NEW LOCATION OF TRACE FOSSILS IN THE MIDDLE EOCENE (LUTETIAN) VOLCANOGENIC-SEDIMENTARY SERIES OF THE ACHARA-TRIALETI FOLD-AND-THRUST BELT (GEORGIA): PRELIMINARY STUDY RESULTS

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Abstract. Within the Borjomi canyon (the central part of the Achara-Trialeti Fold-and-Thrust Belt), one new section containing trace fossils – the Ardagani 4 section has been investigated. The examined for the first time trace fossil assemblage is closest to the *Nereites* ichnosubfacies of the *Nereites* ichnofacies, which is typical of mud- and silt-rich sediments in the distal part of deep-sea turbidite depositional systems (outer fan). The analysis of trace fossil assemblage and sedimentological features of the Ardagani 4 section suggests that the sediments of the lower part of the middle Eocene (Lutetian) of the Borjomi canyon reflect the environment of deep sea sedimentation by bottom currents. Within the Achara-Trialeti extentional basin, the existing Paleocene-lower Eocene turbidite sedimentary environment was preserved even at the beginning of the Middle Eocene.

Key words: Achara-Trialeti Fold-and-Thrust belt; middle Eocene; trace fossils.
საკვანძო სიტყვები: აჭარა-თრიალეთის ნაოჭა-შეცოცებითი სარტყელი; შუა ეოცენი; ნამარხი ნაკვალევები.

გაფართოებული რეზიუმე

ნამარხი ნაკვალევების ახალი ადგილსაპოვებელი აჭარა-თრიალეთის ნაოჭა-შეცოცებითი სარტყლის (საქართველო) შუაეოცენურ (ლუტეციური) ვულკანოგენურ-დანალექ სერიაში: კვლევის წინასწარი შედეგები. ზ. ლებანიძე, ა. უჰმანი, თ. ბერიძე, რ. ჩაგელიშვილი, კ. ლობჟანიძე, ნ. კობახიძე, ს. ხუციშვილი, დ. მაქაძე, ნ. ხუნდაძე. საქართველოს ერთ-ერთი ძირითადი ტექტონიკური ერთეულის – აჭარა-თრიალეთის ნაოჭა-შეცოცებითი სარტყლის (ათნშს) შუაეოცენური (ლუტეციური) ვულკანოგენურ-დანალექი სერიის კომბინირებული იქნოლოგიურ-სედიმენტოლოგიური კვლევები ტარდება 2023 წლი-დან. მათი წინასწარი შედეგები მოცემულია ამ ნაშრომში. ათნშს-ის ცენტრალურ სეგ-მენტში, ბორჯომის ხეობაში, ჩვენ მიერ დადგენილია ნამარხი ნაკვალევების შემცველი ერთი ახალი გამოსავალი. გამოვლინდა, აღიწერა და ინტერპრეტირებულ იქნა რვა იქნოტაქსონი. ნამარხი ნაკვალევების კომპლექსის და სედიმენტოლოგიური ანალიზის საფუძველზე, აღდგენილია ნალექდაგროვების გარემო.

შუაეოცენური (ლუტეციური) ვულკანოგენურ-დანალექი სერია ათწშს-ის დამახასიათებელი ლითოსტრატიგრაფიული ერთეულია და უმნიშვნელოვანეს როლს ასრულებს მისი დასავლური და ცენტრალური სეგმენტების აგებულებაში.

ათწშს-ის ცენტრალურ სეგმენტში ბორჯომის რაიონი ტიპიურია შუაეოცენური (ლუტეციური) ვულკანოგენურ-დანალექი სერიისთვის, სადაც მკაფიოდ გაირჩევა ერთმანეთისგან დიფერენცირებული ბაზალტ-ტრაქიანდეზიტ-დელენიტური ქვაბისხევის წყებით გაყოფილი ორი ბაზალტური დონე: ქვედა - ლიკანის წყება და ზედა - დვირის წყება (Beradze et al.,1985; Adamia et al., 2022).

შესწავლილი ჭრილი ნამარხი ნაკვალევების ადგილსაპოვებლით არდაგანი 4 (GPS კოორდინატები: 41°81.999′N, 043°41.232′E) მდებარეობს ბორჯომის ანტიკლინის ციცაბო, სამხრეთ ფრთაში, დასახლება არდაგანის სამხრეთ-აღმოსავლეთით 900 მ-ში, მდ. გუჯარეთის მარჯვენა ნაპირზე, ბორჯომ-ბაკურიანის გზის გასწვრივ. ნამარხი ნაკვალევების კომპლექსი შედგება შემდეგი ფორმებისგან: *Avetoichnus luisae* Uchman & Rattazzi, *Chondrites affinis* (Brongniart), *Ch. intricatus* (Brongniart), *Ch. targionii* (Brongniart), *Phycosiphon incertum* Fischer-Ooster, *Planolites* isp., *Scolicia* isp., *Thalassinoides* isp.. ჭრილში ნამარხი ნაკვალევები დაკავშირებულია ქვედალიკანის სიზრქის ზედა ნაწილთან, რომელიც აგებულია ვულკანოგენური, იისფერი და ზეთისხილისფერ-ნაცრისფერი თხელშრეებრივი ქვიშაქვებისა და ძალზე თხელშრეებრივი (0,5- 1 სმ) ლამქვების მორიგეობით.

