1st International Scientific Conference "Modern problems in Geophysics", Proceedings,
ISBN 978-9941-36-434-1, ISSN 3088-4349, Tbilisi, Georgia, November 6-8, 2025

DYNAMICS OF THE AFTERSHOCK ZONE OF THE 1988 SPITAK EARTHQUAKE BASED ON 35 YEARS OF DATA.

***Nazaretyan S.N., **Mirzoyan L.B., ***Kazarian A. A., *Mazmanyan L.V.**

**Territorial Survey for Seismic Protection of MIA, Yerevan, Armenia.*
*** Yerevan State University, Yerevan, Armenia.*
**** Institute of Geological Sciences of the National Academy of Sciences of the Republic of Armenia, Yerevan, Armenia.*
snaznssp@mail.ru

Abstract*. The features of aftershock manifestations of the 1988 Spitak earthquake have been studied in sufficient detail, but based on data for the first 2-3 years. The aftershock process is divided into highly active (1988-1991) and weakly active (1992 – present) periods. The overwhelming majority of 14,000 aftershocks (95%) and the predominant part of their energy (98%) were released during the active period. During the weakly active period, relative activation is observed in all the identified segments. Against the general background of attenuation of the number and strength of aftershocks, no patterns in their manifestation are observed.*

Key words: *earthquake, aftershock, segments dynamics.*

Introduction

The 1988 Spitak earthquake (φ = 40.90; λ = 44.20, M = 7.0, I = 9-10 unit by EMS-98, depth – 10 km, main shock duration – 35-40 sec) is one of the most multilaterally and detailed studied earthquakes in the world [6]. The processes of aftershock activity have also been studied in detail: their spatio-temporal distribution, connection with tectonic structures, internal structure of the aftershock zone, periods of activity, etc. However, all this was considered for 07.12.1988-01.01.1992 [1-3, 5]. Little attention was paid to the events after 1992. The **main objective** of this paper is to identify the features of the internal structure and dynamics of the aftershock zone of the 1988 Spitak earthquake over a long period of time (35 years) depending on individual shocks of the main event and the structure of the aftershock zone. To achieve this goal, it is necessary to solve the following main tasks: a) identification of the structural features of the aftershock zone and allocation of the main segments based on the characteristics of the main event, distribution of aftershock epicenters, parameters of the aftershock focal mechanism; b) connection of segments with geological structures formed on the earth's surface as a result of the earthquake; c) presentation of the main features of the dynamics of the aftershock zone development during the weakly active period of development; d) features of the attenuation of the aftershock process in individual segments; e) identification of patterns of occurrence of strong aftershocks, etc.

Main results

As many researchers, as well as the authors of this article, believe that the spatial-temporal distribution of aftershocks is closely related to the main event, more specifically to the parameters of 3 separate shocks of the main event and large structures formed on the day surface – regional faults and seismogravitational structures [6,7]. As will be shown below, the dynamics of aftershock development also depend on these features.

Location of the three shocks of the main event of the 1988 Spitak earthquake

The 1988 Spitak earthquake began under the city of Spitak, at a depth of about 10 km. The population felt a strong vertical shock. Almost all apartment buildings and private 1-2 story stone houses immediately collapsed. The majority of victims were at that moment. The main material and social losses were in the city of Vanadzor as a result of this shock. In the city of Gyumri, as a result of this shock, the losses, in comparison

with the total losses of the Spitak earthquake, were relatively small. On the outskirts of the city of Spitak, a fault 11 km long was formed. According to all calculations, this first shock had a magnitude of about 7.0.

5 seconds after the first shock, the second, weakest, and most superficial (depth about 5 km) shock of all three main events occurred near the village of Alavar. A fault 10 km long was formed. This shock caused minor destruction in the city of Vanadzor. Experts assume that this second shock did not cause any significant damage in Gyumri.

The third, the strongest and deepest (10-15 km) shock of the main event of the 1988 Spitak earthquake, occurred 14 s. after the second, near the village of Dzorashen. As a result of this shock, a continuous, long fault did not form on the earth's surface, but two large seismogravitational dislocations did. Rock masses weighing 2 million tons or more moved along the slope at an angle of about 20^0, forming a 7 m high "wall" in front and a 25 m deep ravine in the rear. The villages located nearby were completely destroyed. The main destruction of buildings and human casualties in Gyumri were precisely due to this third shock, since its epicenter was 20 km from the city. After the first shock of the main event, the population of Gyumri, who were in high-rise buildings, had about 30 seconds to leave the buildings [7]. Quite a few people, during this time, managed to get out from the 3rd floor into the open space and save themselves.

Segmentation of the aftershock zone

The segmentation (division into subzones) of the aftershock zone was based on: a) three separate shocks of the main event of the 1988 Spitak earthquake, occurring within 35-40 seconds; b) the main tectonic structures formed on the earth's surface as a consequence of these shocks. Analysis of the main parameters of the aftershocks showed that different fragments of the aftershock zone have almost the same parameters and focal mechanism, which coincide with similar parameters of a specific shock of the main event. Thus, such a genetic connection can serve as an argument for identifying individual segments of the aftershock zone [6].

