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Micropaleontological Biostratigraphy of Cabagan Formation along Magat River, Isabela Province (Cagayan Valley Basin, northern Luzon, Philippines)

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Abstract The Cabagan Formation is a Neogene sedimentary unit within the Cagayan Valley Basin in northern Luzon, Philippines. Along the Magat River in Ramon, Isabela Province, the formation consists of a 340 m-thick, east-dipping fossiliferous sedimentary unit. Calcareous nannofossil analysis of samples collected from the fine-grained layers of the Cabagan Formation yielded poor to moderately-preserved calcareous nannofossils dominated by members of the genera *Discoaster*, *Helicosphaera*, *Pontosphaera*, and *Sphenolithus*. Based on the occurrence of *Discoaster quinqueramus* and *Discoaster berggrenii*, the samples were assigned to the Calcareous Nannofossil Zone NN11 (Martini, 1971). At the same time, planktonic foraminiferal analysis was conducted using samples from the same section. The foraminiferal assemblage is characterized by dominant occurrences of *Globigerinoides sacculifer* and *Globoturborotalita obliquus* with good to moderate preservation. The presence of an index key species *Globorotalia plesiotumida* and the absence of *Globorotalia tumida* and *Pulleniatina primalis* constrain the age into the planktonic foraminiferal Subzone N.17A (Berggren *et al.*, 1995). Both microfossil results assign the Magat River section of the Cabagan Formation to a Late Miocene age.
Key words: biostratigraphy, Cabagan Formation, calcareous nannofossil, Late Miocene, planktonic foraminifera

Introduction

The Cagayan Valley Basin (CVB) is one of the major sedimentary basins in the Philippines located on the northern part of Luzon Island (Fig. 1; BED, 1986). The basin consists of ~9 km-thick Oligocene to Pleistocene marine/non-marine sediments deposited rapidly on a basement of pre-Oligocene and older volcanic and meta-sedimentary rocks (Tamesis, 1976, 1981; Peña, 2008). Turbidites comprise the majority (~80%) of the sediments, which also include shales, chalks, and biohermal limestones (Mathisen, 1981). The CVB is one of the sedimentary basins in the Philippines that was, and is still being, prospected for their hydrocarbon potential (Tamesis, 1976, 1981; BED, 1986; PNOC-EC, 2003).

While numerous studies have been done in the past in relation to the geology and stratigraphy of the CVB, calcareous nannofossil and planktonic foraminiferal biostratigraphic studies are limited. Of all these studies in the CVB (e.g., Gonzales, 1960, 1961; JICA-MMAJ, 1987; Maac, 1988; Aurelio and Billedo, 1987; Billedo, 1994), none have provided a

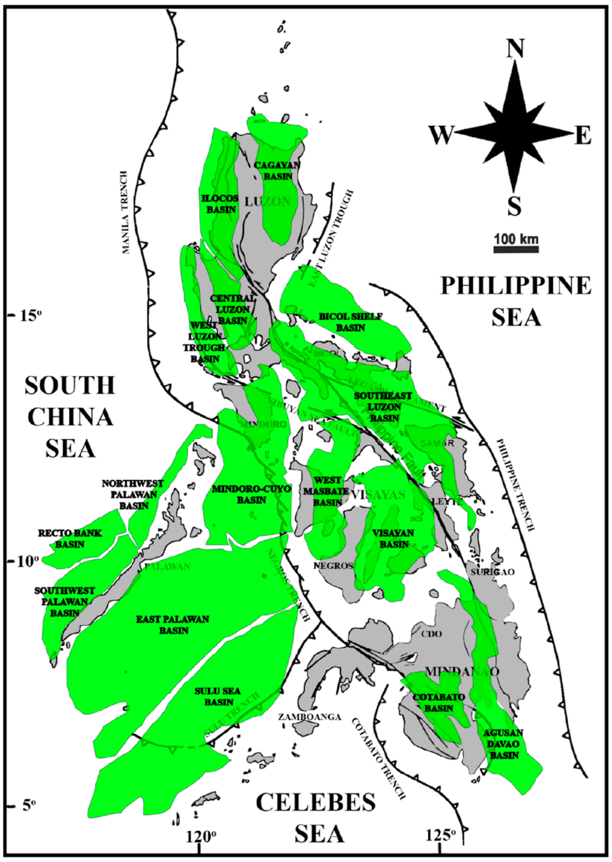

Fig. 1. Map of sedimentary basins in the Philippines (DOE, 2019). The study area is located within the Cagayan Valley Basin (Cagayan Basin), which is located northeast of Luzon Island.

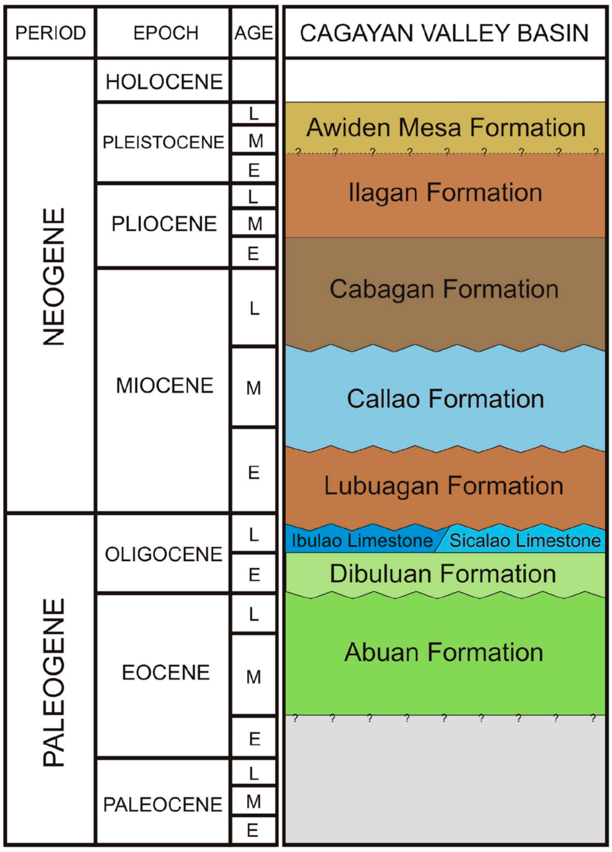

Fig. 2. Generalized stratigraphic column of the Cagayan Valley Basin after Peña (2008).

detailed biostratigraphic study for any of the sedimentary formations in the basin. The present study contributes to the knowledge about the geology and stratigraphy of the CVB by establishing a detailed calcareous nannofossil and planktonic foraminiferal biostratigraphic study of a sedimentary sequence belonging to Cabagan Formation in the southwestern part of Isabela Province.