ნამარხი ნაკვალევების კომპლექსი ყველაზე ახლოსაა *Nereites*-ის იქნოფაციესის *Nereites*-ის იქნოსუბფაციესთან, რომელიც ტიპიურია ლამით და სილით მდიდარი ნალექებისთვის ღრმა ზღვის დეპოზიციური სისტემების დისტალურ ნაწილში (გამოტანის კონუსის გარე ნაწილი) (Seilacher, 1974; Uchman, Wetzel, 2012). ეს დასტურდება ჰორიზონტალური, კვების და კვება-გადაადგილების ნაკვალევების (*Avetoichnus, Phycosiphon, Scolicia*) და ქემიქნიების (*Chondrites*) დომინირებით და შეესაბამება არდაგანი 4-ის ჭრილის ლამით და სილით მდიდარ ფაციესს.

ამრიგად, ბორჯომის ხეობის შუაეოცენურის ქვედა ნაწილის (ქვედალუტეციური) ნალექები ასახავს ფსკერულ დინებებთან დაკავშირებულ ღრმა ზღვის ნალექდაგროვების გარემოს. აჭარა-თრიალეთის რიფტული აუზის ფარგლებში პალეოცენურ-ქვედაეოცენურში არსებული სედიმენტაციური გარემო (Beridze et al., 2021; Lebanidze et al., 2023) შენარჩუნებულია შუაეოცენურის დასაწყისშიც.

INTRODUCTION

The Middle Eocene sedimentary and volcanogenic-sedimentary strata are widespread in the central segment of the Achara-Trialeti fold-and-thrust belt (ATFTB). However, only a few publications (Koiava, 1988; Yilmaz et al., 2001; Adamia et. al., 2013; Lebanidze et al., 2016) mention some minor and fairly general information on trace fossils in these formations (village Akhaldaba, Borjomi district). Besides, the middle Eocene sedimentary and/or volcanogenic-sedimentary facies in the remaining parts of the central part of the ATFTB as well as in its eastern part lack any up-to-date ichnological and sedimentological studies and require detailed

investigations often followed by reinterpretation of identified facies architecture and depositional environments.

Since 2023, the authors have initiated comprehensive ichnological-sedimentological studies of the Middle Eocene (Lutetian) volcanogenic-sedimentary strata of the central and eastern parts of the ATFTB. Preliminary results of these studies are presented in this paper. The description and interpretation of one of the recently established sections with associated trace fossils is presented in the paper. Eight ichnotaxa have been identified within the section. On the basis of the trace fossil assemblage and sedimentological analysis, the corresponding depositional environment has been interpreted.

GEOLOGICAL SETTING AND STRATIGRAPHY

The study area is a part of one of the main tectonic units of Georgia – the Achara-Trialeti Fold-and-Thrust Belt (ATFTB). The latter is located in the frontal part of the Lesser Caucasus orogeny, and it extends in a 45–65 km-wide belt on a distance 360 km along the strike, from the Black Sea coast towards Tbilisi, where it submerges under Oligocene-Neogene sediments of the foreland Kura Basin (Adamia et. al., 2015) (Fig. 1A). The ATFTB resulted from the structural inversion of a deformed back-arc rift basin filling; the basin was the likely eastward prolongation of the Eastern Black Sea, and opened in Cretaceous-Eocene times (Adamia et al., 2011; Sosson et al., 2016). The present-day geometry of the ATFTB is related to the northward thrusting of the basement wedge(s) and was developed during middle–upper Miocene – Pleistocene (Banks et al., 1997; Alania et al., 2017; Corrado et al., 2021; Gusmeo et al., 2021). The ATFTB is composed of syn-rift (Cretaceous–Upper Eocene), post-rift (Oligocene–Lower Miocene) megasequences, and syn-orogenic strata (Middle Miocene–Pleistocene). Their stratigraphic relationships are disturbed by extensional to compressional complex phases of tectonism since the Cretaceous (Alania et al., 2021).

Deposits constituting the ATFTB accumulated in the Achara-Trialeti extensional trough-like basin during Late Cretaceous–Eocene times. Aptian and Albian volcanogenic-sedimentary formations are the oldest units of the trough (Gamkrelidze, 1949; Lordkipanidze et al., 1989; Nadareishvili, 1999). They are overlain by Cenomanian–Maastrichtian alternations of volcanogenic and carbonate rocks and Paleocene (Danian) marls. The Upper Paleocene (Thanetian) and Lower Eocene (Ypresian) stages ascribed as the Borjomi Flysch or the Borjomi Suite (Obruchev, 1923; Gamkrelidze, 1949) are mainly represented by deep-sea deposits (Lebanidze et al., 2019; Uchman et al., 2020; Beridze et al., 2021; Uchman et al., 2022a, b). The relatively thick Eocene basin fill within the study area is represented by deposits of a back-arc extensional basin (Tari et al., 2021). The Borjomi Suite is conformably covered by thick Middle Eocene (Lutetian) volcanic and volcaniclastic series in the ATFTB. The latter is maximum ca. 5000 m thick in Achara (western segment of ATFTB), thins to the east in the Borjomi district (western part of the Trialeti Ridge) to 2000–3000 m, and is only up to ca. 200–300 m thick in the outskirts of Tbilisi (eastern part of the Trialeti ridge). The Upper Eocene (Priabonian)–Oligocene (?) at the western segment of the ATFTB is also represented by volcanogenic-sedimentary formations, which reach their maximum thickness in Achara (western ATFTB). To the east,

they are replaced by clastic turbidites. In the easternmost part of the ATFTB (Tbilisi), Upper Eocene shale-dominated siliciclastic turbidites are conformably overlain by Oligocene–Lower Miocene ones (Adamia et al., 2015; Tari et al., 2021). In the study area, the Upper Eocene overlies the Middle Eocene strata with unconformity and is represented by terrigenous sediments of the Marda Suite, followed by gypsum bearing sediments of the Oligocene Maikop Series. The section terminates by the andesites and volcaniclastic rocks of the Upper Miocene Goderdzi Suite (Obruchev, 1923; Gamkrelidze, 1949; Adamia et al., 2022) (Fig. 2).

