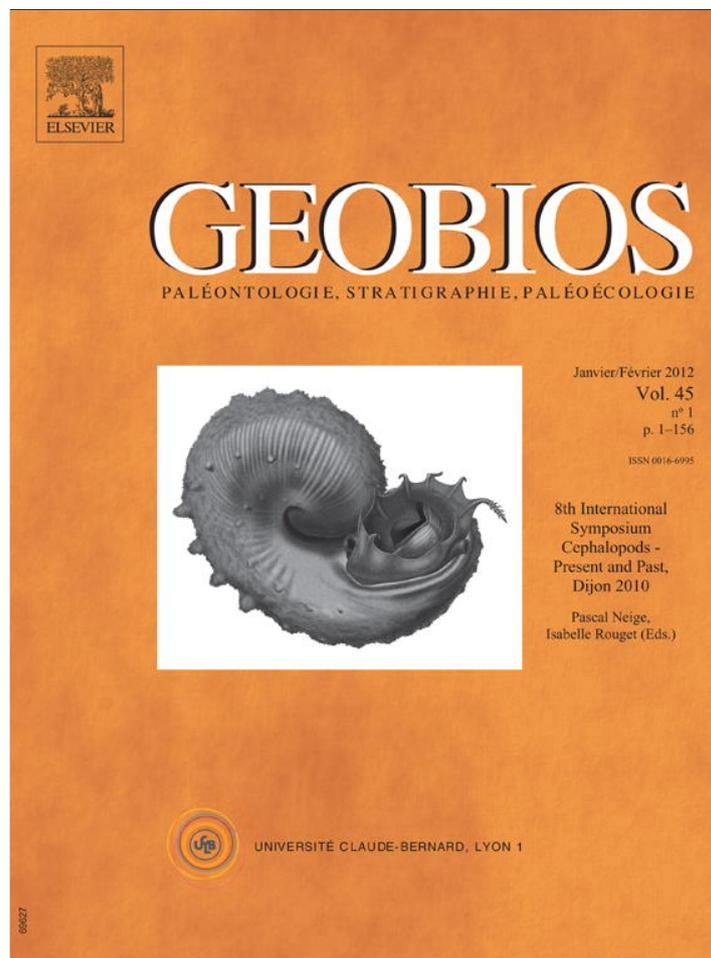


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Original article

## Cephalopod and brachiopod fossils from the Pacific: Evidence from the Upper Cretaceous of the Magellan Seamounts<sup>☆</sup>

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### ARTICLE INFO

#### Article history:

Received 11 October 2010

Accepted 16 November 2011

Available online 26 December 2011

#### Keywords:

Maastrichtian

Ammonoids

Belemnites

Brachiopoda

Carbon isotopes

Magellan Seamounts

### ABSTRACT

Maastrichtian cephalopods and a brachiopod were dredged from the Butakov, Fedorov, Kotsebu, Il'ichev, Govorov, Gelendzhik, and Ita-Mai-Tai guyots in the Magellan Seamounts. The ammonoids *Hypophylloceras* sp., *Phyllopachiceras* sp., *Anagaudryceras*? sp. A, *Anagaudryceras*? sp. B, *Gaudryceras* aff. *propemite* Marshall, *Gaudryceras* sp., and *Pseudophyllites* cf. *indra* (Forbes), and the single brachiopod Basiliolidae gen. and sp. indet. are a first discovery in this oceanic region, following earlier finds of belemnites (*Dimitobelus*? sp., *Dimitobelidae* gen. and sp. nov., and *Belemnitella*? sp.), and two ammonoid species (*Zelandites* aff. *japonicus* Matsumoto and *Tetragonitidae* gen. and sp. indet.). The Late Cretaceous Magellan Seamounts dimitobelid belemnite fauna shows affinities with southern high latitude forms (New Zealand) and the ammonoid fauna with northern, middle and high latitude ones (Hokkaido-Sakhalin and/or Kamchatka). This suggests by the end of the Cretaceous major surface palaeo-currents from S and N sides in direction of the central Palaeo-Pacific, a position coinciding with the plate tectonic reconstruction of the Magellan Seamounts.

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### 1. Introduction

The Magellan Seamounts cover a vast area of the northwestern Pacific (Fig. 1), stretching about 1200 km from the Mariana Islands in the West to the Marshall Islands in the East. The peculiar feature of the bottom topography of this area is, as in some other oceanic areas, a wealth of volcanic islands, atolls and guyots, the latter being underwater mounts topped with carbonate caps. These oceanic carbonate guyot-caps yield abundant biostratigraphically important calcareous macro- and micro-biota. Geological evidence demonstrates that the Magellan Seamounts cover one of the oldest ocean plates. As it is a known fact that, due to subduction of the ocean floor, sequences of Late Jurassic age or younger are the sole preserved, consequently no older ammonoid and belemnite evidence than that can therefore be expected to be gathered from ocean floor sediments. Dredging remaining a difficult task, Late Cretaceous belemnite evidence from the Magellan Seamounts was obtained only recently (Zakharov et al., 2007). Plate-tectonic reconstructions have suggested that by late Campanian times, the Magellan Seamounts were at a palaeo-latitude of 18–19°S in the Central Pacific (Douglas and Savin, 1973).

Cephalopod remains in the Magellan Seamounts area were not studied before our investigation during the 2001–2010 scientific expedition of research ship "Gelendzhik" (Federal Scientific Center "Yuzhmorgeologiya"), with exception of Tithonian-Berriasian ones from basalt covering siliceous limestones in Hole 167. These remains consist of calcitic ammonoid jaws determined to be *Lamellaptychus* cf. *rectecostatus* (Peters), *Lamellaptychus* sp., and *Punctaptychus rectecostatus* (Cuzzi) (Renz, 1973).

Because cephalopod and brachiopod remains are so rare in oceanic sediments, our discovery of 55 Late Cretaceous belemnite rostra (three species; Zakharov et al., 2010) on the Govorov, Gelendzhik, and Butakov guyots, six Late Cretaceous ammonoid shells (two species) on the Fedorov Guyot (Zakharov et al., 2004), and subsequent findings in 2009 of 20 Late Cretaceous ammonoids (13 species) on the Butakov, Il'ichev, Pallada, Fedorov, and Kotsebu guyots and a single brachiopod in the Ita-Mai-Tai Guyot was significant. Belemnite rostra dredged from the Magellan Seamount during the last three–four years are a first discovery in the all Pacific-Atlantic oceanic area. Cephalopod and brachiopod-bearing samples were dredged during the cruises of scientific research ship "Gelendzhik" (Federal Scientific Center "Yuzhmorgeologiya"), expeditions of 2001, 2004, 2005 and 2007–2010, of a total duration of about 16 months. It carried out geological and geophysical surveys within the Magellan Seamounts area aimed at the investigation of the geological structure and Fe-Mn mineralization.

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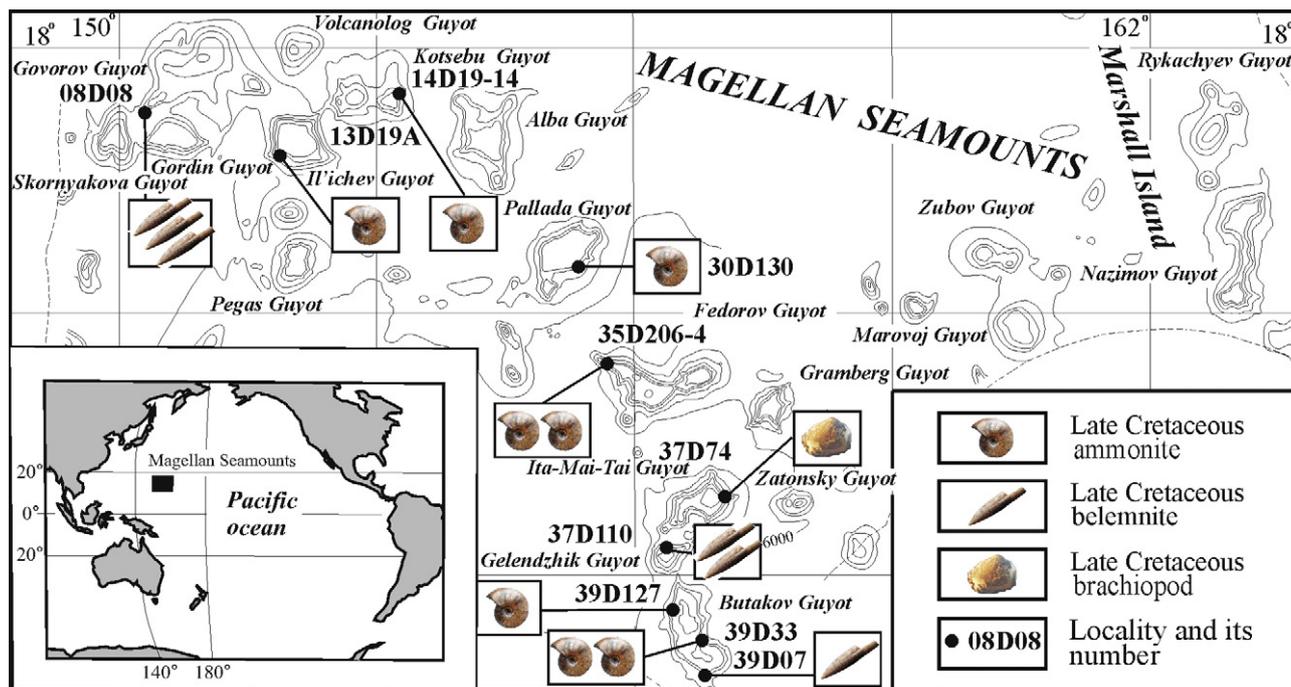


