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Delineation of New Models for Seismogenic Areal Sources in the Caucasus

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ABSTRACT

New seismogenic areal sources were delineated in the Caucasus based on regional seismotectonic conditions, active faults, observed seismicity patterns, and previously published seismogenic source models. The resulting areal source new zonation provides a framework for the estimation of source-specific recurrence characteristics and seismic hazard contributions.

Keywords: *Probabilistic seismic hazard, seismogenic areal source, tectonic unit, active fault.*

1 Introduction

In connection with the reassessment of the seismic hazard of Georgia and its energy and other facilities, several geological, tectonic, and seismological objectives were addressed. These included the estimation of the maximum expected magnitude (Mwmax), the determination of the Gutenberg-Richter earthquake recurrence relationship and its coefficients (a and b), as well as the delineation of new areal source models for the broader region surrounding Georgia, i.e. the entire Caucasus.

The study area extends from 37.5° to 45.0° N and from 40.0° to 52.0° E, encompassing Georgia, Armenia, Azerbaijan, northeastern Turkey, northwestern Iran, the southern part of the Russian Federation, as well as the eastern Black Sea and western Caspian Sea regions. This area represents one of the most seismically active regions of the Alpine-Himalayan belt. In contrast to previously proposed source models, a new homogeneous areal source model was developed for the entire Caucasus region, providing a consistent framework for regional seismic hazard assessment.

Probabilistic seismic hazard analysis (PSHA) relies on the development of seismogenic source models, as the reliability of hazard estimates largely depends on the adequacy of source characterization. Modern PSHA practice commonly employs several types of seismogenic sources, including areal sources, active fault sources, and background seismicity models, to represent the spatial and temporal distribution of earthquake occurrence. However, individual source types do not always satisfy the assumption of relative tectonic and seismological homogeneity, and in some cases the available earthquake statistics are insufficient for robust estimation of recurrence parameters required for probabilistic seismic hazard assessment. Therefore, a regional areal source model was developed for the Caucasus region based on the integrated interpretation of tectonic units, active fault systems, and observed seismicity. The resulting areal sources represent tectonically coherent regions that provide a suitable framework for the estimation of earthquake recurrence parameters and maximum expected magnitudes. The delineation of the areal sources was based on the geometry of the major tectonic units of the Caucasus, subsequently refined using information on active fault systems and the spatial distribution of seismicity.

2 Input data

As noted above, tectonic units, active faults, and seismicity constitute the principal datasets used for the development of the seismogenic areal source model. The present study is based entirely on information published in internationally recognized scientific literature. In particular, the description and geometry of the principal tectonic units of the Caucasus were adopted from Adamia et al. (2011) [1] and Adamia et al. (2017) [2] (Fig. 1). Information on active fault systems was compiled from Caputo and Gamkrelidze et al. (2000) [3], Adamia et al. (2008) [4], Danciu et al. (2018) [5], and Basili et al. (2024) [6] (Figs. 2-5).