Geology and Stratigraphy of the Cagayan Valley Basin

Figure 2 shows the general stratigraphy of the CVB (MGB, 2010; Peña, 2008). The oldest unit in the CVB is the pre-Oligocene Abuan Formation which consists of basaltic and andesitic flows and pyroclastic deposits (MGB, 2010). The Abuan Formation is unconformably overlain by the Dibuluan Formation, composed of volcanic flows, breccias, pyroclastics, sandstones, conglomerates, siltstones and mudstones (Peña, 2008; MGB, 2010). K-Ar radiometric dating of a lava flow indicated/revealed that the formation is late Early Oligocene in age (Billedo, 1994). Unconformably overlying the volcanic units is the Late Oligocene to Early Miocene Ibulao Limestone (JICA-MMAJ, 1987; MGB, 2010). Based on the nannofossil analysis of shale samples at the base of the overlying Lubuagan Formation, however, the younger age limit of Ibulao Limestone was suggested to be late Late Oligocene (Calcareous Nannofossil Zone NP25 in Billedo, 1994). The Ibulao Limestone is thought to be equivalent to the Sicalao Limestone along the western flank of the CVB, which consists of calcirudites and calcarenites (BED, 1986; Peña, 2008). A thick sequence of clastic sediments and pyroclastics, named Lubuagan Formation, unconformably overlies the Ibulao Limestone. BED (1986) assigned the Lubuagan Formation an Early to Middle Miocene age. The formation was assigned to Late Oligocene to Early Miocene Nannofossil Zones NP25 to NN3 (Billedo, 1994). Unconformable over the Lubuagan Formation is the Callao Formation [= Callao Limestone (Corby *et al.*, 1951)]. The formation consists of carbonate and clastic facies (Peña, 2008), and is considered to be coeval with the Cabagan Formation (BED, 1986). Based on foraminifera, Durkee and Pederson (1961) assigned a Miocene age for the Callao Formation. This is supported by nannofossil analysis of the clastic unit which yielded assemblages indicative of a Middle Miocene age (Calcareous Nannofossil Zone NN7 in Peña, 2008).

The Cabagan Formation unconformably overlies the Callao Formation and older rocks in the CVB (Peña, 2008). The formation consists of calcareous shales and sandstones, limestones, siltstones, and conglomerates. The relation between Callao Formation and Cabagan Formation was also reported as intertonguing (Caagusan, 1980). MGB (2010) divided the formation into three lithologic units: (a) lower unit consisting of gray silty to sandy calcareous shale with interbeds of calcareous sandstones and limestones; (b) middle unit, which is essentially dark gray shales with thin beds of nodular limestones; and (c) upper unit, which is dominantly siltstones and fine grained sandstones. A Late Miocene to Pliocene age was suggested for the formation (Caagusan, 1980). Aurelio and Billedo (1987) assigned the formation to calcareous nannofossil zones NN7 to NN11 based on paleontological analysis of shale samples from the upper unit. In MGB (2010), the nannofossil zones were placed within the Late Miocene to late Early Pliocene interval. In the Martini's (1971) zonation scheme, however, the nannofossil zones established by Aurelio and Billedo (1987) should have been reported as late Middle Miocene to Late Miocene.

Regional uplift of the CVB occurred in the Plio-Pleistocene, resulting in the deposition of transitional marine to fluvial sediments comprising the Ilagan Formation and Awiden Mesa Formation (Corby *et al.*, 1951; Durkee and Pederson, 1961; Tamesis, 1976; Mathisen, 1981). The Ilagan Formation has a lower unit consisting of marine shale and sandstone interbeds containing abundant molluscs, and an upper unit of coarse marine sandstone and "continental" conglomerates and sandstones (Caagusan, 1980). BED (1986) assigns an age of Late Pliocene to Early Pleistocene for Ilagan Formation. The youngest formation in the CVB is the Awiden Mesa Formation which is a thick sequence of Pleistocene pyroclastic and fluvial sediments conformably overlying the Ilagan Formation (Mathisen, 1981). The formation yielded proboscidean (*Stegodon*), rhinoceros, tortoise, crocodile, bovid, suid, and cervid fossils (Lopez, 1971; de Vos and Bautista, 2001; Liscaljet, 2012; Ingicco *et al.*, 2016). A Middle Pleistocene age is suggested by Mathisen (1981) based on the association of these extinct large vertebrates and the tektites observed in the

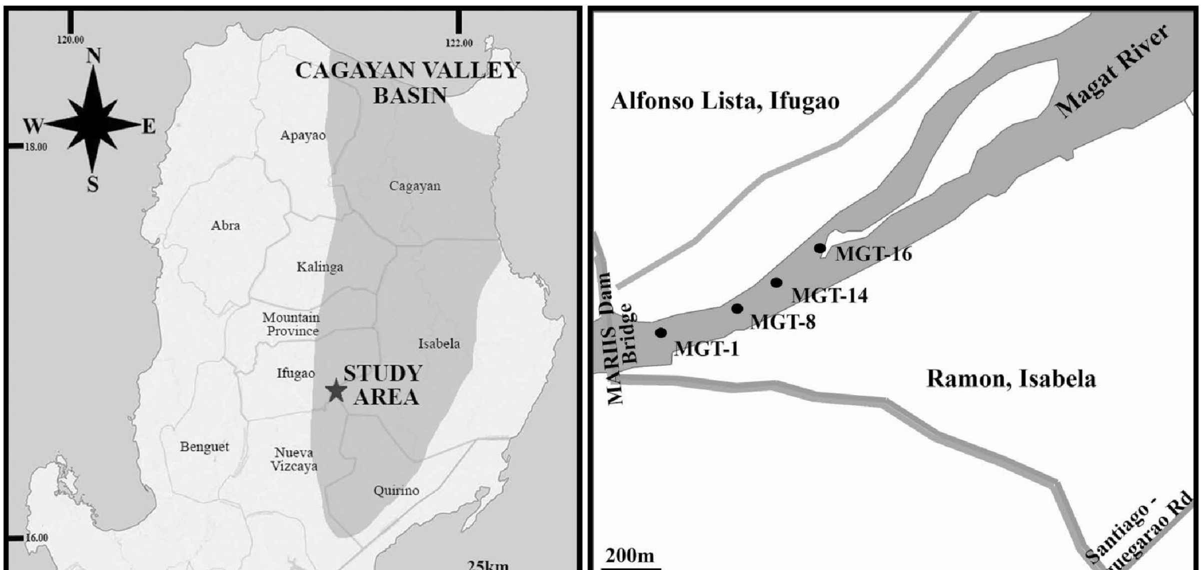

Fig. 3. Location of the study area. The investigated section is located downstream of the MARIIS Dam Bridge in Ramon, Isabela Province. Samples MGT-1 and MGT-16 are located in the lowermost and uppermost parts of the section investigated, respectively.

area.

