

Lithospheric Structure and Alpine Geodynamics of Georgia

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ABSTRACT. The Tethys Ocean was closed in Georgia only in the Late Cenozoic. Geophysical study has led to a detailed model of the deep crustal structure of the region that includes areas of two-layered as well as three-layered continental crust. The thickness of the crust varies from 30 to 60 km, with significant lateral variations in the sedimentary layer (0–25 km). Geological, paleobiogeographical and paleogeographical data supported by paleomagnetic studies indicate the existence of several tectonic units in Georgia and adjoining regions that have distinctive geological histories. Their position against the African and Eurasian continents provides a reason for grouping them into Northern Tethyan and Southern Tethyan domains. The magmatic evolution of the North Tethyan domain is featured by major events corresponding to the Pacific and Mediterranean type stages of Tethyan development. Late Cenozoic magmatic complexes are exposed along the boundaries of the main terrains of the region. The complex network of faults permits region to be divided into a number of separate blocks of different orders. The main part of the seismically active faults represents the boundaries of the main tectonic units of Georgia. The geometry of tectonic deformation is largely determined by the wedge-shaped rigid Arabian block intensively indenting into the mobile area. Submeridional compression reaches its maximum within the central segment of the Caucasus. Westward escape of the western Transcaucasus did not occur either, because of the backstop provided by the stable crust of the eastern Black Sea Basin. There is good correlation between the P and S lowest-velocity anomalies within the upper mantle – asthenosphere and Neogene–Quaternary volcanism of the region. © 2019 Bull. Georg. Natl. Acad. Sci.

Key words: lithosphere, geodynamics, Tethys, subduction, collision

Georgia, the westernmost part of the southern Caucasus is located to the east of the Black Sea, at the junction of the European (Mediterranean) and Asiatic branches of the Alpine-Himalayan orogenic belt. It represents a unique area where the Tethys Ocean, development of which took place during the Neoproterozoic–Early Cenozoic, was completely closed only in the late Cenozoic as a result of

prolonged convergence between the Eurasian and African-Arabian plates. The lithosphere of Georgia and adjacent areas of the Black Sea–Caspian Sea region represents a collage of Tethyan, Eurasian, and Gondwanan terranes. During the late Proterozoic–early Cenozoic, within the convergence area, a system of island arcs and back-arc basins characterized the precollisional evolution of the region [1].

Deep structure. Information on the deep structure of Georgia and adjacent areas was obtained from surface geological, deep and ultradeep drilling, gravitational, seismic, heat flow, and magnetic studies. The region has been crossed by numerous deep seismic sounding (DSS) profiles. Long-term geophysical study has led to a detailed model of the deep crustal structure of the Caucasus that includes areas of two-layered as well as three-layered continental crust. Suboceanic crust within the Eastern Black Sea contains areas devoid of granitic layers, but with an extremely thick sedimentary cover (Fig. 1).

significant lateral variations in the sedimentary layer (0–25 km). Only the central part of the Black Sea and South Caspian Sea is floored by suboceanic crust. There is a direct proportional interdependence between the thickness of the crust and the elevation of the relief; as a rule, the higher the relief, the thicker the crust is. Fig. 1 shows the thickness of the crust in the Caucasian region: 55–60 km-thick crust occurs within the 60–75 km-wide area of the Great Caucasus and 40–45 km-thick crust covers the area of 40–50 km of the Lesser Caucasus. The crust is 40–35 km thick within the 100–130 km wide area of the Transcaucasian massif [2].

