ISSN 0001-4370, Oceanology, 2024, Vol. 64, No. 1, pp. 56–66. © Pleiades Publishing, Inc., 2024.

MARINE GEOLOGY

On Volcanism and Tectonics in the Evolution of the Guyots of the Magellan Seamounts (Pacific Ocean)

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Received December 13, 2022; revised January 18, 2023; accepted February 16, 2023

Abstract—This report analyzes original geological materials on the Magellan Seamounts in the Pacific Ocean, obtained by the authors on numerous cruises of the R/V *Gelendzhik*. This chain of guyouts does not have a common volcanic basement and apparently formed in the second half of the Early Cretaceous on the oldest (Middle–Late Jurassic) fragment of the Pacific Plate. The main viewpoints on the genesis of the Magellan Seamounts are as follows: either they originated at the intersection of fracture zones or the Pacific Plate moved them from the Southern Hemisphere to their present-day position. Because of their high degree of study, the Magellan Seamounts are one of the key sites for understanding the mechanism underlying the origin of linear chains in the ocean. A comprehensive analysis of new geological data on the Magellan Seamounts has established the important role of magmatism and tectonics in the formation of the modern morphological forms, sedimentation, and influence on the paleoceangraphy. The periodic reactivation of these processes from the Early Cretaceous to Late Cenozoic can be traced in the cyclicity of sedimentation, the continuous growth of ore crusts, and the formation of secondary volcanic domes and cones.

Keywords: guyots, volcanic and tectonic complexes, K–Ar and Ar–Ar ages, Magellan Seamounts

DOI: 10.1134/S0001437024010107

INTRODUCTION

The Magellan Seamounts are an arcuate chain of underwater volcanic mountains more than 1300 km long that divides the East Mariana Basin into the Pigafetta and Saipan basins. In the southeast, they are bordered by uplifts of the Marshall and Greater Caroline islands, and in the west, by the Mariana Trench system. Usually, the Western and Eastern Links are distinguished in the ridge of the Magellan Seamounts (Fig. 1). A number of researchers believe that the Magellan Seamounts originally formed at 20°–30° S on the Ontong Java underwater plateau in the SOPITA (South Pacific Isotopic and Thermal Anomaly) hotspot and then were moved by the Pacific Plate to their current location [9, 27]. Others believe that they formed at the intersection of deep faults as a result of shear deformations [20, 21] or other tectonic stretching of the crust during plate movement [17, 18, 34, 35]. The formation of the Magellan Seamounts is dated to a wide age interval from the Late Jurassic to the Early Cretaceous inclusive [5, 8, 27]. All these hypotheses are united by the fact that they are based primarily on geophysical data and information about the bottom topography and have been poorly substantiated by direct geological data on the guyots themselves.

Since the 1980s, the Magellan Seamounts have become an object of continuous geological and geophysical research [1, 5, 6, 10, 22, 25, 32, 33]. This is primarily because the floor of the East Mariana Basin proved the most ancient (Middle Jurassic) section of the crust in the modern World Ocean [23]. Practical interest in them on the part of South Korea, China, Russia, and the USA is due to the discovery of economic reserves of cobalt, manganese, etc., in ore crusts on the surface of guyots of the Magellan Seamounts [12]. Deep-sea drilling on the seamounts was done only on the summit of the Ita Mai Tai guyot (200–202 DSDP), and all boreholes penetrated a section of Eocene–Pleistocene carbonate sedimentary rocks. Deep-water boreholes were also drilled in the neighboring Saipan (199, 585 DSDP and 802 ODP) [25, 26, 32] and Pigafetta (800 and 801 ODP) [22, 23, 28, 34] basins. Drilling of borehole 800A at 21°92.3 N, 152°32.2 E in the northwestern Pigafetta Basin was stopped in a Cretaceous (Aptian?) basalt sill occurring in a sequence of Berriasian radiolarites. Borehole 801C exposed a second layer of oceanic crust with an age of 171.5 ± 1.15 Ma (Bajocian), represented by aphyric and porphyritic basalts [28]. Later, additional drilling of borehole 801C on ODP cruise 185 exposed another 341 m of rock in the basalt layer, the lower 136 m of which are represented by dark red jasper, chert, and recrystallized radiolarian limestones of Middle Jurassic age (Bajossian) interbedded with pillow basalts [23]. This is the most complete geological section in the World Ocean, reflecting its early and long history.

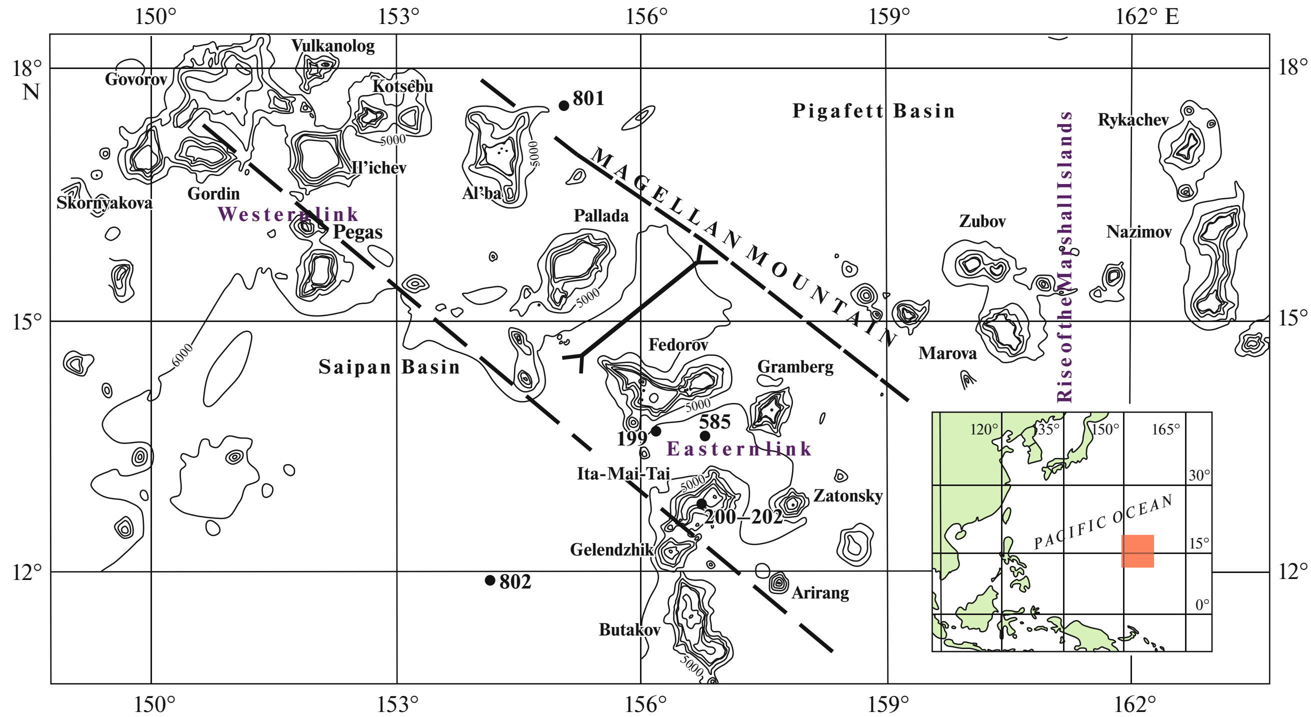

Fig. 1. Bathymetric map (1 : 5000000) of Mariana Basin, chain of guyots of Magellan Seamounts, and adjacent areas. Isobaths are shown in 1000 m intervals. Arrow between Pallada and Fedorov guyots separates Western and Eastern links. Dotted lines delineate Ogasawara fault zone. Black circles, drilling locations for deepwater DSDP and ODP boreholes. Inset: location of Magellan Seamounts in Pacific Ocean.