Fig. 1. Distribution of Late Cretaceous cephalopod and brachiopod fossils in the Magellan Rise area, Pacific. Stations: 39D07, 39D33, 39D127 (Butakov Guyot); 37D110 (Gelendzhik Guyot); 37D74-A (Ita-Mai-Tai Guyot); 35D206-4 (Fedorov Guyot); 30D130 (Pallada Guyot); 13D19A (Il'ichev Guyot); 08D08 (Govorov Guyot). See Zakharov et al. (2004, 2010) and Table 1 for stations' fossil contents.

The aims of this paper are:

- To review a Late Cretaceous cephalopod fauna from the Magellan Seamounts, firstly investigated by us during the last six years;
- To describe the brachiopod and most ammonoid species discovered in the Upper Cretaceous of the Magellan Seamounts in 2009;
- To show an evidence of Late Cretaceous carbon-isotopic anomaly, useful for the correlation of late Campanian-Maastrichtian sequences.

The description of the ammonoid *Zelandites* aff. *japonicus* Matsumoto, dimitobelid and belemnitellid belemnites and isotopic palaeo-temperature data have been published separately (Zakharov et al., 2004, 2010).

## 2. Geological setting

The structure of the Magellan Seamounts consists of three stages. The lower structural stage, encountered at depths of more than 3000 m in the Magellan Seamounts, consists largely of tholeites, oceanites and plagiobasalts. The middle structural stage represents the guyot slopes at less than 3000 m depth; it comprises subalkaline and alkaline basaltic lava flows (Pletnev et al., 2010). These basalts are admittedly dated as Barremian-Santonian in the Magellan Seamounts. The upper or third structural stage of the Magellan Seamounts consists of carbonatic cap-sediments that yield abundant planktonic microfossils, typically foraminifera, allowing the establishment of a detailed Cretaceous and Early Cenozoic biostratigraphy (Pletnev et al., 2010).

### 2.1. Aptian-Cenomanian complex

The sedimentary cap overlies the top of the middle structural stage with an erosional unconformity. It starts with an approximately 300 m-thick Aptian- (?) Turonian sequence, in which reefal and pelagic limestones dominate, with turbidites of volcanic origin

(volcaniclastic breccia, sand- and siltstones) and sedimentary breccias (e.g., Melnikov et al., 2007). The latter rocks are of *in situ* underwater origin (eluvial deposits) for which some authors (e.g., Baturin, 2000; Morozov, 2000) used the name “edaphogenic breccias” (from the Greek “edaphos” for bottom). This type of sedimentary breccias will be referred to in the present text as “edaphogenic breccias”. Reefal limestones (framework, bioherm, organogenic-detrital, oolitic and micritic limestones) are most common on the Il'ichev and Fedorov guyots. Macrofaunal remains in the limestones are usually badly preserved since the rocks are commonly subject to the marbling process.

Melnikov et al. (2007) have determined corals from both the Fedorov and the Alba guyots: *Amphiastrea yabei* Eguchi, *Mesomorpha caheteloides* (Trauth); bivalves *Thyasira* sp., *Liopista* sp., and presumable *Biradiolites* sp., the latter belonging to the order Rudista; and the gastropod *Ovactaonella* aff. *dolium* (Roemer). This macrofaunal assemblage suggests Aptian to presumed Turonian ages (Melnikov et al., 2007). Common planktonic foraminifera are: *Claviblowiella* cf. *C. saundersi* Bolli, *Planomalina buxtoffi* (Gandolfi), *Hedbergella globigerinoides* Huber, *Clavihedbergella* cf. *C. subcretacea* (Tappan), *Ticinella* cf. *T. primula* (Luterbacher). Benthic foraminifera *Patellina subcretacea* Cushman and Alexander, *Orithostella* cf. *O. australiana* Scheib, *Anomalinoidea* cf. *A. indica* Sastri and Sastri, *Dorothia trochoides* (Marsson), and *Lagena* sp. occur in the organogenic-detrital limestones of the Ita-Mai-Tai, Il'ichev, and Kozebu guyots, and in sandstones of the Butakov Guyot. Their age ranges from Aptian to Albian.

A succession of pelagic limestones, sedimentological breccias, and packed clays, varying in thickness from 150 up to 1200 m, is well developed in the Magellan Seamounts area. It is characterised by the presence of the nannofossils *Microrhadulus decoratus* (Deflandre) (Melnikov et al., 2007) and of benthic foraminifera of the Late Cenomanian *Rotalipora cushmani* Zone (e.g., *Anomalinoidea rubiginosus* (Cushman), *Bulimina midwayensis* (Reuss), *Osangularia plummerae* Brotzen, *Gyroidinoides globosus* (Hagenow), *Lenticulina spissocostata* (Cushman), *Cibicidoides* sp.,

and *Florilus* sp. (Pletnev et al., 2010 foraminifera). There is no evidence of Turonian-Coniacian.

## 2.2. Santonian-Maastrichtian complex

Unconformably overlying the Aptian-Cenomanian complex, with an assumed Turonian-Coniacian hiatus, follows the Santonian-Maastrichtian sequence, of a thickness of about 150–200 m. It has many features in common with the underlying complex. This complex consists essentially of a reefal framework, from bioherm to organogenic-detrital (oolitic and micritic), as well as of nannofossil-foraminiferal limestones, volcanoclastic rocks and edaphogenic breccias.

Macrofossils being infrequent in the Magellan Seamounts, most abundant are Campanian nannofossil-foraminiferal limestones. Pletnev et al. (2010) report on the Fedorov Guyot planktonic foraminifera including: *Globotruncata arca* (Cushman), *G. stuarti* (Lapparent), *G. linneiana* (Orbigny), *G. plummerar* (Gandolfi), *Rosita fornicata* (Plummer). On the Alba Guyot, they report *Globotruncata coronatai* (Bolli), *G. arca* (Cushman), *G. stuarti* (Lapparent), *G. rosetta* (Garsey), and *Heterohelix reussi* (Cushman). Framework limestones of the Fedorov and Il'ichev guyots are mainly characterised by the presence of Campanian-Maastrichtian corals: *Thamnasteria*, *Diplogyra*, *Stylopsammia*, *Astrhelina*, *Parasmilia* and *Isis* (Zakharov et al., 2007); and Campanian-Maastrichtian foraminifera such as *Schackonia multispinata* (Cushman and Wickenden) and *Globotruncata contusa* (Cushman). Pletnev et al. (2010) found planktonic foraminifera of the Maastrichtian *Abathomphalus mayararoensis* Zone. This Zone was also recognized on the Butakov, Skorniyakova, and Gordin guyots (Pletnev et al., 2010). Cephalopods (ammonoids and belemnites) of the mentioned complex have been documented in the uppermost part of the Santonian-Maastrichtian sequences on many guyots of the Magellan Seamounts (this study), possibly in relation to a sea level rise.

## 2.3. Upper Palaeocene-Eocene complex

An Upper Paleocene-Eocene sequence of about 150–200 m thickness, overlies disconformably the Cretaceous strata. The lithology remains very similar to that of the Aptian-Maastrichtian interval. The Late Paleocene is characterised by the presence of specific foraminifera such as *Morozovella angulata* (White), *M. inconstans* (Subbotina), *Globigerina triloculinoides* (Plummer), *Planorotalis pseudomenardii* (Bolli), *Acarinina mckannai* (White), and *A. pentacamerata* (Subbotina) (Zakharov et al., 2007).

