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Thin-and thick-skinned nappes of the southern slope of the Georgian Greater Caucasus: indicators of syn-collisional A-type subduction

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ABSTRACT:

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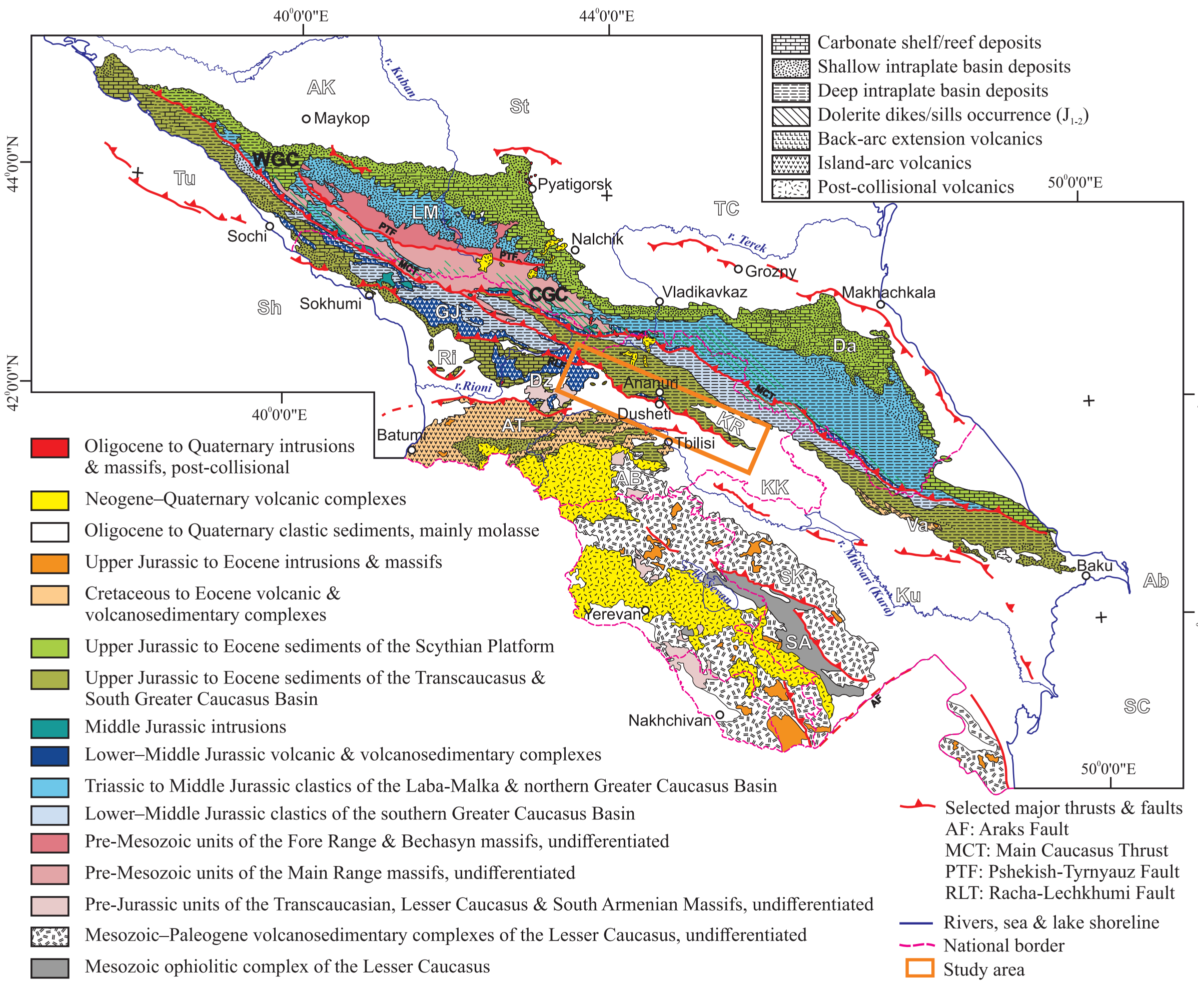
In the region of the Caucasus considered herein two large structural complexes have been identified: an autochthone, including the Gagra-Java zone (GJZ) of the Greater Caucasus fold-and-thrust belt, the Kura foreland basin (KFB), and an allochthone consisting of the Utsera-Pavleuri, Alisisgori-Chinchvelta, Sadzeguri-Shakhvetila, Zhinvali-Pkhoveli nappes and Ksani-Arkala parautochthone. The nappes are established on the basis of paleogeographic reconstructions, structural data, as well as drilling and geophysical data. The leading mechanism for the nappe formation is the advancement to the north and the underthrusting of the autochthone under the Greater Caucasus (A-type subduction). The nappes were formed mainly in the Late Alpine time (Late Eocene–Early Pliocene) and include only the sedimentary cover of the Earth's crust (thin-skinned nappes). However the basal detachment (décollement) of the nappes, according to seismic data, penetrates deeply and cuts the pre-Jurassic crystalline basement, and even the entire Earth's crust representing thick-skinned deformation. The total horizontal displacement of the flysch nappes of the southern slope of the Greater Caucasus in their eastern (Kakhetian) part is 90–100 km. While, considering the folding of the entire Greater Caucasus, the total transverse shortening of the Earth's crust within its limits is equal to 190–200 km.

Key words: Greater Caucasus; Autochthon; Allochthon; Alpine tectonic shortening.

INTRODUCTION

The Greater Caucasus mountain range situated between the Black Sea and the Caspian Sea is a component of the Caucasus (Text-fig. 1) which forms an orogenic system whose geologic structure and position in the Alpine-Himalayan belt is determined by the still converging Eurasian and Arabian lithospheric plates (Allen *et al.* 2004; Gamkrelidze 1986; Jackson 1992; McClusky *et al.* 2000; Tan and Taymaz 2006; Vernant *et al.* 2004, Mosar *et al.* 2022). During Mesozoic–Early Cenozoic times, the region belonged to the now-vanished Neotethys-Eurasia ocean-continent convergence zone (Gamkrelidze 1986; Adamia *et al.* 2011; Adamia and Zakariadze 2011).

The Greater Caucasus Mountain range (fold-and-thrust belt), with a length of more than 1150 km, evolved from an intracontinental basin in the southern margin of the Eurasia (Scythian) plate. In Alpine time (since the Liassic) the Greater Caucasus basin was initiated as a backarc rift basin complementary to the northward subduction of the Neotethyan



Text-fig. 1. Tectonostratigraphic map of the Caucasus (Russian North Caucasus, Georgia, Azerbaijan, and Armenia) indicating its pre-Mesozoic basement massifs, Mesozoic–Cenozoic sedimentary units, Mesozoic–Cenozoic magmatic (intrusive and extrusive) features, and main thrusts after Mosar *et al.* (2022). The Main Caucasus Thrust (MCT) is considered the separation between the northern units (including the Scythian Platform) and the southern units (including the Transcaucasian domain) of the former Greater Caucasus Basin. Dolerite dykes are of Pliensbachian–Toarcian, possibly Aalenian age (J1–J2). Abbreviations: Fore-Caucasus: AK – Azov-Kuban Basin; St – Stavropol High; TC – Terek-Caspian Basin. Greater Caucasus s.l.: Ab – Absheron Sill; CGC – Central Greater Caucasus; Da – Dagestan Fold-and-thrust belt; EGC – Eastern Greater Caucasus; GJ – Gagra-Java Zone; KK – Kura-Mtkvari (Kartli) Foreland fold-and-thrust belt; KR – Kakheti Ridge; LM – Laba-Malka Homocline; Ri – Rioni Foreland fold-and-thrust belt; TS – Terek-Sunzha Foreland fold-and-thrust belt; Tu – Tuapse Trough; Va – Vandam Zone; WGC – Western Greater Caucasus. Transcaucasian domain: AT – Ajara-Trialeti Fold-and-thrust belt; Dz – Dzirula High; Ka – Kartli Basin; Sh – Shatsky Ridge. Lesser Caucasus-South Caspian domain: AB – Artvin-Bolnisi High; Ku – Kura Basin; SC – South Caspian Basin; SK – Somkheto-Karabakh Fold-and-thrust belt; Ta – Talysh Fold-and-thrust belt. South Armenian domain: SA – Sevan-Akera Suture zone.

oceanic crust beneath the Lesser Caucasus – Transcaucasus island arc (Gamkrelidze 1986). The present-day orogenic wedge formed by inversion of this basin during Alpine collisional events (since the Late Eocene) due to the north-south convergence of two plates: the Arabian (as indenter) and Eurasian (as a relatively inactive plate). In modern structure the Greater Caucasus is a doubly verging orogenic system, with the development of south-verging, often isoclinal folding, thrusts and nappes on its southern slope (Gamkrelidze P. and Gamkrelidze I. 1977; Gamkrelidze 1991) that is in pro-wedge, and relatively weak folding and north-directed thrusts on its northern slope representing part of the retro-wedge of the orogen (Kopp and Shcherba, 1985; Dodtuev 1986; Mosar *et al.* 2010, 2018, 2022).

The Greater Caucasus is a real "natural geological laboratory" exposing magmatic, sedimentary, and metamorphic rocks, having a wide range on the geologic time scale (from the Neoproterozoic up to the Quaternary) and different geological structures including nappes.

The subject of this article is the consideration of the structure and the conditions for the formation of the nappes of the southern slope of the Georgian Greater Caucasus.

The assumption about the existence of a nappe in the South-Eastern Caucasus (in the Dibrar system in Azerbaijan) was made as early as 1906 by K. Bogdanovich. A. Ryabinin (1911) also assumed the possibility of discovering nappes in the Kakheti Range. However, V. Rengarten (1924), who singled out the Argun nappe in the Dusheti region of Georgia, had the first specific indications of tectonic overlaps of the nappe type.

The detailed scheme of stratigraphy and tectonic zoning of the Kakheti Range developed by N. Vassoevich is the most reasonable basis for identifying large nappes on the southern slope of the Greater Caucasus (Vassoevich 1930, 1933). The Alisisgori, Pantiani, and Chinchvelta nappes distinguished by him were considered as, separated by denudation, parts of a single nappe that moved under the action of gravitational forces from the north to south from the most elevated part of the Greater Caucasus fold system and was subsequently complicated by folding (Vassoevich 1933, 1940). Then, N. Vassoevich and V. Khain (1940) noted the presence of a large nappe, "Baskal," to the east of the Kakheti Range – in the Lahydzha Mountains and suggested that "in the intermediate area under the younger deposits of the Alazani trough, there are similar in scale, if not more grandiose, nappe formations".