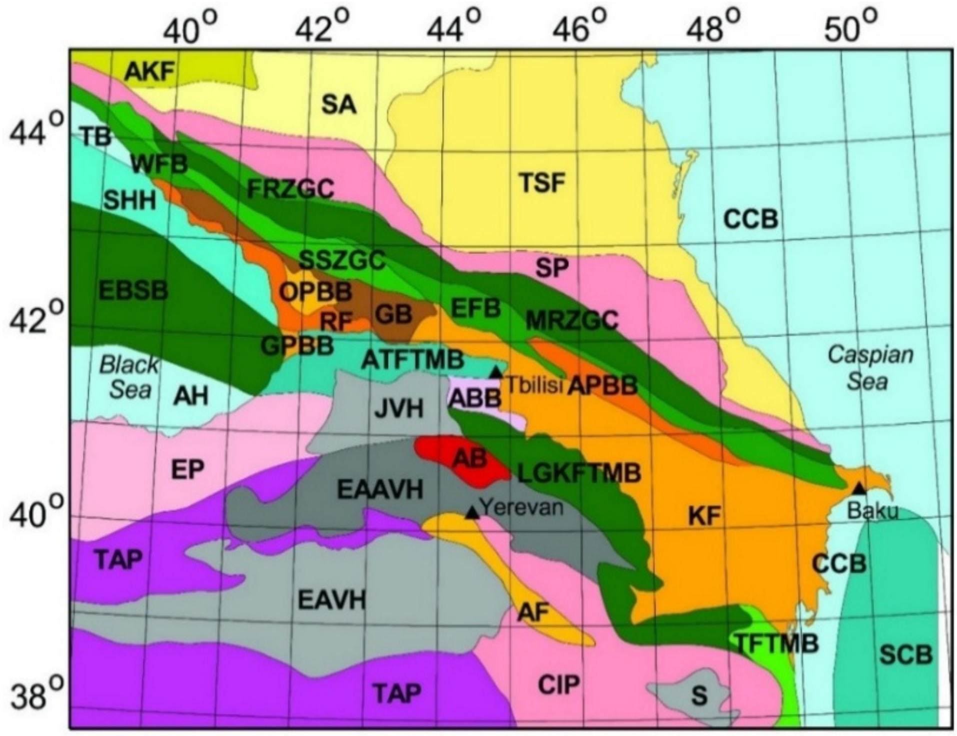

Fig. 1 Tectonic units of the Caucasus according to Adamia et al. (2011, 2017) [1, 2]: AKF – Azov-Kuban Foredeep; SA – Stavropol Arch; TSF – Terek-Caspian Foredeep; SP – Scythian Platform; FEZGC – Fore Range Zone of Great Caucasus; MEZOC – Main Range Zone of Great Caucasus; WFB – Western Flysch Basin; SSZGC – Southern Slope Zone of Great Caucasus; EFB – Eastern Flysch Basin; TB – Tuapse Basin; SHH – Shatsky High; EBSB – Eastern Black Sea Basin; AH – Arkhangelsky High; GB – Georgian Block; OPBB – Odishi Piggyback Basin; RP – Rioni Foreland; GPBB – Guria Piggyback Basin; APBB – Alazani Piggyback Basin; KF – Kura Foreland; ATFTMB – Achara-Trialeti Fold-Thrust Mountain Belt; JVH – Javakheti Volcanic Highland; ABB – Artvin-Bolnisi Block; AB – Armenian Block; LGKFTMB – Loki-Garabagh-Kafan Fold-Thrust Mountain Belt; EP – Eastern Pontides; TAP – Taurus-Anatolian Platform; EAAVH – Eastern Anatolian-Armenian Volcanic Highland; EAVH – Eastern Anatolian Volcanic Highland; AF – Aras Foreland; CIP – Central Iranian Platform; S – Sabalan; TFTMB – Talesh Fold-Thrust Mountain Belt; CCB – Central Caspian Basin; SCB – South Caspian Basin.

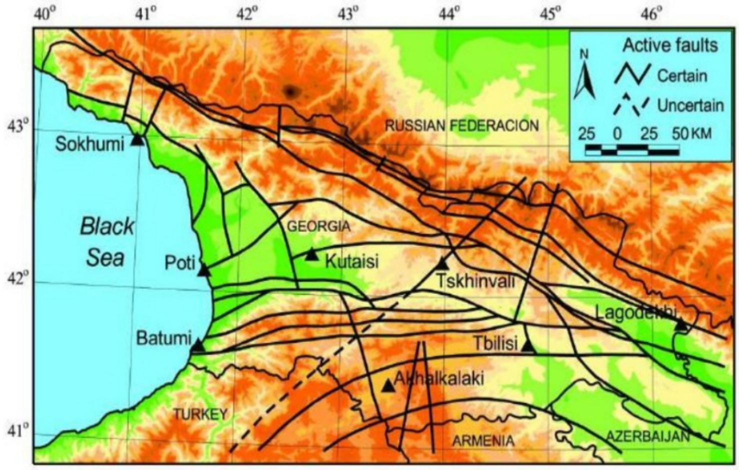

Fig. 2 Active faults in Georgia according to Caputo, Gamkrelidze et al. (2000) [3]

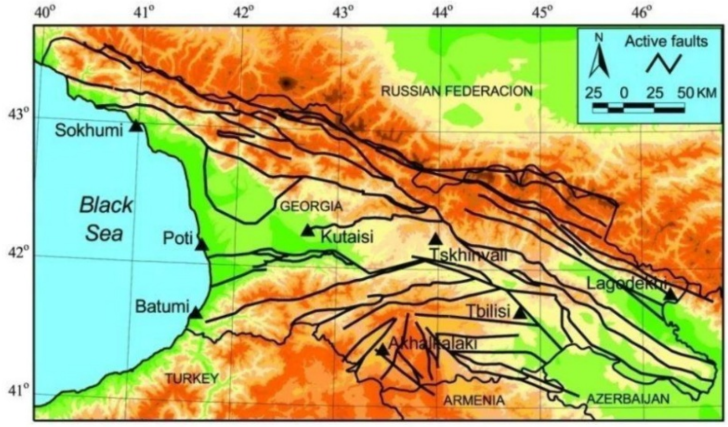

Fig. 3 Active faults in Georgia according to Adamia et al. (2008) [4]