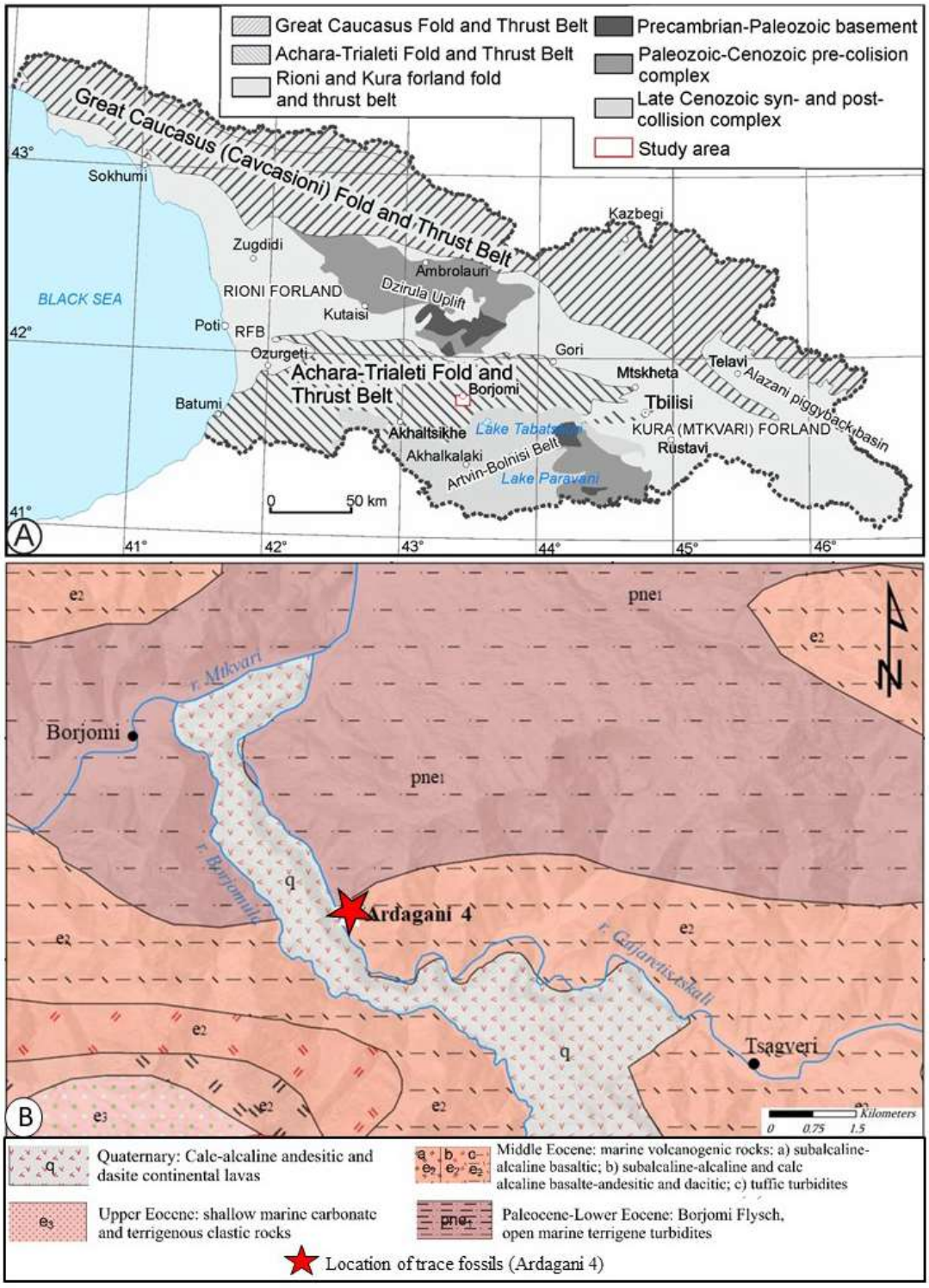

Fig. 1. Location maps. A. map of Georgia, with indication of the main geological units and the study area (based on Adamia et al., 2011). B. map of the Borjomi area, with indication of the section Ardagani 4. (based on Adamia, 2004).