## 3. Material and methods

During the scientific expeditions, samples were collected by cylindrical hard-rock dredges and by means of shallow drilling. Cephalopod-bearing samples were obtained from the Govorov, Kotsebu, Pallada, Fedorov, Gelendzhik, and Butakov guyots, and the brachiopod-bearing sample from the Ita-Mai-Tai Guyot.

For our carbon-isotopic investigation only the 80 samples taken from belemnite rostra from the Govorov, Gelendzhik and Butakov guyots, and 2 ammonite-bearing limestone samples from the Fedorov and Butakov guyots were used because the ammonites from the Magellan Seamounts consist of calcitized shells that therefore are unsuitable for isotopic analyses. The following criteria were mainly used in this study to determine diagenetic alteration:

- Visual signs;
- Degree of integrity of microstructure, determined under a scanning electron microscope;
- X-ray analysis to find any secondary admixtures.

The SEM photographs of the obtained belemnite rostrum calcite (Zakharov et al., 2010) show that belemnite skeletons fulfill diagenetic screening criteria and were therefore considered suitable for isotopic analysis. It was confirmed by negative results of X-ray analyses that show the lack of secondary admixtures, including  $\alpha$ -SiO<sub>2</sub>. Selected belemnite samples, used for isotopic analysis, were examined with a scanning electron microscope Zeiss EVO 50 XVP at the Analytical Center of the Far Eastern Geological Institute (FEGI; Laboratory of Precious Metal Analyses).

Carbon isotope measurements were carried out using a Finnigan MAT-252 mass spectrometer at Far Eastern Geological Institute, Vladivostok. The laboratory gas standard used in the measurements was calibrated relative to calcite NBS-19 and equals  $1.8 \pm 0.1\%$  relative to VPDB for oxygen, and  $-0.9 \pm 0.1\%$  relative to VPDB for carbon. Reproducibility of replicate standards was always better than 0.1%. X-ray powder analyses were carried out using a DRON-3 diffractometer at FEGI and Pacific Institute of Oceanology, following the method of Davis and Hooper (1963).

The material figured is housed in the Far Eastern Geological Institute (DVGI), Russian Academy of Sciences, Far Eastern Branch, Vladivostok, coll. N 891.

## 4. Results

### 4.1. Field sedimentological characteristics and some palaeontological associations

Cephalopod-bearing rocks of the Magellan Seamounts, main subject of this paper, are stratigraphically expended in carbonate and silty-pelitic facies. Both of them were discovered only on the Butakov Guyot (Table 1; Fig. 2(A)). However, only carbonate cephalopod-bearing sediments are known in most other guyots of the Magellan Seamounts (e.g., Gelendzhik, Fedorov, Kotsebu, Il'ichev, and Govorov), and only silty-pelitic ammonoid-bearing sediments (volcanoclastic mudstone) are dominated on the Pallada Guyot. Most cephalopods, listed in Table 1 and Figs. 3 and S1, were collected from carbonate facies.

The latest Cretaceous limestone sample 08D8 G with the most abundant cephalopods (50 belemnite rostra and only a single fragment of an ammonoid living chamber), obtained from the Govorov Guyot (Zakharov et al., 2007), is of particular significance for understanding the sedimentation environments. The limestone sample under consideration is bioturbated by small invertebrates and contains sandy to gravelly grains, detritus, and small pebbles of variable roundness grade. The grains and detritus are dispersed in a carbonate matrix without signs of stratification. Elongated pebbles oval-rounded, trapezoidal, and nearly square-shaped in cross sections are composed predominantly of montmorillonite and have no definite orientation. Some of them are covered on the surface by fine films presumably produced by algae. Casts of palagonitized basalts, phosphorite (?), and chalcedony occur in the rock as well. Belemnite rostra are buried in the sediments predominantly with a definite orientation of their longitudinal axes. Some of them were broken before burial, while others have no indications of mechanical erosion. Worm trails observable in limestone and representing marks of life activity originated before the sediment lithification. They are filled with comparatively loose products excreted from digestive tracts of animals and altered afterward in the course of bacterial limonitization.

The sample 39D33G with the most abundant ammonoids (26 specimens), dragged from the Butakov Guyot, consists almost entirely of micritic limestone. Ammonoid-bearing carbonate cement in edaphogenic breccias of the Fedorov Guyot fills spaces between clasts of red-brown alkaline basalt, which surface separated from the sedimentary rock by veinlets of zeolites of hydrothermal origin.

**Table 1**  
Cretaceous brachiopod and cephalopod (ammonoids and belemnites) fossils from the Magellan Seamounts.

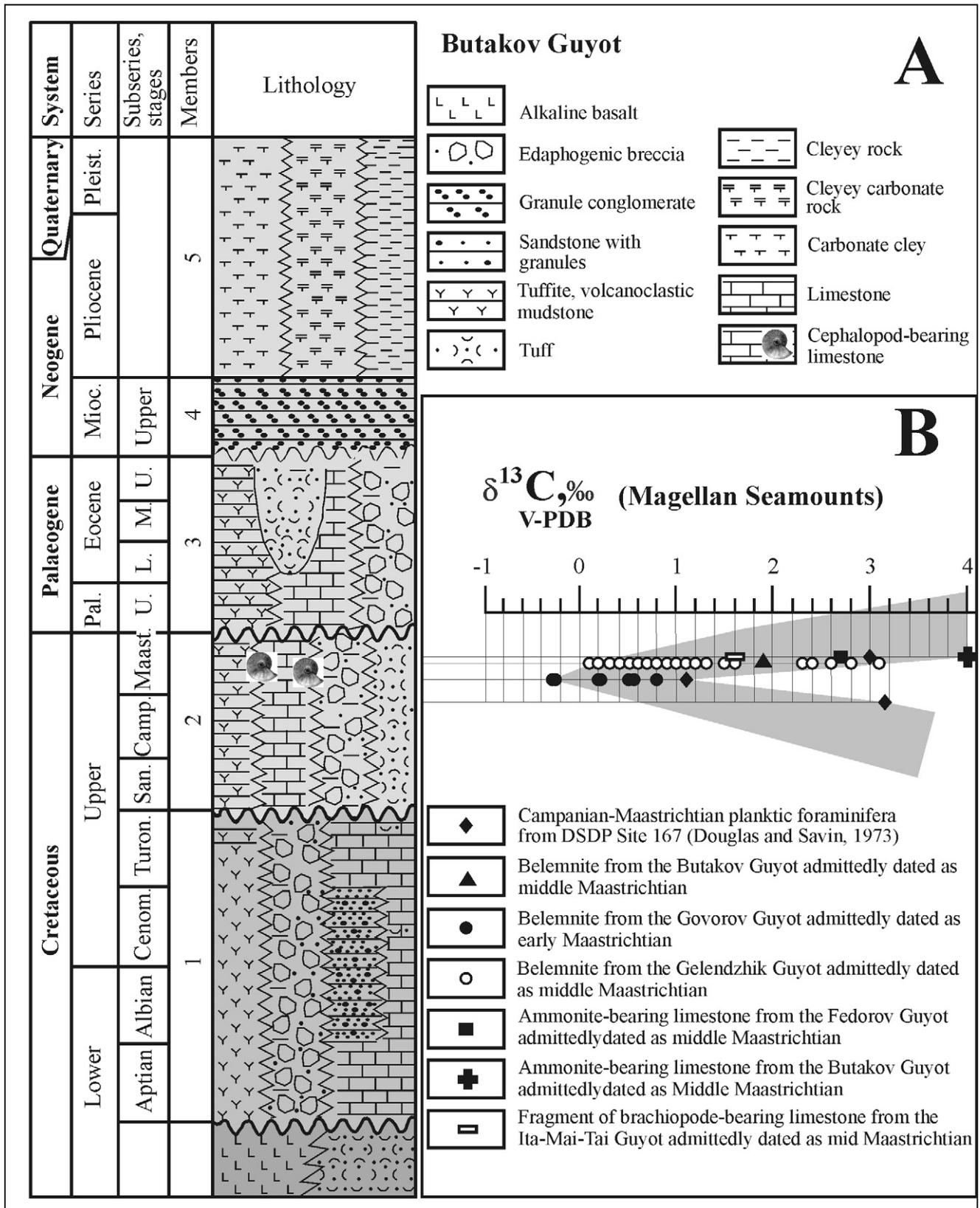
N	Species	Guyot (station, depth)	Latitude, longitude	Rocks	Age	Reference
1	Basililiidae and sp. indet.	Ita-Mai-Tai, eastern slope, (37D74, 2154 m)	12°55.0' N, 157°01.9'E	Block of Cretaceous white limestone in light grey Early Eocene foraminiferal limestone	Late Cretaceous	This study
2	<i>Hypophylloceras</i> sp.	Butakov (39D33, 2834 m), (39D127, 2615 m)	11°35.5'N, 156°46.0'E 11°55.5'N, 156°25.8'E	Micritic limestone Volcanoclastic mudstone	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
3	<i>Hypophylloceras?</i> sp.	Il'ichev, southwestern spur (13D19A, 2660 m)	16°42'30"N, 151°52'10"E	Limestone breccia	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
4	<i>Phyllopachyceras</i> sp.	Butakov (39D33, 2834 m)	11°35.5'N, 156°46.0'E	Micritic limestone	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
5	<i>Anagaudryceras?</i> sp. A	Butakov (39D33, 2834 m)	11°35.5'N, 156°46.0'E	Micritic limestone	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
6	<i>Anagaudryceras?</i> sp. B	Pallada, southeast slope (30D150, 2635 m)	15°31.8'N, 155°21.8'E	Volcanoclastic mudstone	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
7	<i>Gaudryceras</i> sp.	Butakov (39D33, 2834 m)	11°35.5'N, 156°46.0'E	Micritic limestone	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
8	<i>Gaudryceras</i> aff. <i>propemite</i> Marshall	Fedorov, northwestern spur, the crest part (35D-206-4, 2586 m)	14°25'36"N, 155°40'00"	Edaphogenic breccia	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
9	<i>Pseudophyllites</i> cf. <i>indra</i> (Forbes)	Butakov (39D33, 2834 m)	11°35.5'N, 156°46.0'E	Micritic limestone	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
10	Tetragonitidae gen. and sp. indet.	Kotsebu, northeastern Spur (14D16, 1746 m)	17°29'06"N, 153°15'12"E	Micritic limestone	Late Campanian-Maastrichtian, likely middle Maastrichtian	This study
11	<i>Zelandites</i> aff. <i>japonicus</i> Matsumoto	Fedorov, northwestern spur, the crest part (35D-206-4, 2586 m)	14°25'36"N, 155°40'00"	Edaphogenic breccia	Late Campanian-Maastrichtian, likely middle Maastrichtian	Zakharov et al. (2004)
12	<i>Dimitobelus?</i> sp.	Butakov (39D7, about 2800 m)	11°15.0'N, 156°46.0'E	Oolitic limestone	Late Campanian-Maastrichtian, likely middle Maastrichtian	Zakharov et al. (2010)
13	Dimitobelidae gen. and sp. nov.	Govorov, southwestern slope (08D08, 2671 m)	17°16'28"N, 150°17'48"E	Limestone with sandy to gravely grains, detritus and small pebbles	Late Campanian-Maastrichtian, likely early Maastrichtian	Zakharov et al. (2010)
14	<i>Belemnitella?</i> sp.	Gelendzhik, northern slope (37D110, about 2200 m)	12°19'00"N, 156°22'12"E	Oolitic limestone	Late Campanian-Maastrichtian, likely middle Maastrichtian	Zakharov et al. (2010)

