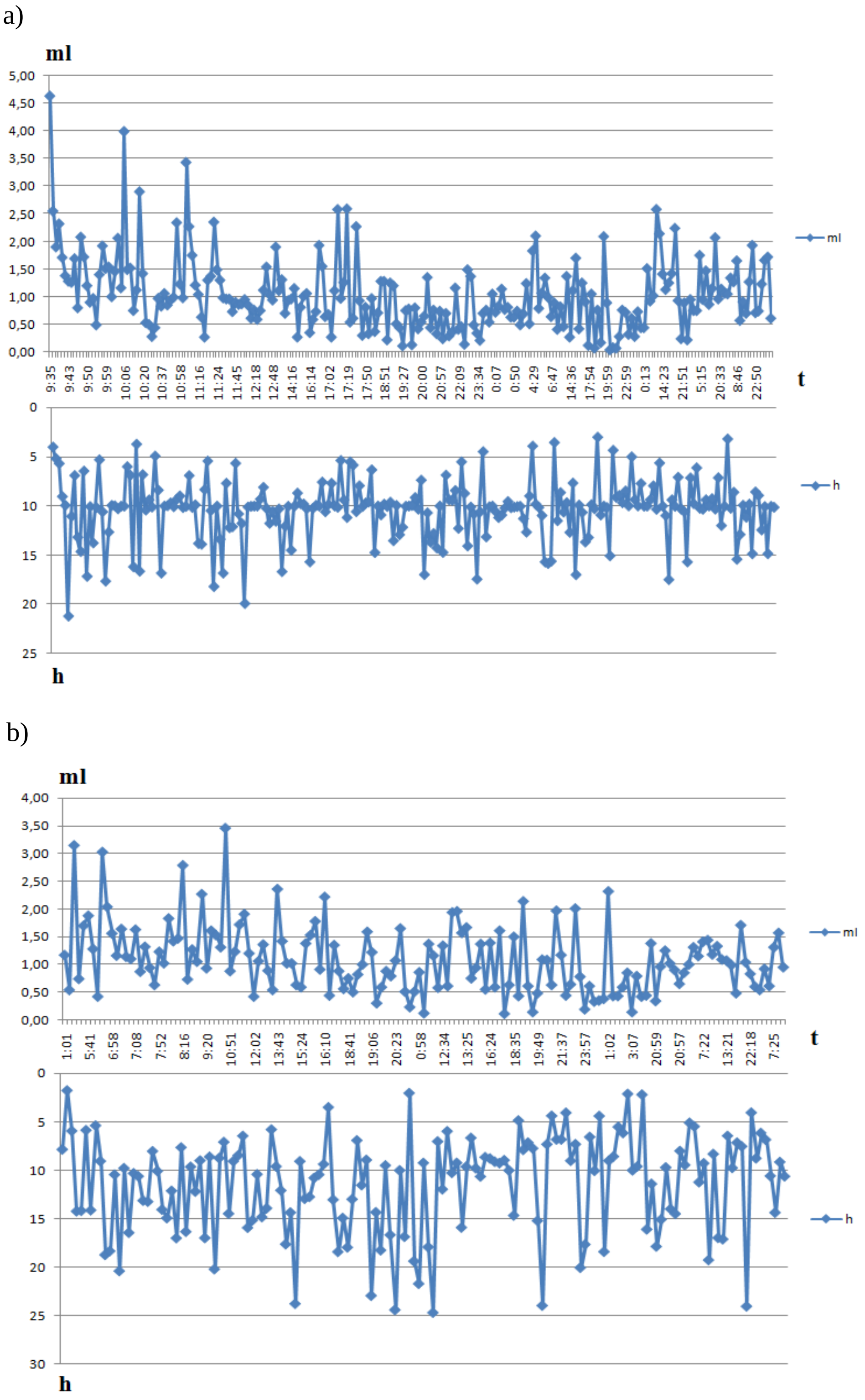


Figure 1. a, b Graphs of distribution of aftershocks of the earthquake on June 3, 2015 with M=4.6 (a) and the swarm sequence in 2013 with M_{max}=3.5 (b)

The catalogue of aftershocks and swarms of earthquakes is given in Tables 1 and 2. As can be seen from Table 1, for the period 2003-2019 7 earthquakes with a maximum magnitude M_{max}=5.3 occurred in the study area, which were accompanied by numerous aftershocks.