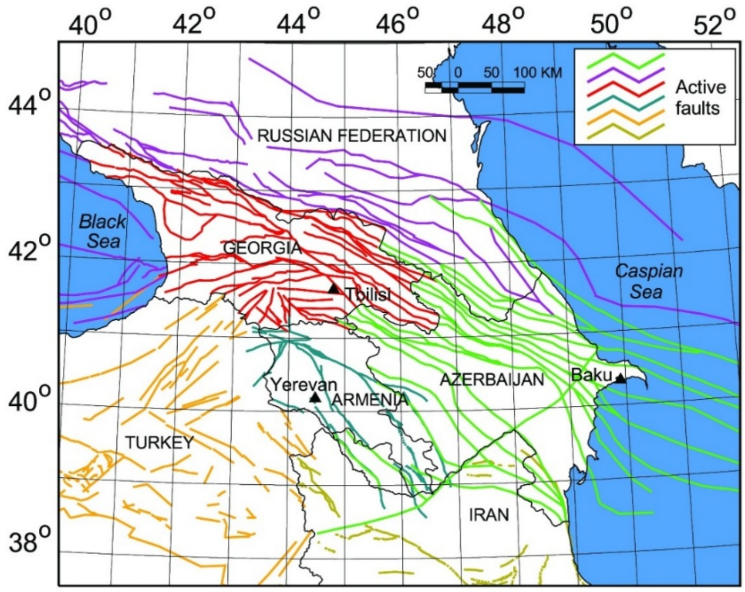

Fig. 4 Active faults in the Caucasus according to the Middle East Seismogenic Source Model – EMME-SSM14 (Danciu et al., 2018) [5]

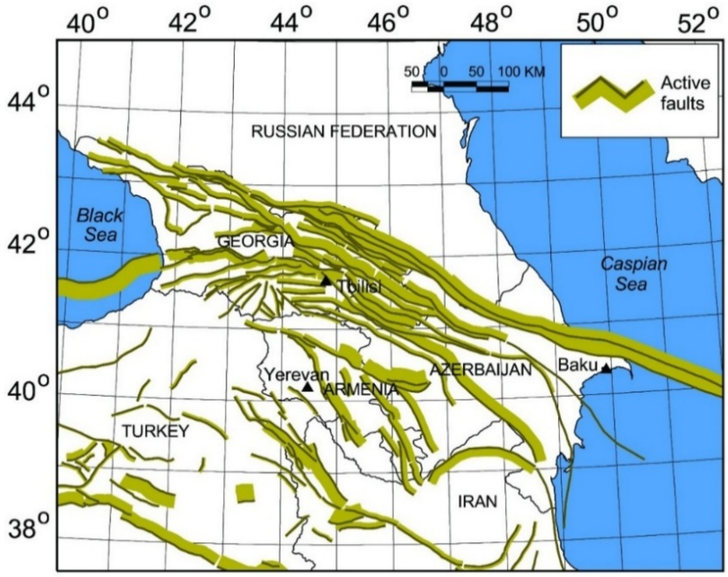

Fig. 5 Active faults in the Caucasus according to the European Fault Source Model – EFSM20 (Basili et al., 2024) [6]

In addition, the newly developed (in M. Nodia Institute of Geophysics of Iv. Javakhishvili Tbilisi State University, IGTSU, 2026) unified earthquake catalogue of the Caucasus was used as the primary seismological dataset for the delineation of the Caucasus areal source model.

3 New models of areal source (AS)

In the process of developing models of such seismogenic areal sources, it should be emphasized that from a methodological point of view, their delineation is based on the zones of tectonic units, active faults within them, and seismicity. The boundaries of areal sources are delineated within tectonic units in such a way as to minimize intersections with active faults. Where possible, the boundaries should not cross active faults; in the case of extensive faults, they should not intersect individual fault segments.

We compared and reconciled geological and seismological data to enable their joint consideration to develop a seismogenic areal source models. The resulting seismogenic areal source models of the Caucasus region defined by regional data on active tectonics and which are correlated with regional observed seismicity.