The planktonic foraminiferal assemblage with *Rugoglobigerina hexacamerata* Brönnimann and *Pseudoguembelina excolata* (Cushman) from ammonoid-bearing limestones of the Butakov and Kotsebu guyots has been considered to be typical of the Maastrichtian (Pletnev et al., 2010). Additional palaeontological evidence was provided by the data from the Fedorov Guyot (Table 1). Ammonoid-bearing limestones of the mentioned guyot associate with foraminifera (e.g., *Abathomphalus*, *Globotruncana* and *Schackoia*), common for both the Campanian and the Maastrichtian, and corals (e.g., *Thamnasteria hiraigaensis* Eguchi, *T. clatrata* Goldfuss, *Diplogyra lamellose* Eguchi, *Smilotrochus galeriformis* (Kner) and *Actinastraea ramosa* (Michelin)), known from the Santonian-Maastrichtian interval (Zakharov et al., 2007). Cephalopod remains (mainly belemnite) from the Govorov Guyot, referred to *Dimitobelus?* sp., Dimitobelidae gen. and sp. indet, and *Belemnitella?* sp. (Zakharov et al., 2010), were found in association with the foraminifera *Globotruncata arca* (Cushman), common in the Campanian-Maastrichtian interval. Additional, Maastrichtian coral *Trochocyathus hemisphaericus* Nielsen (08D48 B) has recently been documented from reefal limestone in the Govorov Guyot. Beside ammonoid systematical data, all the above-mentioned

information, based mainly on the data from foraminifera, suggests that cephalopod-bearing carbonate facies are late Campanian-Maastrichtian, likely Maastrichtian in age. This age is presumed also for cephalopod-bearing terrigenous facies.

Restoration of sedimentary environments made for the Magellan Seamount on the basis of foraminifera (Pletnev et al., 2010) shows that detrital and oolitic limestones were formed in shallow-water conditions. It is in agreement with data on belemnite remains from detrital limestone of the Govorov Guyot, associated with shallow-water bivalve *Cyrtopleura* sp. (family Pholadidae) (Zakharov et al., 2007). In present-day seas, burrows of pholadid molluscs are widespread in the shelf zone within the depth range from 1–2 to 20 m, occasionally down to 30 m (Warme et al., 1971), which additionally confirms our assumption.

The brachiopod Basililiidae gen. and sp. indet. shell, encrusted from its apical part by Mn-oxides, has been identified in fragment of Cretaceous white limestone (with Cretaceous foraminifera *Hedbergella* sp.) of the Ita-Mai-Tai Guyot. It was found in early Eocene sediments–light-grey foraminiferal limestone, characterised by typical early Eocene planktonic foraminifera *Acarina acarinata* Subbotina, and *A. pentacamerata* (Subbotina). The



**Fig. 2.** A. Stratigraphical position of cephalopod-bearing sediments of the Butakov Guyot. B.  $\delta^{13}\text{C}$  values in Campanian-Maastrichtian carbonates from the Butakov, Govorov, Gelendzhik, Fedorov and Ita-Mai-Tai guyots and DSDP Site 167, Magellan Seamounts, showing a  $\delta^{13}\text{C}$  shift in the Lower Maastrichtian (observation from 111 samples, including data on planktic foraminifera from DSDP Site 167; Douglas and Savin, 1973).

