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*Geology*

# Duration of Cenozoic Orogenies (on the Example of Georgia)

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**ABSTRACT. On the basis of litho-facial analysis of Cenozoic depodits that accumulated during the manifestation of orogenies (phases of folding), the processes of sedimentation accompanying these phases, as well as some paleogeographic and structural changes have been considered. Each orogenic phase was accompanied by accumulation of synorogenic regressive formations. They were a direct consequence and criterion of intensification of the tectonic movements. It turned out that in some cases there is no temporal coincidence between orogenic phase and regression, and the manifestation of the same orogenic phase in different tectonic zones is not strictly synchronous. During the Cenozoic time, the most important were the Pyrenean and Styrian orogenies, which, along with the Chegem orogeny, created the principal morphostructural units and mostly predetermined, in general, the character and appearance of present-day geological structure of the region. Taking into account the age of regressive deposits and geochronological data, for the first time the duration of each orogeny was determined for the territory of Georgia.** *© 2013 Bull. Georg. Natl. Acad. Sci.*

***Key words:*** *orogeny, phases of folding, regressive formation, paleogeography.*

Phases of folding, as is known, in modern view is a relatively short-term phenomenon of acceleration and intensification of the actually continuous process of deformation. It was accompanied by tectonic deformations of rocks, on the one hand, and on the other, by the changes in the character of sedimentation manifested in terms of changing facies accumulation and thickness of sediments, the configuration of sedimentary basins and their migration. The study of facies changes and the analysis of sediment depth, especially in the areas with continuous sections and where the direct signs of tectonic movements (break in sedimentation or angular unconformity) are missing, may be decisive in establishing the signs of manifestation of tectonic phases.

In the paper, based on litho-facial analysis of the Mesozoic sediments [1] in the light of recent actual material and "plate tectonics", those facies and palaeogeographic changes that accompanied the orogenies are considered and to the possible extent the time of their manifestation is specified. The duration of each orogeny is defined according to geologic time-scale.

Before turning to the problem, it should be noted that in the study area, in the Mesozoic-Cenozoic time all the orogenies (except the Savian) distinguished

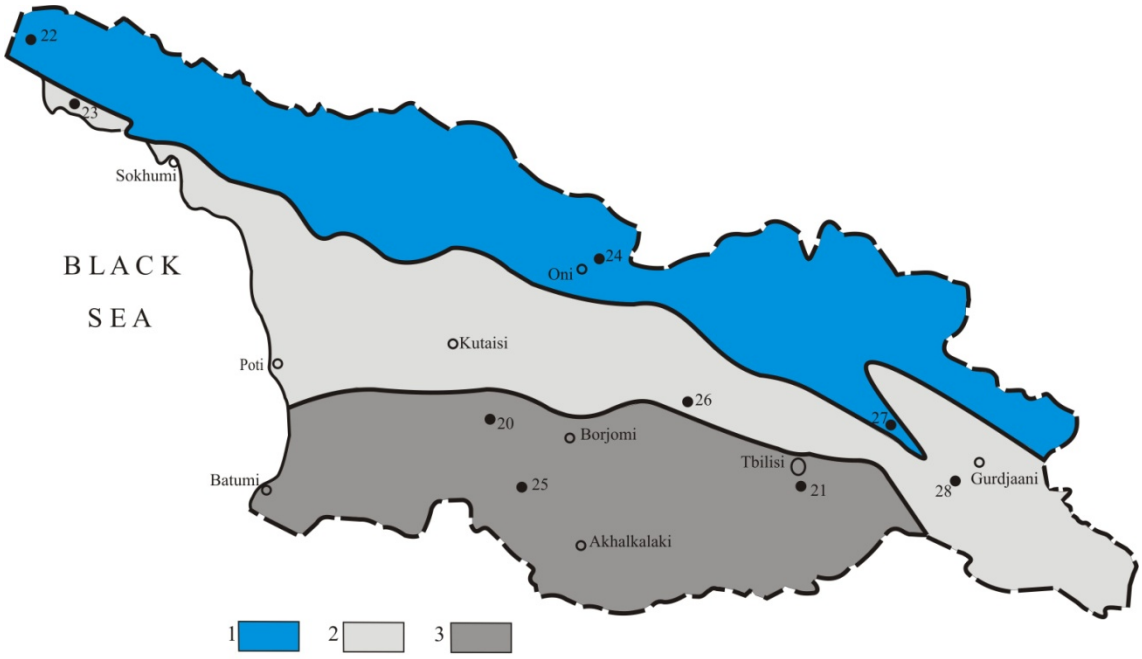



**Fig. 1.** Sheme of tectonic zoning of the territory of Georgia (I.Gamkrelidze, 2000)
• Location of some geographical names mentioned in the text.

