MedGU Mediterranean Geosciences Union
Annual Meeting | Istanbul, 27–30 November 2023

Springer | Publishing Partner

Determination of Volcanic Ash Layers Source of Easter Caucasus Neogene Basin: Evidence from Zircon U-Pb Geochronology and Geochemistry

Avtandil Okrostsvaridze[1], Yuan-His Lee[2], Mehmet Keskin[3], Daniel Tormey[4], Giorgi Boichenko[1], Salome Gogoladze[1], Rabi Gabrielashvili[1], Mirian Makadze[5]

[1]Ilia State University, Institute of Earth Sciences, Tbilisi, Georgia
[2]National Chung-Cheng University, Earth Sciences Department, Chiayi 2018, Taiwan
[3]Istanbul Technical University, Faculty of Mines, Department of Geological Engineering, Istanbul, Türkiye
[4]Catalyst Environmental Solutions, Santa Monica, California, USA
[5]Tbilisi State University, Faculty of Natural Sciences, Tbilisi, Georgia

Abstract. This article presents new zircon U-Pb geochronology and whole rock geochemistry of the volcanic ash layers of the intermountain Neogene basin of the Eastern Caucasus. Our investigation in the region demonstrates that these ash layers, whose eruption source(s) have not been identified previously, have age and geochemical characteristics of the Kura (Mtkvari) ignimbrite flow of the Samtskhe-Javakheti volcanic highland. The current study shows that zircons from both formations crystallized at the same time ~7.50 Ma ago and have complete geochemical and morphological similarity. Taken together with the geography of the region (200-300 km from the volcanic source to the sedimentation areas), it is likely that the source of the ash layers was the Upper Miocene volcanic eruptions on the Samtskhe-Javakheti volcanic highlands. Based on volcanic ash layers distribution, thickness, and age and the analysis of the structure and scale of the Kura ignimbrite flow, the widely-distributed ash likely resulted from a large collapse caldera-forming eruption, in the Samtskhe-Javakheti volcanic highland. These eruptions led to the formation of the large-scale caldera structure (Niala caldera) and the Kura ignimbrite flow. The youngest andesitic flow of this caldera structure has been dated as ~6.5 Ma and appears to mark the termination of the activity associated with the caldera. The supposed caldera extends to the northeastern territory of Türkiye (Turkey), i.e., NE of the Kars Plateau. Ideally, this western portion of the caldera and volcanic highlands can be characterized in the future and a unified structure model of this volcanic center can be established.

Keywords: Eastern Caucasus, Volcanic Ash Layers, Zircon U-Pb Geochronology, Caldera-forming eruptions.

1. Introduction.

Owing to their physical and chemical stability, U-Pb geochronology and geochemistry of detrital zircons can provide valuable constraints to geological processes and source areas. This tool has been used successfully in the last 25 years to reconstruct the geodynamic evolution of regions through age constraints and source determination [1]. Zircon-bearing volcanic ash deposited in bodies of stagnant water is then buried by terrigenous sediments which preserve them [2]. Age dating and geochemistry of these ash layers help establish the provenance of the ash and age constraints on the eruptive source. Isotopic dating of zircons in ash is increasingly used as a tool; zircon isotopic dating and whole rock geochemistry together provide reliable arguments for correlating eruptive centers and deposition areas [3].

Terrigenous ash and sediment deposits in the Neogene basins of the eastern Caucasus intermountain regions contain numerous volcanic ash layers of various thicknesses and compositions which have been mapped and sampled [4]. According to the latest research, the main source of volcanic ash layers is considered to be caldera-forming eruptions (Gumbati eruption) during which the large-volume Kura ignimbrite flow was generated [5, 6]. This study, which is based on the zircon U-Pb geochronological and whole-rock geochemical correlation of the mentioned formations, provides firm geochronological and geochemical constraints to test these hypotheses.