Stratigraphy of the Study Area

The focus of the present study is a section of Cabagan Formation in Ramon, Isabela Province, northern part of Luzon Island (southwest CVB; Figs. 3 and 4). The investigated section is located downstream of the Magat River Integrated Irrigation System (MARIIS) Dam, which is one of the primary sources of irrigation water in the province. The Cabagan Formation along Magat River is exposed only during the dry months of the year (March to May). The section is the best exposure that crops out an almost complete succession of the Cabagan Formation in the CVB ever studied. We had an opportunity to survey and collect samples for paleontological and sedimentological studies in March, 2019.

The Cabagan Formation in the study area is composed of gently east-dipping, 340 m-thick clastic sediments (Fig. 5). The clastic units are composed

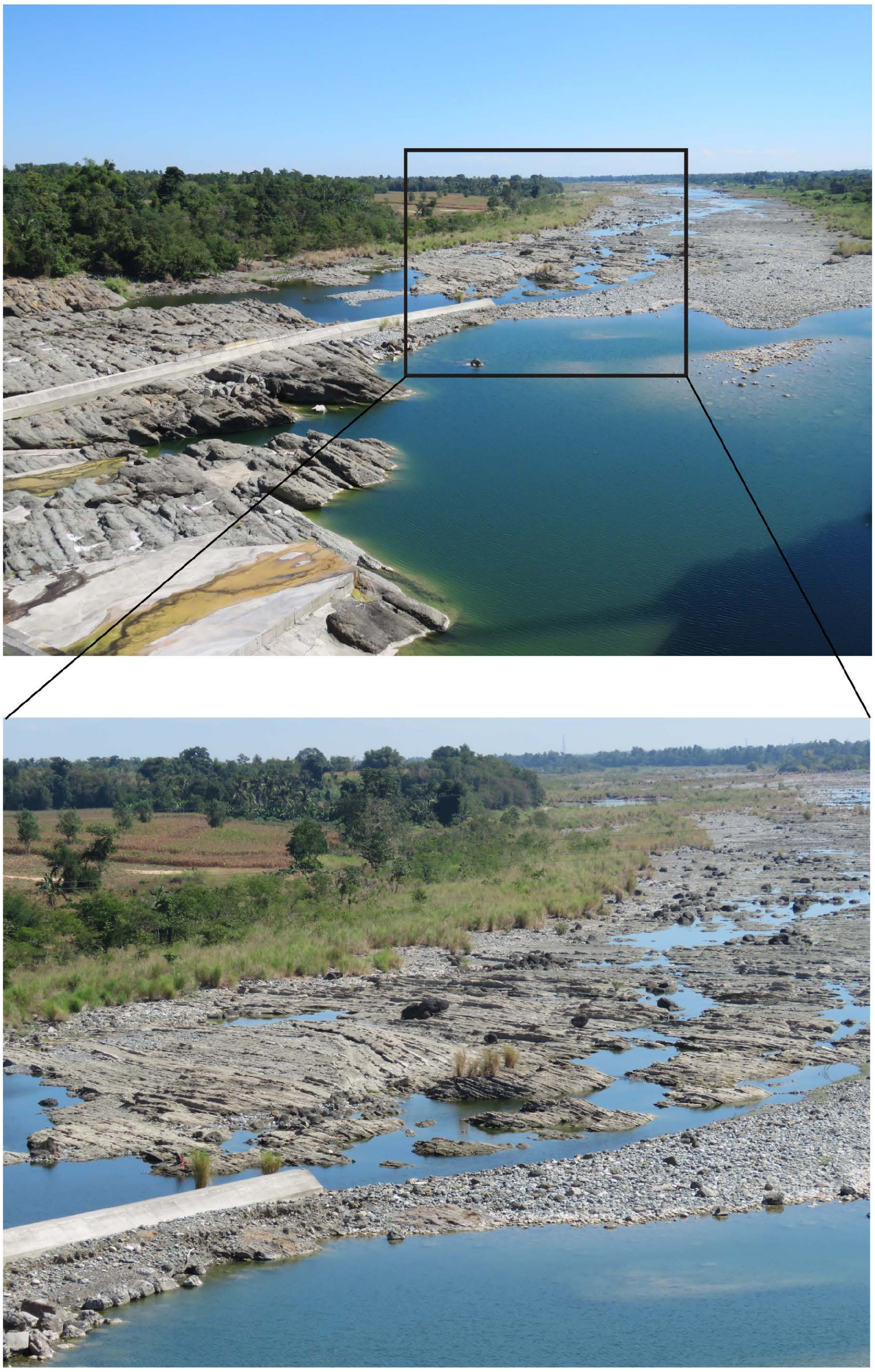

Fig. 4. Exposures of Cabagan Formation along Magat River (downstream of MARIIS Dam), Ramon, Isabela.

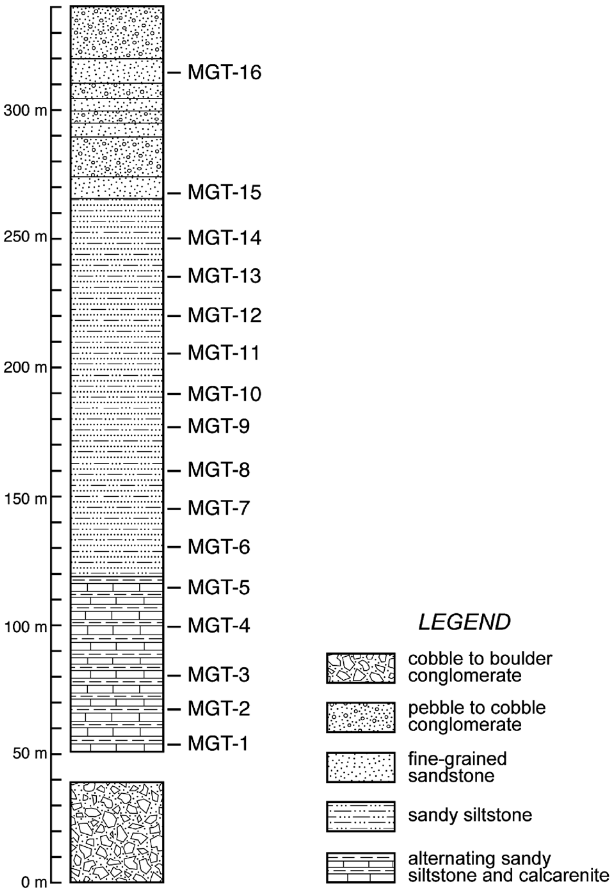

Fig. 5. Stratigraphic log of the Cabagan Formation section investigated along Magat River.