by H.Schtille [2] as well as three new ones – the Donetsk, Chegem and Early Pyrenean (Trialetian) have been established.

## Early Pyrenean (Trialetian) Orogeny

In the Paleogene manifestation of two phases of folding is established. They represent the Pyrenean epoch of tectogenesis and apparently have a global character [3]. The first phase – Early Pyrenean (Trialetian) manifested before the Late Eocene, and the second – Late Pyrenean (proper Pyrenean) - before the Oligocene.

As a result of these phases of folding in the considered region, as well as throughout the Alpine folded area, significant changes of palaeogeographic and facies character took place. With them is associated the beginning of early orogenic stage of its development. In particular, the beginning of this event in the Balkan region is associated with the Early Pyrenean (Illyrian orogeny), and in the Caucasus - with the Late Pyrenean phase of folding.

Early Pyrenean orogeny in the Caucasus was first distinguished by P.D. Gamkrelidze [4] within the Achara-Trialeti folded zone as a Trialetian orogeny. In the Caucasus, it was manifested in different ways and with various strength.

Within the Southern slope of the Greater Caucasus the Early Pyrenean folding is weakly displayed. In the Gagra-Java zone in small areas transgressive bedding of the Upper Eocene deposits on more ancient formations (the Skhanari syncline, northern limb of the Racha-Lechkhumi syncline, Dusheti district, etc.) is observed.

In stable areas (contemporary South Caucasian intermountain area), where the Trialetian orogeny structurally had not left any special trace and where during the Eocene and Oligocene uninterrupted sedimentation (deep areas of the basins) continued, this orogeny, as well as the Late Pyrenean one had a specific manifestation.

At the beginning of the Late Eocene, flysch basins, except for the Southern slope of the Greater Caucasus and partially of the Achara-Trialeti trough, due

to Trialetian folding closing of the most of the Crimea-Caucasian basin and weakening of its connection with the ocean took place and, as a result, a reducible realm of sedimentation was established, where in conditions of hydrogen sulfide contamination of marine environment deposition of *the Egrisi suite* (lirolepis marls) began.

With the Early Pyrenean (Trialetian) orogeny was associated the cessation of the Black Sea - Achara-Trialeti rifting and the beginning of the compression regime and differentiated movements [5] that in the Late Eocene caused an abrupt reduction of volcanic activity in the greatest part of the Achara-Trialeti basin. In the area, at this time a partial inversion of relief and regression of the sea took place, changing the central part of the basin (that was the area of intense sedimentation) into a zone of uplift that divided the Paleogene basin into the northern and southern parts.

In the volcano-sedimentary formations building up most of the Achara-Trialeti zone synorogenic formations are usually hardly detected. Their presence is recorded in the South Imereti piedmont area and on the northern slope of the Meskheti ridge (Fig.1, dot 20), where these deposits make up the upper part of the Middle Eocene *Guria suite* and are represented by regressive formations of the *"horizon of biotite-bearing tuffs"*.

The formation of "Tbilisi olistostromes" ("conglomerates of intricate bedding") at the end of the Middle Eocene was associated with the Trialetian phase [6]. Finally, the manifestation of the Trialetian orogeny in the Achara-Trialeti zone evidenced the angular unconformity between the Upper Eocene rocks and the older ones, including those of the Middle Eocene [4]. With the end of the Middle Eocene is also bound the detachment of the western part of the Tethys and the formation of the Mediterranean Sea – closed relic oceanic basin [7].

## Late Pyrenean Orogeny

Late Pyrenean folding affected a vast territory, not only in the Caucasus but also all over the Alpine folded area.