2. Regional Geology

The Caucasus occupies the northern segment of the Eastern Mediterranean orogen and is distributed across an NW-SE trend over 1,100 km between the Black Sea and the Caspian Sea. Three major structural units are distinguished in the growth and development of the Caucasus: the Greater and Lesser Caucasian orogenic belts and the Transcaucasian Microplate.

Exhumation processes in the Caucasus orogen started at 10-9 Ma [7]. During this process, both the Greater and the Lesser Caucasus were exposed, which were separated by a Neogene marine sedimentary basin. The basin was subdivided into two parts by the Pre-Jurassic Dzirula crystalline massif: the eastern Caucasus intermountain Neogene Basin (Kartli, Kura, and Alazali Basins), and the western Caucasus intermountain Neogene Basin (Rioni and Enguri Basins).

In the Eastern Caucasus intermountain Neogene Basin, sedimentation was present only in molasse depressions, from Lower Miocene to Upper Pliocene [7]. In the Upper Miocene-Pliocene marine deposits, volcanic ash layers of various thicknesses and compositions are identified. The volcanic ash layers preserved in the Upper-Miocene Neogene basins are the subject of this study.

3. Materials and Methods

A suite of 12 ash samples (~3.5 kg each) was collected from the Neogene volcanic ash layers of the Eastern Caucasus intermountain depression for zircon U-Pb geochronology and whole-rock geochemistry. Zircon crystals separated from the aforementioned 12 ash samples are relatively small or sometimes not present; therefore, reliable zircons for geochronology were only available for 10 of the 12 samples. In total, more than 250 zircon grains were separated and dated.

The U-Pb zircon geochronology was conducted at the Department of Earth and Environmental Sciences, National Chung-Cheng University, Taiwan, via laser ablation inductively coupled plasma mass spectrometry equipped with an Agilent 7500s quadrupole and a New Wave UP213 laser ablation system. All twelve volcanic ash layers samples were also analyzed for whole-rock geochemical compositions by a multi-element ICP-AES/MS in MSALABS laboratory, Canada.

4. The volcanic ash layers of the Eastern Caucasus intermountain Neogene Basin

The distribution of Upper Miocene volcanic ash layers in the marine deposits of the Eastern Caucasus Neogene intermountain basin volcanic ash layers of different thicknesses are depicted in Figure 1. The thickness of ash layers within these deposits ranges from 5 m to 10-20 cm.

From the Tskhinvali outcrop (~5 m), the thickness of the volcanic ash layers decreases gradually to the east. For example, the thickness of the volcanic ash layer of the Nadarbazevi Gorge varies between 3 and 2.5 m. To the further east, the thickness of the volcanic ash layer of the Yaghluja ridge decreases to 1-1.5 m. Even further to the east, in the Davitgareji desert, the thickness of the volcanic ash layer decreases to 0.55 m. To the east, namely in Azerbaijan, near the village of Kesman, the thickness of the ash layer exposed in the Upper Miocene sediments varies only within 15-20 cm `

Visually, these layers are mostly dark gray, with some with a milky appearance and some trending to light brown. They are rather dense, fine-grained rocks and are mainly represented by andesites and rarely by rhyolites. The mineral composition of these layers is simple and mainly composed of 0.5–1.7 mm diameter volcanic glass grains, andesine, and hornblende. In some cases, crystals of magnetite, limonite, and zircons are also found.