From the graph of the alternation of earthquakes with aftershocks in time (Fig. 2), it can be seen that for aftershock sequences there is a periodicity in their occurrence, they alternate in the southwest - northeast direction on separate structural blocks. For swarms, this regularity is not observed.

Table 1

Year	Date	Coordinate		D, km	Ml	N	The focal mechanisms of earthquakes
		φ	λ				
2007	23.08.2007	40.64 40.62	48.37 48.48	3 6	4.6 4.3	56	Strik -slip, normal fault
2008	19.12.2008	40.87	48.49	5	4.4	53	Reverse - thrust
2012	07.10.2012	40.70	48.35	41	5.3	95	Normal fault
2015	03.06.2015	40.92	48.57	4	4.6	377	Right lateral strike
2016	13.12.2016	40.80	48.41	8	4.5	23	Reverse – strike -slip
2018	01.01.2018	40.86	48.38	8	3.9	35	Normal fault
2019	05.02.2019	40.78	48.46	8	5.2	413	Right lateral strike

Table 2

Year	Date	Coordinate		D km	Ml	N	Continuation day	The focal mechanisms of earthquakes
		φ	λ					
2004	13.03.2004	40.59 40.72	48.46 48.52	15 22	3.5 3.4	21	2	
2011	07.10.2011	40.61	48.56	10	2.5	23	1	
2013	1-5.08.2013	40.73	48.64	7	3.5	100	5	Normal fault
2016	19.07.2016	40.74 40.71	48.68 40.70	10 8	3.2 3.0	36	2	Strik - slip
2018	18-20.09.2018	40.62 40.61	48.78 48.76	5 7	3.4 3.9	57	3	Normal fault Right lateral strike

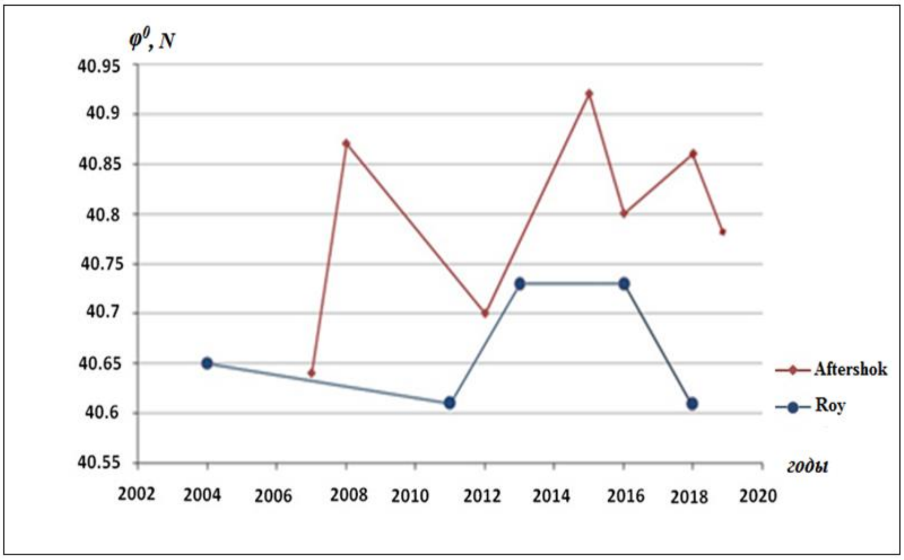


Figure 2. Graph of the distribution of aftershocks and swarms by latitude and by years.