of a cobble-dominated conglomerate, probably deltaic in origin, at the base (basal unit: 0–40 m), alternating fossiliferous sandy siltstone and calcarenite (lower unit: 4–120 m), sandy siltstone (middle unit: 120–265 m), and alternating fine-grained sandstones and conglomerates (upper unit: 265–340 m). The lower and middle units contain diverse mollusks (around 200 species) such as naticids, stromboideans, turrids, conids and arcoideans, suggesting shallow marine, subtidal environments. In contrast, the upper unit yielded large fossilized wood fragments and brackish water gastropods, suggesting freshwater inflows during the deposition. The Cabagan Formation appears to be overlain by the thick conglomerate of the Ilagan Formation, but we could not observe the contact between the two formations.

Materials and Methods

A total of 16 mudstone to fine-grained sandstone samples were collected from the Cabagan Formation exposure along Magat River (Fig. 5). Five samples were collected from the lower unit, 9 samples from the middle unit, and 2 samples from the upper unit. For nannofossil analysis, the simple smear slide method outlined by Bown (1998) was used to prepare smear slides from the samples for calcareous nannofossil biostratigraphic analysis. A polarizing microscope was used to observe the slides at 1000× magnification, with at least 400 fields of view (FOV) observed per sample. Specimens were identified to species level following Perch-Nielsen (1985), Bown (1998) and Young *et al.* (2019). The semi-quantitative abundances of the species observed were recorded using the following categories: abundant (A), ≥25 specimen/FOV; very common (VC), 2–24 specimens/FOV; common (C), 1/1–5 FOVs; few (F), 1/6–10 FOVs; rare (R), 1/11–24 FOVs, and; very rare (VR), 1/≤ 25 FOVs. The nannofossil zones were established using the NN Zones of Martini (1971), supplemented by nannofossil events from Okada and Bukry (1980), and the recent studies of Backman *et al.* (2012), and Raffi *et al.* (2016). Specimens of taxa observed, particularly the marker taxa used for age determination, were photographed using the software Image-Pro Plus 7.0 installed on a desktop computer attached to the Olympus BX51 polarizing microscope. Rock samples, smear slides and original nannofossil images are stored at the Nannoworks Laboratory of National Institute of Geological Sciences, University of the Philippines, and the National Museum of Nature and Science, Tsukuba, Japan.

For planktonic foraminiferal study, 15 rock samples (80 g in dry weight) were disintegrated with water and/or with the use of a saturated sodium sulfate solution. After maceration, each sample was washed on a 120-mesh (125 µm opening) sieve. All samples, except for MGT-10, contain few foraminiferal specimens, and therefore were treated with the carbon tetrachloride floatation method to concentrate the specimens. Planktonic foraminifers were picked up from the residues and were identified at species level under a binocular microscope (×40). The semi-quantitative estimation for the relative abundance of each species was undertaken except for samples containing less than 50 specimens (samples MGT-11, MGT-13 and MGT-14: representing "R" for all species in Table 2). The relative abundance was represented by the following categories: VA, very abundant (＞32%); A, abundant (16-32%), C, common (8–16%); R, rare (＜8%). The planktonic foraminiferal zonation of the present study was based on the traditional Blow's (1969) scheme, partly modified by Berggren *et al.* (1995). The numerical age of each biohorizon was quoted after the current geologic time scale (Gradstein *et al.*, 2012; Hilgen *et al.*, 2012). The specimens illustrated in Figure 8 are stored at the Micropaleontology Section of the National Museum of Nature and Science, Tsukuba, Japan, and other materials examined are at the Department of Geoscience, Shimane University, Matsue, Japan.

Results and Discussion

All samples from the Magat River section of Cabagan Formation yielded poor to moderately-pre-

Table 1. Table 1. Calcareous nannofossil assemblage and abundance in samples from the Magat River section of the Cabagan Formation in Isabela, Philippines. Abbreviations used: Abundance: VR = very rare, R = rare, F = few, C = common, A = abundant, VA = very abundant; Preservation: P = poor, M = moderate.