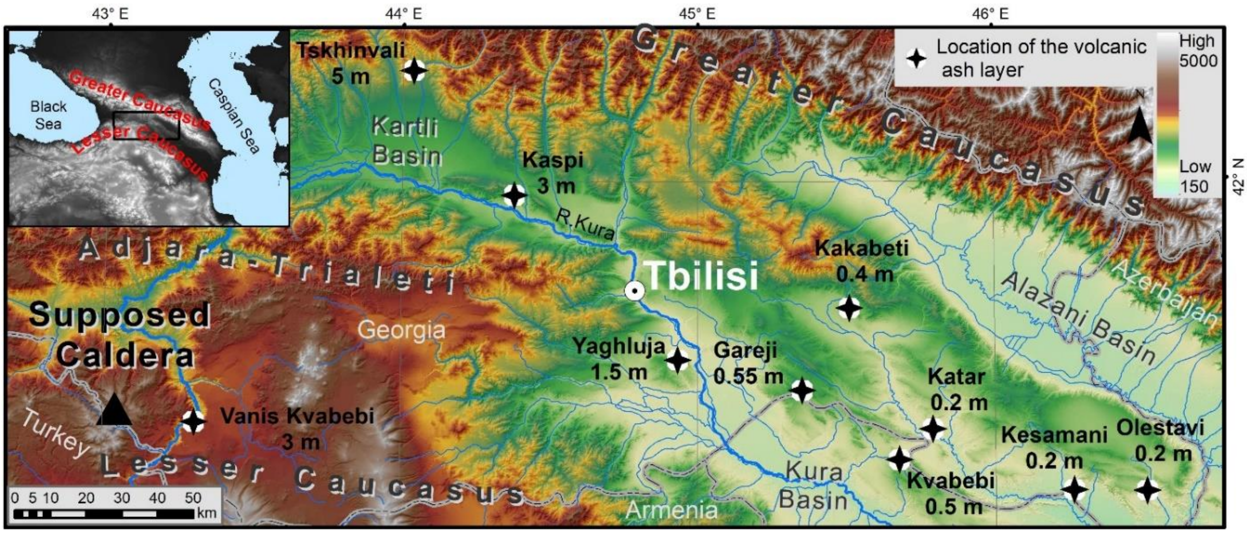

Fig. 1. Distribution of the Upper Miocene volcanic ash layers outcrops in the Eastern Caucasus intermountain Neogene basin. Black color cross indicates the location of exposure, and meter - it's thickness.

5. Samtskhe-Javakheti volcanic highland

Subaerial volcanic activity in Eastern Anatolia and the western Lesser Caucasus started from the Middle Miocene and lasted until the Holocene. This volcanic activity shaped vast volcanic highlands, present in the Georgian, Turkish, and Armenian neighboring territories [8].

Part of the highland, located in Georgia, is known as the Samtskhe-Javakheti volcanic highland. The mean elevation of the highland is about 1500–2000 m above the sea level; individual volcanic edifices, however, reach up to 3000 m. It occupies more than 4500 km^2 and discordantly covers Mid-Eocene tuff-breccias, sandstones and argillites. Our hypothesis for this work is that the volcanic ash layers of the Neogene eastern Caucasus intermountain depression are related to the powerful caldera-forming eruptions in the Samtskhe-Javakheti volcanic highland [5]. The supposed caldera is located somewhere close to the state border between Türkiye and Georgia, in the Kura River valley. This caldera is marked by post-caldera andesitic domes and flows. Mount Gumbati (2996 m.) represents the highest volcanic edifice which topographically dominates in the region. In the Kura river valley for a distance of more than 35 km from Niala's caldera to Khertvisi castle ignimbrite flows crop out, with a thickness of 60-90 m.

6. Results

From the Eastern Caucasus Neogene intermountain basin volcanic ash layer samples, many of the 250 zircon grains were detrital, which were mixed with volcanic ash zircons. The 0.5 m thick outcrop of volcanic ash layers near the Berthubani Lavra (sample #BU20, the Davit Gareji desert) is mainly composed of fine-grained plagioclase, limonite, hornblende, and volcanic glass. 25 zircons grains were extracted from this sample and we were able to date 9 grains. From these nine zircon grains, one grain (307 Ma) is clearly terrigenous and must have been transported from the Pre-Jurassic crystalline basement. The origin of two grains (26.2 Ma and 27.2 Ma) most likely represent the roof rocks of the proposed caldera. We dated these rocks from the Goderdzi pass area (#12Ge02) by the U-Pb method as 24.42±0.35 Ma (MSWD=0.45) (Upper Oligocene). Single zircon crystals of the same age are also observed directly in the Kura ignimbrite flow [6]. These actual data let us assume that the Upper Oligocene zircons in the Upper Miocene ash layers were also the most likely to be brought by volcanic ash clouds. The weighted mean U-Pb age of the remaining 6 zircons corresponds to 7.51±0.2 Ma (MSWD=0.54). These data are in complete geochronological correlation with the Kura ignimbrites zircons of the Samtskhe-Javakheti volcanic highland [6].