An analysis of the spatial distribution of aftershocks from M≥4 earthquakes shows that they are located in the central part of the Shamakhi-Ismayilli zone (Fig. 3a, b). Peculiarities of their concentration on individual geotectonic structures bounded by longitudinal faults have been discovered. It should be noted that they are mainly associated with transverse structural elements, which is in good agreement with fault tectonics according to (Kengerli et al., 2018). The source mechanisms of the considered seismic events (Yetirmishli et al., 2017) also confirm the advantage of fault-shift movements that control seismic activity, which is typical for transverse structures. Of the considered earthquakes with Ml≥4, uplift faults in the sources were obtained only for two (Table 1).

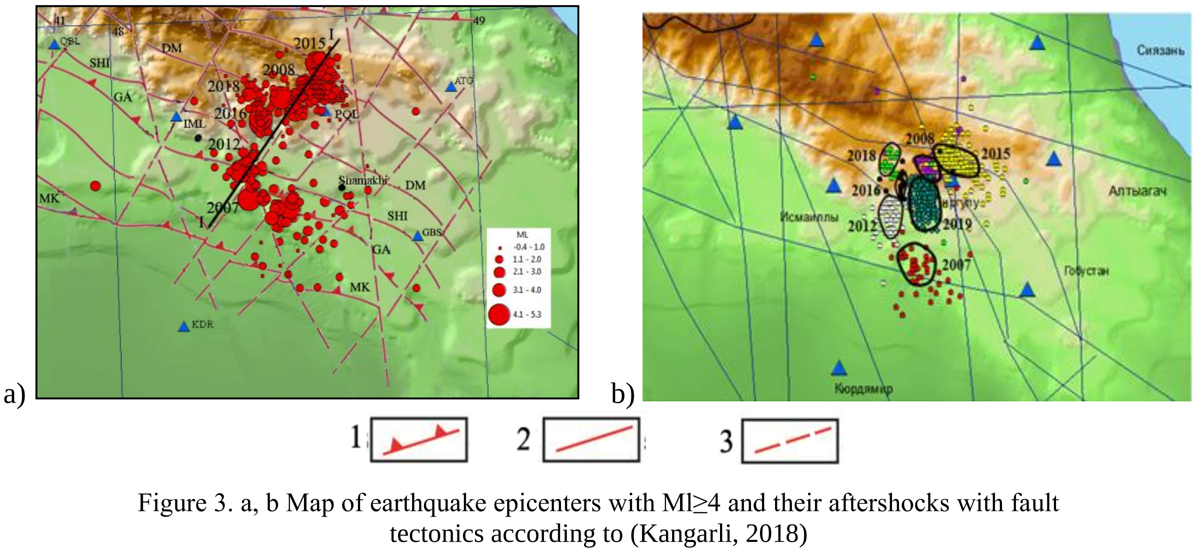


Figure 3. a, b Map of earthquake epicenters with Ml≥4 and their aftershocks with fault tectonics according to (Kangarli, 2018)

1 - Longitudinal deep faults at the boundaries of tectonic blocks: MK - Middle-Kura, GA - Ganikh-Ayrichay-Alyat; 2 - longitudinal deep faults: SHI - Shambul-Ismayilli, DM - Dashaghil-Mudrese, ZG-Zanghi-Gozluchay; 3 - faults and ruptures of the anti-Caucasian strike.

Thus, the field of earthquakes with aftershocks is located at the intersection of faults of general Caucasian strike: Zanghi-Gozluchay, Dashaghil-Mudrese, Shambul-Ismayilli, Ganikh-Ayrichay-Alyat with transverse faults of north-eastern and submeridional orientation [Shikhalibeyli, 1996; Kangarli et al., 2018].

Earthquake swarms with a maximum magnitude of 3.9 were also recorded in the Shamakhi-Ismayilli zone (Table 2). The duration of swarms varies from 1 to 5 days. The swarm field of earthquakes is located compactly in the form of an ellipse with a long SW-NE trending axis (Fig. 4 a, b). It is located in the eastern part of the Shamakhi-Ismayilli zone. The main concentration of swarm epicenters is observed southeast of

Pirgulu station. They are related to the events that took place in 2013 and 2016. In the first case, 100 earthquakes occurred within 5 days, with the highest magnitude Ml_{max}=3.5, in the second case, 36 events were registered in two days with Ml_{max}=3.1.