CALCAREOUS NANNOFOSSIL ABUNDANCE, PRESERVATION, AND ASSEMBLAGE	MGT SAMPLE															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nannofossil Abundance	C	C	F	C	C	C	C	F	F	F	F	F	F	R	F	VR
Preservation	P-M	P-M	P-M	P-M	P-M	P-M	P-M	P-M	P-M	P-M	P-M	P-M	P-M	P-M	P-M	—
Reworked Species																
Catinaster coalitus	—	—	—	R	—	—	—	—	—	—	—	—	—	—	—	—
Coronocyclus nitescens	—	—	—	—	—	VR	—	—	—	—	—	—	—	—	—	—
Cyclicargolithus floridanus	R	R	R	F	R	F	F	—	F-C	F-C	C	R	R	—	F	—
Discoaster deflandrei	—	—	—	—	—	VR	—	—	VR	VR	VR	—	—	—	—	—
Discoaster exilis	—	—	—	—	—	VR	—	—	—	—	—	—	—	—	—	—
Discoaster prepentaradiatus	—	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—
Sphenolithus ciperoensis	—	—	—	—	—	—	—	—	—	VR	—	—	VR	—	VR	—
Sphenolithus heteromorphus	—	—	—	—	—	—	—	—	—	VR	—	—	VR	—	—	—
Long-ranging Species																
Braarudosphaera bigelowii	—	—	R	—	—	—	—	—	—	—	—	—	—	—	—	—
Calcidiscus leptoporus	R	R	F	F	R	F	R	R	R	R	R	R	—	—	—	—
Calcidiscus tropicus	—	—	—	R	—	—	—	—	—	—	—	—	—	—	—	—
Calciosolenia murrayi	—	—	—	—	—	R	—	—	—	—	—	—	—	—	—	—
Coccolithus pelagicus	R	—	—	F	F	F	R	R	F	R	R	—	R	—	—	—
Discoaster brouweri	—	F	R	F	R	R	—	—	—	F-R	—	—	—	—	—	—
Discoaster pentaradiatus	—	—	—	—	—	—	—	VR	—	—	—	VR	—	—	—	—
Discoaster triradiatus	—	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—
Discoaster spp. (5-rayed)	R	R	R	F-R	F-R	R	R	R	R	R	R	—	—	—	—	—
Discoaster spp. (6-rayed)	R	R	R	F-R	F-R	R	R	R	R	R	R	—	—	—	—	—
Florisphaera profunda	R	R	F	C	R	R	—	R	—	R	R	R	—	—	—	—
Helicosphaera carteri	F	C	C	C	C	F-C	C	C	F-R	F	F	F	F	—	R	—
Helicosphaera intermedia	F-R	F-R	—	R	F-R	—	—	R	—	—	—	—	R	—	R	—
Helicosphaera princei	F-R	R	R	F	C	F	R	R	—	R	—	—	R	—	—	—
Pontosphaera discopora	—	R	—	R	F–R	R	—	—	—	—	—	—	—	—	—	—
Pontosphaera multipora	F	R	—	R	R	—	—	—	—	R	—	R	R	—	—	—
Pontosphaera sp.	—	F	R	C	F	R	R	—	—	F	—	R	R	—	—	—
Reticulofenestra minuta	C	C	F	C	F	F	R	R	R	R	R	—	R	—	F	—
Reticulofenestra haqii	C	C	F	F	—	F	—	R	R	C	F	F	F	—	F	—
Reticulofenestra pseudoumbilicus (＜7 μm)	R	F	C	C	F	F	C	C	F	F	R	R	R	—	R-F	VR
Reticulofenestra pseudoumbilicus (＞7 μm)	—	—	—	VR	—	—	—	—	—	VR	—	—	—	—	—	—
Rhabdosphaera clavigera	—	R	—	—	R	—	R	R	R	R	—	—	R	—	R	—
Scyphosphaera sp.	—	—	VR	VR	VR	—	—	—	—	—	—	—	—	—	—	—
Sphenolithus abies	C	C	C	C	C	C	C	C	C	C	C	C	C	R	C	—
Syracosphaera sp.	—	—	—	—	VR	—	—	—	—	—	—	—	—	—	—	—
Umbilicosphaera jafari	R	R	—	F	F	R	R	R	R	—	R	—	—	—	F	—
Umbilicosphaera rotula	—	—	—	R	F	R	R	R	—	R	—	—	—	—	—	—
Marker/Important Species																
Discoaster berggrenii	—	F	F	R	F-R	R	—	R	F-C	F-C	C	R	R	—	F	—
Discoaster calcaris	—	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Discoaster quinqueramus	F	F	F	C	F-C	F	F	F	VR	R	C	C	R	VR	—	—
Discoaster surculus	—	—	—	VR	VR	—	VR	VR	VR	—	—	—	—	—	—	—
Helicosphaera pacifica	—	—	—	—	—	—	—	—	VR	—	—	—	—	—	—	—
Orthorhabdus rugosus	—	—	—	—	VR	VR	—	—	—	—	—	—	—	—	—	—

<table>
<tr><td rowspan="3">NANNOFOSSIL ZONE</td><td>Martini (1971)</td><td colspan="2">NN11</td></tr>
<tr><td>Okada & Bukry (1980)</td><td>CN9a</td><td>CN9b</td></tr>
<tr><td>Backman et al. (2012)</td><td colspan="2">CNM16–CNM19</td></tr>
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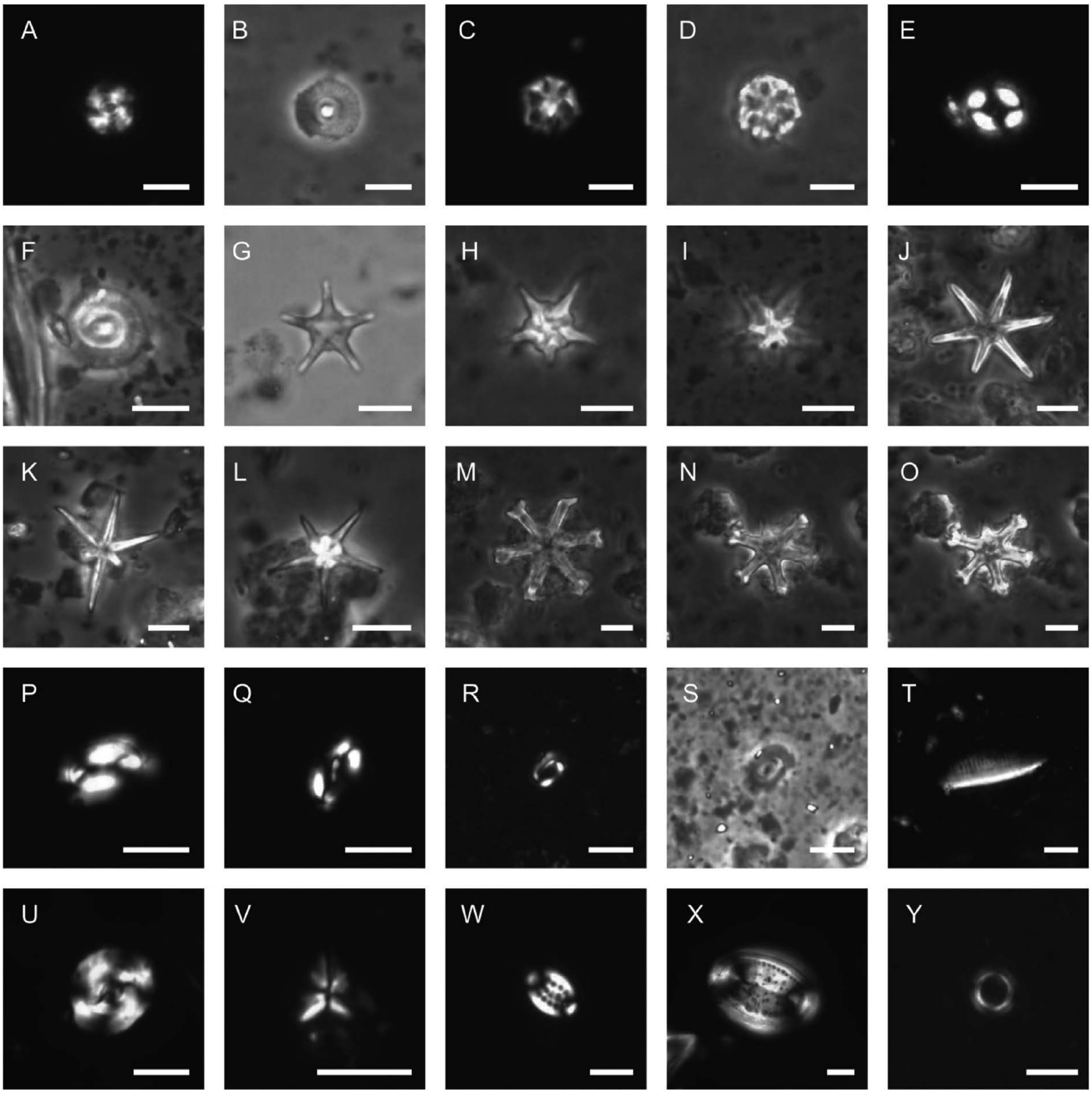