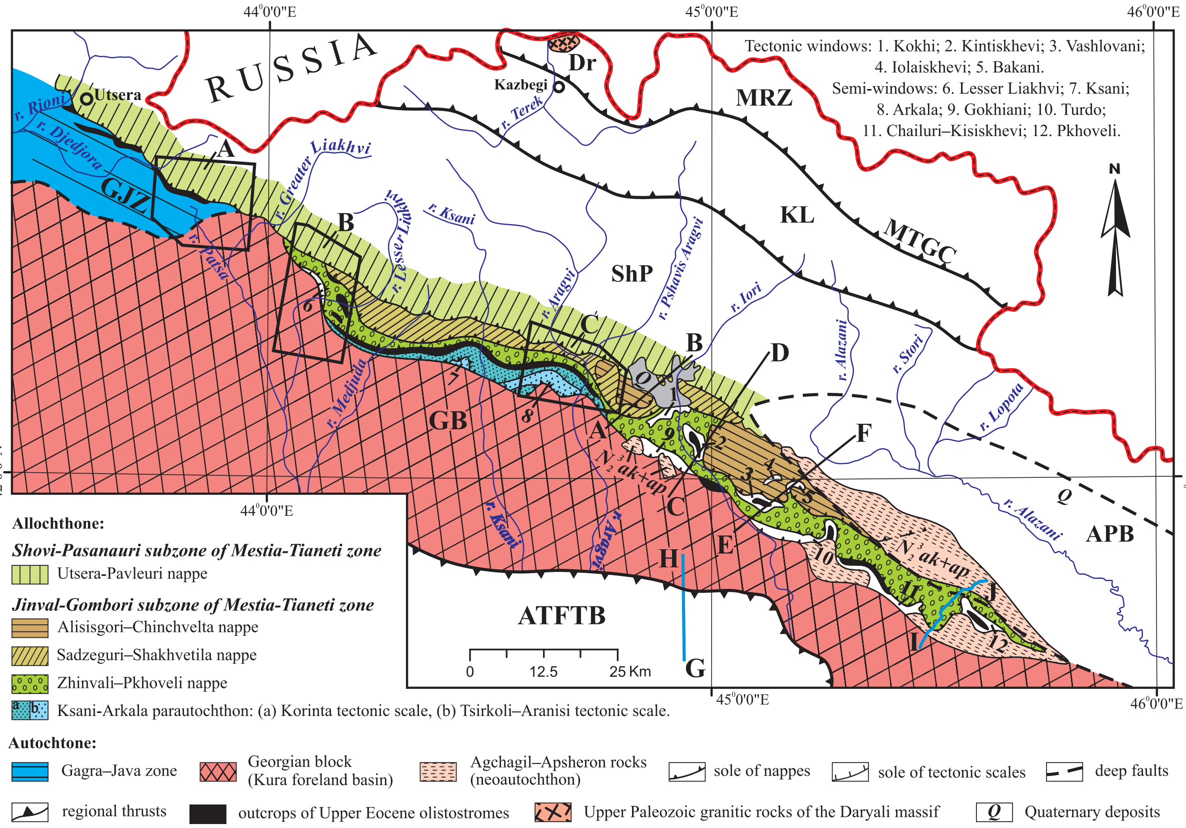
In the Dusheti-Ananuri district, V. Rengarten (1932, 1941) south of the so-called Mtiuleti zone identified four tectonic complexes or nappes: Lalauriskhevi, Khevkrili, Arguno-Zhinvali, and Arkala. Moreover, the Arkala unit was considered a parautochthone.

The above views about the existence of large nappe structures on the southern slope of the Greater Caucasus were not accepted by subsequent researchers and were completely rejected for a long time. As is known, in the forties of the last century, especially in the former Soviet Union, a period of almost complete denial of nappes began. Rather sharp criticism of the views of the ultranappists – L. Kober (1921), R. Staub (1924) and others began in Western Europe as well. In some places, the complete absence of nappes was proved, and in others their relatively limited development was shown. Apparently, this was the reason for the critical attitude to the concept of the nappe structure of the southern slope of the Greater Caucasus adopted by many authors (Janelidze 1950; Varentsov 1950; Kirillova and Sorsky 1952; Janelidze and Rubinshtein 1957; Adamia 1958; Buleishvili 1960). However, along with this, convincing data were presented in favor of the existence of the Baskal and Astrakhan gravitational nappes (Voskresensky 1958; Voskresensky *et al.* 1963; Grigoryants and Isaev 1968).

Since 1962, a systematic thematic study of both the stratigraphy and tectonics of the flysch zone of the southern slope of the Greater Caucasus within the limits of Mountainous Kakheti began in Georgia. As a result of studying the issues of the oil and gas content of Cretaceous and Paleogene deposits by laboratory VNIGNI (All-Union Research Institute of Oil Geology), confirmation was obtained of the irregular distribution of lithofacies types of synchronous formations within individual tectonic units that have tectonic contacts with each other. These phenomena were explained by the existence of large nappes in Mountainous Kakheti (Khatiskatsi and Chichua 1967; Chichua 1971; Chichua *et al.* 1973).

At the same time, detailed studies began to be carried out in the western part of the flysch zone. P. Gamkrelidze (1970) suggested that the overthrust flysch zone at present completely overlaps the cordillera of the Gagra-Java zone of the Greater Caucasus, which fed the suite of block-breccias (olistostromes) of the Upper Eocene flysch basin with clastic material. Conducted by I. Gamkrelidze (1970) and F. Maisadze (1970) studies in the interfluve of the Rioni - Greater Liakhvi, fully confirmed this assumption. Based on paleogeographical analysis and structural field studies, the existence of fairly large horizontal displacements was established in the interfluve of the Greater Liakhvi and Aragvi rivers (I. Gamkrelidze 1970; F. Maisadze 1970; Kandelaki 1973) and in the interfluve of the Aragvi and Iori rivers (Gamkrelidze P. 1970; Kandelaki 1975). A little later, P. Gamkrelidze and I. Gamkrelidze (1977), based on all available data, identified four nappes on the southern slope of the Greater Caucasus: Utsera-Pavleuri, Zhinvali-Pkhoveli, Sadzeguri-Shakhvetila and Alisisgori-Chinchvelta, as well as the Ksani-Arkala paraautochthone and neoautochthone (Pliocene deposits), while the GJZ and the Georgian block were attributed to the autochthone (Text-fig. 2).

The existence of tectonic nappes on the southern slope of the Greater Caucasus was substantiated within the territory of Azerbaijan as well (Shikhalibeili *et al.* 1981; Kangarli 1999, 2005; Kangarly *et al.* 2018). The formation of the nappe complexes is directly confined to the late Aalenian–Quaternary time interval



Text-fig. 2. Location of nappes of the southern slope of Greater Caucasus within Georgia, after Gamkrelidze P. and Gamkrelidze I. (1977), with modifications. Hatched area in inset map, region of study. Tectonic units: MRZ, Main Range zone of the Greater Caucasus – Lower Jurassic slates and clayey shales; KL, Kazbegi-Lagodekhi zone of the southern slope of the Greater Caucasus – Lower to Middle Jurassic slates and clayey shales; ShP, Shovi-Pasanauri subzone of Upper Jurassic–Cretaceous distal flysch (northern subzone of Mestia–Tianeti zone) or Kolosani-Pakhvili zone after Mosar *et al.* (2022); GJZ, Gagra–Java zone of Lower Jurassic–Aalean sandy-shale and Bajocian volcanic rocks; Gb, Georgian block; APB, Alazani piggy-back basin; ATFTB, Achara-Trialeti fold-and-thrust belt; Dr, Daryali massif; MTGC, Main thrust of the Greater Caucasus.

corresponding to the transitional (Late Aalenian–Middle Miocene) and continental (Late Miocene–Quaternary) stages of the Alpine stage of the geological development of the Caucasus.

Thus, today the nappe structure of the southern slope of the entire South-Eastern Caucasus in the territories of Georgia and Azerbaijan is substantiated. In addition, the nappe structure of the Greater Caucasus was considered in a special work by S. Dodtuev (1986).

Most of the works listed above which disputed the existence of large nappes on the southern slope of the Greater Caucasus, were published many years ago, moreover, only in Russian. This is apparently the reason why in some of the latest publications concerning the structure of the Greater Caucasus and its formation, the existence of large tectonic nappes on its southern slope is generally ignored (Forte *et al.* 2013; Sharkov *et al.* 2015; Sokhadze *et al.* 2018; Vasey *et al.* 2020 and others). Some of these authors pay main attention to the Main Caucasian fault (thrust), which is indeed a very important fault, but, according to all data, this has an insignificant horizontal component (Gudjabidze and Gamkrelidze, 2003; Gamkrelidze *et al.* 2015; Gamkrelidze and Maisadze, 2016; Mauvilly *et al.* 2015; Mauvilly *et al.* 2016; Mosar *et al.* 2019, 2022). However, other authors describing the Kura fold-and-thrust belt (Forte *et al.* 2013) believe that "it has accommodated 83–100% of convergence between the Greater and Lesser Caucasus."

This article is an attempt to correct the above situation and, taking into account the latest geological and seismic data, to consider in a new light the nappe structure of the southern slope of the Greater

Caucasus. It should be noted that in recent years, the authors have carried out new field investigations of nappes along the Georgian Military Road and in the eastern (Kakhetian) part of their development.

The authors consider the most general and important issues of the structure and the conditions for the formation of the nappes of the southern slope of the Greater Caucasus within Georgia and, most importantly, argue for their existence.

GEOLOGICAL CHARACTERISTICS OF AUTOCHTHONOUS AND ALLOCHTHONOUS COMPLEXES

The structure of the autochthone

The Gagra-Java zone (GJZ) until the Early Jurassic was the marginal part of the Georgian Block, which at the beginning of the Alpine cycle was crushed, submerged and became part of the basin of the southern slope of the Greater Caucasus, and then the Foldsystem of the Greater Caucasus (Gamkrelidze 1969). Consequently, the Lower Jurassic deposits of this zone are located directly on the pre-Alpine crystalline basement (Neoproterozoic and Paleozoic metamorphites and granitoids).

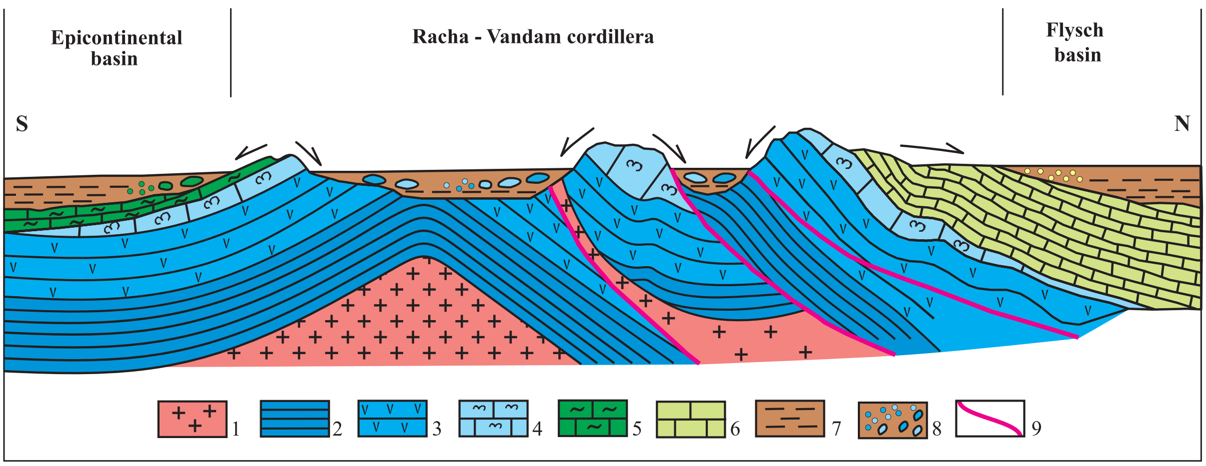
In the part we are considering, the oldest deposits of this zone are sandstones, clay shales, and siliciclastic turbidites of the Toarcian and Aalenian.

An almost continuous development in GJZ is characterized by Bajocian submarine volcanites, represented by calc-alkaline basalts, andesites, less often dacites, rhyolites, their pyroclastolites, and tephroturbidites, with a thickness up to 3000 m (the so-called Bajocian porphyrite series). It is transgressively overlain by Upper Jurassic (Callovian–Lower Oxfordian) terrigenous deposits.

Above are Lusitanian–Tithonian carbonate deposits represented by massive reef limestones of Urgonian facies and marls.

Cretaceous deposits are represented by peculiar facies – carbonate sediments of small thickness (no more than 400 m) with an open sea fauna. In some places, they overlie transgressively the Upper Jurassic limestones and on the southern periphery of the zone – rest directly on the Bajocian Formation.