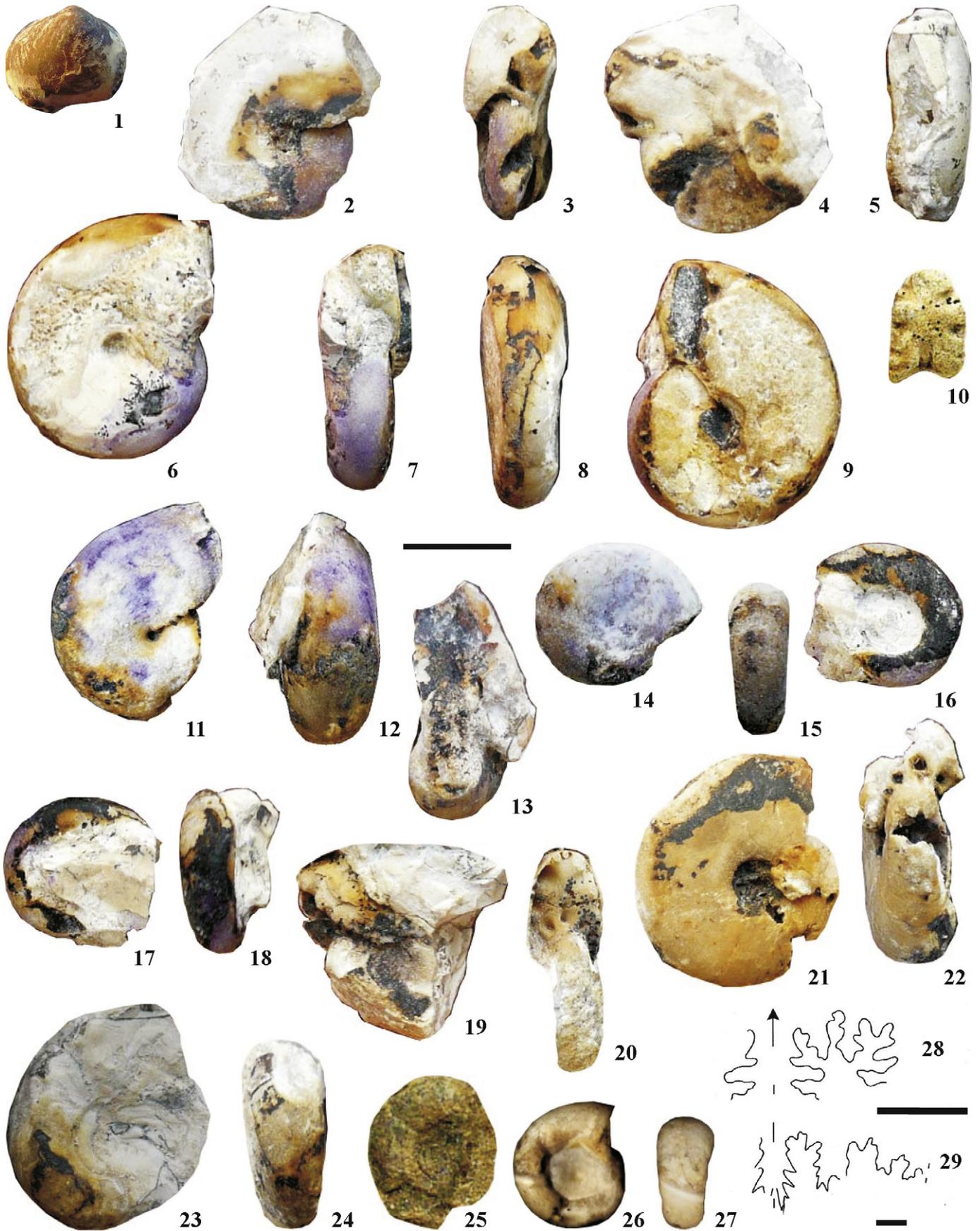


Fig. 3. Cretaceous ammonoid and brachiopod fossils of the Magellan Seamounts: 1. *Basililoidae* gen. and sp. indet., 37D74-A(1)/891, ventral view, Ita-Mai-Tai Guyot, Cretaceous (in block). 2–10. *Hypophylloceras* sp., Butakov Guyot, upper Campanian-Maastrichtian, likely middle Maastrichtian: 2–5, 39D33G-2a/891; 6–9, 39D33G-13/891;

**Table 2**

Phylloceratid, Gauryceratid, and tetragonitid ammonoids from the Magellan Seamounts area: measurements (mm) and ratios.

Species	Specimen no.	D	H	W	U	H/D	W/D	U/D
<i>Hypophylloceras</i> sp.	39D33-G-13/891	25.5	14.1	7.0?	2.0	0.55	0.27	0.08
<i>Hypophylloceras</i> sp.	39D33G-2a/891	22.0	11.8	8.0	2.1	0.54	0.36	0.10
<i>Hypophylloceras</i> sp.	39D127-1A/891	24.0	12.5?	< 7.0	2.2?	0.52	< 0.29	0.09?
<i>Phyllopachiceras</i> sp.	39D33-G-9/891	21.4	12.9	10.0	1.0	0.60	0.48	0.05
<i>Phyllopachiceras</i> sp.	39D33-G-14/891	16.9	9.6	–	0.9?	0.57	–	0.05
<i>Anagaudryceras?</i> sp. A	39D33-G-16(1)/891	18.9	7.2	8.4	6.8	0.38	0.44	0.36
<i>Anagaudryceras?</i> sp. B	30D150-A/891	15.0	5.6	4.0	5.9	0.37	0.27	0.39
<i>Gaudryceras</i> sp.	30D33-G-10/891	15.0	5.2	5.7	6.9	0.20	0.38	0.46
<i>Gaudryceras</i> aff. <i>propemite</i> Marshall	35D206-4B(5)/891	12.0	5.0	5.0	5.2	0.42	0.42	0.43
<i>Gaudryceras</i> aff. <i>propemite</i> Marshall	35D206-4B(4)/891	11.6	4.4	6.0	4.0	0.38	0.52	0.34
<i>Gaudryceras</i> aff. <i>propemite</i> Marshall	35D206-4B(6)/891	8.8	4.0	4.0	3.1	0.45	0.45	0.35
<i>Pseudophyllites</i> cf. <i>indra</i> (Forbes)	39D33-G-1/891	24.9	12.0	10.0	4.9	0.48	0.40	0.20
<i>Pseudophyllites</i> cf. <i>indra</i> (Forbes)	39D33-G-6/891	24?	12.5	9.1	4.0	0.52?	0.38?	0.17?
<i>Pseudophyllites</i> cf. <i>indra</i> (Forbes)	35D206-4B(2)/891	17.2	10.0	5.6	2.6	0.58	0.33	0.15
<i>Pseudophyllites</i> cf. <i>indra</i> (Forbes)	35D206-4B(4)/891	2.4	0.86	–	0.8	0.36	–	0.33

brachiopod shell, found in a white limestone block, associates with Late Cretaceous planktonic foraminifera *Hedbergella* sp., corals, rudist bivalves and gastropods common for the Upper Cretaceous.

#### 4.2. Systematic paleontology

##### 4.2.1. Brachiopoda (A.M. Popov)

Family BASILIOLOIDAE Cooper, 1959

Basiliolidae gen. and sp. indet.

Fig. 3(1), S1(1, 2)

**Locality and material:** Ita-Mai-Tai Guyot, 37D74 station, a single specimen (ventral valve).

**Distribution:** Unknown. The reworked Late Cretaceous Basilolidae gen. and sp. indet. shell was found in a block of white Cretaceous limestone, within an early Eocene light grey planktonic-foraminiferal limestone of the Ita-Mai-Tai Guyot, 37D74 station.

**Measurements:** L = 11.8 mm, W = 11.3 mm, L/W = 1.04,  $\alpha$  (apical angle) = 118°.

**Description:** Shell small, smooth, with fine growth lines. Outline rounded-subpentagonal; widest at about midvalve; ventral valve moderately convex, slightly asymmetric, uniplicate, with shallow sulcus and high subtriangular extension; beak short, slightly incurved; foramen small, circular, submesothyril; deltidial plates small, conjunct, auriculate.

**Remarks:** Closest to our taxon is *Rionirhynchia tsessiensis* Kamyschan and Kvakhadze (Kamyschan and Kvakhadze, 1980) from the Lower Cretaceous (Hauterivian) of western Georgia. It differs from this species by a higher sulcus extension and a lesser incurved beak.

##### 4.2.2. Ammonoidea (Y.D. Zakharov)

Family PHYLLOCERATIDAE Zittel, 1884

Genus *Hypophylloceras* Spath, 1927

*Hypophylloceras* sp.

Figs. 3(2–10), S1(3)

**Locality and material:** Butakov Guyot, 39D33 and 39D127 stations, three shells.

**Age and stratigraphic horizon:** Micritic Limestone and Volcanoclastic Mudstone (Upper Campanian-Maastrichtian, likely middle Maastrichtian).

**Description (Table 2):** Shell discoidal, involute. Venter rounded, without expressed shoulders, flank convex. The umbilicus is narrow with rounded edge and low umbilical wall. The surface of the nucleus is almost smooth, with very weak radial folds. The badly preserved suture of *Hypophylloceras* sp. is represented by a few lobes at the lateral side of the shell, being characterised by an asymmetrically trifid lateral lobe.

**Remarks:** *Hypophylloceras* sp. from the Magellan Seamounts partly resembles *Hypophylloceras simplicatum* Grabovskaya from the Cenomanian *Marshallites* beds of the lower part of the Bykov Formation of the Naiba River, South Sakhalin (Zakharov et al., 1981), and some *Hypophylloceras hetonaiensis* (Matsumoto) shells from the Lower Maastrichtian of the Furenai area, Hokkaido (Shigeta, 1993), differing mainly in the lack of thin radial ribs.

Genus *Phyllopachyceras* Spath, 1925

*Phyllopachyceras* sp.

Fig. 3(11–15)

**Locality and material:** Butakov Guyot, station 39D33, two specimens.

**Age and stratigraphic horizon:** Micritic Limestone (upper Campanian-Maastrichtian, likely middle Maastrichtian).

**Description (Table 2):** Shell thickly discoidal, involute, with rounded venter lacking ventral shoulders; flank quite regularly arched, funnel-shaped near umbilical edge; umbilicus very narrow; umbilical wall very low. Surface of the nucleus is smooth. The badly preserved suture of *Hypophylloceras* sp. is represented by about eight lobes at the lateral side of the shell.