On the Southern slope of the Greater Caucasus origination of local unconformities and accumulation of regressive formations are connected with the given folding. Wide spreading of Upper Eocene olistostromes points to active tectonic movements in this area.

In the Eastern flysch basin (east of the river Didi Liakhvi) Late Pyrenean folding manifested itself in the accumulation of the regressive upper part of Ildokani suite (the rivers Aleura, Mejuda), where separate packets of coarse flysch are present [6].

One of the interesting areas with an abrupt facies change, conditioned by the Late Pyrenean orogeny, is Adler depression (Fig.1, dot 22). The deposits participating in its structure are represented by all stages of the Paleogene that are well-characterized faunally. Upper Eocene formations are of special interest.

Their facial analysis shows that they are represented by lithologically distinctly differing two subfacies. On the one hand, they are subplatform shallow-water deposits (up to 75 m), similar to the sediments of the Georgian block that encompass the lower part of the Upper Eocene (lirolepis marls, upper variegated marls), and on the other hand - thick (up to 350 m) carbonate-terrigenous formations of molassoid type (*Matsesta suite*) characteristic of piedmont trough. The Matsesta suite is divided into three horizons: the lower - sandy-clayey, middle - "horizon with inclusions" (olistostromes) and the upper – argillo-arenaceous.

The lithological character and great thickness of the *Matsesta suite*, compared with the underlying sediments (*Egrisi and Kldiani suites*), undoubtedly indicate its regressive nature. Faunistic characterization and exact age of the horizons composing the *Matsesta suite*, which is a synorogenic formation, give a complete picture of the nature and time of manifestation of the Late Pyrenean folding [8].

In the vicinity, on the Georgian block, in the Bzybi river basin (Fig.1, dot 23) synchronous formations are represented by subplatform facies in the form of lirolepis and variegated marls with total thickness of 70-100 m.

Comparative analysis of lithofacies character and thicknesses of the Upper Eocene formations of the Georgian block and Adler depression clearly indicates that in the second half of the Late Eocene within the Adler depression subsidence of the basin floor and the delivery of a significant amount of terrigene material causing the accumulation of a thick *Matsesta suite* and then in the Oligocene – accumulation of the *Khosta* and *Sochi suites* took place.

Olistostromes, developed in the eastern part of the Southern slope of the Greater Caucasus (to the east of the river Rioni), in our opinion are synchronous to the deposits of the "horizon with inclusions", and thus they fix the moment of maximum display of the Late Pyrenean folding within the limits of the Southern slope of the Greater Caucasus.

Taking into account the above mentioned, as well as the fact that the Upper Eocene olistostromes are widespread in other parts of the Alpine folded system, in our opinion they should be related to the "event deposits." They are a kind of marker formations, enabling correlation of tectonic movements in the Alpine folded system and beyond its limits. Their formation, apparently, is connected with the beginning of the nappe formation process on the Southern slope of the Greater Caucasus.

The Racha-Vandam cordillera zone should be considered in more detail which, as already mentioned, appeared after the Chegem folding and was a significant morphological structure for the subsequent periods, especially in the Late Eocene during the formation of olistostromes. The cordillera zone, located on the northern periphery of the Gagra-Java zone, is now completely blocked by the Cretaceous-Paleogene flysch formations that overthrust from the north. It was a chain of separate cordilleras, extending from the Utsera meridian (the river Rioni) (Fig.1, dot 24) to the west along the southern boundary of the Eastern flysch basin and continued eastward beyond the study area [9].

The existence of Racha-Vandam cordillera zone is confirmed by our study of the Upper Eocene formations of the Southern slope of the Greater Caucasus, especially of olistostromes [10, 6]. The mentioned cordillera zone was one of the main suppliers of terrigenous and clastic material for both flysch and epicontinental basins during the second half of the Mesozoic and the first half of the Paleogene (to the Oligocene). The composition of olistostromes indicates that the cordillera zone was mainly built up of the Mesozoic and partly Lower Paleogene rocks of the Gagra-Java zone and to the east of the river Aragvi – by crystalline rocks of the basement. In the Achara-Trialeti zone the Late Pyrenean orogeny was manifested weaker than the Trialeti phase, but still it caused significant changes in the palaeogeography of the territory, especially in its western part. Regression of the sea and drying of sedimentary basins is associated with this phase. Only in the eastern and northern parts of the Trialeti Range and in Akhaltsikhe depression (Fig.1, dot 25) relic basins with ongoing sedimentation are preserved. In some localities of the environs of Tbilisi in the second half of the Late Eocene sedimentation of regressive formations, represented only by conglomerates (westwards of the village of Okrokana, down the Kojori-Kiketi road, etc.), took place.