In tectonic terms, the swarm field of 2013 and 2016 is located at a complex intersection point of faults of general Caucasian strike with transverse faults of north-western and submeridional orientation (or at the intersection point of the Dashaghil-Mudrese uplift-thrust with the Pirsaatchay north-western fault-shift fault) (Kengerli et al., 2018). Swarm field 2004 and 2011 located somewhat to the south, at the intersection of the Ganikh-Ayrichay-Alyat and West Caspian faults. The location of the swarm field in the anti-Caucasian direction also confirms the presence of a transverse structure in this zone, which controls the location of earthquake swarms.

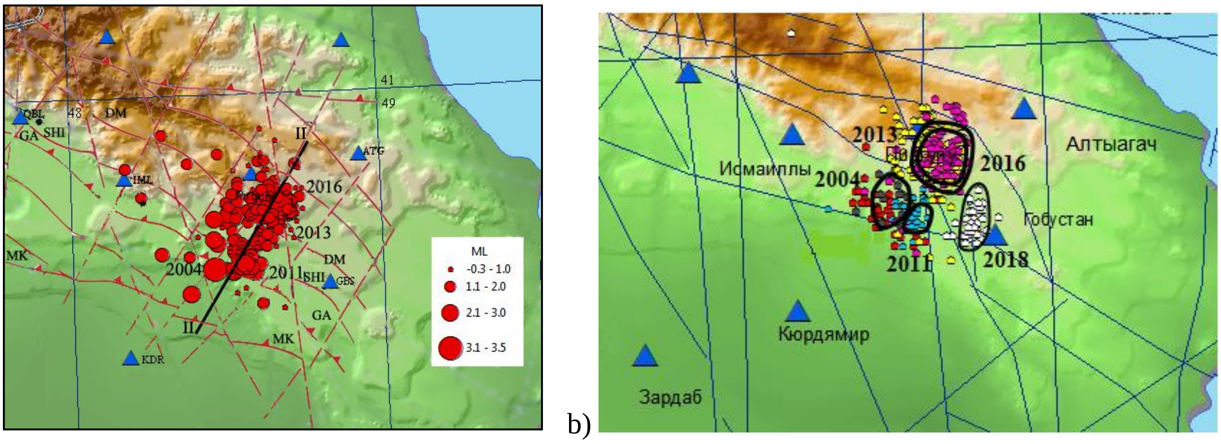
a) b)


Figure 4 a, b Map of the epicenters of swarm sequences in the Shamakhi-Ismayilli zone in 2003-2019 with fault tectonics by [Kangarli]

It can be concluded from the above that earthquakes with aftershocks and swarm sequences of earthquakes form two blocks with different levels of seismic activity (Fig. 5).