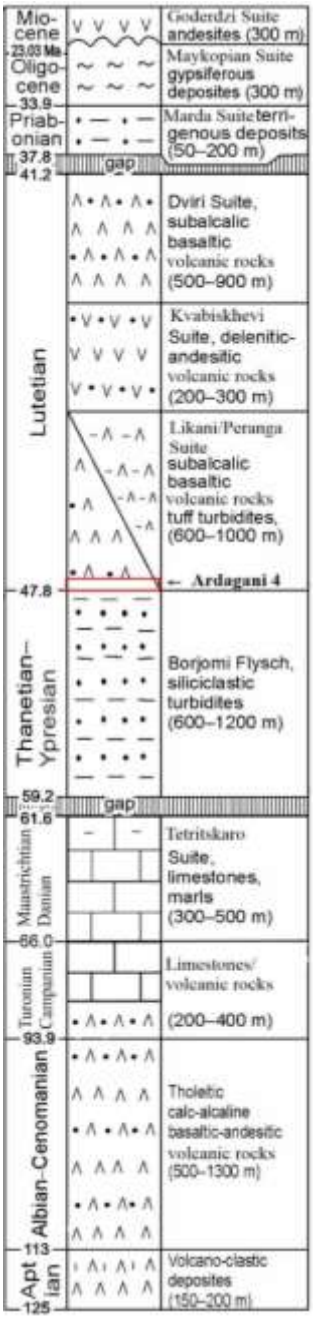

Fig. 2. Stratigraphic column of the Central Achara-Trialeti Fold-and-Thrust Belt (based on Adamia et al., 2015, changed) showing location of the section studied.

The Middle Eocene (Lutetian) volcanogenic-sedimentary series is the characteristic litho-stratigraphic unit of the ATFTB. According to chemical composition, two levels of predominantly subalkaline basalts and their pyroclastic equivalents are clearly defined here. The lower stratigraphic position is occupied by the Likani Suite (subalkaline basaltic volcaniclastics and lava-flows). It is followed by the Dviri Suite (thick-bedded and massive volcaniclastics of subalkaline basalts) with the Kvabiskhevi Suite (diverse series of subalkaline highly aluminiferous basalt-trachyandesite-dellenite rocks with minor calc-alkaline plagiobasalts and andesites) in-

between (Gamkrelidze P., 1949; Lordkipanidze, 1980; Lordkipanidze et al., 1989; Gamkrelidze & Lobzhanidze, 1984; Beradze et al., 1985; Yilmaz et al., 2001; Adamia et al., 2022).

The studied section belongs to the lower part of the Likani Suite (typical locality of the section near village Likani). According to the most up-to date description and interpretation by Yilmaz et al. (2001), the Likani Suite (E_2^2lk) conformably lies over the Paleocene-lower Eocene strata and is represented by gray, greenish, dark-grey, and, in places, brown-reddish, thin- to middle-bedded, comparatively fine-grained volcaniclastic turbidites alternating with calcareous mudstones and marlstones. The rhythmic bedding with the convolute pelitic bands, channelized sandstones, meandering-and-coiled trace fossils (called "meandrites" by the cited authors), flute casts, and other sedimentary features are common in this suite. Up the section, volcanoclastic facies become coarser, argillites and marls disappear, and instead channelized sandstones and slumped beds are observed. According to the cited authors, lithological features (e.g., flute casts, "meandrites") and fossil content of this suite indicate hemipelagic to shallow marine or at least a hemipelagic deposition. The total thickness of the suite in the southern limb of the Borjomi Anticline reaches 1030 m (Gamkrelidze & Lobzhanidze, 1984). Beradze et al. (1985) identified three units within the Likani Suite, i.e., the lower and upper Likani units, which are mainly made up by thinly bedded (1-3 cm), from red to brown and dark grey fine- and medium - grained tuffs and tuffitic sandstones with intercalations of marly and clayey greywacke sandstones and fine-grained siltstones in the lower unit, and coarsening of the material in the middle part of the upper unit. The middle Likani Unit is rich in massive tuffaceous sandstone beds. In the study area, according to these authors, the composition and thickness of units are fairly variable. Although, the presence of very thick (up to 10 m), massive, very coarse-to-coarse, and medium-grained tuffaceous sandstones is typical for all sections. Our preliminary field observations confirm some of the observations made by Yilmaz et al. (2001) and Beradze et al. (1985), but detailed field and desktop studies are still in progress.

STUDIED SECTION AND TRACE FOSSILS

The section Ardagani 4 (N 0372434; E 4628443; h = 908 m a.s.l.) is located in the steep southern limb of the Borjomi Anticline, 900 m SE of the settlement Ardagani, on the right bank of the river Gujareti, along the Borjomi-Bakuriani motorway (Fig. 1B, 3).

The trace fossils are associated with the upper part of the lower Likani unit, which is made up by alternation of purple and olive grey, thinly bedded sandstones, and very thinly bedded (0.5–1 cm) mudstones. The trace fossil assemblage consists of *Avetoichnus luisae* Uchman & Rattazzi, *Chondrites affinis* (Brongniart), *Ch. intricatus* (Brongniart), *Ch. targionii* (Brongniart), *Phycosiphon incertum* Fischer-Ooster, *Planolites* isp., *Scolicia* isp., and *Thalassinoides* isp (Fig. 4).

Fig. 3. The studied deposits of the Ardagani 4 section. View to the outcrop from the SW. The ruler as a scale at the outcrop base (red arrow) -1m.

SYSTEMATIC DESCRIPTION OF TRACE FOSSILS

Avetoichnus **Uchman and Rattazzi, 2011**

Avetoichnus luisae **Uchman and Rattazzi, 2011**

Fig. 4A

Description: Straight or slightly curved, horizontal to subhorizontal, helical spiral around a simple tube; 2.0–4.0 mm in diameter; filling of spiral is darker than matrix.

Behavior(s): Agrichnia.