As a result of the Pyrenean tectogenesis the Western and then (at the end of Late Eocene) the Eastern flysch basins of the Southern slope of the Greater Caucasus was closed. In their piedmont troughs in the Oligocene terrigene sediments of *the Khosta and Sochi suites* (Adler depression) and of *the Quinta suite* (Kakheti zone) accumulated.

As a consequence of expansion of folded regions of the Greater and Lesser Caucasus and subsidence of the Kura depression, intermountain troughs and foredeeps were formed, where during the Oligocene and Early Miocene mainly sediments of *the Maikop series* accumulated.

## Styrian orogeny

Styrian folding that was manifested before the Chokrakian was one of the strongest along with the

Chegem and Pyrenean orogenies. It was expressed in the regression, an angular unconformity of the Chokrakian and changes in the palaeogeographic geotectonic conditions.

The relic basin in the eastern part of the Southern slope of the Greater Caucasus (Kakheti) ceased its existence from the Middle Miocene, where during the Oligocene-Early Miocene sedimentation of the *Quinta suite* took place. As a result of Styrian folding the Achara-Trialeti zone was transformed into a folded structure. However, in many sections (the rivers Kelasuri, Chachiskhevi, villages of Kurzu, Salkhino, Nakuraleshi, Surmushi, northern limb of the Racha-Lechkhumi syncline) in the Lower Miocene part of the *Maikop series* regression is observed. It manifested itself in the occurrence of sandstones and rarely conglomerates in the Maikop clays [11].

Early Miocene regression is most distinctly manifested between the towns of Gori and Mtskheta, where in the upper part of the Lower Miocene deposits sandstones occupy the greatest part of the section and become more coarse-grained (village of Uplistsikhe) (Fig.1, dot 26). The thickness of sandstones of *the Sakaraulo and Kotsakhuri horizons*, among which microconglomerate interlayers occur, reaches 500 m (village of Nadarbazevi).

Due to Styrian tectonic movements in the Maikop basin, along with the deposition of rudaceous facies, the hydrochemical regime of seawater often changes. In the Achara-Trialeti zone, the injection of syenite-diorite intrusives of hyp-abbysal character is involved with this phase [11].

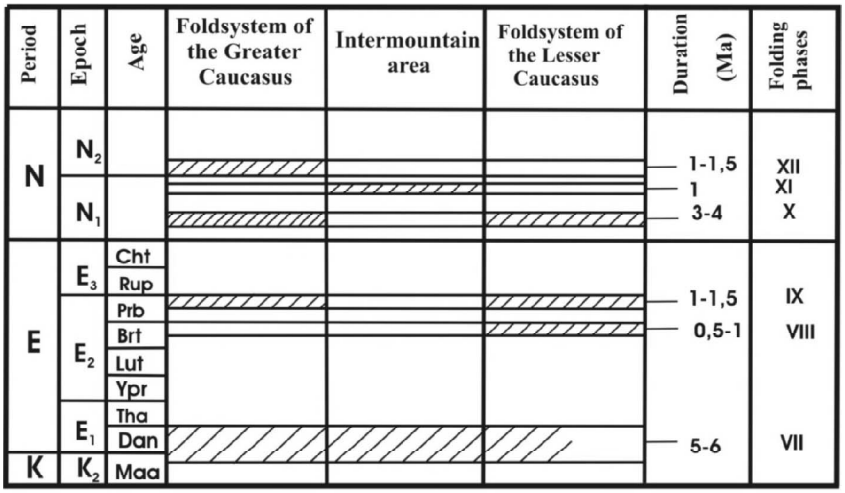
If on the Southern slope of the Greater Caucasus and in the Achara-Trialeti zone in Early Miocene time the ascending movements took place, then at the same time in the Southern Caucasus intermountain area located between them, its relative subsidence and transformation into an intermountain molasse depression was going on, where the Styrian orogeny is well expressed in the Chokrakian transgression and the angular unconformity between the Middle Miocene and the older rocks [12].