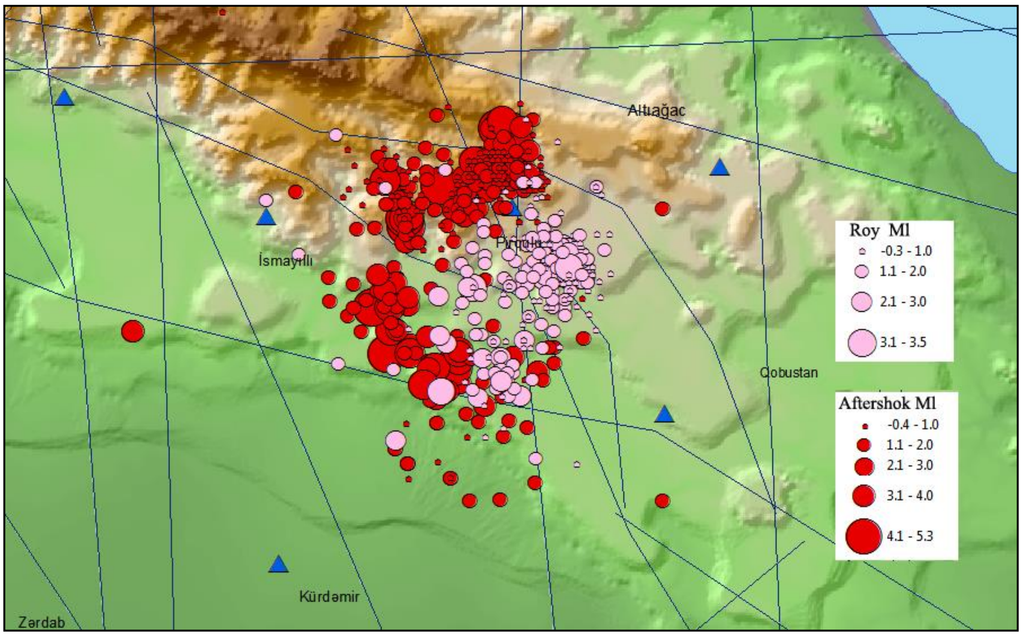


Figure 5. Map of the epicenters of swarm and aftershock sequences in the Shamakhi-Ismayilli zone in 2003-2019.

The considered seismic activity in the Shamakhi-Ismayilli zone is the result of the stressed state of the environment. The stress state of the earth's crust is one of the main factors determining the nature of geodynamic processes. It is of interest to consider the change in the TAU parameter (analogue V_p/V_s) in the study area. As is known, this parameter reflects the nature of the stress field, shows the state of the medium and the average stresses in the environment over a long time [Slavina et al., 2017]. In a seismically active zone, weak earthquakes occur under the influence of a stress field. With the dilatancy process of stretching, "cracking" of the medium, the ratio V_p/V_s decreases. Under compression (closure of cracks), the ratio V_p/V_s increases. When the ultimate strength is reached, earthquakes occur in the compression and tension regions. Figure 6 (a, b) shows maps of the stress field of the territory under consideration. The map clearly shows the zones of tension and compression. The considered swarms most likely sit in areas of extension or dilatancy, while earthquakes with aftershocks are located in the gradient zone (Fig. 7).

a)

b)