In the southern part of GJZ, an Eocene formation is widely distributed, represented by a well-stratified Middle–Upper Eocene stratum 10–160 m thick, which is exposed on the northern edge of the Kartli foreland basin (KFB) and which transgressively overlies Cretaceous and older sediments and is represented mainly by sandstones and limestones. To the north of it, in the form of isolated outcrops in the western part and a narrow strip along the frontal thrust of the flysch zone, in the interfluve of Jejora-Lesser Liakhvi (Text-fig. 2), the olistostrome sequence of the Upper Eocene is exposed, which is also observed inside the flysch zone, where, as will be shown below it represents a retro-overthrust located at different levels of the Cretaceous and Paleogene deposits (Text-fig. 2). In addition, the olistostrome suite is continuously traced in the interfluve of the Greater Liakhvi and Aragvi, and further within the Mountainous Kakheti, in tectonic windows and semi-windows in the lower part of the so-called Kinta suite of Upper Eocene–Lower Miocene age.



Text-fig. 3. Paleogeographic profile of the end of the Late Eocene (after Gamkrelidze and Maisadze 2016). Legend: 1, pre-Alpine crystalline basement; 2, Lower Jurassic–Aalenian sandy–shale Suite; 3, Bajocian porphyritic Series; 4, Upper Jurassic reef limestone; 5, Cretaceous limestone (facies of Gagra–Java zone); 6, Aptian–Paleogene, flysch rocks; 7, Upper Eocene, well stratified and flysch suites; 8, Upper Eocene, olistostromes; 9, thrusts.

The olistostrome sequence of the Upper Eocene is a key formation for reconstructing the paleogeographic setting of that time, both in the autochthonous and allochthonous part of the region under consideration. The olistostromes contain various fragments and blocks of Upper Jurassic reef limestones, Bajocian volcanic rocks, Lower Jurassic sandstones and shales, and Cretaceous limestones, i.e. a complete set of rocks characteristic of GJZ, as well as, to a lesser extent, rocks of the flysch zone. In some places, along with the noted rocks, quite large (up to 50 cm) blocks of Paleozoic granites are observed, which are undoubtedly fragments of the pre-Alpine crystalline basement of the same GJZ (Text-fig. 3).

The Upper Jurassic limestone blocks are usually very large (up to several thousand cubic meters). It is noteworthy that the amount of clastic material in the Upper Eocene formations increases from south to north: medium coarse-grained sandstones pass into block-breccias (olistostromes). Therefore, the location of the source of this exotic material mostly to the north, and apparently within the Eocene basin should not be in doubt (Text-fig. 3). This source was the eastern, cordillera part of GJZ, the so-called Racha-Vandam Cordillera (Maisadze, 1994). This cordillera is now almost completely buried under the overthrust flysch zone. Only in the extreme western part of the cordillera strip, near the village of Utsera, olistostromes are not thrust and preserved as in situ olistostromes (Text-fig. 2).

By the end of the Late Eocene, a significant part of the clastic material accumulated around the land areas and in the subplatform (epicontinental) sedimentation basin, where olistostromes also formed (Text-fig. 3). Locally, conglomerates, gravelstones, sandstones, and pelitolites, which were deposited far from individual cordillera salients, were facially replaced by olistostromes in the lateral direction, close to these salients (Gamkrelidze and Maisadze 2016).

It is noteworthy that coarse clastic material came from the noted Cordillera, which was located south of the flysch zone, not only in the Late Eocene but also in the Aptian, Cenomanian, Maastrichtian, and Paleogene of this zone (Gamkrelidze P. and Gamkrelidze I. 1977). Considering the huge mass and extensive outcrops of Upper Eocene olistostromes (from the Rioni River in the west to the territory of Azerbaijan inclusive), the beginning of horizontal movements should be assumed to have taken place at the end of the Late Eocene (Pyrenean folding phase) (Gamkrelidze P. and Gamkrelidze I. 1977; Maisadze 1994; Text-fig. 3). At the same time, the irregular position of blocks (olistoliths) and slabs (olistoplaks) in the matrix of olistostromes and their tectonic reworking, as well as their large volume and extent, indicate their tectono-gravitational origin (Gamkrelidze and Maisadze 2016).

The Racha-Vandam Cordillera, part GJZ, is currently completely overlain by flysch deposits, thrust from the north, but it has been partially torn off and displaced to the south, representing the Ksani-Arkala parautochthone (Text-fig. 2).

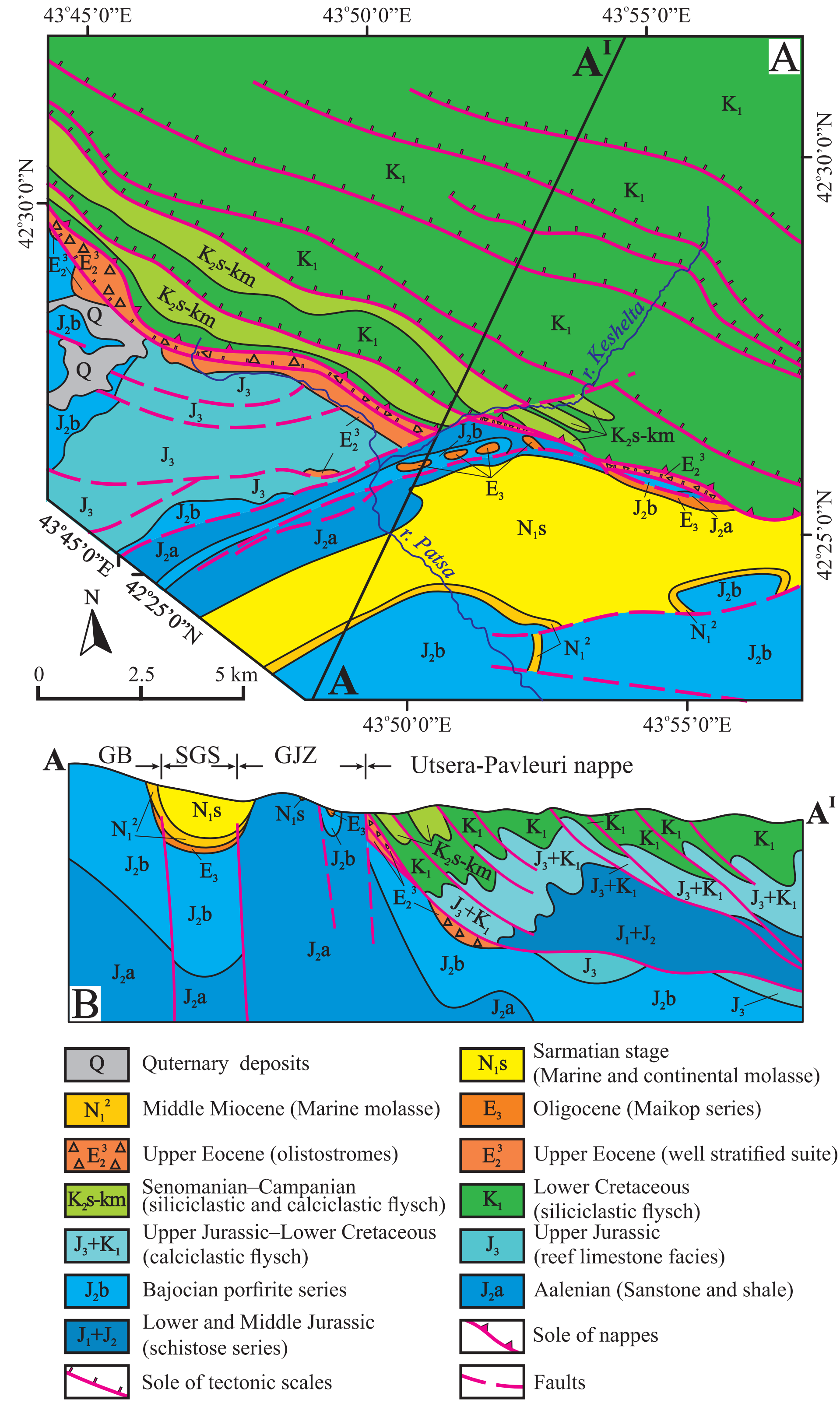
Oligocene deposits which are also developed within GJZ, are mainly represented in the Maikop facies and are located transgressively on older formations up to the Aalenian ones.

Miocene deposits are developed only in a narrow graben-syncline, developed on the border of the GJZ and the Georgian block (Text-fig. 4).

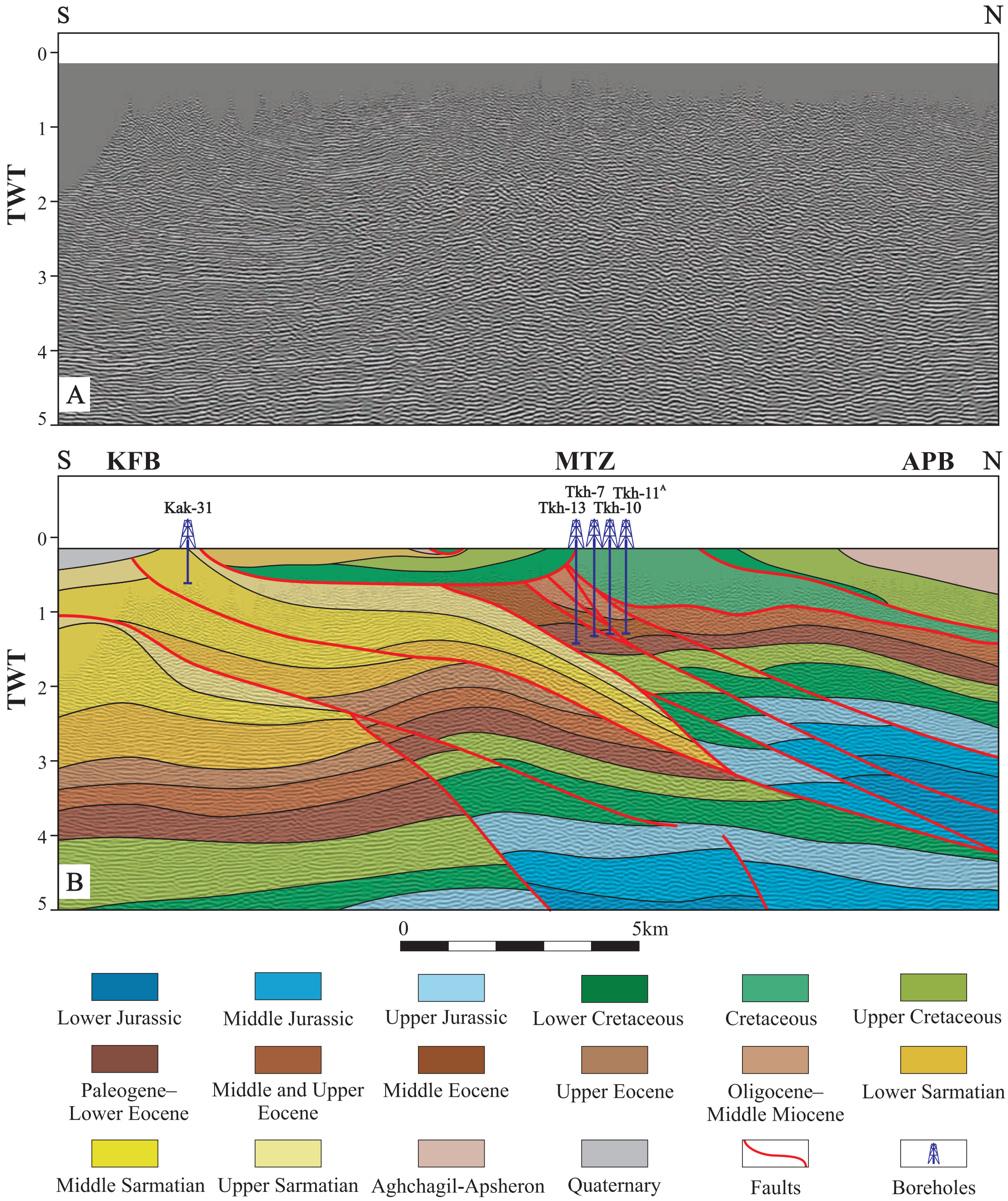
The entire GJZ and its folds of the first order trending approximately E-W which compose it, without signs of flattening, go under the nappes of the flysch zone to the east (Text-figs 2–4A).