**Remarks:** *Phyllopachyceras* sp. from the Magellan Rise is similar with *Phyllopachyceras ezoense* (Yokoyama) (Shigeta, 1993; Maeda and Shigeta, 2005) from the upper Santonian of Hokkaido, Turonian-Santonian portion of the Bykov Formation, and lower Maastrichtian part of the Krasnoyarka Formation of the Naiba River, South Sakhalin (Grabovskaya, 1981; Zakharov et al., 1984), but it is impossible to make more conclusive comparisons because of the lack of full information on a suture line of the described form.

Family GAUDRYCERATIDAE Spath, 1927

Genus *Anagaudryceras* Wright and Matsumoto, 1954

*Anagaudryceras?* sp. A

Figs. 3(25), S1(6)

10, 39D127-1A/891. **11–15.** *Phyllopachyceras* sp., Butakov Guyot, upper Campanian-Maastrichtian, likely middle Maastrichtian: 11–13, 39D33G-9/891; 14, 15, 30D33G-14/891. **16–18.** *Gaudryceras* sp., 39D33G-10; Butakov Guyot, Lower Maastrichtian. **19–20.** *Pseudophyllites?* sp., 39D33G-6/891, Butakov Guyot, Lower Maastrichtian. **21, 22.** *Pseudophyllites* cf. *indra* (Forbes), 39D33G-1/891, Butakov Guyot, Lower Maastrichtian. **23, 24.** *Anagaudryceras?* sp. B, 30D150-A/891, Pallada Guyot, upper Campanian-Maastrichtian, likely middle Maastrichtian. **25.** *Anagaudryceras?* sp. A, 39D33G16(1)/891, Butakov Guyot, upper Campanian-Maastrichtian, upper Campanian-Maastrichtian, likely middle Maastrichtian. **26–29.** *Gaudryceras* aff. *propemite* Marshall, Fedorov Guyot, middle Maastrichtian: 26, 27, 35D206-B(4)/891; 28, 35D206-B(4)/891, suture line at H = 2.7 mm; 29, 35D206-4B(4)/891, suture line at H = 2.5 mm. Scale bars: 10 mm (1–27), 1 mm (28, 29).

**Locality and material:** Butakov Guyot, 39D33 station, one shell.

**Age and stratigraphic horizon:** Micritic Limestone (upper Campanian–Maastrichtian, likely middle Maastrichtian).

**Description** (Table 2): Whorls semi-evolute, serpenticone. Venter rounded, without expressed shoulders; flank convex. Umbilical wall nearly vertical, umbilicus wide, with rounded edge. Surface of the nucleus possesses very weak radial folds and constrictions. Suture has not been identified.

**Remarks:** This form resembles *Anagaudryceras matsumotoi* Morozumi from the upper Maastrichtian of South Sakhalin (Morozumi, 1985; Shigeta and Maeda, 2005), but because of its bad preservation it is impossible to make more conclusive comparisons.

*Anagaudryceras?* sp. B

Fig. 3(23, 24).

**Locality and material:** Pallada Guyot, 30D150 station, one shell.

**Age and stratigraphic horizon:** Micritic Limestone (upper Campanian–Maastrichtian, likely middle Maastrichtian).

**Description** (Table 2): Whorls semi-evolute, serpenticone. Venter rounded, without expressed shoulders; flank convex, slightly flattened. Umbilical wall is low, umbilicus wide, with rounded edge. Surface of the nucleus has very weak radial constrictions. Suture has not been identified.

**Remarks:** This taxon differs from *Anagaudryceras* sp. A, by the thicker shell, which whorls are not so slowly enlarging.

Genus *Gaudryceras* Grossouvre, 1894

*Gaudryceras* sp.

Fig. 3(16–18)

**Locality and material:** Butakov Guyot, 39D33 station, one shell.

**Age and stratigraphic horizon:** Micritic Limestone (upper Campanian–Maastrichtian, likely middle Maastrichtian).

**Description** (Table 2): Whorls in juvenile stage evolute, serpenticone. Venter rounded, without expressed shoulders; flank convex. Umbilical wall is vertical, umbilicus wide, with rounded edge. Surface of the nucleus has very weak radial ribs, stronger at lateral sides. Only badly preserved fragments of the suture line can be recognized.

**Remarks:** *Gaudryceras* sp. from the Magellan Rise partly resembles inner whorls of *Gaudryceras tenuiliratum* Yabe shell from the Santonian–Campanian of Hokkaido and South Sakhalin (Yabe, 1903), but it is impossible to make more conclusive comparisons again because of the lack of full information about a suture line of described form.

*Gaudryceras* aff. *propemite* Marshall, 1926

Fig. 3(26–29)

2004. Tetragnonitidae gen. and sp. indet. – Zakharov et al., p. 202, figs. 5–7.

**Locality and material:** Fedorov Guyot, 35D-206-4 station, three specimens.

**Age and stratigraphic horizon:** Edaphogenic breccia (upper Campanian–Maastrichtian, likely middle Maastrichtian).

**Description** (Table 2): Evolute serpenticone with rounded venter. Ventral shoulders not expressed, flanks convex. Umbilicus wide, with rounded edge. Surface of the nucleus is smooth, with radial constrictions. External part of the suture line with its incised and bifid ventral, lateral and two umbilical lobes is typical of gaudryceratids.

**Remarks:** The shell morphology and configuration of ventral and lateral lobes and first lateral saddle are similar to *Gaudryceras propemite* Marshall from the Upper Cretaceous of New Zealand (Marshall, 1926), but there is possibility to identify this

taxon only in open nomenclature because of its relatively bad preservation.

Family TETRAGONITIDAE Hyatt, 1900

Subfamily TETRAGONITINAE Hyatt, 1900

Genus *Pseudophyllites* Kossmat, 1895

*Pseudophyllites* cf. *indra* (Forbes, 1846)

Fig. 3(21, 22).

1846. cf. *Ammonites indra* Forbes – Forbes, p. 105, pl. 11, fig. 7.

1895. cf. *Pseudophyllites indra* (Forbes) – Kossmat, p. 137, pl. 16, figs. 6–9; pl. 17, figs. 6 and 7; pl. 18, fig. 3.

2005. cf. *Pseudophyllites indra* (Forbes) – Shigeta, Maeda, p. 94, figs. 38.12, 38.13, 38.16, 38.17, 46–50.

**Locality and material:** Butakov Guyot, station 39D33, two shells; Fedorov Guyot, station 39D206-4, three shells.

**Age and stratigraphic horizon:** Micritic Limestone (Upper Campanian–Maastrichtian, likely middle Maastrichtian).

**Description** (Table 2): Shell thickly discoidal, involute, with moderately expanding and slightly depressed whorls. Venter rounded, without expressed shoulders. Flanks are weakly convex. Umbilical wall is low, with rounded edge; umbilicus rather narrow. Surface of the nucleus has fine radial growth lines. Suture line is unknown.

**Remarks:** Although the present form lacks suture lines, its distinctive features of external shell morphology enable us to identify this taxon with probable confidence as *Pseudophyllites* cf. *indra* (Forbes), which seems to be closest to *Pseudophyllites indra* from the Maastrichtian of South Sakhalin (Shigeta and Maeda, 2005). From *P. indra* from the Maastrichtian of southern India (Kossmat, 1895) it differs by somewhat more narrow ventral side of shell whorls (up to 10 mm).

#### 4.3. Carbon isotope stratigraphy (Preliminary results)

Available data are values of  $\delta^{13}\text{C}$  from ammonoid-bearing limestone of the Fedorov (2.7‰) and Butakov (4.06‰) guyots (Fig. 2(B), Table S1), belemnite rostra of the Govorov (fluctuating from -0.3 to 0.8‰) and Butakov (1.9‰) guyots (Zakharov et al., 2010). 80 samples, taken from successive growth portions in the belemnite rostrum 37D110 A (IR1) from the Gelendzhik Guyot, show values of  $\delta^{13}\text{C}$  fluctuating from 0.1 to 3.1‰ (Table S1). Highest  $\delta^{13}\text{C}$  values correspond to the latest ontogenetic stage of the investigated belemnite specimen. Data on oxygen isotopic composition of organogenic carbonates from the Upper Cretaceous of the Magellan Seamounts and calculated palaeotemperatures were discussed in a previous paper (Zakharov et al., 2010).