The U-Pb geochronological data of zircons from the Mount Yagluja volcanic ash layer (63 zircon grains), most of which are terrigenous. An important part of them are compounds of the Middle Eocene zircons (39-44 Ma), which were most likely washed off from the Adjara-Trialeti belt. Some of the zircons were dated as the Upper Carboniferous (306-319 Ma), the source of which should be considered the Transcaucasian crystalline basement. As in the Bertubani outcrop, Upper Oligocene zircons were also found in this outcrop, whose age varies in the interval of 23-29 Ma. Their source, most likely, was the same as that of Bertubani zircons, in particular, they may be roof rocks from the the proposed caldera.

Seven grains of the Upper Miocene zircons were found in the ash layer of the Yaghluja outcrop, whose U-Pb isotopic age corresponds to 6.7-7.7 Ma. These zircons are the youngest from this volcanic ash layer and we consider them to be considered contemporaneous with the deposition of this ash. Therefore, the volcanic ash layer of Mount Yaghluja, as well as Bertubni, was deposited in the Upper Miocene Epoch.

Also, we conducted whole-rock geochemical analyses of major and trace elements in 12 samples. In contrast to the major elements, trace element characteristics can be a better indicator of magmatic source than major element characteristics. The trace element characteristics show that the ash layers and the Kura ignimbrites were possibly derived from the same magma chamber. The above-discussed zircons, showed significant geochemical similarity in their U and Th contents. Specifically, in the Kura ignimbrite flow, U content ranges from 314-574 ppm, and Th content ranges from 200-628 ppm. In the zircons of the volcanic ash layers these contents range from 248-462 ppm and 174-585 ppm respectively. In addition to the geochemical characteristics, the Upper Miocene zircons of the ash layers show complete morphological similarity with the zircons of the Kura ignimbrites flow.

7. Discussion

The geochronological and geochemical evidence presented in this study supports the hypothesis that the volcanic ash layers shared the same source with the Kura ignimbrites of the Samtskhe-Javakheti volcanic highland [5, 6]. According to the U-Pb geochronological study, the young zircons of ash layers were crystallized in the Upper Miocene ~7.5 Ma, at the same time as the Kura ignimbrites flow (~7.5 Ma). The trace element geochemistry and zircon morphology are also nearly identical. It is noteworthy that the ash layers also contain a population of zircon crystals of Upper Oligocene age (23-29 Ma). This age matches the age of the roof rocks of the putative magma chamber that supplied the Kura ignimbrites. This further supports the hypothesis of a common source for both the ash layers and the ignimbrites.

Finally, the thickness distribution of the ash layers (up to 5 m in the near-source locations) indicates a source area in the direction of the Goderdzi volcanic complex. The distance between the ash layers and the caldera source (from 150 km to 300 km) indicates an extremely powerful explosive eruption.

The caldera that was formed in the source area, the Niala caldera, is currently filled with massive andesitic lava flows, domes, and debris flow materials, with the Gumbati dome. Field observation shows that the andesitic flows are the youngest formation, whose zircon U-Pb weighted age corresponds to 6.5±0.4 Ma. If we rely on these data and take into account the age of the Kura ignimbrite flow (~7.5 Ma), then this volcanic center was active for at least one million years, namely in the interval between ~7.5 Ma and ~6.5 Ma.