It is noteworthy that GJZ, due to the facies features of its constituent rocks (the presence of a thick Bajocian volcanogenic series), is relatively rigid and does not undergo minor additional folding.

The Kura foreland basin (KFB) is composed mainly of Paleogene and Neogene deposits. Oligocene and Lower Miocene deposits are represented here by the terrigenous strata of the Maikop series up to 450 m thick. Middle Miocene rocks are represented mainly by clayey-sandy-marl deposits up to 350 m thick. Sarmatian deposits are composed of thick (more than 1500 m) clayey-sandy-conglomerate strata. In the northern part of KFB are developed the most widespread freshwater-continental facies of the so-called Natskhori suite of the Upper Sarmatian, up to 1200 m thick, and the Meotian-Pontian stages with a thickness of more than 2000 m. In the eastern part of KFB, the Agchagil and Apsheron continental formation (neoautochthone) with a thickness of 230–350 m is also widely developed, discordantly overlapping different nappes of the flysch zone, including in the superimposed Alazani piggy-back basin (Text-fig. 2). In this part of KFB several large gently sloping synclines and narrow and steep, sublatitudinal anticlines overturned to the south are found, which are often fractured along the arch, and flatten out at depth. Previously, it was suggested (Gamkrelidze P. and Gamkrelidze I. 1977 that this phenomenon may be caused by the detachment of molasse strata and their displacement to the south along with the flysch nappes of the southern slope of the Greater Caucasus. This opinion was subsequently fully confirmed by the interpretation of seismic reflection profiles (Alania *et al.* 2018; 2021; Gamkrelidze *et al.* 2021; Text-figs 5, 6).



Text-fig. 4. A – Geological map of upper reaches of the Patsa and Keshelta rivers after Gamkrelidze P. and Gamkrelidze I. (1977), with modifications (polygon A in Text-fig. 2); B – Geological profile AA^I. GJZ, Gagra–Java zone; GB, Georgian block; SGS, suture graben-syncline between the Gagra-Java zone and Georgian block.



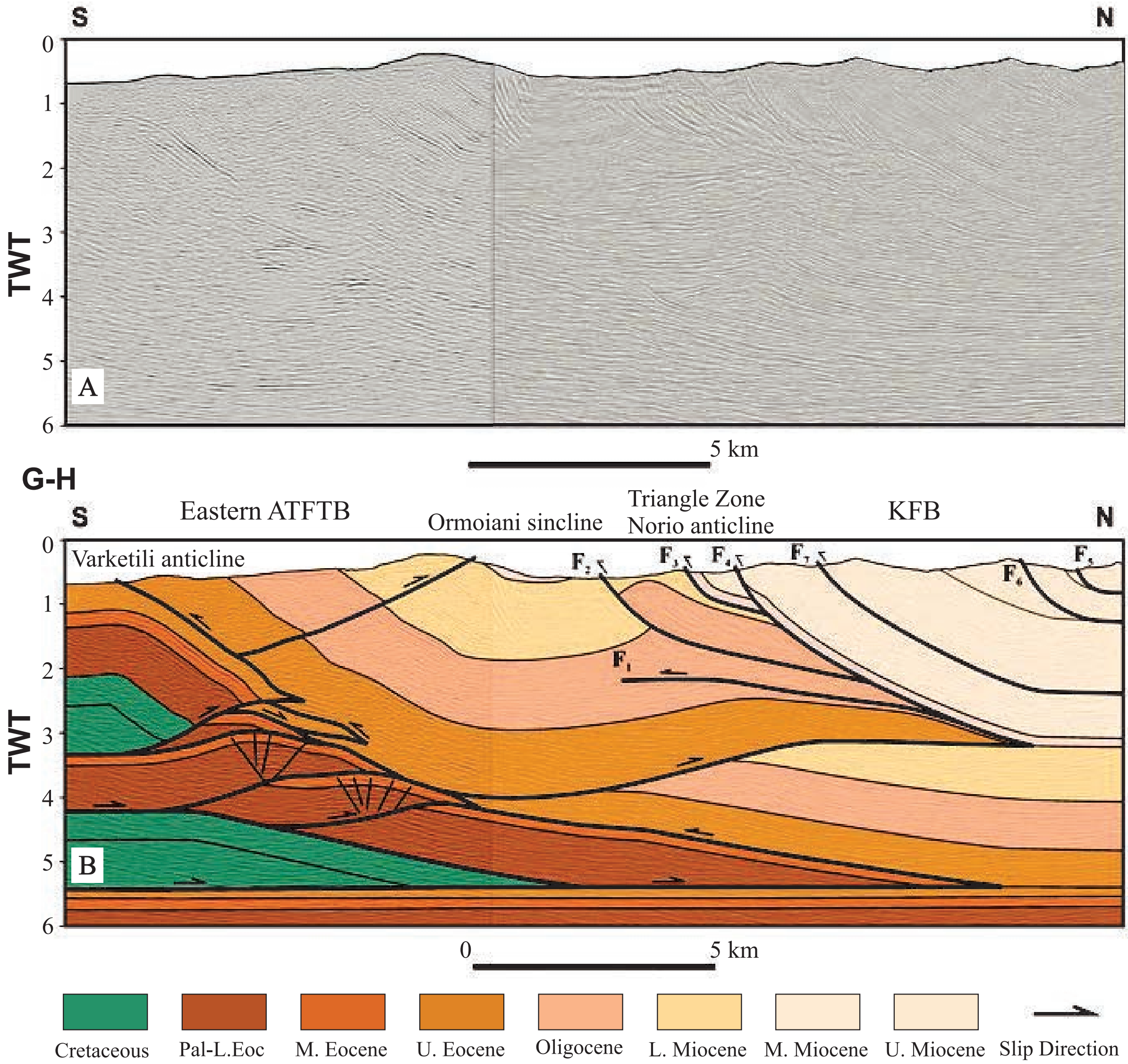
Text-fig. 5. A – Uninterpreted and B – interpreted seismic reflection profiles I-J. Location is shown in Text-fig. 2. Abbreviations: KFB – Kura foreland Basin; MTZ – Mestia-Tianeti Zone; APB – Alazani piggy-back basin (interpreted by Gamkrelidze N.; Gamkrelidze *et al.* 2021).

The structure of the allochthone

Structurally, two different segments are distinguished in the development area of the nappes of the southern slope of the Greater Caucasus: the western one (the interfluve of the Rioni and Aragvi), and the eastern – Kakhetian (Text-fig. 2). That's why we think it expedient to characterize the allochthonous complexes of these segments, which differ in character, separately.

Western segment (interfluve of Rioni and Aragvi)

The Utsera-Pavleuri nappe is composed of a continuous section of calciclastic and siliciclastic (in the lower part) distal flysch from the Cenomanian to the



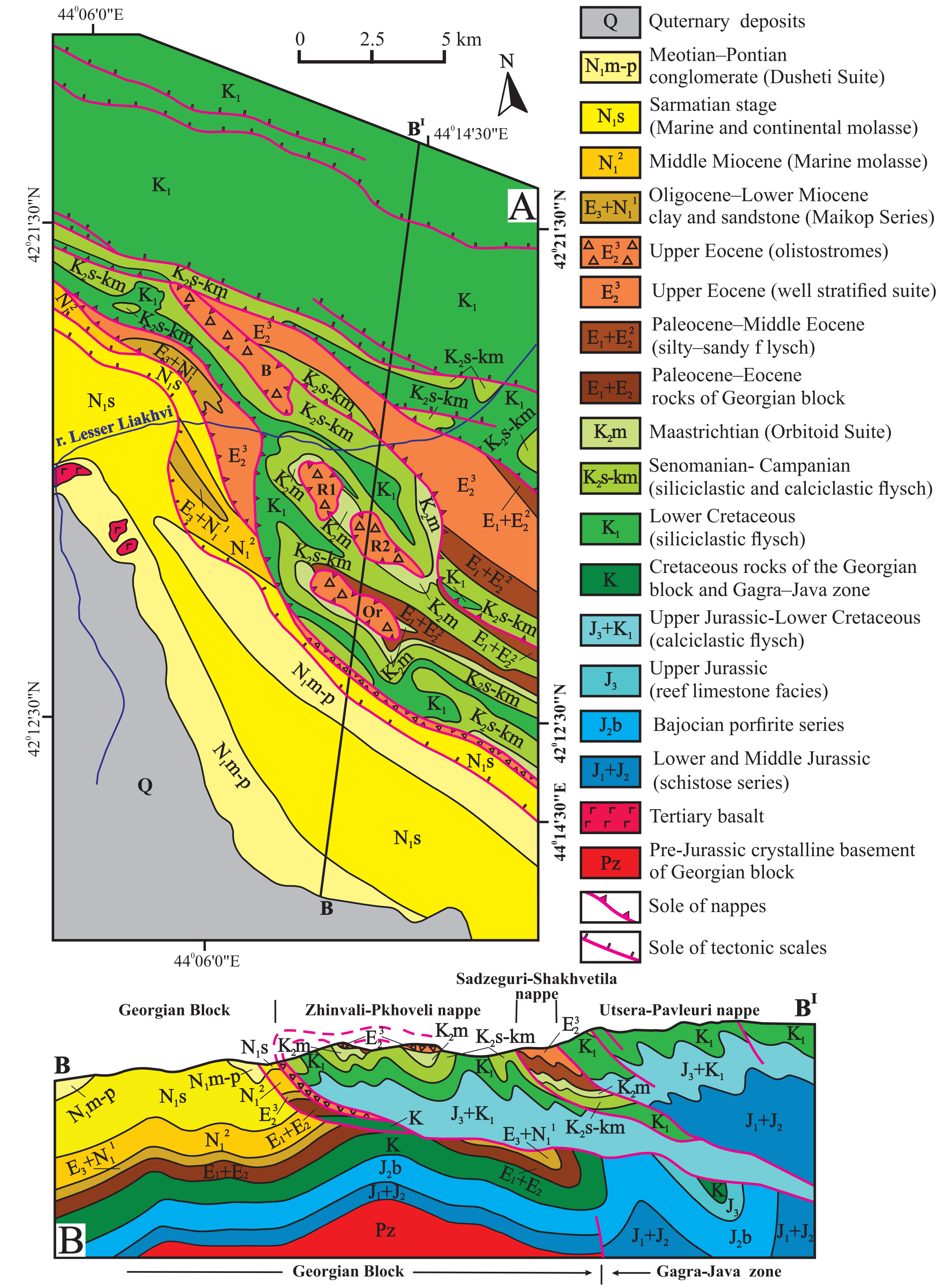
Text-fig. 6. A – Uninterpreted and B – interpreted seismic reflection profiles G-H. Location is shown in Text-fig. 2. Abbreviations: ATFTB – Achara-Trialeti fold-and-thrust belt; KFB – Kura foreland Basin (by Alania *et al.* 2021).

Campanian inclusive, with a total thickness of up to 1000 m. This is an alternation of turbidites, pelagic marls or mudstones and sometimes silicites.

In this segment, the amplitude of the horizontal displacement of the Utsera-Pavleuri nappe from west to east gradually increases and, in the end, it overlappes the entire GJZ (Text-figs 2–4A). The Upper Eocene olistostrome sequence, developed along the frontal thrust, in the south has distinct tectonic contacts with Lower Jurassic, Bajocian, Upper Jurassic, and Cretaceous rocks, as well as with well-stratified Upper Eocene deposits of the GJZ. At the same time, the Upper Eocene olistostromes from the north are also limited by the frontal thrust of the flysch zone (Text-fig. 2).

The Utsera-Pavleuri nappe is characterized by an imbricate structure. This is clearly seen in the upper reaches of the Patsa and Keshelta rivers (Text-fig. 4).