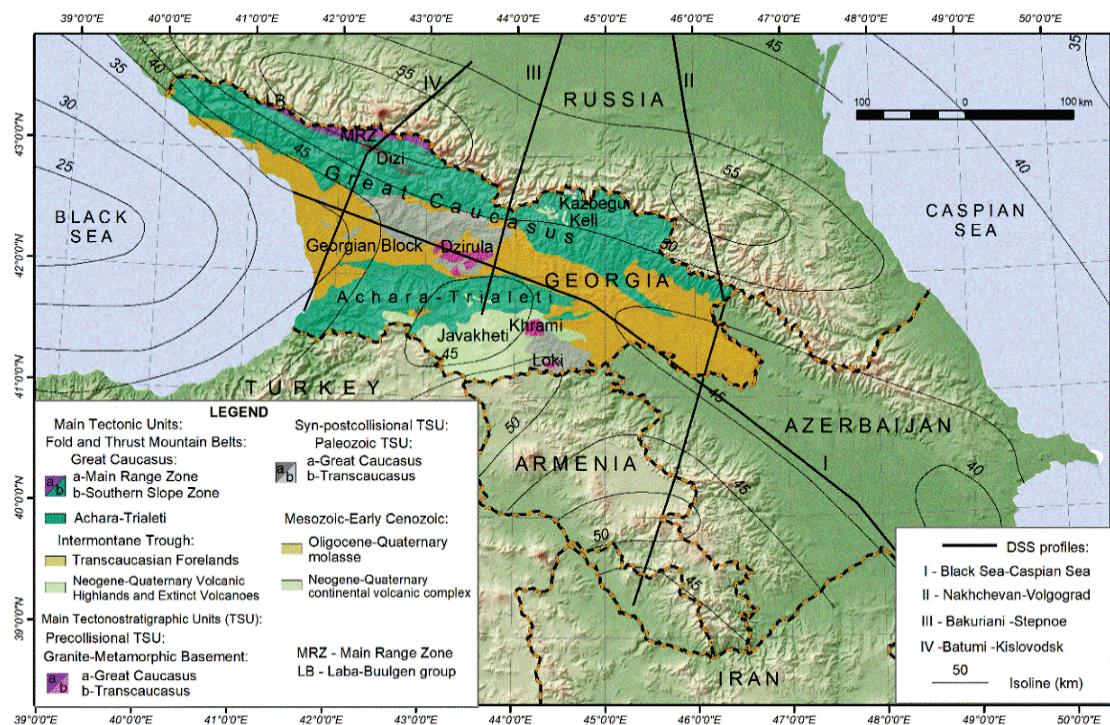


Fig. 1. Isolines of the M discontinuity of the Caucasus [2] and main tectonic units of Georgia; DSS—deep seismic sounding [3].

Current knowledge of the lithospheric structure of Georgia and the adjacent area is based on the surface geology, deep and superdeep drilling data, combined with gravity, seismic, heat flow and magnetic results. Several parts of the region have been traversed by deep seismic sounding profiles. The region is represented by continental crust, the thickness of the crust varies from 30 to 55 km, with

Geological provinces and main tectonic units. Regional geological, geophysical, and paleomagnetic data for Georgia and the Caucasus indicate a position of separate block-microplates in relation to Africa, Arabia, and Eurasia. Geological, paleobiogeographical and paleogeographical data supported by paleomagnetic studies indicate the existence of

several tectonic units in Georgia and adjoining regions that have distinctive geological histories. These are the Scythian platform, the Great Caucasus (Kavkasioni), the Transcaucasus-Pontides, and the Lesser Caucasus (Lesser Kavkasioni) – Alborz–West Iran regions. Their position against the African-Arabian and Eurasian continents provides a reason for grouping them into Northern Tethyan and Southern Tethyan domains [1,3,4].

Magmatic activity. Magmatic evolution is an important event in the formation and development of the geological structure of Georgia, where several reliably dated volcanogenic and volcanogenic-sedimentary formations are established. The region represents a modern analogue of continental collision zone, where subduction-related volcanic activity lasted from Paleozoic to the end of Paleogene. After the Early-Middle Miocene repose, between the Late Miocene and as far as the end of the Pleistocene there occurred the period of syn- postcollisional primarily subaerial volcanic eruptions, which led to the formation of volcanic highlands and plateaus.

Precollisional development. The Paleozoic-Mesozoic-Cenozoic magmatic evolution of the North Tethyan domain is featured by major events corresponding to the Pacific and Mediterranean type stages of Tethyan development. The Mesozoic magmatic assemblages reflect a diversity of paleogeographic environments (Fig. 2). Both the North Transcaucasian and Pontian-South Transcaucasian arc segments are distinct. The latter, characterized by boninitic-tholeiitic volcanism in the Jurassic, represents an incipient largely ensimatic island arc with a near-vertical subduction zone. Zones of rifting and alkaline basaltic volcanism occur on the active margins of the oceanic domain [5].