A great contribution to the study of the geology of this region was made by many years of research by JSC Yuzhmorgeologiya [5, 10]. Numerous expeditions aboard the R/V *Gelendzhik* obtained standard bathymetric maps for individual guyots and acquired collections of igneous and sedimentary rocks and cobalt–manganese crusts. Analysis of these materials made it possible to reasonably accept or reject a number of provisions from earlier proposed hypotheses on the origin of the Magellan Seamounts. At the same time, such issues as the relationship between tectonic and volcanic factors and their influence on the relief and sedimentation conditions in the study area remain poorly studied.

METHOD

Comprehensive studies were carried out from aboard the R/V *Gelendzhik* of JSC Yuzhmorgeologiya: bathymetric survey and geoacoustic, magnetic, gravimetric, and phototelevision profiling of the seafloor [6, 10]. From 2000 to 2018, 11 cruises were carried out, aimed at identifying the prospects for cobalt-rich ferromanganese mineralization, during which an areal bathymetric survey was performed with a Simrad EM12 S-120 multibeam echo sounder on all guyots of the Magellan Seamounts and four guyots of the adjacent section of the Marshall Islands uplift. This echo sounder uses 81 beams and can survey at depths from 50 to 11000 m in a continuous band with a maximum width of up to 3.5 depths. The operating frequency of the signal is 13 kHz; the electrical pulse power is 12 kVA. The radiation period is selected by the echo sounder from 9 to 13°C automatically, as the cycle of processing of received signals is completed. When conducting surveys, the guyots were first contoured around the perimeter in order to track the base. Subsequently, the position of the profiles was selected to ensure 10–15% overlap of the survey bands. As a result of the bathymetric survey for each of the guyots, standard bottom elevation maps on a scale of 1 : 200000 were obtained, as well as maps of the amplitudes of the backscattered echo sounder signal (sonar images), shadow relief maps, and maps of bottom slopes, compiled from grid files with a resolution of 200 × 200 m. The isobaths on the bathymetric maps were drawn every 25 m. For individual sections of the bottom, maps on a scale of 1 : 50000 or larger were obtained, on which more detailed geological studies were out [6, 12].

Rock material was recovered using box dredges and by drilling shallow boreholes with a GBU1/40002 submersible drilling rig designed by NPP Sevmorgeo. A biostratigraphic analysis of sedimentary rocks was carried out, in which fossil Cretaceous–Cenozoic foraminifera, nannoplankton, coral, malacofauna, belemnites, etc., were identified [6, 15]. Paleontological analysis combined with other methods made it possible to divide the sedimentary strata into lithostratigraphic horizons according to individual guyots, time-reference them to a unified geochronological scale, and identify paleogeographic stages in the development of the Magellan Seamounts.

BRIEF OVERVIEW OF TECTONIC CONCEPTS FOR THE STUDY AREA

The underwater volcanic ridge of the Magellan Seamounts does not have a common base, and the guyots themselves are separated by deep intermontane depressions. The floor of the adjacent Saipan and Pigafetta abyssal basins formed from the Middle Jurassic during strike-slip—thrust processes or dispersed spreading and is the most ancient part of the oceanic crust, with an age of 150–170 Ma [23, 29]. The Magellan Seamount chain is confined to the sublatitudinal Ogasawara fault zone, which may be an paleorift valley [23]. It is up to 150 km wide and has distinct sides. The age of the abyssal plate south of the Ogasawara fault zone in the Saipan Basin is Late Jurassic (borehole 802 ODP), and to the north in the Pigafetta Basin, the age is Middle Jurassic (borehole 801 ODP). In this context, the Magellan Seamounts can be seen as a younger, overprinted structure.

The temporal stage of formation of structures of the Magellan Seamounts is determined in different ways. A number of researchers believe that it occurred at the Jurassic–Cretaceous boundary [5]. According to other sources, this happened at the Hauterivian–Barremian boundary [3] or in the Aptian–Albian [27]. Their age, according to paleomagnetic data, is estimated at 129–72 Ma [29, 34]. New isotope dating of igneous rocks showed that the Alba, Govorov, and Kotzebue guyots could have begun their growth in the Middle Cretaceous (Late Barremian) [31]. This agrees well with the above paleomagnetic data and indicates that the volcanic pedestal and base formed in a fairly short time.

It was initially assumed that the formation of intraplate volcanic seamounts was associated with intensification of tectonic and volcanic activity at the Jurassic–Cretaceous boundary, during which numerous linear faults developed [8]. Faults identified along the axes of negative magnetic anomalies were considered crush zones and zones of hydrothermal development of igneous rocks. The horizontal displacement of ocean plate blocks along the Ogasawara fault zone is about 500 km, which suggests the transform nature of this zone [3].

According to A. Koppers et al. [27], the Magellan Seamounts arose as a result of the Pacific Plate passing over the SOPITA hotspot, resulting in the formation of a seamount chain, the age of which increases from east to west. The same authors identify at least two age chains within the Magellan Seamounts. The first, the Skornyakov guyot (MA-10)—Fedorov guyot (IOAH) and on the Alba (Vlinder)—Fedorov segment is dated to the Albian–Cogniacian. The second, confined to the Ita-Mai-Tai—Gelendzhik (MZh-37b) guyots and more southern guyots, is dated to the Aptian. This illogical age distribution for plate tectonics forced the cited authors to assume the origin of the second site from another hot spot. Similar views, based on the provisions of global tectonics and drift from the SOPITA hot spot, were also expressed by other researchers [3, 9, 17, 18].

N. Smoot [36] put forward the megatrend hypothesis—stress reliefzones on the Earth's surface, represented by combinations of fault zones, linear uplifts, and seamounts, often stretching across the entire ocean. According to Smoot, the active eruption of magma during the Cretaceous created many volcanic plateaus and uplifts in the Pacific Ocean. Based on these ideas, the Marcus Wake uplift, located north of the Magellan Seamounts region, is located at the intersection of the Marshall–Gilbert and Mendocino–Surveyor megatrends [36]. The Marshall Islands uplift lies within the Marshall–Gilbert megatrend zone, and the Magellan Seamounts lie outside the megatrends and are an en echelon structure of this megatrend. The megatrend mechanism is associated with the fragmentation of oceanic plates in zones with the greatest curvature of the Earth's surface.