## 5. Discussion

Ammonoids and belemnites are common inhabitants of epicontinental seas (Lehmann, 1976; Westermann, 1996). The presence of their remains in Mesozoic oceanic sequences is extremely limited. This is readily apparent from the following evidences. As far as we know, fossil cephalopods have so far only been collected in the northwestern Pacific from the seven Magellan Seamounts guyots of Govorov, Il'ichev, Kotsebu, Pallada, Fedorov, Gelendzhik and Butakov, and from Borehole 167. Furthermore only two more sites have been described to date:

- The northwestern Pacific Guadalupe Guyot (Poyarkova et al., 1988) that produced a single shell of *Hypophiceras pacificum* Grabovskaya, Mikhailova and Zakharov (Late Albian–Early Campanian);
- The northwestern Pacific Khank Guyot, where a single poorly preserved ammonoid shell was found in a silty-pelitic facies of

admittedly Albian–Cenomanian age (Zakharov et al., 2004). In the North Atlantic (ODP Holes 105, 387, and 391c) a large amount of cephalopod remains consists only of Late Jurassic–Early Cretaceous chitinous and chitinous-carbonate aptychi (Renz, 1978; Norris and Wilson, 1998; Wilson and Norris, 2001). Cretaceous ammonoid shells were apparently also found on the Bermuda Rise Site 385 (Renz, 1979) and Blake Plateau (Shkolnik et al., 1988; Norris and Wilson, 1998; Wilson and Norris, 2001). Although brachiopods were extremely abundant in Palaeozoic epicontinental seas and that recent ones are still common in some areas (e.g., New Zealand shelf), their presence on oceanic seamounts remained unknown so far. Mesozoic formations, exposed on land that yield belemnite rostra like the ones on our oceanic guyots, were interpreted as fossil seamount deposits (e.g., Watkins and Browne, 1989; Sandy and Stanley, 1993; Sandy, 1997; Brand et al., 2009).

The general rarity of Late Jurassic–Cretaceous carbonate cephalopod and brachiopod remains from oceanic areas in available collections may be attributed mainly to one of the following factors:

- Limitation of oceanic habitats suitable for ammonoids and to a lesser extent for brachiopods and belemnites, as the majority of oceanic locations consist of lagoons on atolls, apparently exhibiting at the time of growth excessively shallow-water conditions, different from epicontinental shelf sea habitats, where their basic food resources were concentrated, or being shallow sites in the area of atolls, characterised by overly active hydrodynamics, dangerous for some of them, having thin-walled shells easily collapsing when colliding with reefal limestones;
- Transportation of cephalopod and brachiopod shells below the calcite or aragonite compensation depth where their dissolution took place;
- Inadequate palaeontological collecting and field diagnostics.

As a result of an investigation of the Magellan Seamounts, Cretaceous cephalopod remains have been found on virtually every guyots. This fact gives weight to factor 3 relative to cephalopod fossils, although other reasons must be also taken into account. However our knowledge of Jurassic–Cretaceous brachiopods from the Magellan Seamounts area remains too limited to be discussed.

The Late Campanian–Maastrichtian age of the ammonoid fauna of the Butakov and Fedorov guyots and possibly of some other guyots of the Magellan Seamounts (Kotsebu, Il'ichev, and Pallada) is derived from a close relationship found, after comparison of the *Zelandites* specimen from the Fedorov Guyot with *Zelandites japonicus* Matsumoto in the lower Krasnoyarka Formation (Upper Campanian–Maastrichtian) of South Sakhalin. The latter was previously identified as *Zelandites varuna* (Forbes) var. *japonica* Matsumoto (Zakharov et al., 1984; Tanabe et al., 2000). In the Maastrichtian of Kamchatka, *Zelandites* aff. *japonicus* Matsumoto was also reported (Yazykova, 1994). This late Campanian–Maastrichtian (likely Maastrichtian) age is confirmed by micro-palaeontological data from the Magellan Seamounts (Zakharov et al., 2010).

The carbon-isotope composition of the Late Campanian and Maastrichtian carbonates of the Magellan Seamounts has been studied so far in four bulk samples of planktonic and benthic foraminifera from DSDP Site 167 (Douglas and Savin, 1973). The late Campanian planktonic foraminifera selected by them for their first sample yielded a  $\delta^{13}\text{C}$  value of 3.16‰. The only two other samples taken from the early and apparently middle Maastrichtian planktonic foraminifera of the Magellan Seamounts showed  $\delta^{13}\text{C}$  values of 1.09 and 2.99‰, respectively (Fig. 2(B)).

Carbon isotope curves for the Cretaceous (Barrera et al., 1997) show the main trends in  $\delta^{13}\text{C}$  changes for the Campanian–Maastrichtian interval based on data on benthic and planktonic foraminifera:  $\delta^{13}\text{C}$  values decrease globally in the earliest Maastrichtian and increase subsequently. Similar results on carbon isotopic composition were recently obtained by us from Maastrichtian planktonic foraminifera of the Central Pacific (305, 288a and 289 holes) and North Atlantic (390A and 516F holes) (Zakharov et al., 2006):  $\delta^{13}\text{C}$  values in foraminifera from the early Maastrichtian *Globotruncana tricarinata* Zone fluctuate from 1.3 to 2.0‰, but  $\delta^{13}\text{C}$  values obtained from foraminifera from the middle Maastrichtian *G. gansseri* and *G. contuse* are higher (2.3–2.8‰). This suggests a higher productivity of marine waters during the middle Maastrichtian.

Carbon-isotope data obtained from belemnite rostra and the cephalopod bearing limestones of the Butakov, Fedorov, and possibly Gelendzhik and Ita-Mai-Tai guyots (Fig. 2(B), Table S1), lean in favor of a Middle Maastrichtian age, while the belemnite-bearing limestone of the Govorov Guyot shows an early Maastrichtian age. A large variation in  $\delta^{13}\text{C}$  values from a single belemnite *Belemnitella?* sp. emphasizes a Late Campanian–Maastrichtian, likely middle Maastrichtian age for the oolitic limestone of the Gelendzhik Guyot. This may result from the variation of biological productivity of the Pacific Ocean during the Maastrichtian. However, only highest  $\delta^{13}\text{C}$  values (2.5–3.0‰), recognized in latest ontogenetic stage of a belemnite investigated in detail, were taken into account (Fig. 2). Our first conclusions on this topic, of course, must be further checked. However, the obtained results are in agreement with data from the Maastrichtian planktonic foraminifera *Rugoglobigerina hexacamerata* Brönnimann and *Pseudoguembelina excolata* (Cushman), found in ammonoid-limestones of the Butakov and Kotsebu guyots (this study).

Belemnites from the uppermost Cretaceous of the Magellan Seamounts are dominated by forms of the family Dimitobelidae (Zakharov et al., 2010). Taking into account that cool-water-loving dimitobelid belemnites have been discovered so far only in southern higher palaeolatitudes south of 30°S (New Zealand, New Guinea, Australia, James Ross Island and Alexander Island (Antarctica), Annenkov Island and Patagonia (South America), and southern India (e.g., Blanford, 1861; Stevens, 1965; Doyle, 1985), we suggest that belemnites, listed in Table 1, immigrated into the Magellan Seamounts region just from the mentioned area (Fig. 4). This interpretation is supported by the marked morphological similarity between dimitobelid belemnites from the Butakov and Govorov guyots and *Dimitobelus macgregori* (Glaessner) from the Cenomanian of the Wharfe River (New Zealand) (Zakharov et al., 2010). The higher austral latitude representatives of Dimitobelidae are potential ancestors of most belemnites that occurred in the Central Palaeo-Pacific Magellan Seamounts. This conclusion is supported by recently obtained isotope palaeotemperature data (Zakharov et al., 2010). It is known that lowermost surface palaeotemperatures obtained from early Maastrichtian planktonic foraminifera from higher latitudes of South Atlantic are ~10 °C (Barrera et al., 1987, 1997; Huber et al., 1995). Similar isotopic temperatures (9.0–11.7 °C) were calculated from the oxygen-isotopic composition of belemnites *Dimitobelus?* sp. and *Belemnitella?* sp. from the Butakov and Gelendzhik guyots, southern part of the Magellan Seamounts (Zakharov et al., 2010). Furthermore, palaeotemperatures calculated from belemnite Dimitobelidae gen. and sp. nov. rostra from the Govorov Guyot in the northern part of the Magellan Seamounts, are somewhat higher (13.7–17.1 °C) (Zakharov et al., 2010).