The Artvin-Bolnisi tectonic unit, including the Bolnisi ore district, was developing as a relatively

uplifted island-arc type unit with suprasubduction magmatic events. Volcanogenic complexes are characterized by variable lateral and vertical regional stratigraphic relationships and are subdivided into several formations according to their composition. Volcanics are attributed to calc-alkaline-subalkaline series. Depositional environment of Upper Cretaceous volcanic formations varies from shallow-marine to subaerial settings. Mafic to intermediate volcanic rocks are in subordinate amount [5, 6].

The Eastern Black Sea-Achara-Trialeti intraarc rift was initiated in the central part of the Pontian-Transcaucasian paleo-island arc, splitting it into a southern active volcanic arc and a northern remnant nonvolcanic arc. Intensity of rifting and volcanic activity was progressively increasing from east to west, towards the Black Sea and caused formation of the oceanic crust in the central part of the Black Sea basin [7]. Volcanic activity started in the Albian – Turonian and attained its climax in the Middle Eocene resulting in formation of a thick (5-7-km) predominantly basaltic volcanic sequence. It was characterized by calc-alkaline to shoshonitic high-K alkali basalt magmatism with restricted arc tholeiites. The Achara-Trialeti back-arc basalts have a strong subduction zone signature resulting from the increased level of mantle metasomatism [5].

Syn-postcollisional development. During the Oligocene, marine basins were replaced by euxinic-type basins, which are considered as the beginning of syncollisional development. In the late Miocene-Pleistocene there took place subaerial volcanic eruptions that occurred simultaneously with molasse formation in the foredeep and foreland basins and produced calc-alkaline series of basalt-andesite-dacite-rhyolitic composition.

Late Cenozoic magmatic complexes are widespread in the Great Caucasus, Lesser Caucasus, Turkey and Iran. They are exposed along the boundaries of the main terrains of the region. In Turkey, they construct two sublatitudinal branches. In