According to V.P. Utkin et al. [20], in the origin of the guyots of the Magellan Seamounts, a decisive role was played by shear dislocations of various rank, naturally subordinate and expressed in plicative and disjunctive forms. The cited authors have subdivided the entire chain of Magellan Seamounts into latitudinal areas, considering them anticlinal arches. In our opinion, they ignored the meridional component of the structures, which is most distinctly expressed in the relief. In addition, in their desire to divide everything into latitudinal sections, the authors have divided the Ita-Mai-Tai and Gelendzhik guyots, which form a single volcanotectonic massif, and also ignore the single meridional structure of the Fedorov–Ita-Mai-Tai–Gelendzhik–Butakov seamounts and, conversely contrary, identifed a structure of clearly a lower rank—the Ita-Mai-Tai—Zatonsky.

From the viewpoint of A.A. Gavrilov [4], the Magellan Seamounts are considered part of a central-type ring megastructure, in which the western link forms the north of the ring, and the eastern link, the east. The formation mechanism of such structures is usually associated with mantle diapirism phenomena.

The analysis showed that there is no common viewpoint on the origin of the Magellan Seamounts, although there has been a tendency to understand the importance of the tectonic factor in this process. Below we present examples of the reflection of tectonic and volcanic events on the relief and sedimentation conditions of the study area.

RESULTS

Relief. Until recently, it was generally accepted that the main morphological features of the guyots of the Magellan Seamounts were formed in the Late Cretaceous as a result of magmatic activity [5, 13]. However, medium-scale bathymetric survey of the bottom (1 : 200 000) forced a reconsideration of these views, since it revealed the diversity of Cenozoic mesorelief landforms [10, 12]. The tectonic factor, in addition to volcanism, in the formation of the Magellan Seamounts can be traced already at the level of their spatial location. First of all, the chain of Magellan Seamounts consists of two large links—the Western and Eastern. Both have different linear orientations of the main structures, and each also differs in its morphological characteristics. The boundary between them runs along the line between the Fedorov and Pallas guyots, connecting the Pigafetta Basin in the northeast and the Saipan Basin in the southwest (Fig. 1). The western link as a whole has a submeridional orientation, extending from 149° to 155° E and from 15° to 19° N. The guyots of the Western Link, including the Govorov, Gordin, Skornyakov, Ilyichev, Kotzebue, and Vulcanologist seamounts, form a single volcanotectonic massif within isobaths from 5500 to 4700 m. In this link, three sublatitudinal lines are distinguished, along which the main mountain structures are grouped (Fig. 1). The northern line unites the Govorov, Vulcanologist, and Kotzebue guyots; the Skornyakov, Gordin, Ilyichev, and Alba guyots lie on the central line; and the Pegasus and Pallada guyots can be attributed to the southern line. The Eastern Link is oriented meridionally and lies between 155°30′–158°00′ E and 10°30′–14°30′ N (Fig. 1). It includes (from north to south) the Fedorov, Ita-Mai-Tai, Gelendzhik, Butakov, Gramberg, Zatonsky, and Arirang guyots. Of course, such a geographical zoning of guyots is conditional, and other options may be proposed.

All guyots of the chain can be divided into two groups according to morphological characteristics. The first includes relatively simple structures that generally correspond to the classical ideas about guyots (rounded bases, well-defined summit plateaus covered with sediment, and convex–concave slope profiles). The second group includes the Alba, Govorov, and Kotzebue guyots with irregular angular outlines, often with recessed corners, complicated by numerous satellite structures and spurs. Guyots of the first group are mainly located in the Western Link, and guyots of the second group mainly form the Eastern Link.

New data on gravimetry and magnetometry [21] prove that the modern earth's crust in the region of the Magellan Seamounts is broken by a network of deep faults in sublatitudinal and submeridional directions and its main vectors are in good agreement with the planetary rhegmatic network [1, 27]. The most striking examples of the presence of a system of faults in a latitudinal direction include the northern and southern slopes of the Fedorov, Pegasus, Ilyichev and Pallada guyots. You can also note the eastern spurs of the Gramberg and Ita Mai Tai guyots. In some cases, systems of volcanic complicating structures are grouped into sublatitudinal lineaments. This situation was noted within the southern dome of the Butakov guyot. The meridional system in the relief can be traced most clearly on the western and eastern slopes of the Butakov, Alba, Pegasus, and Ilyichev guyots.

Among the mesoforms are spurs, volcanic edifices, terraces, ledges, radial grabens, trenchs, etc. The most widely developed secondary volcanic structures are represented by cones and domes. The former have a peak-shaped summit, while the latter have a smoothed summit, gentler than the slopes. The shapes of the bases of both are more often rounded. The transverse dimensions of the bases of cones and domes vary over a very wide range: from a few hundred meters to 10 km. At the same time, edifices dominate (83%) with transverse dimensions of the bases of 1.0–2.5 km and areas of 1–6 km^2. The relative height of cones varies from 100 to 650 m, and of domes, from 50 to 400 m. Volcanic edifices may be present on guyots in large numbers: several dozen or even more than a hundred on one guyot. The most widely developed cones and domes are in the Western Link on the large Govorov and Kotzebue guyots (22 edifices per 1 thousand km^2). Conversely, occurrence frequency on the Gramberg, Ilyichev, and Zatonsky guyots is less than three edifices per 1000 km^2. A detailed bathymetric survey (1 : 50 000) of individual guyots revealed an even greater development intensity of such forms per unit area.

Domes and cones can predominate on slopes or spurs, but more often they cover the summit plateaus. A group of five cones is localized on the Alba guyot plateau [12]. The largest is located closer to the northeastern spur, has a base diameter of 5.1 km, and a height of about 750 m (Fig. 2). The minimum elevation above the guyot is 551 m. Geological sampling of the surfaces of the cones leaves no doubt about their volcanic origin, since they are composed of alkaline basaltoids, their tuffs, and tuffites. The geological age of the structures was determined as Middle Miocene based on K–Ar and biostratigraphic dating [12]. It should be added that the cones are located in pairs on the continuations of faults–scarps that bound a radial graben localized on the northern slope of the guyot (Fig. 2). This, on the one hand, suggests that they form a single system, and on the other hand, the formation of the graben can probably be dated to the Middle Miocene. On the Govorov guyot, an extended lineament has been identified, which is a chain of more than 30 km of volcanic cones and domes, stretching along the northeastern edge of the summit plateau [12].

Satellite edifices with a base diameter of up to a few tens of kilometers are very typical of large guyots of the Magellan Seamounts (Pallada, Alba, Fedorov, etc.).

