საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 13, №2, 2019
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 13, no. 2, 2019

*Geophysics*

# Attenuation in the Javakheti Plateau (Georgia) Using Different Coda Methods

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**ABSTRACT. The attenuation properties of the lithosphere in the Javakheti Plateau have been investigated. The main goal of the study is to calculate the quality factor Qc using the single back-scattering model in the frequency range of 1-32 Hz and connecting them to the tectonics and seismicity of the study region. One hundred and fourteen local earthquakes in 2005-2016 were analyzed and Qc values were estimated. Coda window ranged from 20 to 60s. Obtained Qc values increase both with respect to lapse time and frequency. The results show that the region is seismically active with high heterogeneities. The variation (increasing) of Qc with lapse time shows that the lithosphere becomes more homogeneous with depth.** *© 2019 Bull. Georg. Natl. Acad. Sci.*

**Key words**: Coda waves, attenuation parameters, single scattering model

The attenuation of seismic waves is one of the important parameter in seismology. It helps to understand the physical laws related to the propagation of the elastic energy of an earthquake through the medium. Seismic wave attenuation mainly caused by geometric spreading, intrinsic attenuation due to the absorption by inelasticity of the medium and scattering attenuation due to the scattering at heterogeneities distributed in the Earth [1,2]. Attenuating property of a medium can be expressed by the inverse of the quality factor $Q^{-1}$. In general, the dimensionless quantity $Q$ is defined as the ratio of wave energy to the energy dissipated per cycle of oscillation. The goal of the study is to determine quality factor $Q_c$ using the coda waves for the Javakheti Plateau. The seismic coda wave is caused by the scattering of seismic waves from numerous randomly distributed heterogeneities in the Earth's crust and the upper mantle [3]. Aki and Chouet [3] proposed the single back-scattering model to characterize coda waves and introduced seismic attenuation parameter coda $Q_c$, which is the measure of the decay rate of coda waves within a certain frequency interval. Scientific works show that the coda $Q_c$ is sensitive to the geological environment; in general, it is lower in tectonically active regions and higher in the stable regions [2]. We chose the territory of the Javakheti Plateau which is situated in the south of Georgia and is interesting from both seismic and tectonic points of view (Fig. 1). The Javakheti Plateau is an area of intensive manifestation of Neogene-Quaternary volcanism. From the structural point of view, the Javakheti Plateau occupies the central part of the Caucasian–Asia Minor segment of the Alpine-Himalaya belt; it is located in the zone of the Transcaucasian transverse uplift [4]. Among the seismic areas of the Caucasus, the Javakheti Plateau is notable for its frequent small-magnitude earthquakes. Large earthquakes are distributed mainly in the peripheral part of the Javakheti Plateau along major faults.

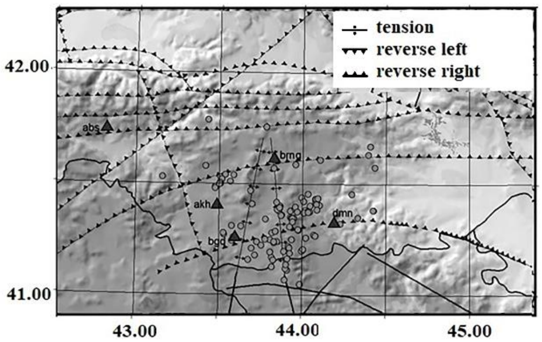


**Fig. 1.** Map of Javakheti Plateau with active faults [4]. The epicenter of earthquakes (circles) and location of used stations (triangles) are also shown.

## Data and Method

Digital seismic waveform data, recorded by stations AKH, ABS, BGD, DMN, BRNG were used to study the attenuation property of coda waves in this region. We analyzed 114 local earthquakes recorded during 2005-2016 (Fig. 1). More than 400 seismograms with good signal-to-noise (S/N) ratio were selected and processed for coda $Q_c$ calculations. In general, we discovered practically no significant differences for the seismogram envelopes between north–south and east–west components on the coda portion; therefore, we collected north–south components of seismograms for $Q_c$ estimation [5]. Features of the data are the following: the epicentral distances are less than 70 km. The local magnitude range of the earthquakes is 1.7–4.2 with shallow focal depth (up to 20 km). In order to investigate on lapse time dependence of $Q_c$ values, we have estimated quality factors in four different coda windows (Fig. 2).We used the single back scattering model of Aki and Chouet [3] to measure seismic wave attenuation from the coda wave. According to the single-scattering model, the coda wave amplitudes $A(f,t)$ obtained for each frequency band centered at $f$ and at lapse time $t$ measured from the earthquake origin time, are described as:

$$A(f,t) = S(f)t^{-\alpha} \exp(-\pi ft)Q_c(f)), \qquad (1)$$

where $S(f)$ represents the source factor at frequency $f$ and is considered as a constant, α is the geometrical spreading parameter and is equal to 1.0, 0.5 or 0.75 for single scattering of body waves, surface waves or diffusive waves, respectively [1,2], $Q_c(f)$ is the quality factor. The QCODA program [6] is used for coda wave analysis and for the estimation of the quality factor $Q_c$ in this study. We used three methods available in the package: (1) the back-scattering model of Aki and Chouet [1] with the source and receiver in the same location. The model of Aki and Chouet is valid for coda waves arriving after twice the *S* wave travel time. (2) The single-scattering model of Sato [2] in the time domain. (3) The single-scattering model in the frequency domain using FFT for estimating the power spectrum for the overlapping windows. The second and third methods are applied at once and twice the *S*-wave travel time. In order to investigate on lapse time dependence of $Q_c$ values, we have estimated the quality factors *Q* in four coda windows using all three methods (Fig. 2). We selected $Q_c$ values with error less than 10%.

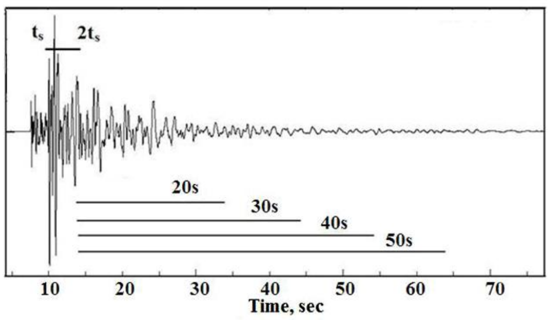


**Fig. 2.** Example of seismogram of local earthquake (2010/09/15, M2.2) recorded at station AKH and the four coda windows over which the estimation of $Q_c$ were applied, $t_s$ is a travel time of *S* wave.

## Results and Conclusion

**Table. Mean value of $Q_c$ along their standard deviation at different central frequencies and lapse times**

| Frequency, Hz | 20s | 30s | 40s | 50s |
|---|---|---|---|---|
| (a) Aki and Chouet's method AC | | | | |
| 1.5 | 53±3 | 74±4 | 84±5 | 98±6 |
| 3 | 131±5 | 149±7 | 279±11 | 200±17 |
| 6 | 240±12 | 300±21 | 363±23 | 437±21 |
| 12 | 533±24 | 580±38 | 673±41 | 740±38 |
| 24 | 1272±78 | 1331±69 | 1477±92 | 1603±94 |
| (b) Sato's Method S1 | | | | |
| 1.5 | 64±4 | 90±5 | 97±7 | 109±6 |
| 3 | 140±7 | 161±9 | 188±14 | 213±19 |
| 6 | 257±12 | 322±19 | 387±25 | 449±29 |
| 12 | 544±21 | 599±33 | 699±49 | 757±43 |
| 24 | 1291±81 | 1364±78 | 1491±89 | 1613±101 |
| (c) Sato's Method S1 Applied at the S-Wave Travel Time | | | | |
| 1.5 | 59±3 | 81±4 | 94±6 | 107±7 |
| 3 | 138±11 | 154±6 | 181±16 | 201±15 |
| 6 | 253±29 | 310±33 | 365±38 | 401±39 |
| 12 | 541±38 | 591±42 | 671±54 | 818±54 |
| 24 | 1280±87 | 1338±70 | 1457±88 | 1591±94 |
| (d) Lee's Method L1 | | | | |
| 1.5 | 73±5 | 98±5 | 113±6 | 126±9 |
| 3 | 163±19 | 183±15 | 192±18 | 227±24 |
| 6 | 261±26 | 351±35 | 399±47 | 461±44 |
| 12 | 568±47 | 609±44 | 701±59 | 769±78 |
| 24 | 1315±88 | 1387±103 | 1499±100 | 1618±110 |
| (e) Lee's Method L2 Applied at Twice the S-Wave Travel Time | | | | |
| 1.5 | 65±4 | 92±7 | 112±7 | 119 ±7 |
| 3 | 154±15 | 172±23 | 188±17 | 214 ±19 |
| 6 | 260±33 | 343±46 | 375±35 | 441 ± 46 |
| 12 | 557±56 | 698±67 | 688±48 | 744±59 |
| 24 | 1300±99 | 1371±106 | 1489±106 | 1593±99 |
| (f) All Three Methods Used Simultaneously | | | | |
| 1.5 | 65±4 | 92±5 | 112±7 | 119±8 |
| 3 | 154±14 | 172±19 | 188±19 | 214±21 |
| 6 | 260±23 | 343±41 | 375±30 | 441± 44 |
| 12 | 557±47 | 698±62 | 688±44 | 744±73 |
| 24 | 1300±97 | 1371±100 | 1489±96 | 1593±104 |