Fig. 6. Selected microphotographs of some taxa observed from the Magat River section of Cabagan Formation (Ramon, Isabela Province). XPL for cross-polarized images and PC for phase contrast images. **A**, **B**, *Coccolithus tropicus*, XPL (A), PPL (B); **C**, **D**, *Catinaster coalitus*, XPL (C), PPL (D); **E**, **F**, *Coccolithus pelagicus*, XPL (E), PPL (F); **G–I**, *Discoaster berggrenii*, PPL; **J**, *Discoaster brouweri*, PPL; **K**, *Discoaster calcaris*, PPL; **L**, *Discoaster quinqueramus*, PPL; **M**, *Discoaster* cf. *D. surculus*, PPL; **N**, **O**, *Discoaster surculus*, PPL; **P**, *Helicosphaera carteri*, XPL; **Q**, *Helicosphaera intermedia*, XPL; **R**, **S**, *Helicosphaera pacifica*, XPL (R), PPL (S); **T**, *Orthorhabdus rugosus*, XPL; **U**, *Reticulofenestra pseudoumbilicus* (>7 μm), XPL; **V**, *Sphenolithus abies*, XPL; **W**, *Pontosphaera multipora*, XPL; **X**, *Pontosphaera* sp., XPL; **Y**, *Umbilicosphaera rotula*, XPL. Scale bars = 5 μm.

served calcareous nannofossils. Twenty seven species were observed from the samples, mostly belonging to the following genera: *Discoaster*, *Helicosphaera*, *Pontosphaera*, *Reticulofenestra*, *Sphenolithus*, and *Umbilicosphaera* (Table 1, Fig. 6). The common occurrence of helicosphaerids and pontosphaerids from the samples indicates deposition in a relatively shallow marine environment (Perch-Nielsen, 1985). Marker taxa used to establish the age of the sediments include *Discoaster quinqueramus*, *Discoaster berggrenii*, and *Discoaster surculus*.

In addition to calcareous nannofossils, ascidian spicules, foraminifera, and the calcareous dinoflagellate *Thoracosphaera* sp. were also observed in some of the samples.

Based on the occurrence of *D. quinqueramus* and *D. berggrenii* in all of the samples, the Cabagan

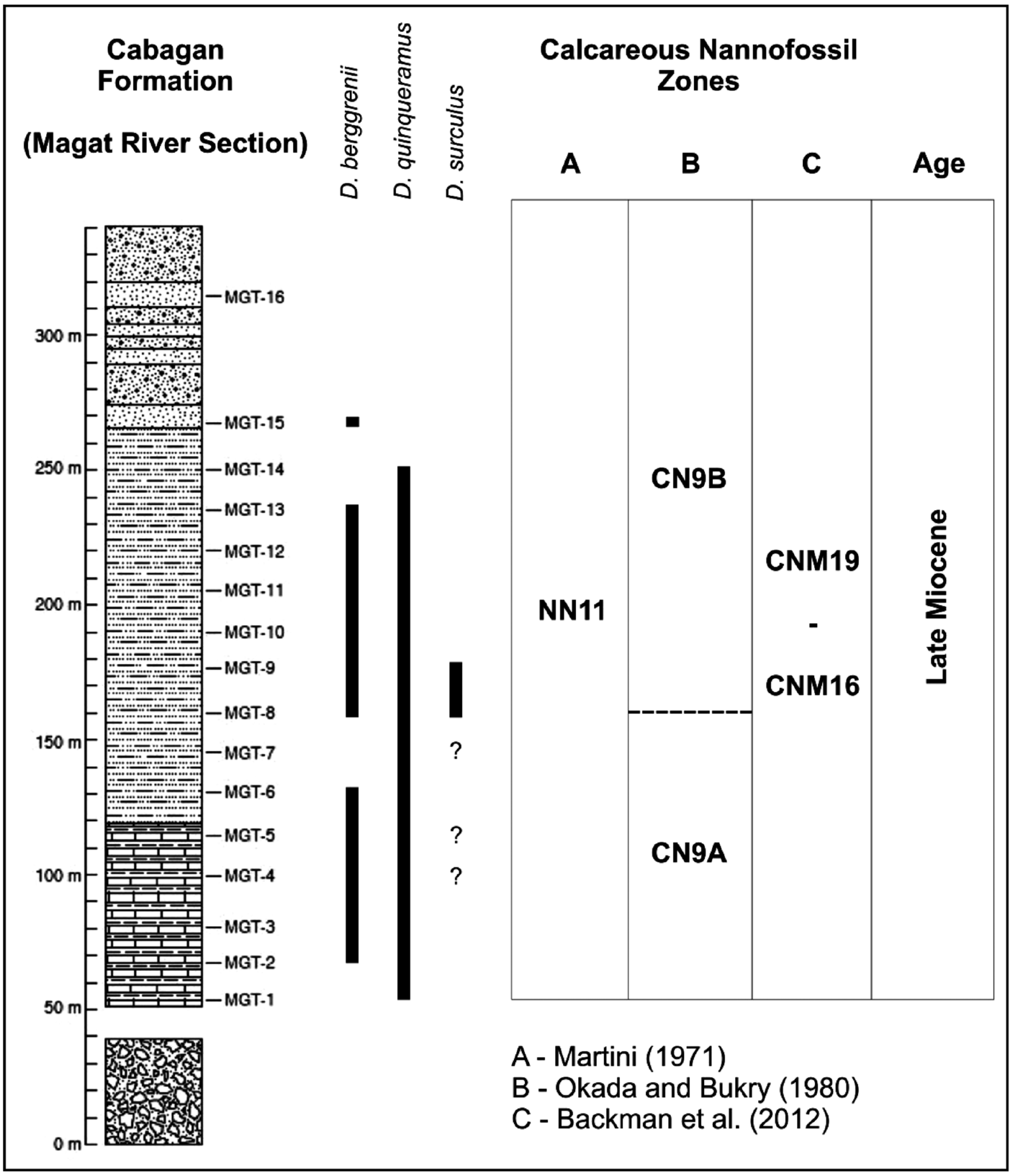

Fig. 7. Calcareous nannofossil zone assignment of the Magat River section of the Cabagan Formation using the Martini (1971), Okada and Bukry (1980), and the Backman *et al.* (2012) zonation schemes. Based on the marker species observed in the samples, the Cabagan Formation is Late Miocene in age.