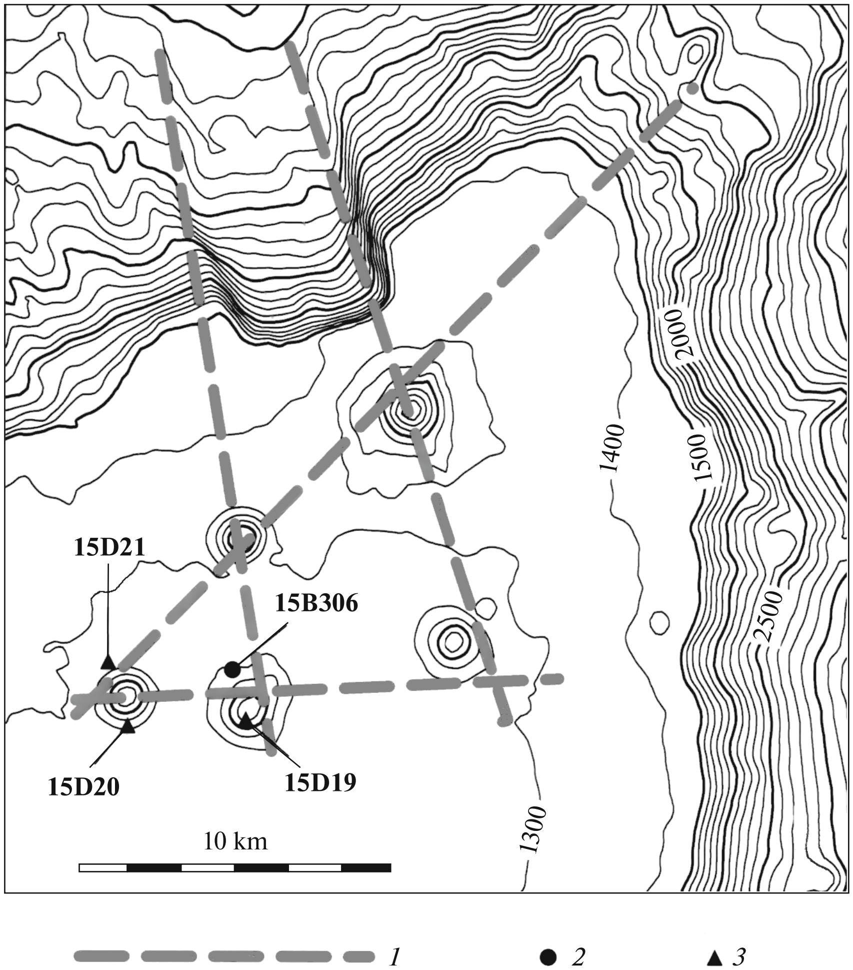

Fig. 2. Group of volcanic cones on summit plateau of Alba guyot. Geostructural interpretation is given; isobaths are drawn every 100 m; (*1*) inferred position of fault lineaments; (*2–3*) sampling stations where geological age of volcaniclastic rocks was determined: (*2*) shallow boreholes; (*3*) dredging stations. At station 15D21, absolute age of basanites was also determined as Miocene [11].

According to their morphology, they can also have a pointed, leveled, or dome shape. Both the Vulcanologist guyot itself and its satellites have a unique structure. Elongated and extended spurs give the main edifice the appearance of a truncated tetrahedral pyramid. Its two satellites, to the east and southwest of the central massif, are also represented as triangular pyramidal edifices.. From the genetic viewpoint, a number of satellite structures on the Govorov and Alba guyots can be considered tectonic outliers [27].

Tectonic activity in the Cenozoic is also indicated by the presence of radial grabens, representing subsidence structures. Such structures are formed due to sliding of blocks from marginal areas of the summit plateau. On sections of slopes within grabens, which are slickensides, relatively ancient rocks are exposed: Cretaceous basalts and reef limestones. An example of a radial graben is shown on the northern slope of the Alba guyot (Fig. 2). The formation of such structures is associated with the intrusive phase of development, when laccoliths are emplaced in guyots [37]. On the Butakov and Gordin guyots, combinations of radial grabens are noted, stretching along the edge of the summit for 12–22 km. We gave a more complete description of mesoforms on guyots of the Magellan Seamounts earlier [6, 12].

Igneous rocks. Identification of the sequence of volcanic complexes of the Magellan Seamounts made it possible to establish the hierarchical subordination in the structure of the guyots, the time of their formation, and the place of each in the global scale of paleogeographical events. Based on analysis of radioisotope dating data (107 K–Ar and Ar–Ar determinations) (Fig. 3) of igneous and sedimentary rocks and deep-sea drilling materials, we identified five large age volcanic complexes on the guyots of the Magellan Seamounts: (1) Late Jurassic–Early Cretaceous (160–140 Ma ago?); (2) Early Cretaceous (Late Barremian (?)–Aptian–Albian, 127–96 Ma ago); (3) Late Cretaceous (Late Cenomanian (?)–Turonian–Early Campanian, 95–76 Ma ago); (4) Late Cretaceous (Late Campanian–Maastrichian, 74–66 Ma ago); (5) Cenozoic

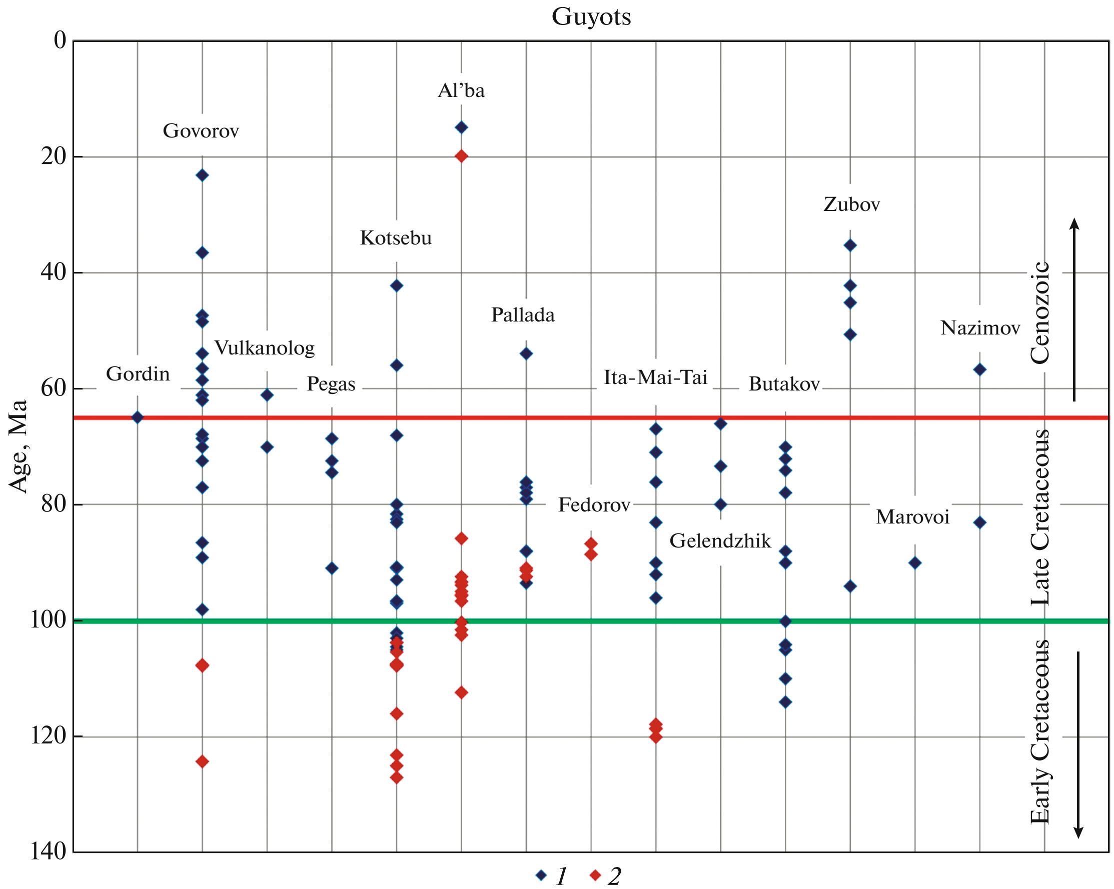

Fig. 3. Time of manifestation of volcanism on guyots of Magellan Seamounts [19]: (*1*) K–Ar determinations; (*2*) Ar–Ar determinations.