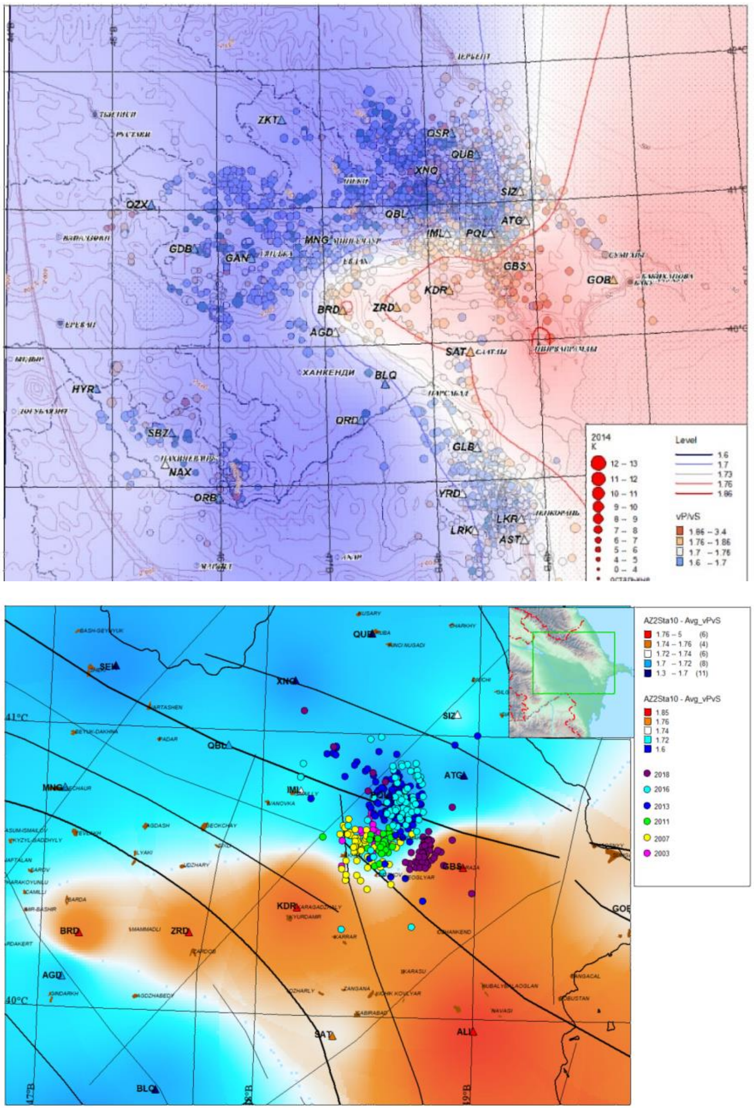


Figure 6 *(a,b). Map of the stress field of the territory of the republic (a), the study area with plotted swarms (b).*

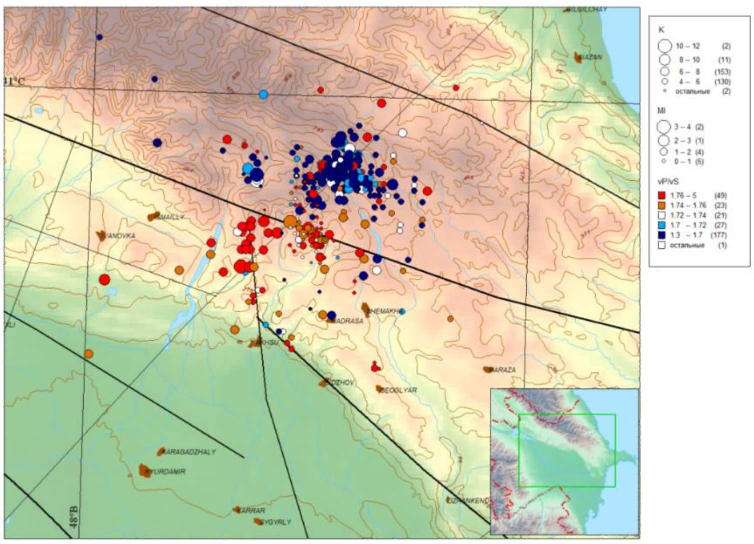


Figure 7. Distribution map of earthquakes with aftershocks, coloured by V_p/V_s.

An analysis of the distribution of hypocentres of earthquakes with Ml≥4 with aftershocks based on a schematic section along profile I-I SW-NE (Fig. 3) showed that the main shocks are relatively shallow within 3–8 km, with the exception of the earthquake in 2012 (Fig. 8). The shallow depth of 3 km and 4 km is characteristic of the main shocks that occurred in 2007 and 2015 with the same magnitudes Ml=4.4. However, aftershock activity propagates to a depth of 18–20 km, covering the upper part of the basement (Yetirmishli et al., 2011).

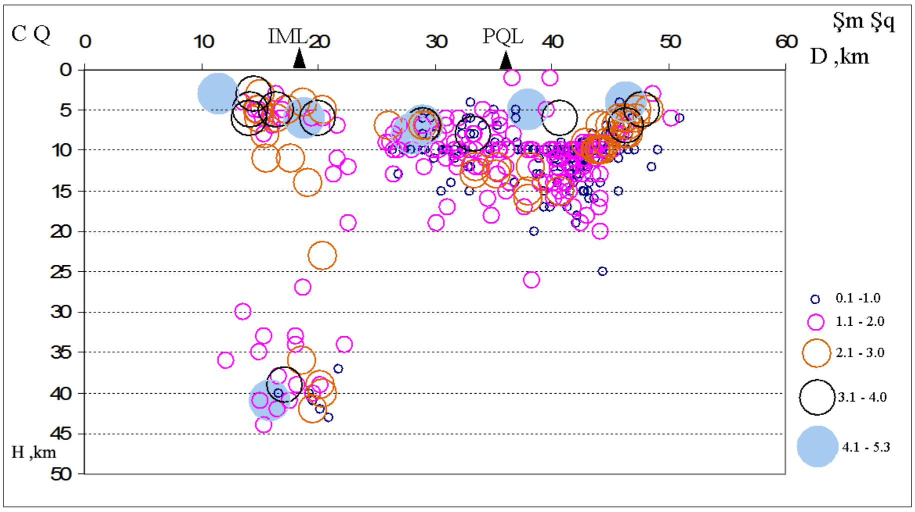


Figure 8. Seismological section along profile I-I.