In Fig. 1. the aftershock zone is divided into 4 segments, which differ from each other in important aftershock parameters. The 3 segments (No 1, 2 and 3) correspond to the three shocks of the main event, and the 4th segment is a consequence of the influence of the fault junction. If there were no fault node (the intersection of the Sarikamish and Pambak-Sevan regional faults), then this segment probably would not exist. Despite the fact that the 3 separate shocks of the main event are elements of a single fault formation process (upthrust-slip), their consequences, i.e. aftershocks and their segments, differ from each other. Segmentation of the aftershock zone is important for considering the features of the aftershock process development.

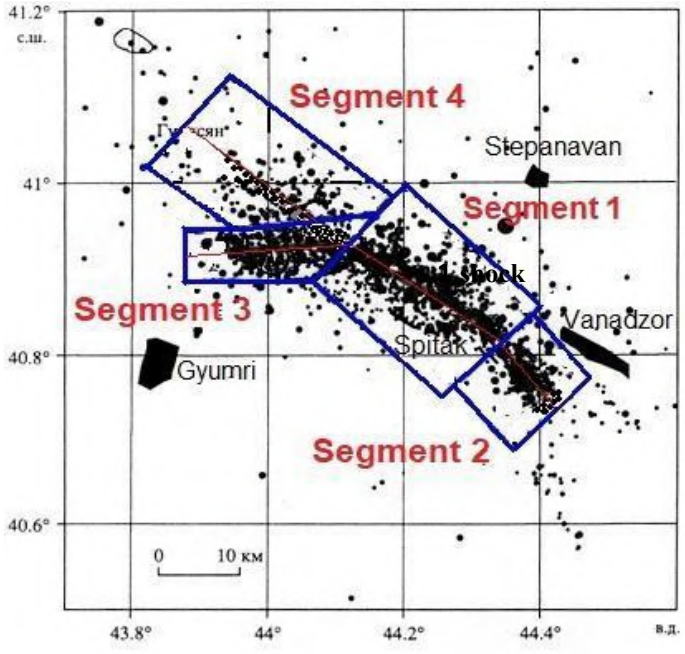

Fig. 1. Map of the aftershock zone segments of the 1988 Spitak earthquake and the distribution of about 14,000 aftershock epicenters for 09.12.1988-01.01.2025 with M≥1.0 [5,6].

Periods of the aftershock process

Usually, experts divide the aftershock process into two periods: highly active and weakly active. For the 1988 Spitak earthquake, the active period ends in early 1992, when the number of aftershocks sharply decreases (Fig. 2 and Fig. 3). The processes of this period have been studied by experts in sufficient detail and from many sides based on a rich database. The vast majority of the 14,000 aftershocks (95%) and the bulk of the total energy released by them (98%) occurred during the highly active period [1,2,6].

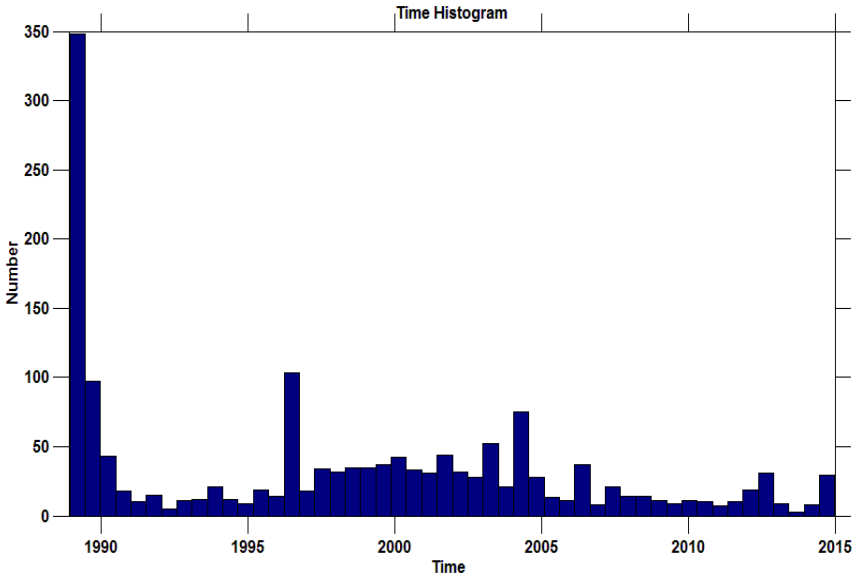

Fig. 2. Distribution of aftershocks of the 1988 Spitak earthquake from 1988 to 2016 [5].
It is obvious that most of the aftershocks occurred in the first three years after the earthquake, in 1988-1991. Aftershocks with magnitude 1.0≤M≤5.0 continue to this day.