The seismic potential, or Mwmax, of each seismogenic super source was estimated using several methods presented in Varazanashvili and Tsereteli (2020) [7]. Three of these methods are seismological and two are geological. The final Mwmax values are obtained of averaging the individual values by the five methods.

Specifically, 27 seismogenic areal source (AS) zones have been delineated in the Caucasus region. **AS zone 1** within the study region includes part of Azov-Kuban Lowland and its seismic potential is estimated to be – Mwmax=5.5; **AS zone 2** includes part of Stavropol Arch – Mwmax=6.0; **AS zone 3** includes part of Terek-Caspian Foredeep – Mwmax=7.0; **AS zone 4** includes norten part of Central Caspian Basin – Mwmax=7.0; **AS zone 5** includes western part of Scythian Platform – Mwmax=6.5; **AS zone 6** includes eastern part of Scythian Platform – Mwmax=6.5; **AS zone 7** ncludes Fore Range Zone of Great Caucasus, western part of Main Range Zone of Great Caucasus, Southern Slope Zone of Great Caucasus, Western Flysch Basin, western part of Eastern Flysch Basin – Mwmax=7.5; **AS zone 8** includes eastern part of Main Range Zone of Great Caucasus, Eastern Flysch Basin, western part of Alazani Piggyback Basin – Mwmax=7.5; **AS zone 9** includes Georgian Block, Rioni Foreland, part of Tuapse Basin, Shatsky High – Mwmax=6.5; **AS zone 10** includes part of Georgian Block, Odishi Piggyback Basin – Mwmax=6.5; **AS zone 11** includes Kura Foreland, eastern part of Alazani Piggyback Basin – Mwmax=7.0; **AS zone 12** includes part of Eastern Black Sea Basin, part of Arkhangelsky High – Mwmax=6.5; **AS zone 13** includes part of Kura Foreland part, Guria Piggyback Basin, Achara-Trialeti Fold-Thrust Mountain Belt, part of Javakheti Volcanic Highland –

Mwmax=7.0; **AS zone 14** includes Artvin-Bolnisi Block, part of Loki-Garabagh-Kafan Fold-Thrust Mountain Belt part – Mwmax=7.0; **AS zone 15** includes part of Arkhangelsky High – Mwmax=6.0; **AS zone 16** includes Eastern Pontides – Mwmax=6.0; **AS zone 17** includes Javakheti Volcanic Highland, Armenian Block – Mwmax=7.5; **AS zone 18** includes part of Taurus-Anatolian Platform, part of Eastern Anatolian Volcanic Highland – Mwmax=8.0; **AS zone 19** includes Eastern Anatolian-Armenian Volcanic Highland part, part of Taurus - Anatolian Platform, part of Armenian Block – Mwmax=7.5; **AS zone 20** includes Eastern Anatolian Volcanic Highland, part of Taurus-Anatolian Platform, part of Central Iranian Platform part – Mwmax=8.0; **AS zone 21** includes Aras Foreland, part of Central Iranian Platform – Mwmax=7.0; **AS zone 22** includes part of Taurus-Anatolian Platform part – Mwmax=8.0; **AS zone 23** includes part of Central Iranian Platform part – Mwmax=7.5; **AS zone 24** includes Sabalan – Mwmax=5.5; **AS zone 25** includes part of Loki-Garabagh-Kafan Fold-Thrust Mountain Belt, part of Talesh Fold-Thrust Mountain Belt – Mwmax=7.5; **AS zone 26** includes part of Central Caspian Basin southern – Mwmax=6.5; **AS zone 27** includes South Caspian Basin – Mwmax=6.0 (see Figs. 6 and 7).

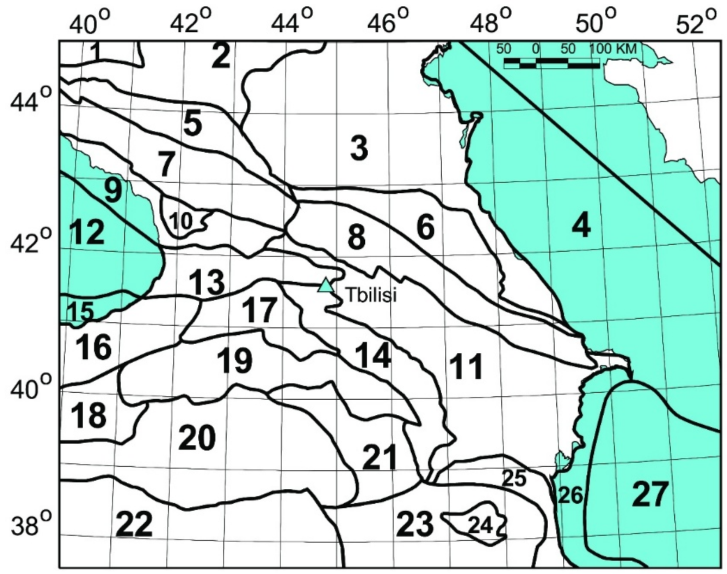

Fig. 6 New seismogenic areal source zones of the Caucasus region.