The Sadzeguri-Shakhvetila nappe is composed of a section of calciclastic and siliciclastic (in the lower part) proximal flysch deposits dating from the Albian to the Danian inclusive, with a total apparent thickness of up to 400 m (the foot of the Aptian is not exposed), which are transgressively overlain by siliciclastic flysch deposits of the Paleocene–Middle



Text-fig. 7. A – Geological map of upper reaches of the Lesser Liakhvi River after Gamkrelidze P. and Gamkrelidze I. (1977), with modifications (polygon B in Text-fig. 2). B – Geological profile BB^I. Relics (klippes) of retro-overthrust: B, Beloti; R1, R2, Rekhi; Or, Orbodzala.

Eocene, with a total thickness of up to 550 m. In some places in this nappe, Upper Eocene deposits have also been preserved, represented by a rhythmic alternation of schistose clays, sandstones, and less often bituminous clays with a total thickness of up to 1100 m. In contrast to the Utsera-Pavleuri nappe, in the Sadzeguri-Shakhvetila nappe, frequent breaks in sedimentation and the transgressive location of the Cenomanian, Maastrichtian and Paleocene are observed. Pebbles at the base of these stages include fragments and blocks of rocks that make up the Racha-Vandam Cordillera; in particular – Upper Jurassic reef limestones, Bajocian volcanic rocks, and at the base of the so-called Maastrichtian orbitoid suite, blocks of Paleozoic granites 200 m^3 in size.

The main structure of this nappe is the so-called Sadzeguri syncline, composed mainly of Paleogene rocks and complicated by numerous folds of second and higher orders.

The Zhinvali-Pkhoveli nappe is located south of the Sadzeguri-Shakhvetila nappe and is composed of a section of siliciclastic proximal flysch dating from the Aptian to the Upper Cenomanian (siliciclastic turbidites and pelagic mudstones), with a total thickness of up to 900 m. This nappe is built up of Paleocene–Middle Eocene sediments, represented by siliciclastic flysch, with a total thickness of up to 300 m. Here, there are also frequent breaks in sedimentation and the transgressive location of the Cenomanian, Maastrichtian, and Paleocene. The pebbles at the base of these stages include pebbles and rock fragments that make up the Racha-Vandam cordillera; in particular – Upper Jurassic reef limestones, Bajocian volcanic rocks and, very rarely, Paleozoic granites.

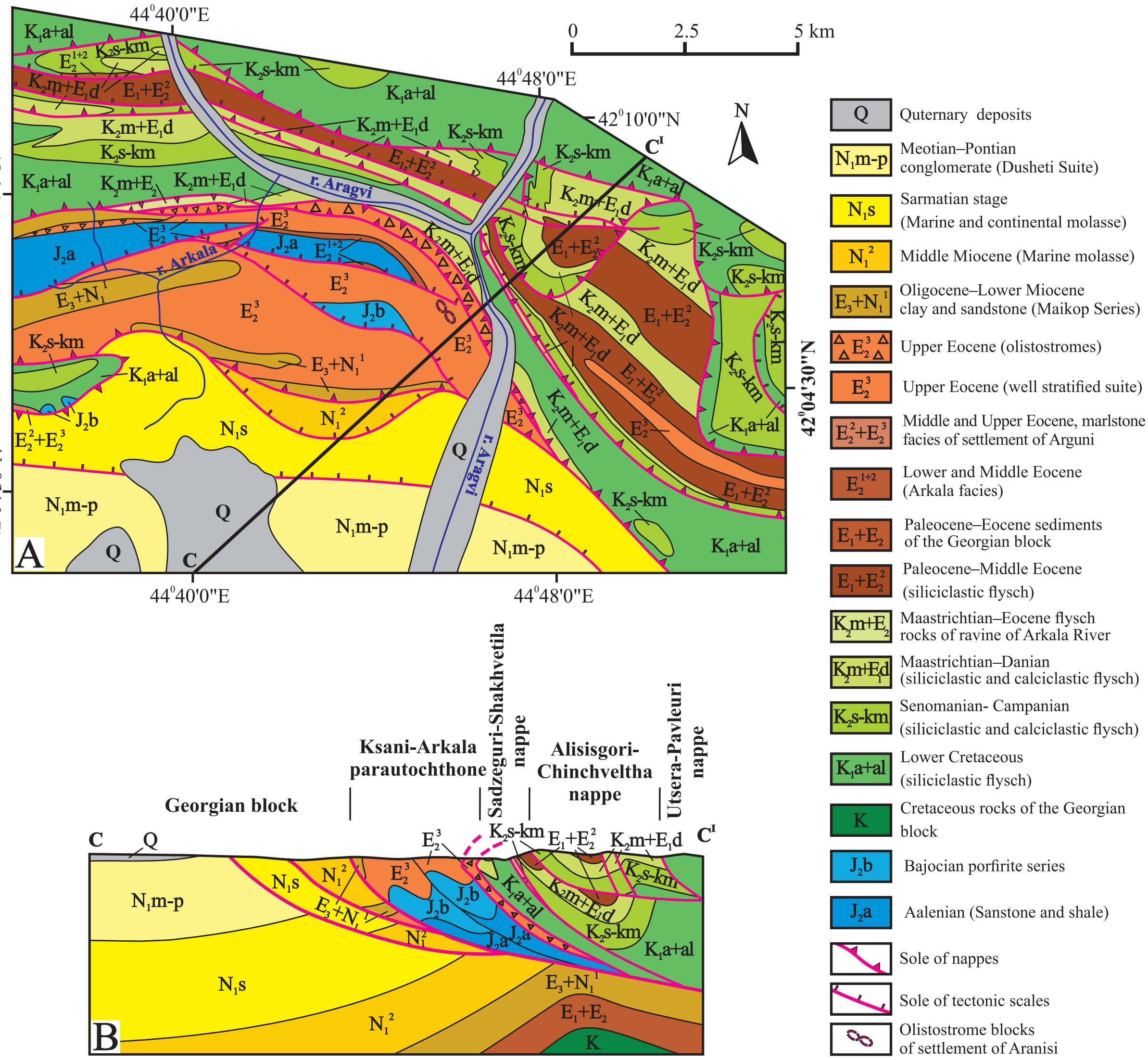
The Zhinvali-Pkhoveli nappe, or rather, the corresponding structural-facies zone, represents the southernmost marginal part of the flysch basin, and at present, it is the frontal part of the proper allochthonous complex of the western segment of the area of development of the nappes.

It should be noted that in this nappe, the Upper Eocene olistostromes, as noted, are observed in the basin of the river Lesser Liakhvi, inside the flysch zone (Text-fig. 7). These are outcrops of olistostromes in the Orbodzala and Rekhi mountains (two exposures) and in the village of Beloti. On the Orbodzal ridge, the thickness of the olistostrome sequence is about 100 m, and it almost entirely consists of huge blocks of Upper Jurassic reef limestones, and in the lower part of smaller fragments of Bajocian volcanic rocks. Similar rocks are also observed on Mount Rekhi, where the fragments are smaller and among them there are fragments of Upper Cretaceous limestones of the flysch zone. The thickness of the olistostromes here reaches 150–200 m. Marly rocks predominate in the outcrop near the village of Beloti. The study of the above-mentioned outcrops of the Upper Eocene olistostrome sequence within the flysch zone showed that they are located on different folded horizons of the Upper Cretaceous and normally stratified Upper Eocene (Beloti village), Lower and Upper Cretaceous (Mount Rekhi) and Paleocene (Mount Orbodzala) of the Zhinvali-Pkhoveli nappe (Text-fig. 7). Consequently, they are small thrust sheets and are fragments (klippes) of retro-overthrust. These slabs moved from south to north and therefore had an opposite sign of movement relative to the main direction of rock movement on the southern slope of the Greater Caucasus (Gamkrelidze and Maisadze 2016).

The Ksani-Arkala parautochthone is the southernmost thrust plate and represents the southern part of the autochthonous GJZ. It is composed of Aalenian sandstones and shales, Bajocian volcanic rocks, Aptian and Albian carbonate rocks, Cenomanian felsic volcanics, Turonian limestones, and well-stratified Upper Eocene. It is established that in the gorge of the river Ksani Cretaceous and Eocene deposits are exposed in the form of a tectonic semi-window in a plate thrust from the north, which is composed of Lower and Middle Jurassic rocks (Gamkrelidze I. 1970) (Text-fig. 2).

Two independent large tectonic scales are distinguished in the composition of the Ksani-Arkala parautochthone: the northern one is Korinta, composed mainly of Lower and Middle Jurassic rocks and completely overlapped by the Zhinval-Pkhovel nappe to the west and east (Text-fig. 2) and the southern one – the Tsirkoli-Aranisi scale, which is just exposed in the form of a tectonic semi-window in the gorge of the Ksani river (Gamkrelidze I. 1970) and also to the east, in the area of Zhinvali and Ananuri settlements, where this tectonic scale is composed of Aalenian sandstones and shales, Bajocian volcanic rocks, very thin Lower and Middle Eocene located transgressively directly on the Aalenian rocks, well-stratified Upper Eocene, rather thick Oligocene–Lower Miocene (Maikop series) and Middle Miocene sandstones. Here, Upper Cretaceous rocks are exposed only in the Arguni klippe (Text-fig. 8).

The nature of the internal structure of all the above nappes, as well as more northern zones of the southern slope of the Greater Caucasus and the zone of its Main Range, can be seen in Text-fig. 9.

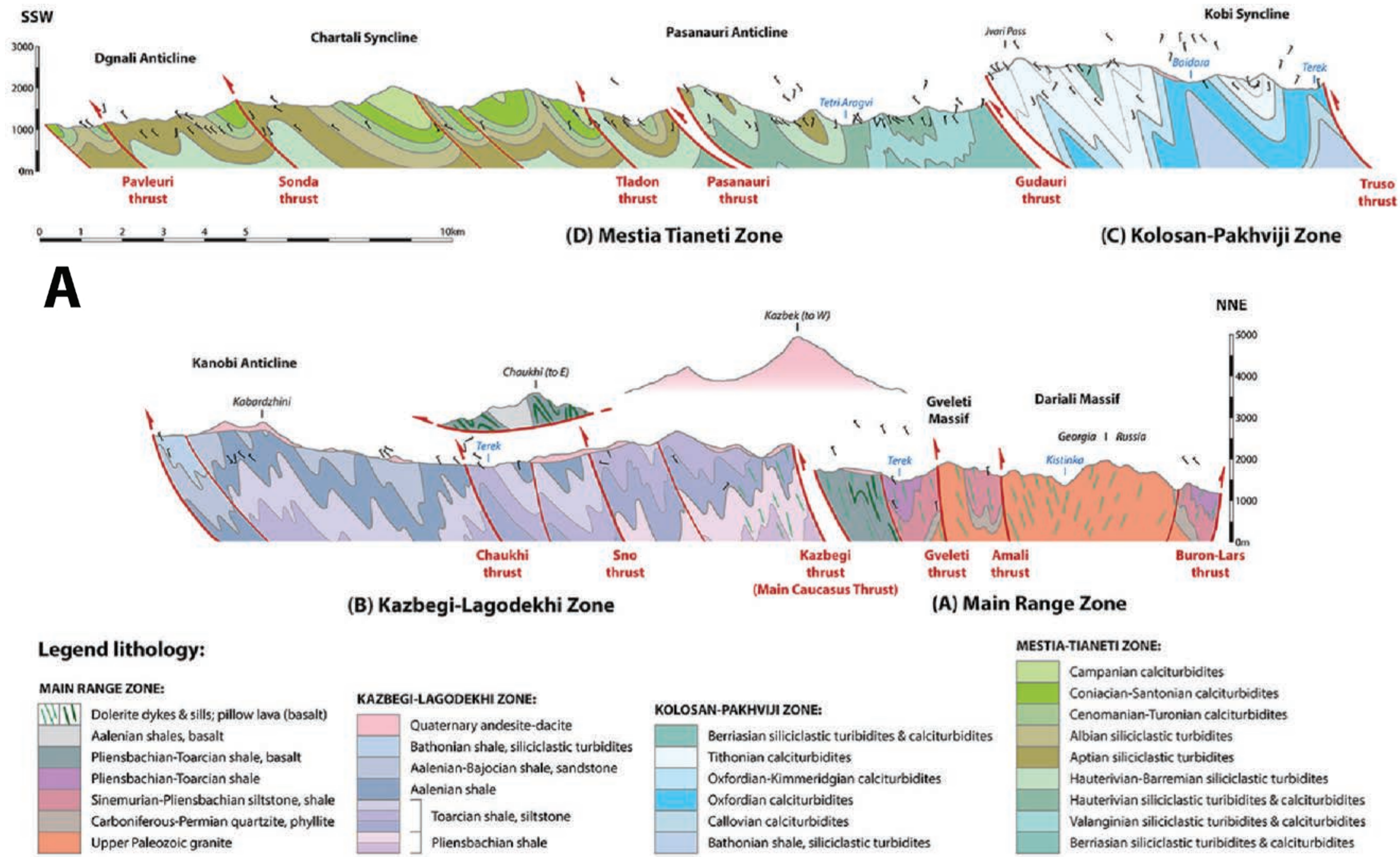


Text-fig. 8. A – Geological map of the Aragvi River (in the area of settlements Zhinvali and Ananuri) after Gamkrelidze P. and Gamkrelidze I. (1977), with modifications (polygon C in Text-fig. 2). B – Geological Profile CC^{I}.