(66 Ma ago–now) [19]. Each of them corresponds to a certain time stage in the evolution of the Magellan Seamounts and occupies a structural niche in the structure of the guyots (pedestal, base, secondary domes, and cones). The oldest complex has so far only been tentatively dated due to the lack of geological material. Its time is estimated indirectly, based on general regional ideas. Borehole 801 ODP in the neighboring Pigafetta Basin are exposed from bottom to top: tholeiitic basalts of Middle Jurassic (171.5 ± 1.15 Ma ago) age; alkaline sills of the Late Jurassic (157.4 ± 0.5 Ma ago), and volcanoclastic turbidites of Aptian–Early Cenomanian age [23, 33]. The first date reflects the age of the abyssal plate, where red deep-sea clays predominantly accumulated in the place of the future Magellan Seamounts until the Aptian.

The first complex forms the lower part of the base of the guyot, which rises almost 2000 m above the bottom. It is probably composed of Hawaiian-type differentiated tholeiites. The most ancient igneous rocks on the Alba, Govorov, and Kotzebue guyots are dated 127–124 Ma ago (Late Barremian–Early Aptian) [31]. Volcanic rocks of the second complex lie 1500 m above the first and form the main body of the guyots. They are represented by a variety of subalkaline and alkaline basalts. The volcanic rocks of the third complex are formed by fairly consistent mineralogical and chemical characteristics of the rock, which are attributed to the formational-geochemical type of volcanic rocks of oceanic islands and uplifts of volcanic origin [6]. Most of its surface part was apparently eroded by subsequent abrasion and denudation. This is supported by the fact that the largest amount of rock material was raised from the slopes of seamounts.

The formations of the fourth and fifth volcanic complexes are secondary volcanic domes and cones that complicate the surface of the guyots. They arose at the very end of the Cretaceous and Cenozoic during the ordinary tectonomagmatic activations (Fig. 3). Japanese researchers associate the origin of such volcanic "petit-spot" structures with faults that arise when a plate sinks into a trench [24]. Our analysis of the areal distribution of volcanic mesoforms on the guyots of the Magellan Seamounts and the Marshall Islands uplift showed that on the Govorov and Rykachev guyots at different distances from the trench (Fig. 1), their highest density is 22.1 and 23.8/1000 km^2 respectively. And on a number of guyots, there is a low density of such edifices: Ita-Mai-Thai, 5/1000 km^2; Ilyichev, 3/1000 km^2; and Gramberga, 1.5/1000 km^2. Thus, no linear age ordering from west to east was noted [6]. In the Cenozoic, we noted Eocene and Neogene generations of secondary volcanic structures. We believe that the formation of volcanic cones and domes reflects an independent volcanotectonic stage of the entire chain of Magellan Seamounts.

Eruptive activity led to the growth of seamount structures and determined the “regressive” nature of sedimentation in the study area. Eustatic sea level fluctuations intensified or weakened these processes. For example, the first Late Cretaceous transgression reached its culmination in the Turonian, when sea levels in epicontinental basins rose by 150–200 m [30]. At the same time, a regressive sedimentation phase due to volcanism (third volcanic complex) was recorded on the Magellan Seamounts [19].

Sedimentary Rocks: The sedimentary cover has been most studied on the Fedorov, Ita-Mai-Tai, Gelendzhik, Butakov, Govorov, and Alba guyots. The structure of the sedimentary sections of the Western and Eastern links has similar age complexes and a similar set of lithological rocks therein. Based on biostratigraphic analysis, the following age complexes have been identified: Aptian–Cenomanian, Santonian–Maastrichtian, and Late Paleocene–Eocene [6, 15]. The geological section is crowned by unlithified Neogene–Quaternary sediments. In the Oligocene–Early Miocene (?), a regional stratigraphic sedimentation hiatus was noted (Fig. 4).

At the base of the sedimentary cover lie reefogenic limestones and shallow-water terrigenous rocks of Aptian–Albian age [16]. They occupy the upper plateau of guyots and their periphery. Deeper, down to 2000–3000 m isobaths, Late Cretaceous and Paleogene (nanoforaminiferal) limestones and edaphogenic breccias occur. Even lower downslope, they are replaced by various detrital deposits, the size of which decreases down towards the foot of the guyots.

Based on the relationship between representatives of shallow-water macrofauna (corals, sea urchins, etc.) and planktonic foraminifera, regressive and transgressive phases of development of guyots of the Magellan Seamounts have been established, reflected in the cyclicity of sedimentary rocks formation. Transgressions (Late Albian–Cenomanian, Late Campanian–Middle Maastrichtian, the start of the Early Eocene, Oligocene, Late Cenozoic) and regressions (Aptian, Coniacian–Santonian, Late Maastrichtian–Early Paleocene) controlled the rate and nature of sedimentation. During regressive epochs, shallow-water sedimentation zones expand, and in the Cretaceous, even sedimentation hiatuses occur. The appearance of Cretaceous pelagic limestones on guyots is associated with a sharp rise in sea level during eustatic (Late Albian–Cenomanian and Late Campanian–Maastrichtian) transgressions. The rise in sea level at this time by 150–200 m caused flooding of low-lying areas of reefs of the subaerial mountains and increased the removal of shallow sediments into neighboring deep-sea basins. In the Early Paleogene, the guyots slightly subsided, and only in the Oligocene, did they subside by 1000–1500 m.

A significant amount of work has been carried out to determine the age of individual layers in sections of ore crusts of the Magellan Seamounts based on planktonic foraminifera [11]. It has been shown that development of crusts is a long process (Late Cretaceous–Pleistocene) and discrete in time: periods of layer formation are separated by hiatus of several million years. The longest hiatus in crustal growth was noted in the Oligocene and Early Miocene. The consistency of a single time section of crusts is noted not only within the Magellan Seamounts, but also on the neighboring guyots of the Marcus Wake, Wake Necker, and Marshall Island rises [11]. This permits an important conclusion about the staged nature of the growth process of ore crusts in the region under study. The time of active growth of ore crusts in the Cretaceous and Paleogene coincides well with the transgressive phases of guyot development. It is noteworthy that the ore genesis of crusts occurred in completely different oceanological environments: the “warm” Late Cretaceous and relatively “cold” Late Cenozoic. The guyots simultaneously underwent vertical displacement caused by isostatic and tectonic subsidence, which exposed them to water masses with different chemical compositions. However, this did not affect the cessation of ore formation processes on seamounts. Possible triggers for the resumed growth of Co–Mn crusts could be deep endogenic heat and gas-geochemical flows, which, via the complex interaction of oceanological and biological processes, created favorable conditions in the ecosystems above the guyots for crust-type ore genesis.