Consequently, it may be suggested that the dimitobelid and belemnitellid belemnites from the Pacific palaeotropical stratigraphic interval (Zakharov et al., 2010) were deep-water dwelling nekto-benthonic organisms (assuming that the simulated

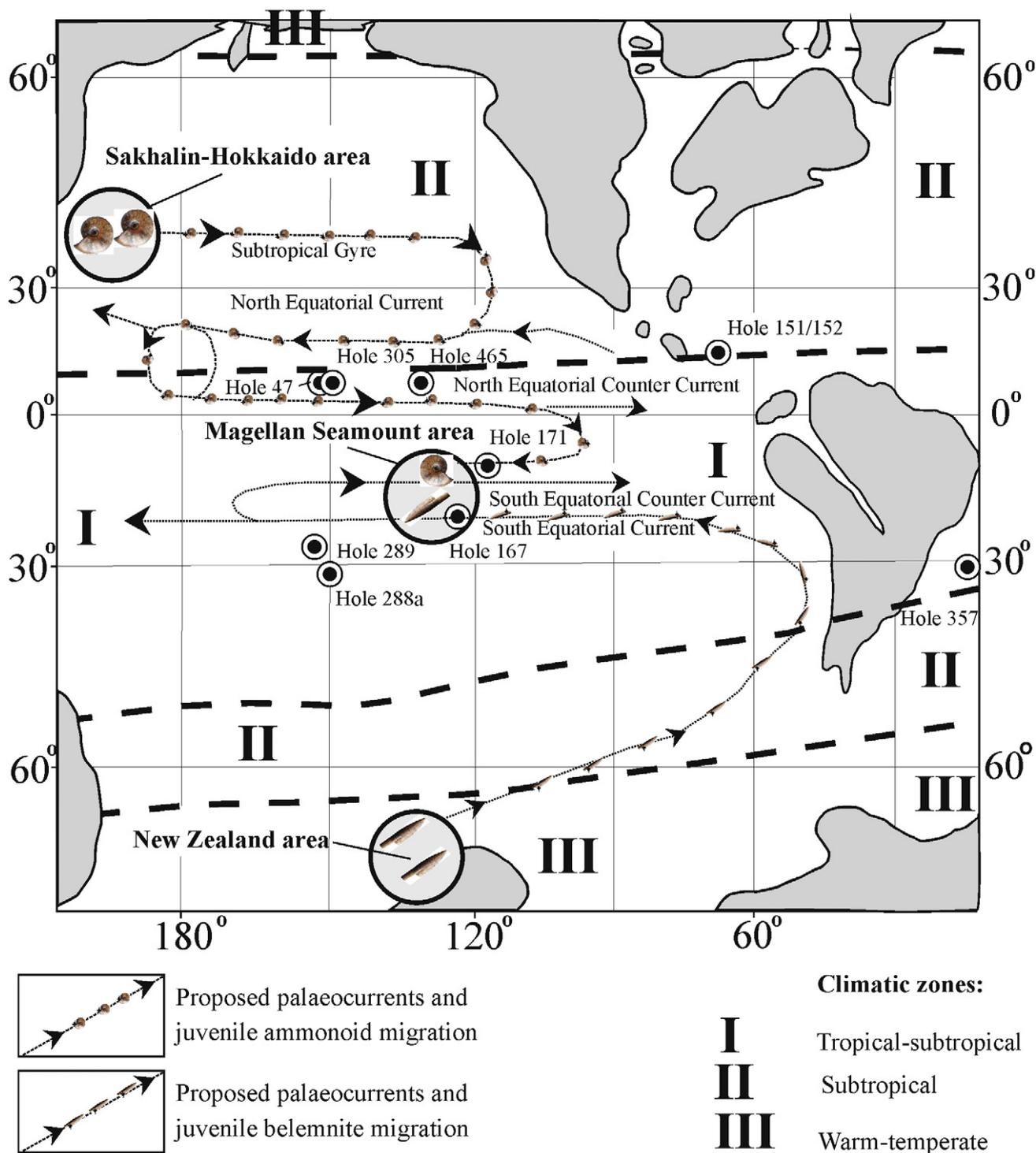


Fig. 4. Supposed migration of cephalopod faunas in the Pacific during Maastrichtian time (map based on Zonenshain et al., 1984).

temperatures fluctuating from 9.0° to 17.1 °C cannot be found in the tropical shelf area). Judging from the isotopic palaeotemperature data, they most probably migrated also from higher palaeolatitudes, where belemnites lived in similar temperature conditions. This hypothesis fits to our calculation, to Stevens and Clayton (1971) isotopic data for the Maastrichtian New Zealand habitat conditions of *Dimitobelus* (around 10.2° to 14.1 °C; Zakharov et al., 2010), and with palaeontological data. Palaeotemperatures, calculated from the isotopic composition of all known Late Albian belemnites (*Parahibolites* and *Tetrabelus*) in the Trichinopoly district of southern India

are inferred to range from 14.3° to 15.9 °C for the mesopelagic zone and from 14.9° to 18.5 °C for the epipelagic zone (Zakharov et al., 2011). On the other hand, Early to mid Albian dimitobelid belemnites from the James Ross Basin (Antarctica), southern Argentina, and western Australia, calcified in cooler (6.1–11.3 °C) environments (Ditchfield et al., 1994; Pirrie et al., 2004).

Examination of the *Zelandites* aff. *japonicus* Matsumoto specimen of the Fedorov Guyot has revealed a close resemblance with both *Z. japonicus* Matsumoto and *Z. aff. japonicus* of the upper Campanian-Maastrichtian in South Sakhalin and Kamchatka,

respectively. This area seems to be the radiation centre of the ammonoids that dwelled as far as in the Magellan Seamounts area. However, the ammonoid migration patterns remain uncertain, taking into account cosmopolitan ammonoid elements, such as *Phylloceras forbesianum* (d'Orbigny) from the latest Cretaceous (Y. Shigeta, personal communication, 2011).

## 6. Conclusions

Because Cretaceous cephalopod remains in the Magellan Seamounts have been found on many guyots, we suggest that the relative poorness of available collections of Late Jurassic–Cretaceous cephalopods from the oceanic areas may be mainly caused by inadequate palaeontological sampling and field diagnostics. The palaeontological and carbon isotope data on cephalopod-bearing sequences of the Magellan Seamounts reported herein, and their Late Campanian–Maastrichtian (more likely early to middle Maastrichtian) age, are consistent with the regional foraminiferal assemblage data. The Late Cretaceous cephalopods found on the Magellan Seamounts apparently migrated, from both austral higher palaeolatitude areas (belemnite fauna) and boreal middle and higher palaeolatitudes (ammonoid fauna), taking into account that beyond the bounds of the Magellan Seamounts, cool-water-loving dimitobelid belemnites are known only in New Zealand, New Guinea, Australia, Antarctica, and southern India, and that *Zelandites* from the Fedorov Guyot (Magellan Seamounts) is most similar to both *Z. japonicus* in South Sakhalin and *Z. aff. japonicus* in Kamchatka.

## Acknowledgments

Our cordial thanks are due to Prof. F. Hirsch (Naruto University of Education, Naruto, Japan) for assistance with the manuscript. We extend our gratitude to Prof. R.W. Scott (Precision Stratigraphy and University of Tulsa, Cleveland, USA), Prof. N.H. Landman (American Museum of Natural History, New York, USA) and an anonymous reviewer for stimulating remarks that substantially improved our paper; Dr. Y. Shigeta (National Museum of Nature and Science, Tsukuba, Japan) for providing valuable comments on phylloceratid, gaudryceratid, and tetragonitid ammonoids from the Magellan Seamounts area, and *Phyllopachyceras ezoense* (Yokoyama) from Sakhalin and Hokkaido; T.A. Velivetskaya (Analytical Center of the Far Eastern Geological Institute, FEB RAS, Vladivostok, Russia) for isotopic measurements; A.A. Karabtsov (Analytical Center of the Far Eastern Geological Institute, FEB RAS, Vladivostok) and A.V. Mozherovsky (Pacific Oceanological Institute, FEB RAS, Vladivostok) for investigation of analysis of volcanoclastic mudstone, using DRON-3. This research was made under the financial support of DVO RAN grant (09-III-A-08-402).

## Appendix A. Supplementary material

Supplementary material (Table S1, Fig. S1) associated with this article can be found, in the online version, at [doi:10.1016/j.geobios.2011.11.011](https://doi.org/10.1016/j.geobios.2011.11.011).

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