The obtained $Q_c$ values for each given frequency band and lapse time were averaged at each station. $Q_c$ values estimated using each method were averaged over all stations for each central frequency and coda window. The results are reported in the Table. For each lapse time the differences in $Q_c$ values obtained at different stations and methods are relatively small. The obtained $Q_c$ values for the Javakheti Plateau are found to be the strong functions of frequency in the high frequency range. Estimated $Q_c$ values were fitted to the power law of the form $Q_c(f)=Q_o(f)^n$ for the study region in all four lapse times, where $Q_0$ is the quality factor at 1 Hz and $n$ is the frequency parameter. We obtained the following relationships $Q_c(f)$ using all three models simultaneously for 20, 30, 40 and 50 sec lapse times, respectively:

$$Q_c = (41 \pm 4) f^{1.064\pm0.041},\ Q_c = (57 \pm 5) f^{0.979\pm0.056},$$
$$Q_c = (66 \pm 5) f^{0.966\pm0.059},\ Q_c = (75 \pm 6) f^{0.96\pm0.063}. \quad (2)$$

The observed $Q_c$ values increase both with respect to lapse time window length as well as frequency. Moreover, $Q_0$ increases and $n$ decreases systematically with increasing lapse time (Table). The most reasonable explanation for increasing $Q_c$ over time is probably the change in attenuation with depth. According to [7] in the single scattering model seismic coda waves sample a circular volume of radius $v_s t/2$, where $t$ and $v_s$ are the average lapse time and average velocity of $S$ waves, respectively. For the lapse time duration of 20, 30, 40, and 50s coda waves sample the circular area with radius of 34, 51, 68, 85km, respectively. So, the longer the coda window, the larger the average volume from which coda waves are recorded and variations in $Q_c$ reflect the variation of coda attenuation from deeper zones of study region. In our analysis the maximum sampling depth is about 85 km and as the crust thickness is about 50 km in Georgia, estimated $Q_c$ values are characteristic of the whole crust and part of the upper mantle. Our results show low values of $Q_c$ beneath the study region. Such high attenuation may be due to some heterogeneity in the medium causing the loss of the energy. The Javakheti Plateau consists of numerous faults and cracks [8]. Increasing the $Q_c$ values with the time window indicate, that the deeper crust is less heterogeneous than the shallow crust. In overall observed $Q_c$, $Q_0$ and $n$ values show that the region is seismically active with high heterogeneities. The estimation of $Q_c$ in Javakheti Plateau will be an important parameter for the assessment of seismic hazard, for better understanding of the tectonics and the seismicity of the given region.

The work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG) №217604.

*გეოფიზიკა*

# ჯავახეთის ზეგნისათვის (საქართველო) დაცხრომის მახასიათებლების შესწავლა კოდას სხვადასხვა მეთოდის გამოყენებით

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გამოკვლეულია კოდა ტალღების დაცხრომა ჯავახეთის ზეგნისათვის. გამოყენებულია მარტივი ერთჯერადი გაბნევის მოდელი. 1-32 ჰც სიხშირულ დიაპაზონში შეფასებულია კოდას ვარგისიანობის კოეფიციენტი $Q_c$. მიღებული მონაცემები დაკავშირებულია რეგიონის ტექტონიკასა და სეისმურობასთან. განხილულია 2005-2016 წლებში მომხდარი 114 ლოკალური მიწისძვრა და $Q_c$ სიდიდე შეფასებულია 20-60 წმ-ის ინტერვალებში. ჩვენ მივიღეთ, რომ $Q_c$ სიდიდე იზრდება სიხშირისა და კოდას დროითი ინტერვალების ზრდასთან ერთად, რაც გვიჩვენებს, რომ ჯავახეთის ზეგნის ლითოსფერო სეისმურად აქტიური და არაერთგვაროვანია. ხოლო სიღრმის მატებასთან ერთად ლითოსფერო უფრო ერთგვაროვანი ხდება.

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*Received April, 2019*