## Attic Orogeny

The Late Miocene-Pliocene was characterized by manifestation of new tectonic movements. The main among them was the Attic phase of folding, which, according to the facies analysis of the Miocene formations, started from the second half of the Middle Sarmatian and continued throughout the Late Sarmatian.

The uplifting of the mountain ranges of the Greater Caucasus and of the Achara-Trialeti continued during the Attic orogeny. They intensively supply the Southern Caucasus molasses basin with rudaceous material. Against the general background of subsidence, which began here from the Oligocene, in some areas as a result of the Attic orophase from the second half of the Middle Sarmatian shallowing of the sea is observed. It was manifested in the change of clayey facies by arenaceous ones containing conglomerate packets (village of Ninotsminda, the Tsiv-Gombori ridge, northern part of Kartli depression, etc.) As a result of regression in some places a continental regime of sedimentation was formed and from the Late Sarmatian deposition started of the freshwater-continental *Natskhori suite* composed of clays and sandstones (Kartli depression, southern slope of the Tsiv-Gombori ridge). In another part of the Southern Caucasus molasse basin (adjacent to the Iori strip of Gare-Kakheti) freshwater-continental conditions were established in the second half of the Late Sarmatian, which promoted deposition of the clayey-sandy *Eldari suite*.

At the end of the Late Sarmatian with the completion of Attic folding in the greater part of the Southern Caucasus intermountain area a final retreat of the sea took place. Folding associated with the given orophase is well observed in Western Georgia (Guria, Samegrelo, Abkhazia), where an angular unconformity between the Middle Sarmatian and Pliocene (the river Kodori, Guria, etc.), confined to the large anticlinal uplifts, is recorded [12]. Angular unconformity established between the Meotian and Pontian is of local character (environs of Sokhumi). Simultaneously




Folding fases: VII - Laramide; VIII - Early Pyrenean (Trialetian); IX - Late Pyrenean (Pyrenean proper); X - Styrian; XI - Attic; XII - Rhodanian.
▨ - regressive deposits

**Fig. 2.** Time and duration of manifestation of Cenozoic folding phase saccording to regressive deposits.

with the folding in separate segments of the Southern Caucasus intermountain area (Samegrelo) due to insignificant short-term ascending movements, small islands subjected to the erosion in the Pontian were formed [12]

## Rhodanian orogeny

Rhodanian (East Caucasian) folding manifested before the Akchagilian. Because of lithologic homogeneity of Pliocene formations. It is impossible to reveal any change induced by the Rhodanian folding according to the facies features. Structurally, this orogeny is well observed in the eastern part of the Greater Caucasus (Kakheti), where the Akchagil-Apsheronian molasse formations of *the Alazani series* with a significant angular unconformity overlap more ancient formations, including the Meotian-Pontian (*Shiraki suite*) and the Oligocene-Lower Miocene ones (*Quinta suite*).

Transgressive, almost horizontal bedding of the Alazani series on heavily dislocated overthrust flysch sediments of the Southern slope of the Greater Caucasus (the river Mtsarekhevi, Mt.Tsivi (Fig.1, dot27), etc.), definitely points to the completion of the thrust-formation process before the Akchagilian. It should be noted that the aforementioned relationship of the Alazani series with more ancient rocks in some places (the river Lakbe) (Fig.1, dot 28) is disturbed, which was the reason for reconsideration of the pre-Akchagilian age of thrust-formation on the Southern slope of the Greater Caucasus [13]. This inference, however, in our opinion, disagrees with reality, because such disturbances are the exception conditioned by local factors [14].

In the Quaternary period manifestation of two phases of folding is evidenced: the Valakhian (pre-Bakinskaya) and the Pasadenian (pre-Middle Quaternary). Because of their lithologic homogeneity (alluvial and alluvial-marine deposits) their evaluation by the lithology and facies changes fails. From the viewpoint of tectonics with these orogenic phases, a general uplifting of the territory and the formation of river terraces are induced [12].