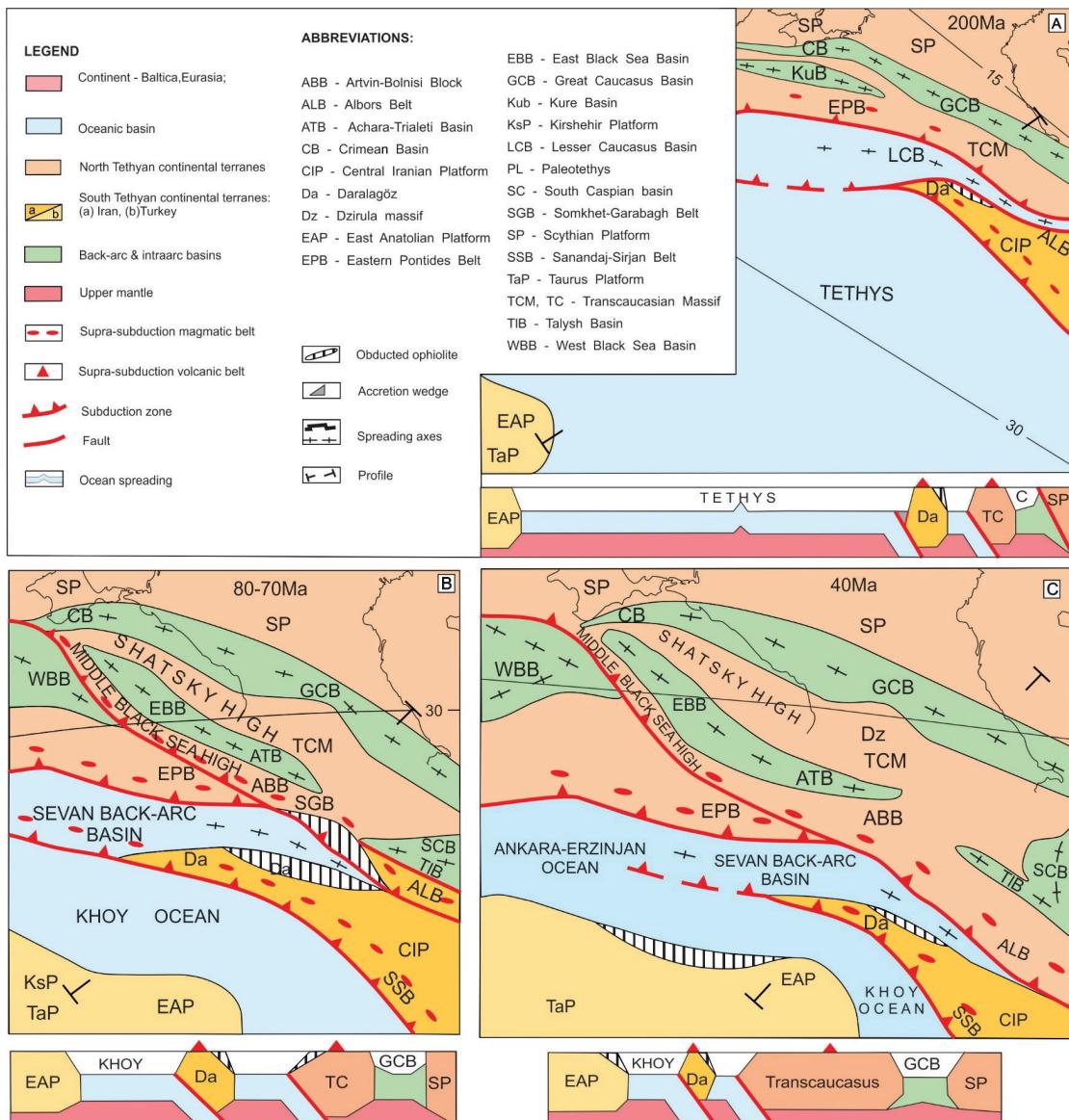


Fig. 2. Paleotectonic reconstructions of the region: (A) early Mesozoic, (B) late Mesozoic; (C) early Cenozoic [3].

the Lesser Caucasus and Iranian Azerbaijan, they outcrop along the Sevan-Zangezur-Garadag ophiolite suture. The southern magmatic belt extends along the Bitlis-Zagros suture. The northernmost, relatively short submeridional branch of Neogene-Quaternary magmatic formations runs through the central part of the Caucasus.

Postcollisional volcanic complexes in the southern Georgia (Javakheti Highland) are represented by well-differentiated basalt-rhyolite series and occupy the transitional field between calc-alkaline and tholeiitic series. This trend is characteristic for the entire set of

Neogene-Quaternary volcanic formations. Miocene-Quaternary volcanic rocks indicate their suprasubduction type of volcanism [8]. Long-lasting subduction of the Tethys Ocean was completed by continent-continent collision in the region. Post-collisional volcanism is caused by continuation of northward convergence of the Arabian plate and by recommencement of effect of water-saturated slab [8].

Active tectonics. The active tectonics of Georgia and adjacent areas of the region are due to their position in the wide zone of the late Cenozoic continent-

continent collision between the Eurasian and Africa-Arabian plates. According to geodetic data, the rate of the convergence is ~20–30 mm/yr, of which some two thirds is likely adopted by the areas south of the Lesser Caucasian ophiolite sutures. The rest of the S-N-directed relative plate motion has been accommodated in the South Caucasus, chiefly by crustal shortening and deformation [9–11]. Tectonic stresses induced by the northward motion of the Africa-Arabian plate are absorbed to a considerable degree in the peri-Arabian ophiolitic suture zone and in the Zagros fold-and-thrust belts. North of these lineaments, the stresses are propagated toward the central Caucasus–Georgia by means of relatively rigid tectonic units.

Oligocene-Miocene paleotectonic reconstructions [12] suggest the post-Eocene collision of the Africa-Arabian and Eurasian continents. Thermochronological data support the topographic inversion (uplift) and rapid exhumation of the Transcaucasus, Great Caucasus, and Lesser Caucasus in the late Cenozoic [11, 13, 14]. More recent thermochronological data also show that rapid exhumation occurred in the southeastern Black Sea region during the middle Miocene [15].

Due to the continental collision and resultant crustal strain accumulation and large earthquakes, Georgia is one of the best places for studying tectonic, seismologic, and morphologic processes, which directly affect populations and economies. Valuable information about strong earthquakes in Georgia is available in seismological, historical, archaeological, and geological sources and compiled in earthquake catalogs [16].