Possible tracemaker: "Worm"-like invertebrate.

Thalassinoides **Ehrenberg, 1944**

Thalassinoides **isp.**

Fig. 4B

Description: Endichnial, horizontal, tubular, Y-shaped branched burrow, about 10 mm in diameter, with distinct margins. The branching point swollen to a width of 25 mm.

Behavior(s): Deposit-feeding and dwelling.

Possible tracemakers: Crustaceans.

Chondrites targionii **(Brongniart, 1828)**

Fig. 4C

Description: Endichnial, horizontal to oblique, flattened tubular tunnels, 1.8–2.0 mm wide, with a dendroid branching pattern and commonly slightly curved branches. The tunnels are filled with sediment lighter than the host rock.

Behavior(s): Chemichnia, fodinichnia.

Possible tracemakers Sipunculid or other marine "worm"-like organism similar to modern polychaetes.

Scolicia de Quatrefages, 1849

Scolicia isp.

Fig. 4D

Description: Two morphotypes of unspecified *Scolicia* have been found. Form A is a horizontal, hypichnial straight band, 20–22 mm wide, bounded by two strings, each about 5 mm wide. In form B, the filling is weathered out, and the trace fossil is visible as an endichnial groove with an axial string and ribbed slopes.

Behavior(s): Locomotion or feeding trace.

Possible tracemakers: Irregular echinoids.

Chondrites intricatus (Brongniart, 1823)

Fig. 4E

Description: A system of downward penetrating, tree-like branching and flattened tunnels, up to 1 mm in diameter. The tunnels are straight and show phobotaxis. There are first-, second-, and rarely third-order branches, diverging at acute angles. In cross-section, this form shows patches of circular to elliptical spots and short bars. The tunnels are filled with material that is commonly darker than the host rock.

Behavior(s): Chemichnia, fodinichnia.

Possible tracemaker: Sipunculid or other marine "worm"-like organism similar to modern polychaetes.

Phycosiphon Fischer-Ooster, 1858

Phycosiphon incertum Fischer-Ooster, 1858

Fig. 4F

Description: Epichnial, small horizontal lobes, up to 4 mm across, encircled by a narrow marginal tunnel less than 1 mm wide.

Behavior(s): Deposit feeding.

Possible tracemakers: A "worm"-like organism.

Planolites Nicholson, 1879

Planolites isp.

Fig. 4F

Description: Simple, unlined, unbranched cylindrical, or subcylindrical infilled burrows without walls, straight to gently curved, horizontal to oblique to bedding planes. Burrows may crossover. The lithology of the filling may differ or not from that of the host rock.

Behavior(s): Deposit feeding, dwelling.

Possible tracemakers: Various invertebrate burrowing organisms, including "worms".