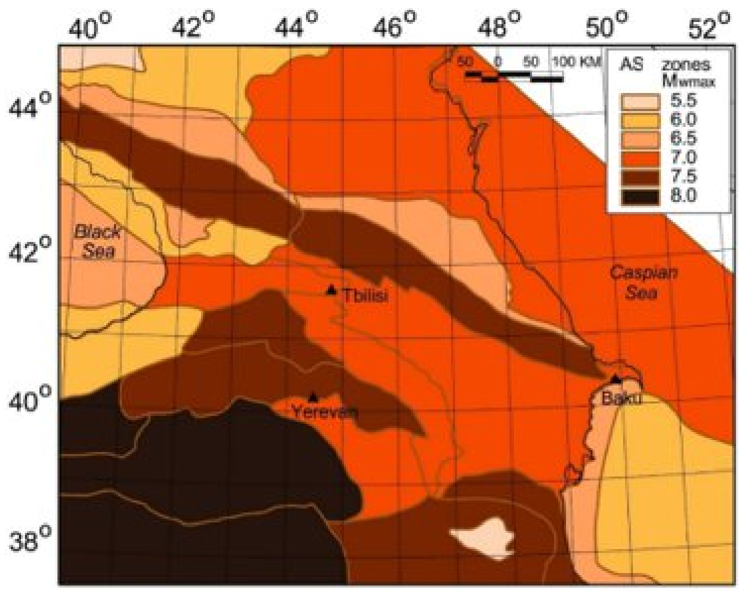

Fig. 7 Seismic potential of seismogenic areal source zones in the Caucasus region.

4 Conclusions

Existing seismogenic source models do not always satisfy the assumption of relative tectonic and seismological homogeneity or provide reliable estimates of the earthquake recurrence parameters required for probabilistic seismic hazard assessment (PSHA).

To address the reassessment of seismic hazard for the territory of Georgia and its critical facilities, a new set of seismogenic areal source models has been developed for the Caucasus region. These models are based on the integrated interpretation of tectonic units, active fault systems, and instrumental and historical seismicity.

The present study is based entirely on geological information published in internationally recognized scientific literature and on the newly developed Unified Earthquake Catalog of the Caucasus (2026), compiled at IGTSU.

As a result of this study, 27 new seismogenic areal source zones were delineated within the Caucasus region. These zones provide a robust framework for determining earthquake recurrence relationships and for conducting probabilistic seismic hazard assessments.

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სეისმოგენური არეალური წყაროების ახალი მოდელების გამოყოფა კავკასიაში

ო. ვარაზანაშვილი

რეზიუმე

ახალი სეისმოგენური არეალური წყაროები გამოიყო კავკასიაში რეგიონული სეისმოტექტონიკური პირობების, დანაკვირვები სეისმურობის, აქტიური რღვევებისა და ადრე გამოქვეყნებული სეისმური წყაროს მოდელების საფუძველზე. შედეგად მიღებული არეალური წყაროს ახალი ზონირება უზრუნველყოფს კონკრეტულ წყაროებში განმეორებადობის სპეციფიკური მახასიათებლებისა და სეისმურ საშიშროებაში წვლილის შეფასებას.

საკვანძო სიტყვები: სავარაუდო სეისმური საფრთხე, სეისმოგენური არეალის წყარო, ტექტონიკური ერთეული, აქტიური რღვევა.

Выделение новых моделей сейсмогенных площадных источников на Кавказе

О. Варазанашвили

Резюме

Новые площадные сейсмогенные источники были выделены в Кавказе на основе региональных сейсмотектонических условий, активных разломов, наблюдаемых закономерностей сейсмичности и ранее опубликованных моделей сейсмогенных источников. Полученное в результате новое зонирование площадных источников обеспечивает основу для оценки специфических характеристик повторяемости конкретных источников и вклада в сейсмической опасности.

Ключевые слова: Вероятностная сейсмическая опасность, сейсмогенный площадной источник, тектоническая единица, активный разлом.