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Seismic structure of the crust and uppermost mantle beneath Caucasus based on regional earthquake tomography

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ABSTRACT

We present a new seismic model of the crust beneath the Caucasus based on tomographic inversion of P and S arrival times from earthquakes occurred in the region recorded by regional seismic networks in the Caucasian republics. The resulting P and S velocity models clearly delineate major tectonic units of the study area. A high velocity anomaly in Transcaucasian separating the Great and Lesser Caucasus possibly represents a rigid crustal block corresponding to the remnant oceanic lithosphere of Tethys. Another high-velocity pattern coincides with the southern edge of the Scythian Plate. Strongly deformed areas of Great and Lesser Caucasus are mostly associated with low-velocity patterns representing thickened felsic part of the crust and strong fracturing of rocks. Most Cenozoic volcanic centers of Caucasus match to the low-velocity seismic anomalies in the crust. For example, the Kazbegi volcano group is located above an elongated low-velocity anomaly squeezed between high-velocity segments of Transcaucasian and Scythian Plate. We propose that mantle part of the Arabian and Eurasian Plates has been delaminated due to the continental collision in the Caucasus region. As a result, overheated asthenosphere appeared nearly the bottom of the crust and facilitated melting of the crustal material that caused the origin of recent volcanism in Great and Lesser Caucasus.

1. Introduction

Caucasus is a part of the world's largest Alpine–Himalayan collision belt. It forms an elongated mountain system between the Black Sea to Caspian Sea with the total length of more than 1300 km. The origin of the Caucasus orogeny in Cenozoic is caused by the convergence of the Arabian and Eurasian Plates (Khain, 1975; Adamia et al., 2011a,b) that is associated with closure of the Tethys Ocean occurred approximately 35 Ma ago. As follows from geodetic measurements, shortening of the collision area between the Arabian and Scythian Plates still continues with the rate of 1–2.5 mm/years (Reilinger et al., 2006; McClusky et al., 2000). This shortening is responsible for the active mountain building (Mosar et al., 2010). Intensive regional displacements mostly occur along well developed fault systems that lead to intensive seismic activity in the region. The collisional processes are thought to be responsible for recent volcanic manifestations. To understand the mechanisms of all these processes, detailed investigations of the crustal and mantle structures are required.

Structure of the mantle and crust beneath the Caucasus and surrounding regions has been studied by several authors using different geophysical methods. Global and regional seismic tomography models constructed with the use of travel times of body waves (e.g., Al-Lazki et al., 2004; Bijwaard et al., 1998; Koulakov et al., 2012; Maggi and Priestley, 2005; Hearn and Ni, 1994), surface waves (Villasenor et al., 2001; Ritzwoller and Levshin, 1998) and attenuation (Gök et al., 2003; Sarker and Abers, 1998) have provided generally consistent images of crustal and mantle heterogeneities. Most of these studies reveal prominent low-velocity anomalies in the uppermost mantle beneath the collision belts and higher velocities in areas of stable continental plates (Scythian, Arabian and Eurasian Plates). These tomography results are generally supported by the receiver function studies (Gök et al., 2011).

The present work can be considered as a continuation of the study by Koulakov et al. (2012) in which they used global travel

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time data from the catalogues of the International Seismological Center (ISC). They obtained seismic models down to the depth of 800 km beneath Caucasus and surrounding regions. Based on the distributions of mantle heterogeneities, they proposed that delamination of the continental lithosphere of the Arabian and Eurasian Plates takes place in the collision zone. Because of sinking the mantle lithosphere parts, the asthenosphere beneath Caucasus ascend to relatively shallow depths. Unfortunately, the tomography procedure used in (Koulakov et al., 2012) got unstable for depths above 100 km depth and, thus, it did not provide the information about the interaction between the asthenosphere upwelling and crustal structures. In the present study, we use regional seismicity data recorded by seismic stations in the Caucasus region. The resulting seismic models cover the depth interval from the surface down to 70–80 km depth that allows closing the gap existed in the previous study. Joint consideration of these two models will allow identifying the mechanisms responsible for the present tectonic and volcanic activity in Caucasus.

2. Geological settings

Present geological structure of Caucasus has been formed during complex multistage evolution of the lithosphere. From the Paleozoic to Cenozoic, the formation of the main geological complexes in this area was associated with the evolution of the Paleotethys Ocean situated between Gondwana and Eurasia (Adamia et al., 2011a,b). Among the structures dated in this time range, there are both accreted fragments of Eurasia and Gondwana. The Gondwana complexes are mostly identified as parts of passive continental margins, whereas the Eurasian blocks are associated with arc volcanogenic complexes and sedimentary series indicating the presence of subduction (Khain, 1975). The final collision stage of the Arabian and Eurasian Plates occurred in the Neogene to Quaternary periods (Adamia et al., 2011a).