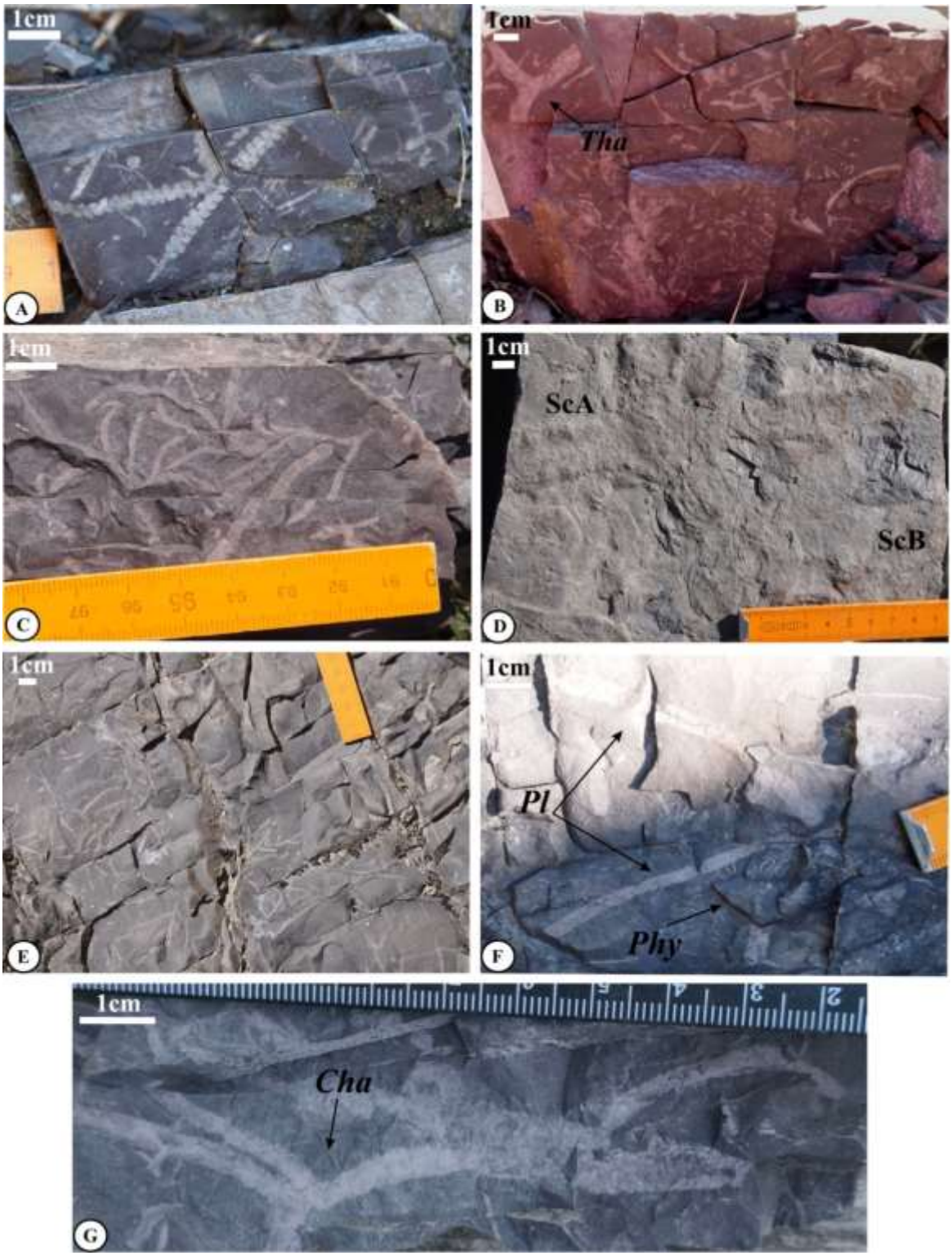

Fig. 4. Trace fossils in the Ardagani 4 section. A. *Avetoichnus luisae.* B. *Thalassinoides* isp. (Tha.). C. *Chondrites targionii.* D. *Scolicia* isp. Form A (ScA) and Form B (ScB). E. *Chondrites intricatus.* F. *Planolites* isp. (*Pl*) and *Phycosiphon incertum* (Phy). G. *Chondrites affinis (Cha).*

Chondrites Sternberg, 1833

Chondrites affinis (Brongniart, 1849)

Fig. 4G

Description: Structure composed of almost horizontal, unlined, branched tunnels, which are 3–4 mm wide. The tunnels are filled with sediment lighter than the host rock. The structure is over 70 mm wide.

Behavior(s): Chemichnia, fodinichnia.

Possible tracemaker: Sipunculid or other marine "worm"-like organism similar to modern polychaetes.

DISCUSSION

In the Ardagani-4 section trace fossils *Avetoichnus luisae* Uchman & Rattazzi, *Chondrites affinis* (Brongniart), *Ch. intricatus* (Brongniart), *Ch. targionii* (Brongniart), *Phycosiphon incertum* Fischer-Ooster, *Planolites* isp., *Scolicia* isp., *Thalassinoides* isp. occur in the upper part of the lower Likani unit, which is made up by alternations of purple and olive grey, thinly bedded sandstones, and very thinly bedded (0.5–1 cm) mudstones. The trace fossil assemblage is atypical of any exactly defined ichnofacies, but is closest to the *Nereites* ichnosubfacies of the *Nereites* ichnofacies, which is typical of mud- and silt-rich sediments in the distal part of deep-sea turbidite depositional systems, mostly outer fan (Seilacher, 1974; Uchman, Wetzel, 2012) and, for example, is similar to the Eocene Bystrica Formation (Magura Nappe, Carpathian Flysch, Poland) section (Uchman, 2008). This is exemplified by the dominance of horizontal, feeding and feeding-locomotion traces (*Avetoichnus*, *Phycosiphon*, *Scolicia*) and chemichnia (*Chondrites*). This corresponds well to the mud- and silt-rich facies of the Ardagani-4 section. It should be noted that the richest in trace fossils sections Ardagani-1 (Paleocene) and Ardagani-3 (Lower Eocene) were investigated by the authors of this paper in the stratigraphically lower (Paleocene–lower Eocene) parts of the section (Uchman et al., 2020; Beridze et al., 2021; Lebanidze et al., 2023), which indicate the deep-sea turbiditic depositional environment.

Thus, the deposits of the lower part of the Middle Eocene (Lutetian) of the Borjomi canyon record the environment of deep-sea sedimentation by bottom currents. The Paleocene–lower Eocene sedimentary environment within the rift Achara-Trialeti Basin (Uchman et al., 2020; Beridze et al., 2021; Lebanidze et al., 2023) was continued during the beginning of the Middle Eocene.

CONCLUSIONS

The results of recent ichnological-sedimentological studies allow us to assume:

- The trace fossil assemblage identified in the Ardagani-4 section is closest to the *Nereites* ichnosubfacies of the *Nereites* ichnofacies, which is typical of mud- and silt-rich sediments in the distal part of deep-sea depositional systems (outer fan);

- Deposits of the lower part of the Middle Eocene (Lutetian) strata of the Borjomi canyon reflect the environment of deep-sea sedimentation by bottom currents.
- The Paleocene-Lower Eocene depositional environment in the Achara-Trialeti rift basin was preserved during the beginning of the Middle Eocene as well.

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REFERENCES

Adamia Sh. (ED). (2004). Geological Map of Georgia 1: 500,000. Tbilisi, Georgia. Department of Geology, Nodia Institute of Geophysics. http://www.ig-geophysics.ge/Georgia_Geology_1.jpg.

Adamia Sh., Chkhotua T., Gavtadze T., Lebanidze Z., Lursmanashvili N., Sadradze N., Zakaraia D., Zakariadze G. (2015). Tectonic setting of Georgia – eastern Black Sea: a review. In: Sosson M., Stephenson R., Adamia S. (Eds). Tectonic Evolution of the Eastern Black Sea and Caucasus //Geological Society, London, Special Publications, 428, pp. 10-40.