Formation in the Magat River section can be assigned to calcareous nannofossil zone NN11 of Martini (1971) which is equivalent to Late Miocene [8.30 Ma–5.60 Ma (Young, 1998); 8.20 Ma–5.53 Ma (Backman *et al.*, 2012); Fig. 7]. In Young (1998), the first occurrence (FO) and last occurrence (LO) of *D. quinqueramus* define the lower and upper boundaries of NN11, while in Backman *et al.* (2012) and Rosenthal *et al.* (2017), the FO of *D. berggrenii* (8.20 Ma) and the LO of *D. quinqueramus* (5.53 Ma) define the lower and upper boundaries of NN11, respectively. According to Backman *et al.* (2012), *D. quinqueramus* "appears just after" *D. berggrenii*. Rea *et al.* (1993) placed the FO of *D. quinqueramus* at 8.12 Ma. The LO of *D. berggrenii* was reported by Young (1998) to be confined within the NN11A subzone, although Young *et al.* (2019) reported its LO near the top of the NN11 Zone (5.90 Ma).

The NN11 Zone is divided into the NN11A and NN11B subzones by the FO of *Amaurolithus primus* (Young, 1998; Aubry, 2015). In the Okada and Bukry's (1980) zonation scheme, these subzones correspond to the CN9a and CN9b subzones. In

Table 2. Planktonic foraminifer assemblage and abundance in samples from the Magat River section of the Cabagan Formation in Isabela, Philippines. Abbreviations used: Abundance: VA = ＞32%, A = ＞16%, C = ＞8%, R = ＜8%; Preservation: VG = very good, G = good, M = moderate, P = poor, VP = very poor.

ABUNDANCE PRESERVATION SPECIES	SAMPLE													
	MGT-1	MGT-2	MGT-3	MGT-4	MGT-5	MGT-6	MGT-7	MGT-8	MGT-9	MGT-10	MGT-11	MGT-12	MGT-13	MGT-14
Abundance	A	A	VA	VA	A	A	A	A	A	C	R	VR	VR	C
Preservation	G	G	G	G	G	G	G	G	G	M	M	M	M	M
Dentoglobigerina altispira altispira	R	R	R	R	R	R	R	R	R	R	R	—	—	R
Dentoglobigerina altispira globosa	R	R	R	R	C	R	R	R	—	—	—	—	—	–
Dentoglobigerina baroemoenensis	R	—	R	R	R	—	—	R	R	—	—	—	—	R
Globigerina bulloides	R	R	—	—	—	C	A	R	R	R	R	R	—	–
Globigerinella obesa	R	—	—	—	—	—	—	—	R	—	—	—	—	–
Globigerinella siphonifera	R	—	—	R	R	—	R	R	R	R	—	—	—	–
Globigerinita glutinata	R	R	R	—	R	R	R	—	—	—	—	—	—	–
Globigerinoides ruber	R	R	—	—	R	—	R	R	R	R	—	—	—	R
Globigerinoides sacculifer	A	VA	VA	A	A	A	C	C	C	A	—	—	R	A
Globigerinoides trilobus	R	R	C	R	R	—	R	R	C	C	—	R	R	A
Globoconella conoidea	—	R	R	—	—	—	—	—	—	—	—	—	—	–
Globoquadrina venezuelana	R	—	R	—	—	—	—	—	R	—	—	—	—	–
Globorotalia plesiotumida	—	R	R	R	—	—	R	—	—	—	—	—	—	–
Globoturborotalita decoraperta	R	R	R	R	R	C	C	R	R	R	R	—	—	R
Globoturborotalita extremus	—	—	R	—	R	R	—	R	—	—	—	—	—	–
Globoturborotalita nepenthes	R	R	—	R	—	—	R	R	—	—	—	—	—	–
Globoturborotalita obliquus	VA	VA	VA	VA	VA	VA	C	VA	VA	A	R	—	R	A
Globoturborotalita woodi	—	—	—	—	—	—	C	C	R	R	R	—	—	R
Menardella cultrata	—	—	R	R	—	—	—	—	—	—	—	—	—	–
Menardella limbata	—	—	—	R	—	—	—	—	—	—	—	—	—	–
Menardella menardii	—	R	R	—	—	—	—	—	—	—	—	—	—	–
Neogloboquadrina acostaensis	R	R	R	R	R	R	R	R	—	—	—	—	—	–
Neogloboquadrina dutertrei	—	—	—	—	—	—	R	R	—	—	—	—	—	–
Neogloboquadrina cf. praeatlantica	—	—	—	—	—	—	R	—	—	—	—	—	—	–
Orbulina suturalis	R	R	R	R	R	R	R	R	R	R	—	—	—	R
Orbulina universa	R	R	R	R	C	C	R	R	—	R	—	—	—	R
Sphaeroidinellopsis seminulina	—	R	—	—	—	—	—	—	—	—	—	—	—	—

Backman *et al.* (2012), the FO of *A. primus* is placed at 7.39 Ma. In the studied section, however, *A. primus* was not observed. Therefore, the FO of *D. surculus* (supplementary event in Young, 1998) was used to approximate the boundary between NN11A and NN11B (Fig. 7). The FO of *D. surculus* at 7.79 Ma is reported below the FO of *A. primus* (Young, 1998; Lourens *et al.*, 2004; Backman *et al.*, 2012). Other species supporting the age assignment of the section include *Helicosphaera princei*, which was reported to have its FO within the NN11 Zone (da Gama and Varol, 2013), and *Discoaster calcaris* and *Helicosphaera pacifica*, which are both reported to have LOs within the NN11 Zone (Boesiger *et al.*, 2017; Browning *et al.*, 2017). The NN11 Zone corresponds to the CN9a and CN9b subzones of Okada and Bukry (1980), and to the CNM16–CNM19 Zones of Backman *et al.* (2012). The markers used to separate the CNM16 from CNM19 Zones (*A. primus* and *Nicklithus amplificus*) were also not observed in the samples.