Let us consider the depth distribution of swarm hypocenters based on a schematic section along profile II-II (Fig. 4) of SW-NE strike (Fig. 9). The main swarm shocks of 2011 2013 and 2016 located at depths of 6-10 km and confined to the sedimentary layer. A high density of hypocenters is observed down to a depth of 20 km, covering the upper part of the basement, slightly higher than the depth of the 2004 earthquake sequences.

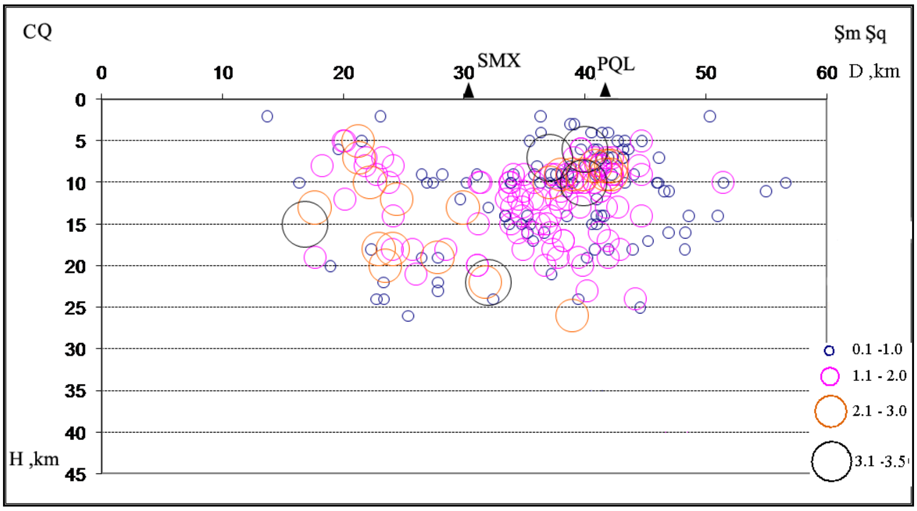


Figure 9. Seismological section along profile II-II.

As a result of the analysis of the spatial and temporal distribution of earthquake sources for the period 2003-2019 the dynamics of seismic activity in the Shamakhi-Ismayilli seismogenic zone has been traced. The study of the spatial distribution of earthquakes with M≥4 and their aftershocks, as well as swarm sequences in the considered zone, leads to the following conclusions:

- discharge of geodynamic stresses in the central part of the zone occurs due to earthquakes with aftershocks, in the eastern part due to swarms of earthquakes;

- sources of stronger earthquakes with Ml≥4 (Ml_{max}=5.3) are located in the central part of the Shamakhi-Ismayilli zone and migrate in the meridional and anti-Caucasian directions, the sources of earthquakes of the swarm sequence with Ml_{max}=3.9 are located in the eastern part of the zone and also migrate in the anti-Caucasian direction, which indicates the presence of transverse structures that control the placement of sources of seismic events;

- the centers of all considered events are located in zones located at the intersection nodes of multidirectional faults and controlled by the main structural elements of the West Caspian fault zone;
- Earthquakes with aftershocks are located in the gradient zone of the stress field, swarm sequences occur in extension areas;
- the hypocenters of the main seismic shocks with Ml≥4 have shallow depths of H≤8 km, except for 2012, and are located in the sedimentary strata of the Vandam and Shamakhi-Gobustan tectonic zones, while the hypocenters of most of their aftershocks are distributed at depths of up to 20 km. The hypocenters of shocks of the swarm sequence (6-26 km) are distributed both in the sedimentary sequence and in the upper part of the basement.

Thus, the release of geodynamic stresses in different parts of the Shamakhi-Ismayilli seismogenic zone occurs at different energy levels and is associated with the stressed state of the environment and with different levels of seismic activity of transverse faults.

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