Adamia Sh., Sadradze N., Alania V., Talakhadze G., Khmaladze K., Sadradze G. (2022). Geology and Geodynamics of the Lithosphere of Georgia; 1:200000-scale Digital Geological Map and Explanatory Note of Georgia. Ivane Javakhishvili Tbilisi State University, Mikheil Nodia Institute of Geophysics, Proceedings, vol. LXXIV, pp. 1-169.

Adamia Sh., Sadradze N., Zakaraia D., Tsereteli N., Zakariadze G., Migineishvili R. (2013). Gudauri-Mtskheta-Borjomi-Tbilisi. In: Tectonic Evolution of the Eastern Black Sea and Caucasus//Field Guide: June 26-29. Darius Program, pp. 77-85.

Adamia Sh., Zakariadze G., Lordkipanidze M., Salukvadze G. (1974). The geological structure of Achara. In: Gamkrelidze, P., Rubinshtein, M. (Eds). Problems of the Geology of the Achara-Trialeti//Proceedings of the Geological Institute of the Academy of Scinces of the GSSR. "Metsniereba", Tbilisi, 44, pp. 60-69 (in Russian).

Alania V., Beridze T., Enukidze O., Chagelishvili R., Lebanidze Z., Maqadze D., Razmadze A., Sadradze N., Tevzadze N. (2021). The geometry of the two orogens convergence and collision zones in Central Georgia: new data from seismic reflection profiles. In: Bonali F., Mariotto F., Tsereteli N. (Eds.). Building Knowledge for Geohazard Assessment and Management in the Caucasus and other Orogenic Regions//NATO Science for Peace and Security, Series C: Environmental Security, Springer, Dordrecht, pp. 73-88.

Alania V., Chabukiani A., Chagelishvili R., Enukidze O., Gogrichiani K., Razmadze A., Tsereteli N. (2017). Growth structures, piggyback basins and growth strata of Georgian part of Kura foreland fold and thrust belt: implication for Late Alpine kinematic evolution//Geological Society, London, Special Publications 428, pp. 171-185.

Banks C., Robinson A., Williams M. (1997). Structure and regional tectonics of the Achara-Trialeti fold belt and the adjacent Rioni and Kartli foreland basins. Republic of Georgia. In: Robinson, A.G. (Ed.). Regional and Petroleum Geology of the Black Sea and Surrounding Region//AAPG Memoir. 68, pp. 331-346.

Beradze R., Gamrekeli G., Bandzava D., Kavtaradze S., Areshidze R., Labadze I., Zhgenti A., Geguchadze L., Lebanidze Z., Sabanadze M., Sagiridze L. (1985). Report (#16838) of the Trialeti geological-prospecting party about 1:25000 scale mapping within the sheets K-38-75-Б-в, г and K-38-75-Г-а, б (the central part of the Achara-Trialeti economic region) on the basis of conducted works in 1982–1985// Geological-Geophysical expedition for regional exploration, Trialetian geological mapping party, Geological Department of the Ministry of Geology of the Georgian SSR, Tbilisi, 1-400. Catalogue of the geological fund of the National Agency of Mineral Resources, Georgia, pp. 1-400 (in Russian).

Beridze T., Lebanidze Z., Uchman A., Lobzhanidze K., Khutsishvili S., Chagelishvili R., Kobakhidze N., Makadze D., Khundadze N., Koiava K. (2021). Ichnological-sedimentological indicators of deep-sea environment in Lower Eocene deposits of the Borjomi region (Georgia) // In: 35th Meeting of Sedimentology: Prague, Czech Republic 21–25 June 2021, Book of Abstracts (eds. Bábek O., Vodrážková S.), Palacký University of Olomouc, pp. 55-56.

Buatois L.A., Mángano M.G. (2011). Ichnology: Organism-substrate interactions in space and time. Cambridge University Press, Cambridge, pp. 1–358.

Corrado S., Gusmeo T., Schito A., Alania V., Enukidze O., Conventi E., Cavazza W. (2021) Validating far-field deformation styles from the Adjara-Trialeti fold-and-thrust belt to the Greater Caucasus (Georgia) through multi-proxy thermal maturity datasets. Marine and Petroleum Geology, 130: 105-141.

Gamkrelidze I., Lobzhanidze G. (1984). Geology of Central Adjara-Trialeti and the Problem of Borjomi Mineral Water//Proceedings of Geological Institute of Academy of Sciences of GSSR. 83, pp. 1-81 (in Russian).

Gamkrelidze P. (1949). Geological Structure of Achara-Thrialethi Fold System//Academy of Scinces of the GSSR, pp. 1-507 (in Russian).

Geology of the USSR. (1964). Gamkrelidze P. (ed). Georgian SSR., v. X, Moscow, Nedra Publisher, pp. 1–655 (In Russian.).

Gusmeo T., Cavazza C., Alania V., Enukidze O., Zattin M., Corrado S. (2021) Structural inversion of back-arc basins - The Neogene Adjara-Trialeti fold-and-thrust belt (SW Georgia) as a far-field effect of the Arabia-Eurasia collision. Tectonophysics, 803: 228702.

Koiava V. (1988). Litology//TSU Publisher, pp. 1-591 (in Georgian).

KU Ichnology. Trace fossils. Invertebrate.