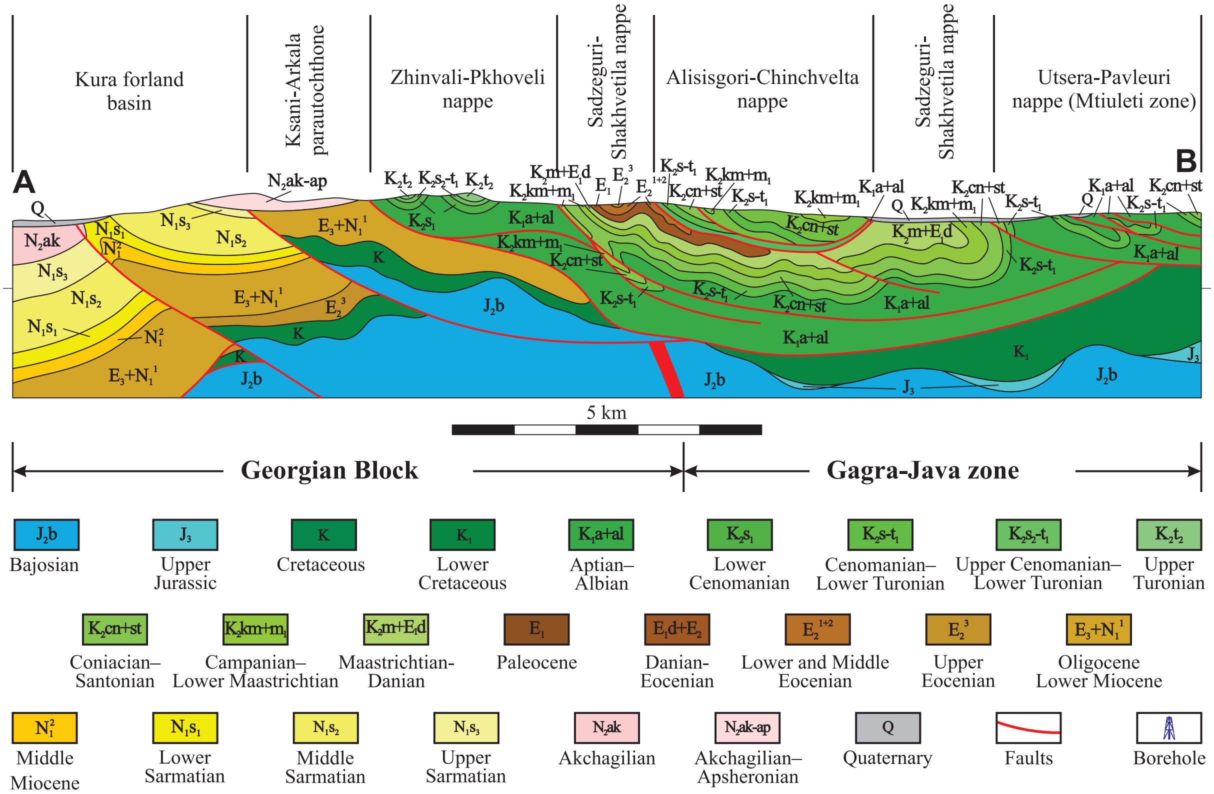
Eastern (Kakhetian) segment

The Utsera-Pavleuri nappe. This nappe is known in Mountainous Kakheti and in the interfluve of the Aragvi and Alazani under the name of the Mtiuleti zone (Chichua 1975). According to G. Chichua here the Upper Cretaceous formations differ from the coeval deposits of the western segment. The Lower Cenomanian deposits lie without visible unconformity on the Aptian deposits, which are underlain by the calciclastic flysch of the Upper Hauterivian–Barremian, which in turn continues the Upper Jurassic succession, represented by calciclastic flysch (alternation of calciclastic turbidites and pelagic marls and mudstones). The deposits of the Upper Cenomanian–Campanian of the described nappe, with a total thickness of up to 550–600 m, are represented by a calciclastic distal flysch.

Maastrichtian and Danian deposits are not known in the Mtiuleti zone. In the gorge of the Ilto river the Utsera-Pavleuri nappe plunges sharply under the Agchagil, Apsheron and Quaternary formations (neoautochthone) of the Alazani piggy-back basin, the deposits of which, according to drilling data, are characterized by subhorizontal bedding (Chichua *et al.* 1973). The Utsera-Pavleuri nappe in the Kakheti segment has a very significant amplitude, since it completely covers the root zones of the Alisisgori-



Text-fig. 9. Surficial geological cross-section of the Greater Caucasus Main Range Zone and Southern Slope zones (after Mosar *et al.* 2022). The section is assembled from five cross-sections most representative of the observed structures along the Georgian Military Road (Location is shown in Text-fig. 13B).



Tex-fig. 10. Geologic profile A-B (modified after Chichua 1975). Location is shown in Text-fig. 2.

Chinchvelta and Sadzeguri-Shakhvetila nappes (Text-figs 2 and 10, 11).

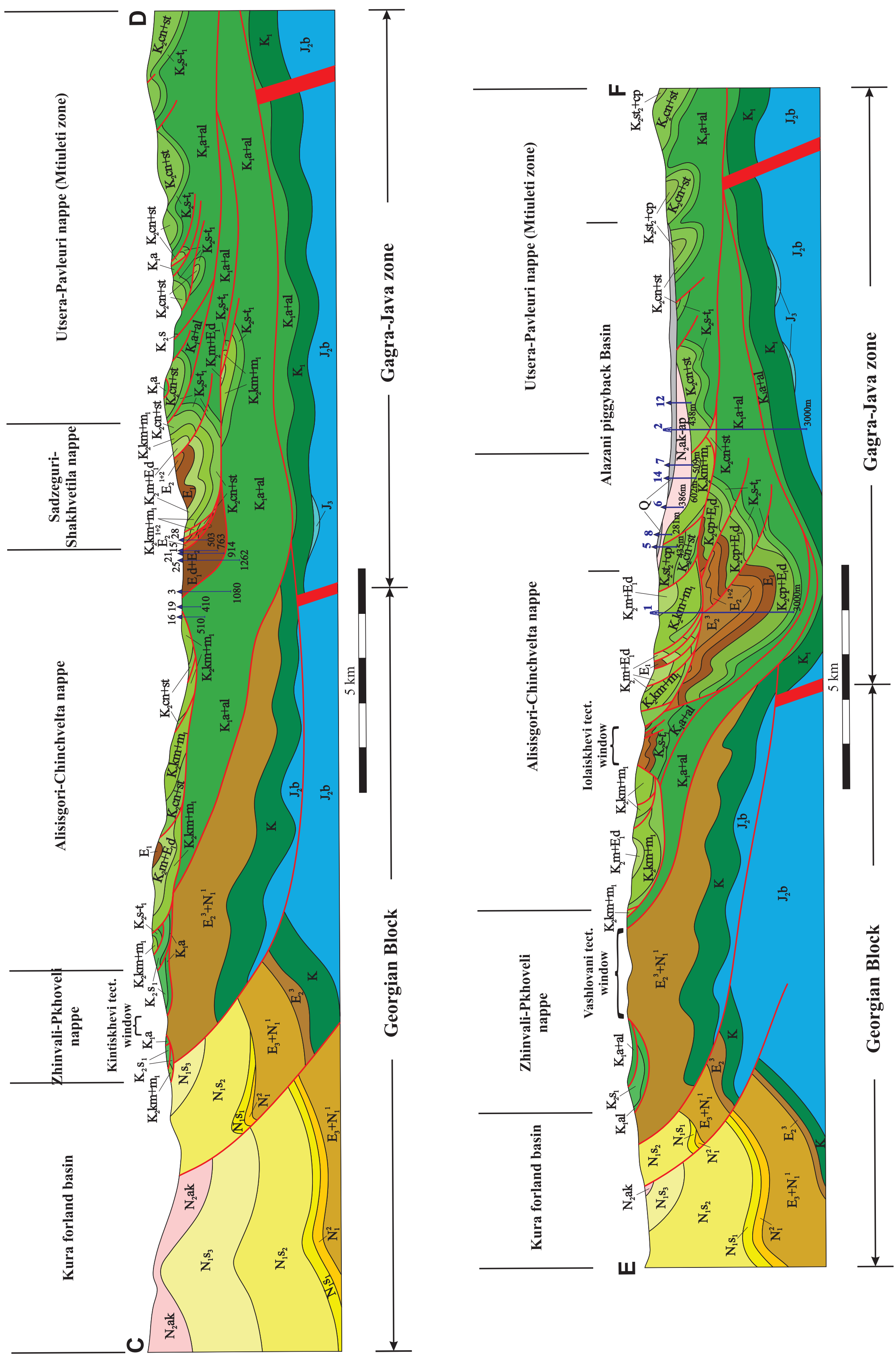
The Alisisgori-Chinchvelta nappe, or rather the structural-facies zone corresponding to it, was developed only in the eastern part of the flysch trough (Text-fig. 2). The nappe is now completely torn off from its roots and overlaps different zones, from which it differs both in facies features and in the nature of the structure. This nappe is composed in the lower part (Albian and Lower Cenomanian) of siliciclastic flysch (alternation of siliciclastic turbidites and variegated pelagic clays), up to 200 m thick, and in the upper part (Upper Cenomanian–Danian) of calciclastic flysch (alternation of calciclastic turbidites and variegated pelagic marls, limy clays and, in some places, silicites), with a thickness of up to 1200 m.

Then follow Paleocene deposits, represented by alternating multi-colored siliciclastic turbidites, pelagic clays and black cherts (in the lowest horizons). Their total thickness reaches 250 m.

The Albian deposits of the Alisisgori-Chinchvelta nappe overlap the Sadzeguri-Shakhvetila syncline composed of Paleogene deposits (Text-figs 2 and 11).

The erosional remnant of the Alisisgori-Chinchvelta nappe has been preserved on the left bank of the river Iori. The Coniacian–Santonian deposits that make up this remnant in the east tectonically overlie the Paleogene sediments of the Sadzeguri-Shakhvetila nappe, and in the south and west, the Lower Cretaceous deposits of the Zhinvali-Pkhoveli nappe (Text-figs 2 and 11). The nappe completely covers the Sadzeguri-Shakhvetila nappe, partially creeps onto the Zhinvali-Pkhoveli nappe and the eastern continuation of the Ksani-Arkala parautochthone (Text-fig. 2). In the northeast, the rear part of the nappe is overlain by the Upper Miocene and Quaternary deposits of the Alazani piggy-back basin (Text-figs 2 and 11).