Analysis of representative species of planktonic foraminifera in sedimentary sections of individual guyots of the Magellan Seamounts showed that the fossil fauna confirmed an almost complete sequence of changes in subglobal biozones for this fossil group for the Late Paleocene–Eocene and Late Miocene–Pleistocene [6]. However, this general sequence may be violated when comparing local biozones of two neighboring guyots. On the one hand, these facts indicate that the sedimentation of pelagic deposits since the Late Paleocene has been stable, with the exception of the Oligocene hiatus. On the other hand, the diachronicity of the boundaries of short-term hiatuses in sedimentation indicates that the specific features of the relief and uniqueness of bottom hydrodynamics on each of the guyots could have violated the unified spatiotemporal model of sedimentation on the Magellan Seamounts.

DISCUSSION

There is still no consensus on the genesis of linear volcanic chains on oceanic plates, although various

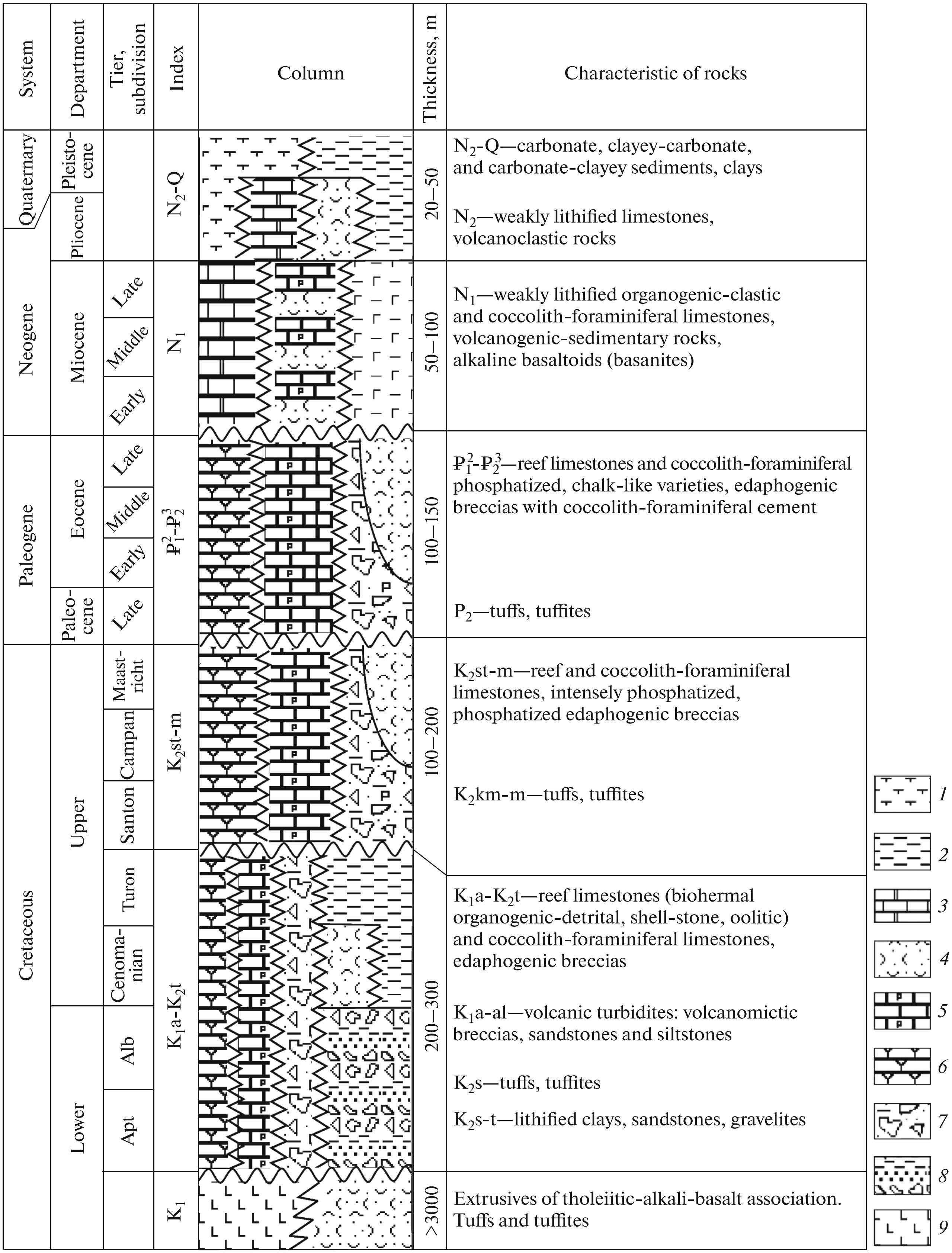

Fig. 4. Summary geological section of Fedorov and Butakov guyots. (*1*) Carbonate, clayey-carbonate sediments; (*2*) carbonate-clayey sediments, clays; (*3*) poorly lithified limestones; (*4*) tuffs and tuffites; (*5*) planktogenic limestones phosphated; (*6*) reef limestones; (*7*) edaphogenic breccias; (*8*) volcanic turbidites; (*9*) effusives of Hawaiian Group.

models of their formation exist (see above). The hot spot hypothesis is captivating, at first glance, in its harmony, but the geological data we obtained for the Magellan Seamounts contradict a number of its provisions. First, there is a discrepancy between biostratigraphic and radioisotope age determinations of rocks. Paradoxically, based on organic remains, sedimentation on a number of guyots—the Fedorov, Butakov, and Pallada—began earlier than the formation of their volcanic base [6]. Second, the beginning of shallow-water sedimentation in the Aptian–Albian is recorded simultaneously on the guyots of both the Western and Eastern; inks. That is, there is no linear trend of increasing age of guyots from east to west. There is also no expected trend for the summits of the guyots to deepen as the oceanic plate cools (subsides) and moves westward. On the contrary, we see a consistent increase in the depths of the tops of the plateau of the guyots of the Eastern Link from north to south: the margin of the plateau of the Fedorov guyot on the western peak is at a depth of 1800 m; the Ita-Mai-Tai, 2000 m; the Gelendzhik, 2100 m; and the Butakov, 2650 m.

Therefore, it is no coincidence that in recent years researchers have returned to the ideas of V.I. Belousov [2] that the formation of linear seamount chains is possibly associated with deep-seated fault tectonics. The appearance of mountain structures in the Magellan Seamounts could be due to the interaction of tectonic movements (vertical and horizontal) along faults and intraplate magmatism along zones of increased permeability. Here, the main energy source of mountain formation is no longer a stationary mantle chamber, but a pulsating flow of thermal energy and magma the reactivation of deep-seated tectonic fissures. The fomration of tectonic) fissures is mainly associated with deformation of oceanic crust, in which compression and extension zones are created [17, 35]. Seamounts and the intermontane basins separating them are considered as the result of compensation of tectonic stresses in oceanic crust.