Lebanidze Z., Koiava K., Khutsishvili S., Chagelishvili R., Khundadze N., Beridze T. (2016). Trace Fossils in the Paleogene Deposits of Borjomi Area (the Central Segment of the Achara-Trialeti Fold and Thrust Belt, Georgia): Preliminary Data of Ichnological Studies. In: Baucon A., Neto de Carvalho., Rodrigues J. Ichnia 2016: Abstract Book //UNESCO Geopark Naturtejo/ International Ichnological Association, Castelo Branco, Portugal, pp. 42-43.

Lebanidze Z., Uchman A., Beridze T., Kobakhidze N., Lobzhanidze K., Makadze D., Khutsishvili S., Chagelishvili R., Koiava K., Khundadze N. (2023). Ichnofacies Interpretation of Trace Fossils Occurrences in the Paleocene-Lower Eocene Deposits of the Borjomi Canyon//Bulletin of the Georgian National Academy of Sciences 17, N3, pp. 49-54.

Lordkipanidze, M. 1980. Alpine volcanism and geodynamics of the central segment of the Mediterranean belt. Proceedings of A. Janelidze Geol. Inst. of Academy of Sciences of GSSR, 69, pp. 1–162 (in Russian).

Lordkipanidze M., Meliksetian B., Djarbashian R. (1989). Mesozoic-Cenozoic magmatic evolution of the Pontian Crimean-Caucasian region//Mem. Soc. Géol. France. 154, pp. 103–124.

Nadareishvili G. (1999). Cretaceous volcanic formations of Georgia. Proceedings of A. Janelidze Geological Institute of Academy of Scinces of Georgia, 114, pp. 79-194 (In Russian.).

Obruchev S. (1923). Geological outline of the Borjomi region//Proceedings of Institute of Applied Mineralogy and Petrography 1, pp. 1–104 (In Russian).

Seilacher A. (1974). Flysch trace fossils: evolution of behavioural diversity in the deepsea. Neues Jahrb. Geol. Paläont. Monatsh pp. 233–245.

Sosson M., Stephenson S., Sheremet Y., Rolland Y., Adamia S., Melkonian R., Kangarli T., Yegorova T., Avagyan A., Galoyan G., Danelian T., Hässig M., Meijers M., Müller C., Sahakyan L., Sadradze N., Alania V., Enukidze O., Mosar J. (2016). The Eastern Black Sea-Caucasus region during Cretaceous: new evidence to constrain its tectonic evolution. Compte-Rendus Geosciences, 348, pp. 23–32.

Tari G., Vrsic A., Gumpenberger T., Mekonnen E., Hujer W., Fallah M., Tevzadze N., Janiashvili A., Pace P., Ricciato A., Alania V., Enukidze O. (2021) Eocene volcaniclastic reservoir rocks in the Kartli Basin, Georgia: a fractured reservoir sequence. Journal of Petroleum Geology 44, pp. 413–434.

Uchman A. (2008). Stop 8, Zbludza, Beloveža Formation (Eocene) and Bystrica Formation (Eocene): Outer fan ichnology and sequential colonization of turbidites. In: Pieńkowski, G. & Uchman, A. (Eds), The Second International Congress on Ichnology, Cracow, Ichnological sites of Poland: The Holy Cross Mountains and the Carpathian Flysch, The Pre-congress and Post-congress Field Trip Guidebook. Polish Geological Institute, Warsaw, pp.124–131.

Uchman A., Rattazzi B. (2011). The new complex helical trace fossil *Avetoichnus luisae* igen. n. et isp. n. from the Cainozoic deep-sea sediments of the Alpine realm: a non-graphoglyptid mid-tier agrichnion. Neues Jahrbuch für Geologie und Paläontologie – Abhandlungen, Band 260, Heft 3, pp. 319–330.

Uchman A., Wetzel A. (2012). Deep-sea fans. In: Bromley, R.G., Knaust, D. (Eds.), Trace fossils as indicators of sedimentary environments. Dev. Sedimentol, 64, pp. 643–671.

Uchman, A., Lebanidze, Z., Beridze, T., Kobakhidze, N., Lobzhanidze, K., Khutsishvili, S., Chagelishvili, R., Makadze, D., Koiava, K., Khundadze, N. (2020). Abundant trace fossil *Polykampton* in Paleogene deep-sea flysch deposits of the Lesser Caucasus in Georgia: palaeoecological and paleoenvironmental implications. Palaeogeography, Palaeoclimatology, Palaeoecology 558: 109958.

Yilmaz A, Engin T., Adamia S., Lazarashvili T. (Eds.). (2001). Geological Studies of the Area Along Turkish-Georgian Border//Mineral Reseaarch and Exploration Institute (MTA) of Turkey, Ankara, 388 p.

Zakariadze G., Dilek Y., Adamia S., Oberhänsli R., Karpenko S., Bazylev B., Solov'eva N. (2007). Geochemistry and geochronology of the Neoproterozoic Pan-African Transcaucasian Massif (Republic of Georgia) and implications for island-arc evolution of the late Precambrian Arabian–Nubian Shield//Gondwana Research 11, pp. 92–108.

Zakariadze G., Karamata S., Korikovsky S., Ariskin A., Adamia S., Chkhotua T., Sergeev S., Solov'eva N. (2012). The Early-Middle Paleozoic oceanic events along the southern European margin: The Deli Jovan Ophiolite Massif (NE Serbia) and paleooceanic zones of the Great Caucasus//Turkish Journal of Earth Sciences 21, pp. 635–668.

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