Earthquake sources and active faults. Georgia and adjacent areas are earthquake-prone region where devastating earthquakes have repeatedly caused significant loss of lives and damage to infrastructure and buildings. Structurally, the epicenter region represents a boundary zone between two main tectonic units: the Great Caucasus fold-and-thrust mountain belt, and the

rigid Georgian block. The northern periphery of the Georgian block is dissected by a system of active W-E- and NW-SE-trending faults, which are grouped in two clusters of thrusts and reverse faults with different vergencies. The overwhelming majority of strong shocks (including the main shock) were associated with the southern branches of these seismoactive structures.

The complex network of faults permits region to be divided into a number of separate blocks of different orders, varying from each other by their dimensions, genesis, and geologic nature. Geological and paleomagnetic data provide evidence that these terranes, before being accreted together into a single complex of fold-and-thrust belts, underwent long-term and substantial horizontal displacements within the now-vanished oceanic area of the Tethys. The boundary zones between these terrains represent belts of intense tectonic, volcanic, and seismic activities. The main part of the seismically active faults represents the boundaries of the main tectonic units of Georgia and hosts the foci of strong earthquakes.

Kinematics of Active Structures. As a result of the continuing northward push of the Africa-Arabian plate in post-Oligocene times, the Caucasus region, including Georgia, has become an intracontinental mountain belt, with active structures and topography intensely being developed since the late Sarmatian (7 Ma). The postcollisional subhorizontal shortening of the Caucasus is estimated at hundreds of kilometers [12]. Such a considerable shortening of Earth's crust has occurred in the region through different ways: (1) compressional deformation by folds and thrusts, reverse faults, and nappes; (2) warping and displacement of crustal blocks by uplift and subsidence; and (3) lateral tectonic escape.

The geometry of tectonic deformation is largely determined by the wedge-shaped rigid Arabian block intensively indenting into the mobile area [10, 17 - 19]. All structural-morphological lines

have a clearly expressed arcuate northward-convex configuration reflecting the contours of the Arabian block. However, farther north, the geometry of the fold-and-thrust belts becomes somewhat different: for example, the Achara-Trialeti structure trends E-W, the Great Caucasian fold-and-thrust belt extends in a WNW-ESE (300° - 120°) direction, while the chains of Neogene–Quaternary volcanoes in the Lesser Caucasus are oriented in a submeridional (N-S) direction, which is also in compliance with the general NNE-SSW subhorizontal compression of the region. Submeridional compression reaches its maximum within the central segment of the Caucasus, along a line running through the central part of the Transcaucasus. This line actually represents the watershed between the basins of the Black Sea and southern Caspian Sea. Westward of this line, compression is replaced by tension caused by the escape of central Anatolia, where the territory of the Black Sea is experiencing weak submeridional compression.

The Caucasus region is subject not only to S-N but also to E-W compression, since it is directly adjacent to the eastern Black Sea on the west and the Caspian Sea on the east, which both have suboceanic high-density crust that hampers lateral tectonic escape of the western and eastern Caucasus, respectively. Therefore, the surrounding compression caused the formation of piggyback basins in western Georgia. Westward escape of the western Transcaucasus did not occur either, because of the backstop provided by the stable crust of the eastern Black Sea Basin, so such compression led to formation of the seismoactive structure represented in Rioni forland by the chain of anticlines that fully delineates the Odishi piggyback basin [4].

Recent geodynamics and deep structure. Active tectonics, seismicity, recent magmatic activity, and the geodynamics of Georgia and adjacent areas are predominantly the result of the continental collision

and the continuing convergence of the Eurasian and Africa-Arabian lithospheric plates [20, 21].

The deep seismic structure beneath the Caucasus region has been investigated in a number of global and regional seismic modeling studies using traveltimes of body and surface waves [1]. Most of the studies yielded generally consistent features with higher seismic velocities in areas corresponding to the platforms and basins, and low velocities beneath the folded belts.

