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Active Tectonics and Pliocene-Pleistocene volcanic rocks of Almopia and Charopo (Sitsi-Kamen) areas in Northern Greece

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Several episodes of magmatic activity characterize the Paleogene-Quaternary geological history of Greece. Set in a back-arc geotectonic environment, this activity is the result of the south-southwestward migration of the post-collisional geodynamic settings of the Alpine orogeny (Agostini et al., 2010). The undergoing widespread regional extension of the geodynamical Northern Aegean region has been active since Eocene-Early Miocene and has resulted in the formation of distinct magmatic rock groups of plutonic to volcanic origin (Melfos and Voudouris, 2017; Sakellariou and Tsampouraki-Kraounaki, 2019). Specifically, the Cenozoic rocks of volcanic origin comprise: a) the Lower to Middle Miocene shoshonites and adakites of the northeastern Aegean region, b) the Middle Miocene to Pliocene volcanic rocks of the southeastern Aegean region, c) the Pliocene-Quaternary volcanic rocks of the northwestern Aegean region, d) the lamproites and alkaline basalts of the Aegean Islands and western Anatolia, and e) the subduction-related volcanic rocks of the southern Aegean volcanic arc (Pe-Piper and Piper, 2007).

The Pliocene to Quaternary volcanic rocks at Almopia, Charopo (Sitsi-Kamen), Doirani, Strymonikon, Euboecos, Psathoura, Vlichades, and Mikrothive belong to the group of the northwestern Aegean region (Vougioukalakis et al., 2004; Pe-Piper and Piper, 2007). This refer area corresponds with the geodynamical Northern Aegean region where the North Anatolian trough fault zone has a major role in structural control dynamics. According to Pe-Piper and Piper (2007) these rocks are the result of a slab tear at the depth of 300 km spanning from Albania to the Gulf of Corinth.

The present study focuses on the Almopia and Charopo trachytic to rhyolitic rocks which are the northernmost volcanic rocks of Pliocene to Pleistocene age found in northern Greece (Fig. 1) (Pe-Piper and Piper, 2007). They are located at Voras mountains and Aridaia plain and at the northern part of the Strymon basin respectively and their occurrences are strongly structurally controlled (Maratos, 1966; Vougioukalakis et al., 2004). At the area of Voras, the volcanic activity initiated at 6.5 Myr and terminated at 1.8 Myr shifting from east to west in an area of approximately 70 km^2. Dacites, trachytes, latites, and andesites and a rhyolitic dome describe the Voras volcanic rocks (Vougioukalakis et al., 2004). In addition, volcanic tuffs and lapilli deposits cover large areas both around these rocks and Aridaia plain (Vougioukalakis et al., 2004). The Quaternary Charopo (Sitsi-Kamen) volcanic outcrops are located near Charopo village covering an area of approximately 12 km^2 (Maratos, 1966). Rhyolitic tuffs constitute the main volcanic rocks at Sitsi-Kamen, while lavas are scarce at the surface (Maratos, 1966). The Pliocene-Quaternary hydrothermal activity is documented by the present day low-enthalpy geothermal fields occurring in both areas (Karydakis et al., 2005; Lambrakis et al., 2014).

Geological mapping at both areas has revealed the significant relation between the volcanic activity and the regional structural control mechanisms (Maratos, 1966; Vougioukalakis et al., 2004). Both regions are characterized by limited fault zones exhibiting NW-SE, NNW-SSE, and NE-SW orientations. Nevertheless, NE-SW and E-W trending remarkable fault zones highlight the predominant structural settings at the Voras and the Sitsi-Kamen areas, respectively. At Almopia region, the Voras and Aridaia volcanic activity were structurally controlled by several fault zones fragmenting the metamorphic rocks of the Almopia Subzone (Axios Zone) at the footwalls of the North Almopia-Promachi and South Almopia fault zones. The volcanic material at Charopo was extruded through the fault zone defining the border between the metamorphic rocks of the Rhodope Massif and the Quaternary sediments of the Strymon basin (Kastanoussa-Petritsi fault) (Caputo and Pavlides, 2013).