8. Conclusion

Investigation of the zircon U-Pb geochronology showed that the ash layers preserved in the intermontane Neogene basin of the Eastern Caucasus were deposited ~7.5 million years ago, in the Upper Miocene epoch. The U-Pb geochronology, trace element geochemistry, orientation of the distribution of volcanic ash layer thickness, and zircon morphology of young zircons from these ash layers all support the hypothesis that these layers had a common source with the ignimbrites of the Samtskhe-Javakheti volcanic highland These ignimbrites include the Kura ignimbrite flow (~7.5 Ma) and the other river ignimbrites of the Samtskhe-Javakheti highland.

Based on the distribution of the volcanic ash layers (up to 300 km from this source area) and the analysis of the structure and scale of the Kura ignimbrite flow, we conclude that both the ignimbrites and volcanic ash layers were deposited from a large collapse caldera-forming eruption or eruptions in the Samtskhe-Javakheti volcanic highland. This event formed the large-scale caldera. The youngest andesitic flow of this caldera structure has been dated as ~6.5 Ma and is interpreted as the conclusion of this volcanic cycle, lasting approximately 1 Ma. This caldera also extends to the northeastern territory of Türkiye (NE part of the Kars Plateau), where fieldwork is anticipated to support a unified structure model of this large-scale volcanic center.

This research was funded by the Shota Rustaveli National Sciences foundation of Georgia (SRNSF) (Project # 04/02) and the Scientific and Technological Research Council of Türkiye (TUBİTAK) (Project # 118Y272).

References

1. Cawood PA, Hawkesworth, CJ, Dhuime B.: "Detrital zircon record and tectonic setting". Geology 40(10):875–878. https://doi.org/10.1130/G32945.1 (2012).

2.. Dacre HF, Grant ALM, Harvey NJ, Thomson DJ, Webster HN, Marenco F.: Volcanic ash layer depth: Processes and mechanisms. Geophys Res Lett 42:637-645. https://doi.org/10.1002/2014GL062454 (2015).

3. Willcock M, Cas RAF, Giordano G, Morelli G.: The eruption, pyroclastic flow behaviour, and caldera in-filling processes of the extremely large volume (> 1290 km(3)), intra- to extra-caldera, Permian Ora (Ignimbrite) Formation, Southern Alps, Italy Journal of Volcanology and Geothermal Research 265:102-126. https://doi.org/10.1016/j.jvolgeores.2013.08.012 (2013).

4. Skhirtladze NI.: On the use of volcanic ashes for dating volcanic formation. XXII International Geological Congress, 14–22 December, New Delhi, p 207–214 (1964).

5. Okrostsvaridze A, Gagnidze N, Bobrova I, Skhirtladze I.: Late Miocene Volcanic Ash Layers of the Intermountain Depression of the Eastern Caucasus: the Products of the Megacaldera Eruption? In Proceeding of UNESCO IGCP pr. #610 meeting. Palermo, Italy, pp 148-152 (2017).

6. Okrostsvaridze A, Chung SL, Chang YH, Skhirtladze I.: Geology and Zircon U-Pb Geochronology of the Mtkvari Pyroclastic Flow and Evaluation of Destructive Processes affecting Vardzia rock-cut City. Quaternary International 540(25):137-145. https://doi.org/10.1016/j.quaint.2019.03.026 (2019).

7. Gamkrelidze I, Okrostsvaridze A, Maisadze F, Basheleisvili L, Boichenko G, Skhirtladze I.: Main Features of Geological Structure and Geotourism Potential of Georgia, the Caucasus. Journal Modern Environmental Science and Engineering 5(5):422-442. https://doi.org/10.15341/mese(2333-2581)/05.05.2019/010 (2019).

8. Keskin M.: Eastern Anatolia: A hotspot in a collision zone without a mantle plume, Plates, plumes, and planetary processes. Editors: Foulger, G.R., and Jurdy, D.M. USA: Geological Society of America Special Paper 430, p. 693–722, doi: 10.1130/2007.2430(32) (2007).