Thus, in the Rhodanian orogeny the formation of folded structures of the Greater and Lesser Caucasus continued. Their relief was considerably lower than today, acquiring its present-day framework already in the Quaternary period [15].

## Conclusions

Each orogenic phase was characterized to a different extent by palaeogeographic and structural changes, which in their turn had an effect on the nature of sedimentation. This was primarily manifested in the ac-

cumulation of regressive deposits, which is mainly a direct consequence and criterion of the duration of orogenic movements. Based on the aforesaid, identification of the stratigraphic range of manifestation of orogenic phases depends mainly on establishing the exact age of regressive formations. In this respect, according to stratigraphic and fauna data, most reasonable, in our opinion, are the ages of regressive sediments, deposited during the Chegem and Late Pyrenean phases of folding, which are respectively defined as the Late Bajocian-Middle Bathonian inclusive and the second half of the Late Eocene to Oligocene.

It turned out that in some cases there is no temporal coincidence between the orogenic phase and the regression, and the manifestation of the same orogenic phase in different tectonic zones is not strictly synchronous.

Among the considered orogenies, the most significant were the Chegem, Pyrenean and Styrian ones. As a result of Chegem folding the Svaneti uplift was formed dividing the integrate marginal sea of the Southern slope of the Caucasus into two parts. With this orogeny the origination of cordilleras and sedimentary basins is also involved, which have largely determined the subsequent nature of geological development of the region. With the Pyrenean era of tectogenesis in the Caucasus is associated the beginning of early orogenic stage of its development. This process for the Lesser Caucasus began with the Early Pyrenean phase of folding, whereas for the Greater Caucasus - with the Late Pyrenean orogeny. In the latter, as a result of this orogeny, the closure of the Western flysch basin and then of the Eastern one took place. After the Styrian orogeny a complete cessation of residual sedimentary processes on the Southern slope of the Greater Caucasus (Kakheti) and transformation of the Achara-Trialeti zone into the folded structure took place. Simultaneously, the Southern Caucasus intermountain region, as a result of the relative subsidence, turned into a depression of intermountain molasses. All the considered Mesozoic-Cenozoic orogenic phases contributed, to a various degree, to the formation of the folded structures of the Greater and Lesser Caucasus, the final formation of which took place already in the Quaternary.

*გეოლოგია*

# კაინოზოური ოროგენული ფაზისების ხანგრძლივობა (საქართველოს მაგალითზე)

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**კაინოზოური ნალექების ლითოლოგიურ-ფაციესური ანალიზის საფუძველზე განხილულია ის სედიმენტაციური, პალეოგეოგრაფიული და სტრუქტურული ცვლილებები, რაც ოროგენულ ფაზისებთანაა დაკავშირებული. დანაოჭების ყოველ ფაზისს თან ახლავს უმეტესად სინოროგენული რეგრესიული ნალექების წარმოშობა, რომლებიც ამ ფაზისების პირდაპირ შედეგს და მათი**

ხანგრძლივობის საზომს წარმოადგენს. გამოირკვა, რომ ცალკეული ოროგენული ფაზისთვის რეგრესია დროში არ ემთხვევა ერთმანეთს და ამდენად, სხვადასხვა ტექტონიკურ ზონაში ერთიდაიგივე ოროგენული ფაზისის გამოვლენა მკაცრად სინქრონული არაა. კაინოზოურ დროში ყველაზე მნიშვნელოვანი პირენეული და შტირიული ფაზისებია. მათ, ჩვენებურ ფაზისთან ერთად, ჩამოაყალიბეს ის ძირითადი მორფოსტრუქტურული ერთეულები, რომლებმაც მნიშვნელოვნად განაპირობეს რეგიონის გეოლოგიური აგებულების თანამედროვე ხასიათი. რეგრესიული ნალექების ასაკის და გეოქრონოლოგიური მონაცემების გათვალისწინებით საქართველოსთვის პირველადაა განსაზღვრული ცალკეული ოროგენული ფაზისის ხანგრძლივობა.

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