One of the most reliable and accurate ways of determining the neotectonic activity is satellite geodesy, based on permanently installed GPS/GNSS stations. Regarding the study area of Voras, 12 different stations record the primary geodetic data, including the east and north velocity components, while the corresponding stations, collecting geodetic data for the wider Sitsi-Kamen region, are totally 15. It is mentioned that the aforementioned data was collected for the seven-year time period 2008 – 2014, while the recording was implemented every 30 seconds in a daily basis. The reference frame of geodetic data is European Terrestrial Reference Frame 2000 (ETRF2000) that is coincident with the stable part of the Eurasian Plate. Concerning the data processing, the triangulation method was applied in order to extract a series of parameters (results), revealing information about the neotectonic and geodynamic setting. The principal of the triangulation method is based on the combination of the primary geodetic data of three different GPS/GNSS stations, forming a triangle (each station is located on a triangle vertex), while the use of the triangle medians leads to the estimation of the triangle centroid (Lazos et al., 2018). The implementation of the primary geodetic data into equations, expressing the surficial deformation, results in an extraction of parameters for the triangle centroid. The calculated parameters are the following: 1) maximum horizontal extension, b) minimum horizontal extension, c) area strain and d) rotation (http://www.unavco.org/). Based on the combinations of the GPS/GNSS stations of the study area, 190 different triangles were constructed (Figure 1), while the aforementioned parameters were calculated for each triangle centroid. The

extracted parameter values were geostatistically processed in a grid pattern in order to be distributed throughout the study area.

The analysis of the parameters shows that the volcanic rocks within the two study areas are directly associated with the active tectonics of the broader area. In particular, the combination of the maximum and minimum horizontal extension values confirms the regional extensional regime which favored the extrusion of the volcanic rocks. Furthermore, the area strain parameter reveals the dilatation, related to the dominant extension of the study areas. Regarding the rotational regime, the counter-clockwise rotation dominates in both areas (approximately 67% of the triangle centroids show counter-clockwise rotation) in contrast with the general clockwise rotational regime of Northern Greece. The transition from the clockwise to the counter-clockwise rotational regime documents the neotectonic activity of the study area, related to the volcanic rocks presence. In conclusion, the Pliocene-Quaternary volcanic activity of northern Greece is directly associated with the extensional regional neotectonic setting.

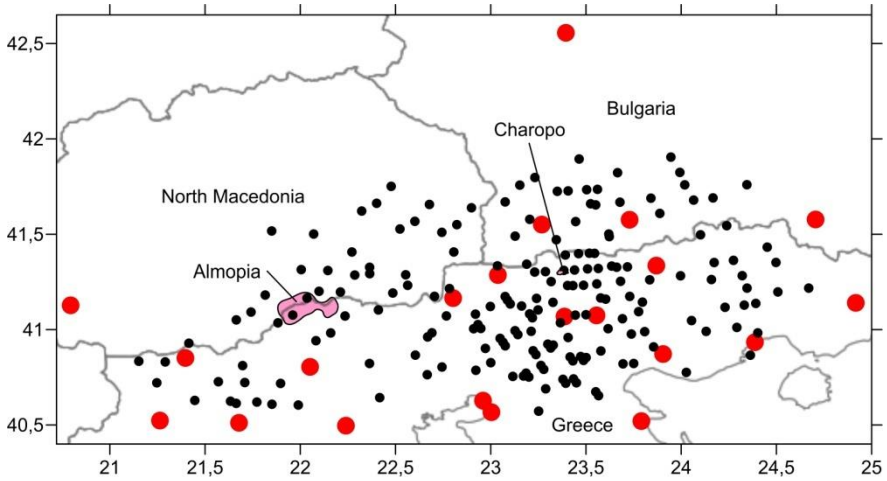

Figure 1. Permanently installed GPS/GNNS stations (red dots) and the 190 different triangle centroids (black dots) of the study area. The occurrence areas of the Almopia and Charopo (Sitsi-Kamen) volcanic rocks are highlighted.

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