Planktonic foraminifera from the Magat River section show good to moderate preservation, with some specimens showing fragmentation. A total of 27 foraminiferal species were recognized from 14 samples (Table 2, Fig. 8). The assemblage is characterized by the dominant occurrence of the tropical oligotrophic species *Globigerinoides sacculifer* and *Globoturborotalita obliquus.* An important zonal maker species, *Globorotalia plesiotumida*, was observed from samples MGT-2, MGT-3, MGT-4, and MGT-7. The FO of this species defines the lower boundary of Zone N.17 of Blow (1969). With respect to the absence of *Pulleniatina primalis* defining the lower boundary of Subzone N.17B of Berggren *et al.* (1995), the interval containing *G. plesiotumida* might be assigned to Subzone N.17A of Berggren *et al.* (1995). In addition to this, the entire studied interval should be restricted in age from Late Miocene to Middle Pliocene because of the occurrence of *Neogloboquadrina acostaensis* from the lowest sample, and the occurrence of *Dentoglobigerina altispira altispira* from the highest sample — the FO of the former species defines the lower boundary of Zone N.16 of Blow (1969), and the last occurrence age of the latter species was astronomically determined to 3.47 Ma (Hilgen *et al.*, 2012).

According to the current geologic time scale (Gradstein *et al.*, 2012; Hilgen *et al.*, 2012), the

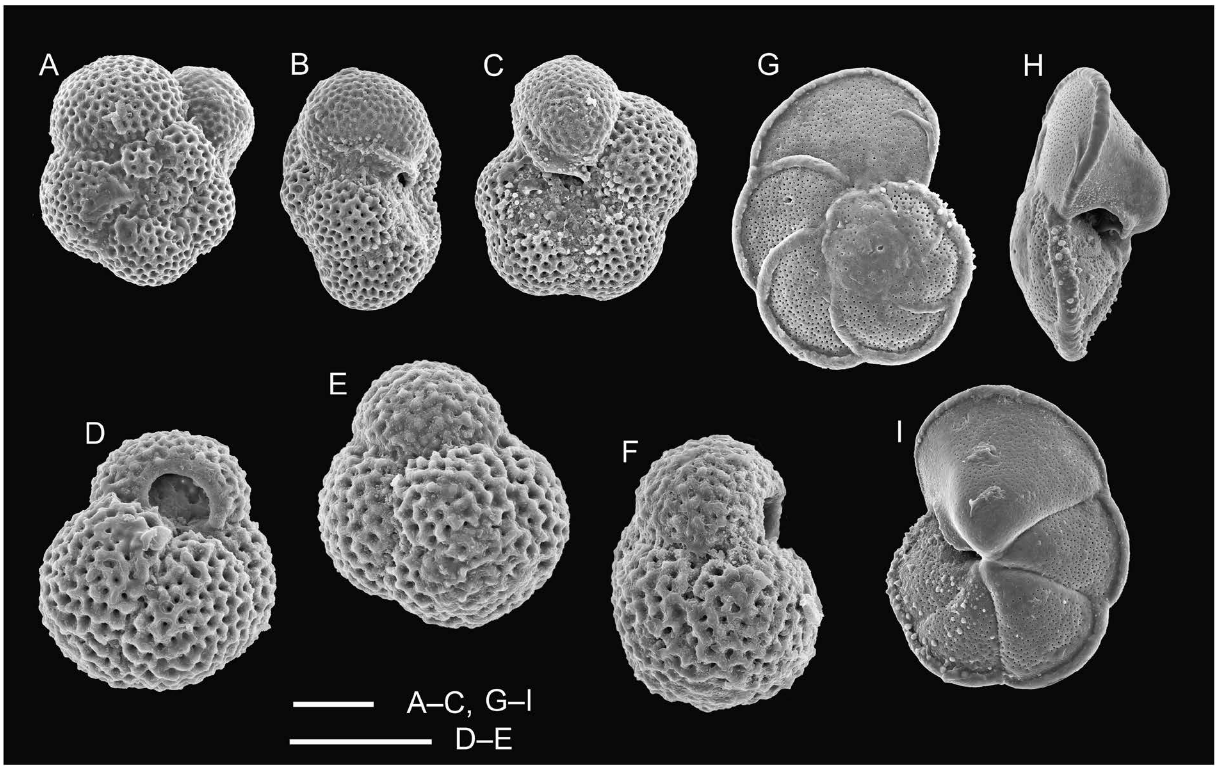

Fig. 8. Photographs of selected planktonic foraminiferal species from the Magat River section of the Cabagan Formation (Ramon, Isabela Province). **A–C**, *Neogloboquadrina acostaensis*, sample NMNS MPC-42341, from MGT-4; **D–F**, *Globoturborotalita nepenthes*, sample NMNS MPC-42342, from MGT-2; **G–I**, *Globorotalia plesiotumida*, sample NMNS MPC-42340, from MGT-7. Scale bars = 100 μm.

results of calcareous nannofossils and planktonic foraminifera are concordant with each other. Therefore, we employ the age of the calcareous nannofossils for the Magat River section of the Cabagan Formation. The sequence is correlated with the Calcareous Nannofossil Zone NN11, and is Late Miocene in age. This is different from the previous study by Aurelio and Billedo (1987) which assigned the formation to Calcareous Nannofossil Zones NN7 to NN11, and from the study of Caagusan (1980), which assigned a Late Miocene to Pliocene age for the Cabagan Formation.

Using the results of Aurelio and Billedo (1987), MGB (2010) placed Cabagan Formation within the Late Miocene to late Early Pliocene interval even though the NN7 to NN11 Zones correspond to the late Middle Miocene to Late Miocene interval. In the present study, Pliocene calcareous nannofossils were not observed, thus, restricting the age of Cabagan Formation to Late Miocene. Reworked Oligocene to Middle Miocene nannofossils are also consistently present in the samples, suggesting mixing of sediments eroded from older rock units within the Cagayan Valley Basin. The age of the formation will be further verified by an ongoing calcareous nannofossil biostratigraphic study of samples from a well drilled south of the study area.

Conclusions

– The Magat River section of the Cabagan Formation is within Calcareous Nannofossil Zone NN11 of Martini (1971). At the same time, a part of the section might be restricted into planktonic foraminiferal Subzone N.17A of Berggren *et al.* (1995). Both micropaleontologic results are mostly consistent and suggest a Late Miocene age for Cabagan Formation.
– The nannofossil zone assignment for the Magat River section of the Cabagan Formation restricts the age assignment of the formation to Late Miocene, compared to the previously reported Late Miocene to Early Pliocene age of Peña (2008) and MGB (2010).
– Based on the common occurrence of helicosphaerids and pontosphaerids in the samples,

the Magat River section is interpreted to have been deposited in a shallow marine environment. This supports the observed overall shallowing marine sequence based on lithology, mollusc and foraminifera data.

– Further calcareous nannofossil biostratigraphic studies of other sections/exposures of Cabagan Formation is recommended to further refine its age, which is crucial in understanding the geologic evolution of the Cagayan Valley Basin.

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