This nappe is characterized by numerous tectonic windows and semi-windows, in which Paleocene (including Danian) and Eocene deposits are exposed in the facies of the Sadzeguri-Shakhvetila nappe, which stands out here under the name Tianeti-Sadzeguri subzone. These are, in particular, the Bakani and Iolaiskhevi tectonic windows, in which deposits of the Middle Eocene of the Sadzeguri-Shakhvetila nappe are exposed, and Vashlovani tectonic window where



Text-fig. 11. Geologic profiles C-D and E-F (modified after Chichua 1975). Location is shown in Text-fig. 2 and legend in Text-fig. 10.

the Upper Eocene–Lower Miocene of the Kinta suite of the eastern continuation of the Ksani-Arkala parau-rochthone are observed (Text-figs 2 and 11).

The Zhinvali-Pkhoveli nappe (Kakheti subzone according to Khatiskatsi G. and Chichua G. 1967) as noted, in the eastern segment completely overlaps the Ksani-Arkala parautochthon in some places. Here it is characterized by the presence of many tectonic windows and semi-windows, in which the Kinta suite of the Upper Eocene–Lower Miocene is exposed, which contains (in the lower part) the well-known olistostromes, with olistoliths of rocks from GJZ. This suite is known to belong to the Ksani-Arkala parautochthone. In the western part of the Zhinali-Pkhoveli nappe, two large tectonic windows are developed – Kokhi and Kintiskhevi, and in the south, the Gokhiani tectonic semi-window is exposed (Text-figs 2 and 11).

In the Pkhovel semi-window which is observed in this nappe, over an area of about 8 m^2, deposits of the Kinta suite are again exposed, and on the south side the semi-window is overlapped by conglomerates of the Agchagil-Apsheron Alazani series (Text-fig. 2).

The next semi-window – Chailuri-Kisiskhevi, the eastern part of which is separated from its main part by a narrow strip of deposits of the Alazani series, is exposed in the eastern part of the Zhinali-Pkhoveli nappe (Text-fig. 2). A high meridional ridge, composed of Cretaceous rocks, separates the outcrops of the Kinta suite of the Chailuri-Kisiskhevi and the Turdo semi-windows developed in front of the Zhinvali-Pkhoveli nappe (Text-fig. 2).

The Ksani-Arkala parautochthone. As noted, in the Kakhetian segment of development of the nappes, the Ksani-Arkala parautochthone is covered by various nappes and only appears through them in the tectonic windows and semi-windows noted above, in which Paleogene and Cretaceous formations, as well as volcanic rocks of the Bajocian, protrude in places. At the same time, it is clearly seen that the Ksani-Arkala parautochthone has been torn off and thrust over the Miocene molasses of the KFB (Text-figs 2 and 10, 11).

DISCUSSION

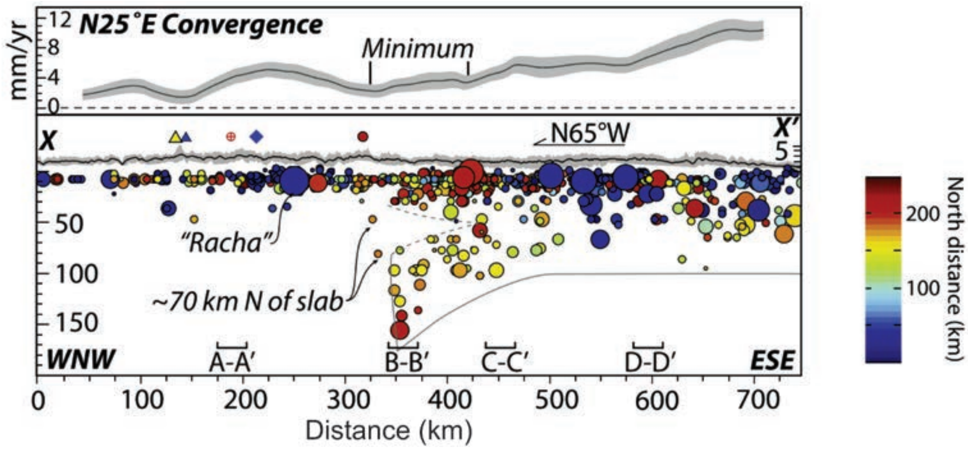
The above description of the geological structure of the autochthonous and allochthonous complexes has shown that the flysch basin of the southern slope of the Greater Caucasus was fed by clastic material from the Racha Vandam cordillera of the GJZ of the Southern slope located to the south of it. This cordillera was eroded especially intensively at the beginning of the Aptian, Cenomanian, Maastrichtian, and Paleocene, but most intensively during the late Eocene, when a thick and extended olistostrome sequence accumulated. The flysch basin consisted of independent structural-facies zones separated by synsedimentary normal faults that were reactivated as thrusts and then as soles of the nappes during the collisional events since the Late Eocene (Gamkrelidze P. and Gamkrelidze I. 1977).

In the south, closer to the eroded Racha-Vandam Cordillera of the GJZ, there were naturally located structural-facies zones corresponding to the Zhinvali-Pkhoveli and Sadzeguri-Shakhvetila nappes, with the development of proximal flysch, and in the north, more distant facial zones corresponding to the Alisisgori-Chinchvelta and Utsera-Pavleuri nappes, with the development of the distal flysch.

Structurally, two different segments are distinguished in the development area of the nappes of the southern slope of the Greater Caucasus: the western one (the interfluve of the Rioni and Aragvi), which is generally characterized by primary transverse structural-facies zonality undisturbed due to the formation of nappes, and the eastern one – Kakhetian, where there is a complete overlap even “crawling” and rolling of the northern structural-facies zones over the more southern ones.

The formation of all nappes of the southern slope of the Greater Caucasus began apparently as early as the Late Eocene. It coincides with the beginning of the Alpine orogenic stage (uplift-exhumation) of the Greater Caucasus (Gamkrelidze P. and Gamkrelidze I. 1977; Saintot *et al.* 2006; Mosar *et al.* 2010, 2022; Vincent *et al.* 2018). But the main phase of nappe formation was the pre-Late Pliocene (Rodanian) phase of folding, since the nappes are overlapped in different places by the Agchagil and Apsheron conglomerates of the Alazani Series (neoautochthon) and consequently all nappes are syncollisional.

It should also be noted that the above-described nappes, as can be seen from all geological profiles (Text-figs 4, 7, 8 and 10, 11) include only the sedimentary cover of the Earth’s crust and do not include the rocks of the pre-Jurassic crystalline basement, thus representing thin-skinned nappes. But, as will be seen below, according to seismic data, basal detachment (décollement) of the nappes at depth cuts crystalline basement and even the entire Earth’s crust and represents a thick-skinned deformation (Text-fig. 12).



Text-fig. 12. Swath profiles of earthquake hypocenters and topography through the Greater Caucasus (after Mumladze *et al.* 1915).

Another important feature of the nappe complex is that paleogeographic data and structural constructions force us to admit the overthrust of rocks of deeper distal facies originating from the most bent northern part of the flysch basin, which overlap the already torn and thrust more southerly nappes, composed of proximal flysch.

The above features of the tectonic nappes of the southern slope of the Greater Caucasus are very important in elucidating the mechanism of formation of these nappes and in determining the magnitude of the shortening of the Earth's crust in the region.

We believe that the leading mechanism for the formation of the studied nappes is the intense lateral collisional compression of the Greater Caucasus fold-and-thrust belt, which is mainly due to the advancement to the north (under the influence of the Arabian indenter together with the Lesser Caucasian folded arc) and the underthrusting under it of the relatively rigid autochthonous GJZ and the rigid Georgian block i.e A-type subduction takes place, which caused the formation of many gently sloping sliding surfaces inclined to the north, along which rock slices of various sizes moved.

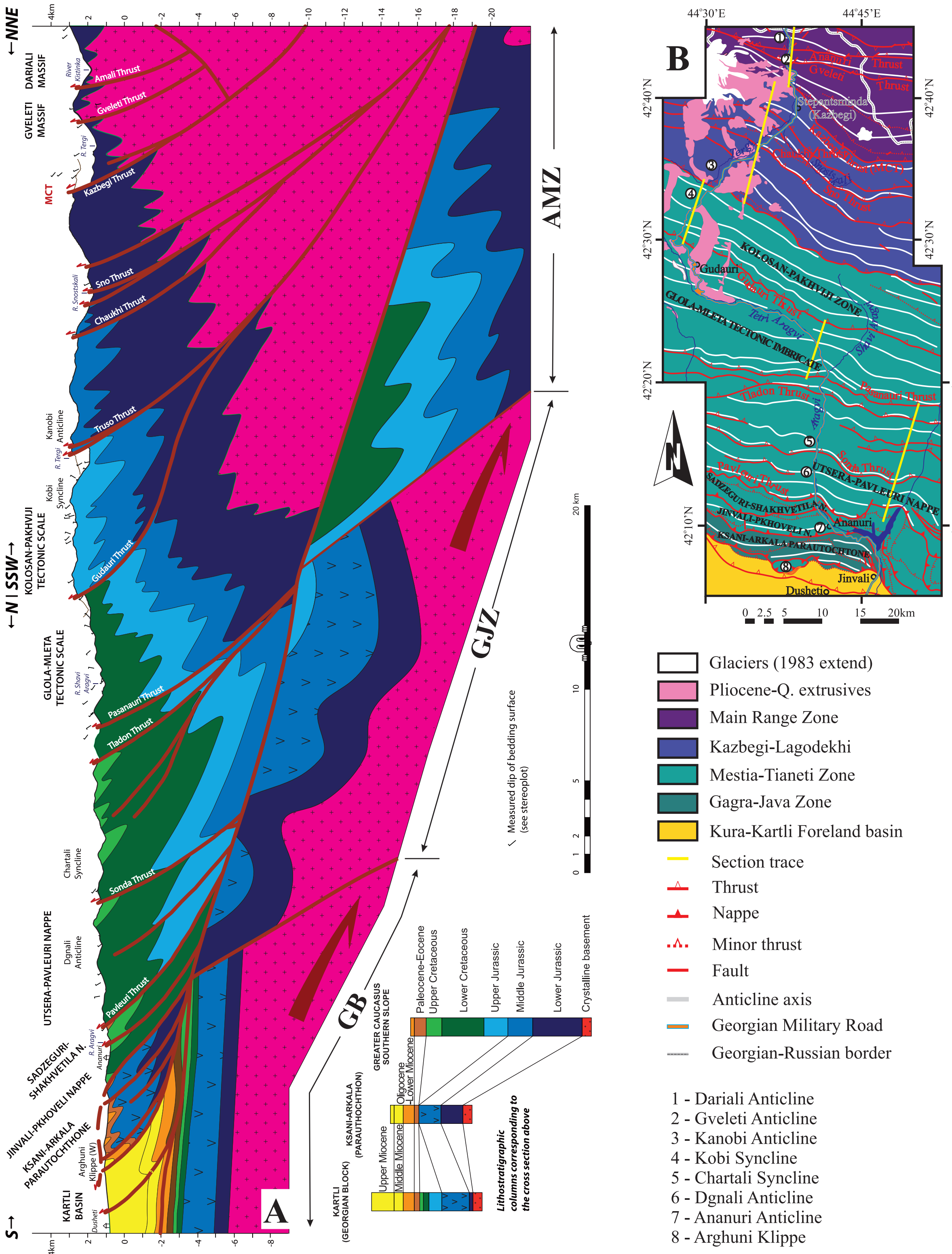
In our opinion, the active underthrusting of the autochthon under the formed Greater Caucasus fold-and-thrust belt is indicated by a gradual reduction in the amplitude of displacement of individual nappes from south to north, as well as the phenomenon of overlapping or "sealing" of the already detached and overthrust southern nappes by their more northerly counterparts. In particular, the Alisisgori-Chinchvelta nappe overlaps the already overthrust Zhinvali-Pkhoveli nappe and Ksani-Arkala parautochthone, and the Utsera-Pavleuri nappe, in turn, overlaps the Alisisgori-Chinchvelta nappe and its root zone.