It is generally accepted that the main orogenic factor in the formation of the guyots of the Magellan Seamounts was volcanism [13]. However, a number of researchers recognized the significant role of tectonics [7, 35, 36]. Thus, N. Smoot [36] believes that tectonic processes were factors in the formation of global structures, while the appearance of individual seamounts resulted from volcanic eruptions. The morphological differences between the Western and Eastern links allow them to be considered independent tectonic structures. Medium- and large-scale surveys of the relief showed that the outlines of many guyots of the Magellan Seamounts are not round, but angular, and the direction of the isobaths in the segments between slope flexures is predominantly linear [1, 6]. In addition, secondary volcanic structures often form chains along linear faults (see section Relief). The examples we have presented at different scales allow us to consider tectonics as an integral part of the general mountain-building process, and individual large guyots can be elevated blocks of the ocean floor. Academician I.P. Gerasimov pointed out for the first time the block nature of the guyots of the Magellan Seamounts. [7]. Later, construction of the stress deformation field by S.I. Petukhov et al. [14] made it possible to substantiate the block model of the structure of a number of guyots of the Western Link of the Magellan Seamounts. The same authors suggest that block uplift occurred along latitudinal fault zones and stress relief was marked by meridional collapses.

New data from the study of sedimentary rocks showed that the sequence of sedimentation conditions on the Magellan Seamounts was not quite the same as previously thought [28, 32, 34]. Judging from our paleontological findings, the first sedimentary formations on the Magellan Seamounts in the Western and Eastern links begin to form simultaneously in a shallow-water setting beginning from the Aptian [6]. That is, by this time, the appearance of the future guyots not only had time to take shape, but also normal marine conditions for the development of bioherms had occurred above them. Fluctuations in sea level occurred, but the relatively shallow-water setting persisted for much longer than previously thought, perhaps as late as the Middle Eocene. This was facilitated by the widespread development in the Cenozoic of secondary volcanic structures with heights of up to 300–500 m. In the Late Cretaceous and Early Paleogene, the paleogeographic setting was determined by the complex interaction of volcanic processes, changes in sea level, abrasion, and reef growth. The change from shallow- to deeper-water conditions due to eustatic phenomena and volcanism led to the cyclic accumulation of similar material complexes of rocks in the geological section, represented by alternating reef-forming and pelagic limestones, edaphogenic breccias,and coarse-grained rocks (Fig. 4). During regressive epochs, pelagic sedimentation in the near-summit parts of a guyot decreased or completely ceased. At the end of the Cenomanian and Turonian, activation of volcanism in the Magellan Seamounts led to the growth of mountain structures and regression, although planetary transgression was developing at the same time [30]. The formation of flat-topped seamounts/guyots occurred in the Cretaceous due to abrasion and denudation, and in the Cenozoic, due to sedimentary filling of negative relief forms on the summit plateau. In the second half of the Paleogene (Oligocene) and Early Miocene, general tectonic subsidence of the guyots was noted. The Upper Miocene benthic foraminiferal complexes of the summit parts of the guyots acquire an ecological appearance similar to the modern fauna [6].

The beginning of the transgressive phases of development of the Magellan Seamounts was accompanied by sharp changes in the water column. The end-to-end nature of these processes and their coverage of the entire oceanosphere is indicated by the continuous growth of layers of the Cenozoic section of ore crusts on the Magellan Seamounts, the Wake Rise, and Marshall Islands. Their growth in time surprisingly coincides with the beginning of the transgressive phases we identified [11]. Although the problem of the genesis of ore formations on the Magellan Seamounts causes much controversy, their intermittent growth is definitely somehow related to resumption of magmatism and a sharp change in the oceanological setting.

CONCLUSIONS

The obtained geological data on rocks allows us to document the chronology of events in the Magellan Seamounts only from the Aptian, when mountain structures began to emerge from the water as an archipelago with a large difference in depth to the bottom. This conclusion agrees well with the data on radioisotope ages of igneous rocks on the Alba, Govorov, and Kotzebue guyots, among which the earliest dates (127–124 Ma ago) correspond to the Late Barremian–Aptian boundary [31]. The main morphological features of the Aptian–Albian guyots had already formed, but during further sedimentation, their lower and middle parts were covered with sediments and became difficult to access by geological sampling methods other than drilling. The bottom of the East Mariana Basin is lined with tholeiitic basalts and dolerites of the Middle Jurassic in the Pigafetta Basin and the Late Jurassic in the Saipan Basin. In the Middle Jurassic–Cretaceous, biosiliceous clays predominantly accumulated in the Pigafetta Basin, and only twice, in the Aptian–Albian and Campanian–Maastrichtian, was this sedimentation interrupted by the accumulation of allochthonous volcanomictic material with remains of shallow-water fauna—as a result of the removal of erosion products from the guyots of the Magellan Seamounts due to denudation and abrasion. In the Late Barremian–Aptian, as a result of strike-slip–thrust tectonics or dispersed spreading, volcanic foundations and bases of the future guyots of the Magellan Seamounts formed on a fragment of the old Pacific Plate along the Ogasawara fault zone. In the Late Cretaceous and early Paleogene, the morphological appearance of guyots was determined by the complex interaction of volcanic processes with changes in sea level, and abrasion and reef fouling processes. Apparently, the guyots of the Magellan Seamounts can be considered a volcanotectonic formation. This is supported by the long, intermittent creative role of volcanism, which has been traced on the well-studied Alba, Govorov, and Butakov guyots for almost 100 Ma. Tectonic processes through fissures reactivated magmatic feeder conduits, and at the end of the Cretaceous–Cenozoic, determined the appearance on the surface of guyots of new relief mesoforms in the form of volcanic cones and domes with heights of 300–500 m, terraces, ledges, and radial grabens. The resumption of volcanism on the Magellan Seamounts is reflected in the cyclical structure of the sedimentary cover, litho- and biostratigraphic hiatuses, and the discrete growth of ore crusts.

Further research may correct the presented scenario for the evolution of the Magellan Seamounts. Halmyrolysis causes secondary alterations in igneous rocks, which often leads to distorted isotope signals and true age of the sample. The completeness of geological sections is determined by the frequency and availability of dredging and, in our case, does not rule out stratigraphic hiatuses.

FUNDING

The study was supported by the Ministry of Science and Higher Education, topic “Paleoceanology and Paleoclimatology of the Marginal Seas of East Asia and Adjacent Areas of the Arctic and Pacific Oceans, Modern and Mesozoic–Cenozoic Sedimentation, Geodynamics, Magmatism, and Ore Genesis” (state registration no. 121021700342-9), as well as in accordance with the project “Geosystems and Mineral Resources of Continent–Ocean Transition Zones and the Open Ocean” (GEOMIR) within the framework of the UN Decade “Ocean Science for Sustainable Development (2021–2030).”