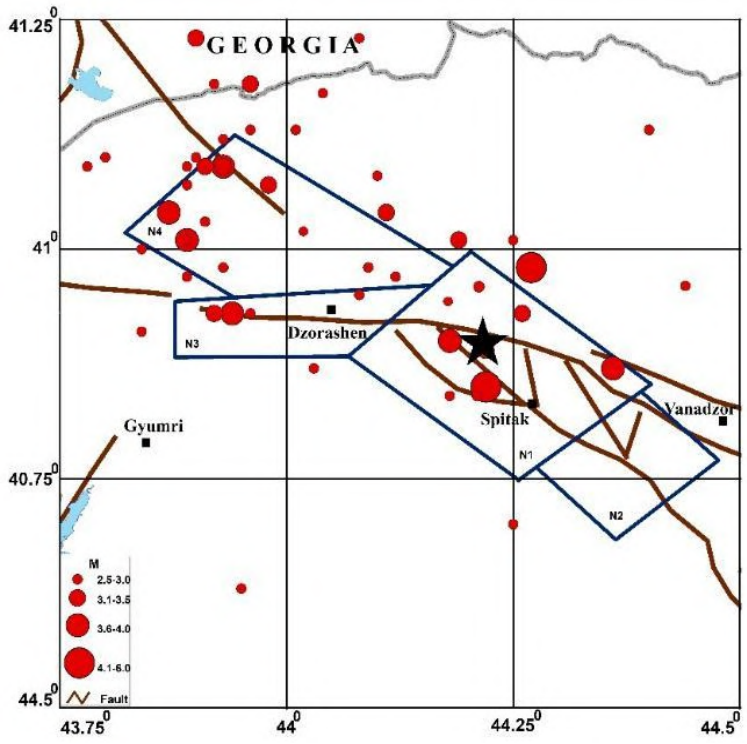

Fig. 3. Map of regional faults [4, 8], 4 segments of aftershock zone of 1988 Spitak earthquake, and epicenters of earthquakes with M≥2.5 for 01.01.2018-01.01.2025. The map shows the epicenter of the Spitak earthquake of 12/07/1988 as a star.

Conclusion

During the weakly active period, i.e. from 01.01.1992 to 01.01.2025, the following patterns of aftershock dynamics are observed:

- The activity of the aftershock process is still observed.
- The number and released energy of aftershocks during the weakly active period in the aftershock zone is significantly higher than in the adjacent areas.
- In the period 1995-2005, a certain activation (in terms of the number and energy of aftershocks) was observed in all 4 segments of the zone (Fig. 3).
- It is assumed that the 2nd segment, which corresponds to the weakest and most superficial shock of the main event of 07.12.1988, has already ceased to show aftershock activity in 2018 (Fig. 3).
- Against the general background of the attenuation of the number of aftershocks and their strength, no pattern in the manifestation of strong aftershocks is observed.

References

1. Cisternas A., Philip H., Arefiev S.S., Bousquet J.C., The Spitak (Armenia) earthquake of 7 December 1988: Field observations, seismology and tectonics. // Nature, vol. 339, N 6227, 1989, pp. 675-679. DOI:10.1038/339675a0
2. Dorbath L., Dorbath C., Rivera L., Fuenzalida A., Cisternas A., Tatevossian R., Aptekman J., Arefev S., Geometry, segmentation and stress regime of the Spitak (Armenia) earthquake from the analysis of the aftershock sequence. // Geophys. J. Intern, vol.108, 1992 pp. 309-328. https://hal.science/hal-03186267/document
3. Haessler H., Deschamps A., Dufumier H., Fuenzalida H. and Cisternas A**.,** The rupture process of the Armenian earthquake from broad-band teleseismic body wave records. // Geophys. 1. Int. 109, 1992, pp. 151-161. https://academic.oup.com/gji/article/109/1/151/573691
4. Karakhanyan A., Arakelyan A., Avagyan A., Sadoyan T., Aspects of the seismotectonics of Armenia: New data and reanalysis. Tectonic Evolution, Collision, and Seismicity of Southwest Asia: In Honor of Manuel Berberian's Forty Years of Research Contributions. Geological Society of America, 2017, pp. 445–477. https://doi.org/10.1130/2016.2525(14)
5. Mirzoyan L.B., Nazaretyan S.N., Features of the structure and dynamics of the development of the aftershock zone of the Spitak earthquake of 1988. // Bulletin of the NAS RA. Earth Sciences. LXI, №1, 2008, pp. 32-38 (in Russian). https://arar.sci.am/Content/119524/file_0.pdf
6. Nazaretyan S.N., The Seismic Hazard and Risk of territories of cities located in the zone of 1988 Spitak earthquake. (Editor- Dr., Prof. Darbinyan S.). // Publ. house Gitutiun- Sciences of National Academy of Sciences of Armenia, Yerevan: 2013, 205 p. (in Russian), ISBN: 978-5-8080-0999-8
7. Nazaretyan S.N., Durgaryan R.R., Shakhbekyan T.A., Mirzoyan L.B., Grigoryan A.G., Regional faults of the territory of the Republic of Armenia according to geophysical data and their seismicity. // "Gitutyun" National Academy of Science. Yerevan, 2015, 198 p. (in Russian). https://www.geokniga.org/books/20055
8. Nazaretyan S.N., Igityan G.A., Assessment of the maximum seismic risk for the territory of Armenia. // Issues of engineering seismology, Vol. 52, No. 2, 2025, pp. 38–54 (in Russian). DOI: https://doi.org/10.21455/VIS2025.2-3