Tomographic modeling for Georgia [22, 23] was produced using arrival times of seismic body waves reported in the worldwide International Seismological Centre (ISC) catalogue (2001) in the time period from 1964 to 2007. Despite the complex pattern of variations in the P and S velocities for the depths of 5, 15, 25, and 60 km, the computed seismic model reveals a clear correlation between anomalous lower P and S velocities and the late Cenozoic fold-and-thrust mountain belts of the Great- and Lesser Caucasus (located near the surface thick warm “granitic”/consolidated layer) and also with the areas of Neogene–Quaternary volcanism of the region.

There is good correlation between the P and S higher-velocity anomalies and the pre-Caucasian foredeeps and Transcaucasian forelands, which are underlain by rigid platforms with thick cold sedimentary cover and lowest-velocity anomalies are characteristic of the areas affected by Neogene–Quaternary volcanism, such as the Elbrus-Chegem, Kazbegui, and Keli areas, the Georgian (Javakheti), Azerbaijanian, and Armenian Highlands. The Neogene–Quaternary volcanism is traced as deep as ~ 300 km and is associated with the locations of magma chambers within the upper mantle–asthenosphere as well as the continental crust.

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გეოფიზიკა

საქართველოს ლითოსფეროს სტრუქტურა და ალპური გეოდინამიკა

ნ. სადრამე

ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, მ. ნოდიას გეოფიზიკის

ინსტიტუტი, დედამიწის ფიზიკისა და გეომაგნეტიზმის სექტორი, თბილისი, საქართველო

(წარმოდგენილია აკადემიის წევრის თ.ჭელიძის მიერ)

ტეთისის ოკეანე საქართველოს ფარგლებში გვიანდაინოზოურში დაიხურა. გეოფიზიკური კვლევების შედეგად შემუშავებულია კავკასიის ქერქის სიღრმული სტრუქტურული მოდელი, რომელიც მოიცავს კონტინენტური ქერქის როგორც ორშრიან ასევე სამშრიან არეებს. ქერქის სიმძლავრე იცვლება 30-60 კმ. ფარგლებში, რასაც თან ახლავს დანალექი საფარის ლატერალური ცვალებადობა (0-25 კმ.). პალეომაგნეტური კვლევებით გამყარებული გეოლოგიური, პალეობიოგეოგრაფიული და პალეოგეოგრაფიული მონაცემები მიანიშნებს საქართველოში და მის მიმდებარე ტერიტორიებზე რამდენიმე ტექტონიკური ერთეულის არსებობაზე მათთვის დამახასიათებელი გეოლოგიური განვითარების ისტორიით. მათი პოზიცია აფრიკისა და ევრაზიის კონტინენტების მიმართ საშუალებას იძლევა ისინი დავაჯვუფოთ ჩრდილოეთ და სამხრეთ ტეთისის რეგიონებად. ჩრდილოეთ ტეთისის რეგიონის ფარგლებში მაგმატიზმის ევოლუცია ტეთისის განვითარების წყნაროკეანური და ხმელთაშუაზღვიური ტიპის ეტაპებისთვის დამახასიათებელ ძირითად მოვლენებს შეესაბამება. გვიანდაინოზოური მაგმური კომპლექსები რეგიონის მთავარი ტერეინების საზღვრების გასწვრივ არის განლაგებული. რღვევების რთული ბადე საშუალებას იძლევა რეგიონი დაიყოს სხვადასხვა რიგის რამდენიმე ბლოკად. სეისმურად აქტიური რღვევების ძირითადი ნაწილი საქართველოს მთავარი ტექტონიკური ერთეულების საზღვრებს წარმოადგენს. ტექტონიკური დეფორმაციის გეომეტრია მნიშვნელოვანწილადაა განპირობებული არაბეთის სოლის მყარი ბლოკის ინტენსიურად შეჭრით მობილურ უბანში. სუბმერიდიანული კუმშვა მაქსიმუმს აღწევს კავკასიონის ცენტრალური სეგმენტის ფარგლებში. დასავლეთ ამიერკავკასიის დასავლეთით მიგრაცია არ მოხდა, რადგან ამ პროცესს აბრკოლებდა აღმოსავლეთ შავი ზღვის აუზის სტაბილური ლითოსფერო. იკვეთება პოსტკოლიზმიური ვულკანიზმის მკაფიო კორელაცია რეგიონის ლითოსფეროს სიღრმულ აგებულებასთან.

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