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

1. V. M. Anokhin, *Global Disjunctive Network of the Earth: Structure, Origin and Geological Significance* (Nedra, St. Petersburg, 2006) [in Russian].
2. V. V. Belousov, *Earth’s Crust and Upper Mantle of the Oceans* (Nauka, Moscow, 1968) [in Russian].
3. Yu. V. Brusilovskii, A. M. Gorodnitskii, and V. A. Sokolov, “Volcanotectonic evolution of the Magellan Seamounts in the light of their geomagnetic studies,” Geotektonika, No. 5, 96–106 (1992).
4. A. A. Gavrilov, *Current Theoretical Issues of Geomorphological and Morphotectonic Research* (Dal’nauka, Vladivostok, 2022) [in Russian].
5. *Guyots of the Western Pacific and Their Ore Potential* (Nauka, Moscow, 1995) [in Russian].
6. *Geology of Guyots of the Magellan Seamounts (Pacific Ocean)* (Dal’nauka, Vladivostok, 2020) [in Russian].
7. I. P. Gerasimov, *Problems of Global Geomorphology* (Nauka, Moscow, 1986) [in Russian].

8. V. I. Golovinskii, *Tectonics of the Pacific Ocean* (Nedra, Moscow, 1985) [in Russian].
9. *Ferromanganese Crusts and Nodules of Pacific Ocean Seamounts* (Nauka, Moscow, 1990) [in Russian].
10. M. E. Mel'nikov, *Deposits of Cobalt-Rich Manganese Crusts* (GNTs Yuzhmorgeologiya, Gelendzhik, 2005) [in Russian].
11. M. E. Mel'nikov and S. P. Pletnev, "Age and conditions of formation of cobalt-rich manganese crusts on guyots of the Magellan Seamounts," Litol. Polezn. Iskop., No. 1, 3–16 (2013).
12. M. E. Mel'nikov, S. P. Pletnev, V. M. Anokhin, et al., "Volcanic edifices on guyots of the Magellan Seamounts (Pacific Ocean)," Russ. J. Pac. Geol. **10**, 435–442 (2016).
13. H. W. Menard, *Geology of the Pacific Sea Floor* (Springer, Berlin, 1959).
14. S. I. Petukhov, V. M. Anokhin, and M. E. Mel'nikov, "Features of geodynamic conditions in the area of the northwestern part of the Magellan Seamounts (Pacific Ocean)," Vestnik KRAUNTs. Nauki o Zemle **20** (2), 78–88 (2012).
15. S. P. Pletnev, "Main types of Aptian–Cenomanian sedimentary rocks on guyots of the Magellan Mountains, Pacific Ocean," Russ. J. Pac. Geol. **13**, 436–445 (2019).
16. S. P. Pletnev, M. E. Melnikov, T. A. Punina, et al., "New paleontological data on Govorov, Vulkanolog, and Kocebu guyots (Magellan Seamounts, Pacific)," Russ. J. Pac. Geol. **11**, 148–153 (2017).
17. A. P. Sedov, V. V. Matveenkov, L. P. Volokitina, et al., "Qualitative model of the formation of seamount chains," Vestnik KRAUNTs. Nauki o Zemle, No. 5, 24–44 (2005).
18. A. P. Sedov, G. I. Kazakevich, V. V. Matveenkov, et al., "Mechanism of the formation of volcanic chains of French Polynesia," Oceanology **48** (4), 578–587 (2008).
19. V. T. S''edin, S. P. Pletnev, and T. E. Sedysheva, "Volcanic complexes and tectono-magmatic stages of the evolution of the Magellan Seamounts (Pacific Ocean)," Vestnik KRAUNTs. Nauki o Zemle **56** (4), 90–116 (2022).
20. V. P. Utkin, A. I. Khanchuk, E. V. Mikhailik, and L. B. Khershberg, "The role of strike-slip faulting of oceanic crust in the formation of the Magellan Guyots (Pacific Ocean)," Dokl. Ross. Akad. Nauk **395** (5), 646–650 (2004).
21. B. D. Uglov and M. E. Mel'nikov, "Tectonics of the ore province of the Magellan Seamounts of the Pacific Ocean according to geophysical data," Rudy i metally, No. 4, 26–38 (2015).
22. L. J. Abrams, R. L. Larson, T. H. Shiply, and Y. Lancelot, "The seismic stratigraphy and sedimentary history of the East Mariana and Pigafetta basins of the western Pacific," in *Proceedings of ODP Scientific Results* (College Station, TX, USA, 1992), Vol. 129, pp. 551–569.
23. A. Bartolini, R. Larson, and P. O. Baumgartner, "Bajocian radiolarian age of the oldest oceanic crust in situ (Pigafetta Basin, Western Pacific, ODP Site 801, Leg 185)," in *Proceedings of the Ninth Meeting the International Association of Radiolarian Paleontologists InterRad (2000)* (Reno, Nevada/Blairsden, California, 2000), pp. 15–16.
24. N. Hirano, S. Machida, H. Sumino, et al., "Petit-spot volcanoes on the oldest portion of the Pacific Plate," Deep-Sea Res. **154** Part I, 103–142 (2019).
25. *Initial reports of the Deep-Sea Drilling Program* (U.S. Govt. Printing Office, Washington, DC, 1973), Vol. 20.
26. *Initial reports of the Deep-Sea Drilling Program* (U.S. Govt. Printing Office, Washington, DC, 1985), Vol. 89.
27. A. A. P. Koppers, H. Staudigel, J. R. Wijlbrans, and M. S. Pringle, "The Magellan seamount trail: Implication for Cretaceous hotspot volcanism and absolute Pacific plate motion," Earth Planet. Sci. Lett. **163**, 53–68 (1998).
28. Y. Lancelot and R. L. Larson, *Proceeding of the Ocean Drilling Program, Initial Reports* (Texas, 1990), Vol. 129.
29. T. G. Lee, J. W. Moon, and M. S. Jung, "Three-dimensional flexure modelling of seamounts near the Ogasawara Fracture Zone in the western Pacific," Geophys. J. Int. **177**, 247–258 (2009).
30. K. G. Miller, M. A. Kominz, J. V. Browning, et al., "The Phanerozoic records of global sea-level," Science **310**, 1293–1298 (2005).
31. I. S. Peretyazhko, E. A. Savina, I. A. Pulyaeva, and D. S. Yudin, "Intraplate volcanism of the Alba Guyot: Geodynamic formation models of the Magellan Seamounts in the Pacific Ocean for 100 million years," Russ. Geol. Geophys. **63**, 1–27 (2022).
32. S. I. Premoli, J. Haggerty, F. Rack, et al., *Proceeding of the Ocean Drilling Program. Initial reports* (Texas, 1993), Vol. 144.
33. M. S. Pringle, "Radiometric ages of basalts basement recovered at Sites 800, 801 and 802, Leg 129 Western Pacific Ocean," Proc. ODP, Sci. Results **129**, 389–404 (1992).
34. W. W. Sager and J. A. Tarduno, "Paleolatitude inferred from Cretaceous sediments, Hole 865A, Allison Guyot, west central Pacific Ocean," Proc. ODP, Sci. Results **143**, 399–403 (1995).
35. N. C. Smoot, "The Marcus-Wake seamounts and guyots as paleofracture indicators and their relation to the Datton Ridge," Mar. Geol. **88**, 117–131 (1989).
36. N. C. Smoot, "Orthogonal intersections of megatrends in the Western Pacific ocean basin: A case study of the Mid-Pacific mountains," Geomorphology **30**, 323–356 (1999).
37. H. Staudigel and D. A. Clague, "The geological history of deep-sea volcanoes," Oceanography **23** (1), 58–71 (2010).