However, at the later stages of development, in the presence of an appropriate slope and isolated plates, separate parts of some nappes could experience gravitational movement. For example, the Arguni "wandering'' klippe (Text-fig. 10).

The existence of an underthrusting (alpino-type subduction) beneath the Greater Caucasus on the base of structural data has long been assumed by P. Gamkrelidze and I. Gamkrelidze (1977), I. Gamkrelidze (1984, 1991) and according to seismic data – E. Khalilov *et al.* (1987), V. Khain and L. Lobkovsky (1994).

R. Mellors *et al.* (2012), using data of A. Godzikovskaya (1988) and A. Godzikovskaya and G. Reysner (1989), located six earthquake hypocenters at depths of 80 to 120 km based on local network arrival times. An additional 26 events were inferred to be subcrustal based on observed waveform characteristics. V. Khain and L. Lobkovskiy (1994) interpreted these events as indicating a northeasterly dipping present-day subduction below the Eastern Greater Caucasus.

T. Mumladze *et al.* (2015), using a new database of earthquakes from local networks in Georgia, Russia, and Azerbaijan, together with previously published hypocenter locations, showed that "the central and eastern mountains of the Greater Caucasus are underlain by a zone of mantle seismicity dipping to the northeast, which is interpreted as a subduction slab". According to these authors, "under the central part of the Greater Caucasus (east of 45°E), the seismic zone extends to a depth of at least 158 km with a dip of ~40°N. and plate length 130–280 km" (Text-fig. 12). They believe, that "active subduction beneath the



Text-fig. 13. A – Scheme of transition from thin-skinned to thick-skinned deformation in the A-type subduction zone of the southern slope of the Greater Caucasus compiled based on the cross-section in their central part (along the Georgian Military Road) after Mosar *et al.* (2022), but with a change of interpretation of the deep structure of the section based on seismic data. Abbreviations: GJZ, Gagra–Java zone; GB, Georgian block, AMZ, remains of the autochthonous part of the Mestia-Tianeti flysch zone (root zone); B – Regional tectonic map (after Mosar *et al.* 2022).

eastern Greater Caucasus presents a potentially larger seismic hazard than previously recognized and may explain historical records of large magnitude (M 8) seismicity in this region."

Thus, the above seismic data indicate that the basal detachment (décollement) of the nappes continues to develop, penetrates deeply, and cuts the pre-Jurassic crystalline basement, and even the entire Earth's crust, representing thick-skinned deformation (Text-fig. 13).

Quite remarkable are GPS data obtained by R. Reillinger *et al.* (2006), A. Karakhanyan *et al.* (2013) and G. Sokhadze *et al.* (2018). These data indicate movement of the Earth's crust to the north-northeast in the territory of both Western and Eastern Georgia including the Greater Caucasus and they indicate that the principal convergence between the Lesser and Greater Caucasus in Eastern Georgia occurs along the northern boundary of the Lesser Caucasus. G. Sokhadze *et al.* (2018) suggest that the southward offset of convergence along the strike of the ridge is associated with the onset of the collision of the Lesser and Greater Caucasus and the closure of the intermediate Kura foreland basin, which, together with the Lesser Caucasus, is the most advanced (with higher velocities of displacement on average, about 8 mm per year, compared with velocities within the Greater Caucasus – about 5 mm per year) in this segment of the collision zone. Thus, it is quite obvious that the subduction both of its footwall and hangingwall are displaced to the north, but the footwall is ahead of the movement of the hangingwall thereby causing its subduction under the Greater Caucasus.

It should be noted that the underthrusting mechanism for the formation of the nappes (A-type subduction) is universal throughout the Alpine-Himalayan collisional belt (Gamkrelidze 1991). In particular, such a mechanism is accepted as a principle for the nappe structures of the Carpathians (Stille 1953; Grecula and Roth 1978; Mahel 1979, 1980; Gamkrelidze 1984), the Alps (Stille 1953; Gamkrelidze 1991) the Himalayas (Khain and Lomize 2005) and the Dabie-Sulu orogenic belt in East Central China (Wencai 2000). Generally, over the past 4 decades, issues of the genesis and evolution of thrust-and-fold belts and their modeling have been considered by many researchers (Boyer and Elliott 1982; Butler 1987; Cotton and Koyi 2000; Liu *et al.* 1992; Merle 1998; Morley 1988; Nemčok *et al.* 2005; Sieniawska *et al.* 2010).

We can make an estimate now of the horizontal amplitude of the nappes of the southern slope of the Greater Caucasus. Taking into account the overlapping of the entire GJZ and a significant part of the KFB by the allochthonous complex, the magnitude of displacement of the flysch nappes along the basal décollement under the Greater Caucasus in their central part will be about 40 km (Text-fig. 13). If we add to this the total magnitude of the syn-collisional displacement between the parautochthon and flysch nappes and individual nappes with respect to each other (about 30 km), and thrusts at the base of many tectonic scales on the southern slope of the Greater Caucasus, then the total amount of overlapping in their central part can be estimated at 70–80 km, but in the eastern (Kakhetian) part, taking into account the displacement along the Alisisgori-Chinchvelta nappe (Text-figs 10, 11) – 90–100 km.

The taking into account of these data is necessary to determine the amount of total lateral contraction (shortening) of the Earth's crust within the Greater Caucasus, but of course we must add the shortening caused by the folding of the entire Greater Caucasus. The value of the horizontal shortening of the Greater Caucasus was initially obtained from the results of the unfolding of folds based on the analysis of restored sections (Yakovlev 2005; Kopp 2007). Since these calculations were made not only for the flysch zone of the Southern slope, but also for the zone located to the north (i.e. for the Kazbeg-Lagodekhi zone of Jurassic slate and clay shales of the Southern slope (Text-fig. 2), where isoclinal folds with sub-vertical axial planes dominate, then at least the same amount should be added to the figure of the total horizontal displacement of nappes by 90‒100 km, and it turns out that the total shortening of the entire Southern slope, recorded in folding and nappes, reaches 170–190 km. If we add to this the folding of the remaining part of the Greater Caucasus (i.e. its Main Range zone), counting also displacement along the northward backthrusts of its northern slope (in the Dagestan Fold-and-thrust belt), then the total transverse shortening of the Earth's crust within the Caucasus in its eastern part will be at least 190 –200 km.

It is noteworthy that, according to Cowgill et al. (2016), the entire Greater Caucasus sedimentary basin during Late Mesozoic to Early Cenozoic time could have been on the order of ~350 to 400 km wide. The present width of the entire Greater Caucasus, in the section we are considering, including the Dagestan Fold-and-thrust belt (which is part of a retro-wedge) is approximately 160 km. That is, with this calculation, its total collisional shortening is approximately 200–250 km.

CONCLUSION

The existence of the nappes of the southern slope of the Greater Caucasus is proved herein on the basis of paleogeographic reconstructions of late Eocene time, indicating the complete overlapping by the nappes of the flysch zone of the Racha-Vandam cordillera of the GJZ and this entire autochthonous zone of the southern slope of the Greater Caucasus, as well as a significant part of the KFB – eastern subsidence of the Georgian block. This is also evidenced by drilling data and structural data, in particular, the existence of some subhorizontal overthrust plates and many tectonic windows and semi-windows in them, as well as the interpretation of seismic reflection profiles.

The above data and considerations about the morphological and kinematic features and conditions for the formation of the nappes of the southern slope of the Greater Caucasus allow us to come to the following conclusions:

1. In the geological past the nappes discussed here were independent structural-facies zones separated by syn-sedimentary listric deep faults. The western segment of the development of the nappes is characterized by primary transverse structural-facies zoning, which is generally undisturbed due to the formation of nappes, while in the eastern segment, the Kakhetian one, there is a complete overlapping, even "crawling" and rolling of the northern structural-facies zones over the more southern ones.

2. In the western segment, from north to south, are distinguished: the Utsera-Pavleuri nappe characterized by a continuous section of distal flysch from the Cenomanian to the Campanian inclusive; the Sadzeguri-Shakhvetila and Zhinvali-Pkhoveli nappes, composed of proximal flysch from the Aptian or Albian to the Middle Eocene, and which, in contrast to the Utsera-Pavleuri nappe, are characterized by frequent breaks in sedimentation and the transgressive location of the Aptian, Cenomanian, Maastrichtian and Paleocene deposits.

3. The southernmost thrust sheet (Ksani-Arkala parautochthone) is a detached part of the autochthonous GJZ.

4. In the eastern (Kakhetian) segment of the development of the nappes the Utsera-Pavleuri and Alisisgori-Chinchvelta nappes are distinguished. In this segment, the sediments that make up the Utsera-Pavleuri nappe are somewhat different from the synchronous deposits of the western segment, but in general it is also composed of distal flysch from the Cenomanian to the Campanian inclusive. The Utsera-Pavleuri nappe in this segment has a significant amplitude, overlapping the root zones of the Alisisgori-Chinchvelta and Sadzeguri-Shakhvetila nappes.

5. The Alisisgori-Chinchvelta nappe, or rather the corresponding structural-facies zone, was developed only in the eastern part of the flysch trough. The nappe developed from this zone is now completely detached from its roots and overlaps different nappes. This nappe is composed of a continuous section of distal flysch from the Albian to the Paleocene inclusive. This nappe is characterized by numerous tectonic windows and semi-windows, in which Danian, Paleocene (included Danian) and Eocene deposits of the Sadzeguri-Shakhvetila nappe are exposed. In the eastern segment, the Zhinvali-Pkhoveli nappe completely overlaps the Ksani-Arcala parautochthone, which is also covered by other nappes and only appears through them in tectonic windows and semi-windows. In this segment, in the Zhinvali-Pkhoveli nappe there are also many tectonic windows and semi-windows, in which the Kinta suite of the Upper Eocene–Lower Miocene is exposed, which belongs to the eastern continuation of the Ksani-Arkala parautochthone.

6. The formation of all the tectonic nappes of the southern slope of the Greater Caucasus began as probably early as the late Eocene (beginning of the Alpine uplift-exhumation of the Greater Caucasus) but the main phase of the nappe formation was the pre-Late Pliocene Rodanian orogeny.

7. The leading mechanism for the formation of the nappes is the intense lateral compression of the Greater Caucasus fold-and-thrust belt, mainly due to the advance to the north and underthrusting under it of the relatively rigid autochthonous GJZ and the rigid Georgian block, i.e. there takes place an alpinotype subduction, which caused the formation of many gently sloping sliding surfaces inclined to the north, along which already folded flysch deposits moved.

8. The enumerated nappes, forming in the time of collisional, are developed in the sedimentary cover of the Earth's crust and do not include the rocks of the pre-Jurassic crystalline basement, thus representing thin-skinned nappes. But according to seismic data, the basal detachment (décollement) of the nappes at depth cuts the crystalline basement, even the entire Earth's crust and represents, consequently, thick-skinned deformation.

9. The underthrust mechanism of formation of the nappes (alpinotype subduction) is universal for the entire Alpine-Himalayan collision belt. In particular, it is characteristic of the Carpathians, the Alps, the Himalayas and some other orogenic belts. This is

also confirmed by their analogue modeling (sandbox experiments).

10. The total horizontal amplitude of displacement of the flysch nappes in their eastern (Kakhetian) segment can be estimated as 90–100 km, while the magnitude of the total transverse shortening of the Earth's crust within the Greater Caucasus, can be estimated equal to 190–200 km.

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