The Great Caucasus Range (Figs. 1 and 2) is an anticline structure with the kernel composed of Pre-Mesozoic rocks having similar properties as the basement of the Scythian Plate. The Great Caucasus Range also includes the Paleozoic ophiolites alternated with arc volcanogenic and sedimentary complexes (Khain, 1975). The marginal areas of the Great Caucasus are mostly composed of Jurassic and Carboniferous strata (Adamia et al., 2011b).

To the south of Great Caucasus, there is a series of depressions of the Transcaucasian complex consisting of the Oligocene–Neogene–Quaternary sedimentary basins (e.g., Kura and Riona valleys). They are presumed to be remnant parts of the Paratethys (Khain, 1975).

The evolution of the Lesser Caucasus (Figs. 1 and 2) is associated with the development of volcanic arcs in a period of time between Jurassic and Late Carboniferous. There is a clear differentiation in rock composition between northern and southern parts of Lesser Caucasus. The tholeiitic series mostly dominate to the south, whereas calc-alkaline lava differentiated basalt–andesite–rhyolite series are widely distributed to the north.

In Neogene–Quaternary periods, active volcanic processes took place throughout Caucasus. In Great Caucasus, two major volcanic areas, Elbrus and Kazbegi, can be identified (Fig. 2). In the Elbrus volcanic zone, there is an apparent southward migration of volcanism. It evolves from the Minaralvodes volcanism with the age of 7–5 Ma (Lebedev et al., 2006) to Chegem zone with the age of volcanism of 4–3 Ma (Gazis et al., 1995), Tyzyl lava flows of ~0.9 Ma (Hess et al., 1993), and to the youngest Elbrus volcanic complex. The activity of Elbrus started approximately 800,000 years ago and its most recent eruptions are dated back to the age of 20 Ka (Chernyshev et al., 2001). Another volcanic complex of the Great

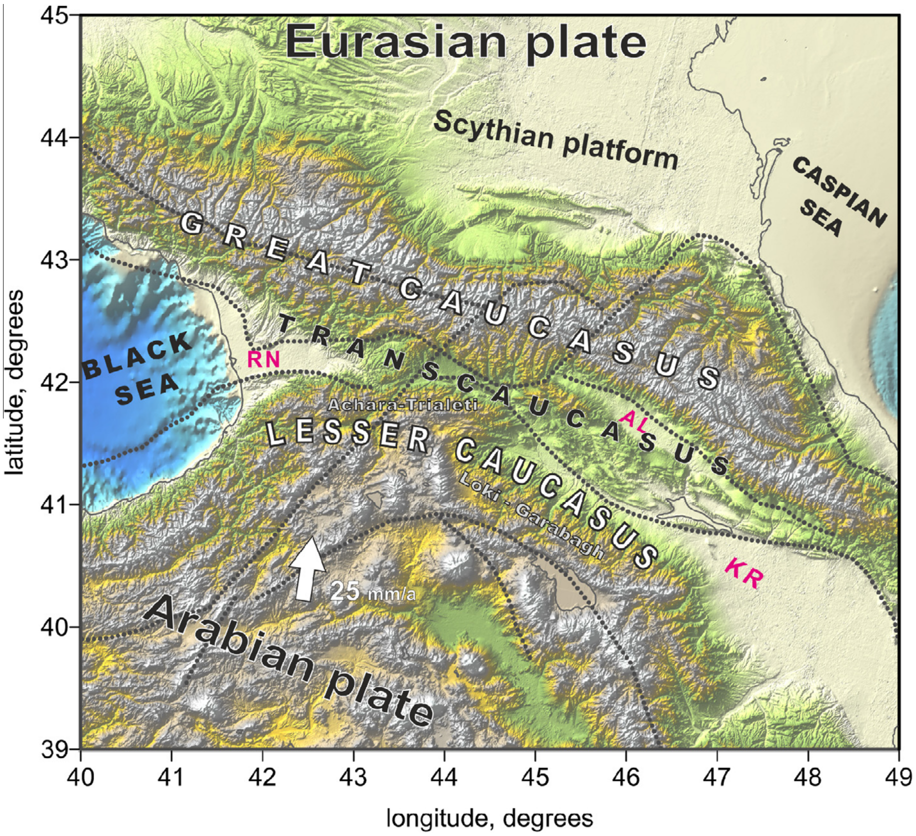

Fig. 1. Topography and major structural and tectonic elements in Caucasus and surrounding areas. Dotted lines depict the major thrust zones in Caucasus. RN – Rioni bassin, AL – Alazani bassin, KR – Kura bassin. Arrow marks the displacement of the Arabian Plate in respect to the Eurasian Plate.