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Calcareous nannofossils from Cretaceous units in Catanduanes Island, Philippines

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Abstract The paper presents the results of the calcareous nannofossil investigation of samples collected from known Cretaceous localities in Catanduanes Island, eastern Philippines. The study was conducted in order to verify and refine the ages of Yop and Codon Formations, the oldest lithostratigraphic units in the island. Based on the analysis of samples collected from exposures of Codon Formation in the southeast and southwest parts of the island, two distinct nannofossil assemblages (and, therefore, ages) were established. In Nagumbuaya Point (southeast Catanduanes), the limestones were assigned to the UC10–UC12 zones (Coniacian–Santonian) based on the occurrence of *Eprolithus moratus* and *Micula staurophora*. The limestones in southwestern Catanduanes (Bonag-bonag and Codon Points), on the other hand, were dated Campanian–Maastrichtian based on the occurrence of *Micula* spp. (*M. cubiformis*, *M. praemurus*, *M. staurophora* and *M. swastica*). Two samples from Codon Point were specifically assigned to the UC20b subzone (late Maastrichtian) due to the presence of *Micula murus*. A previously unmapped black mudstone-fine-grained sandstone outcrop in Bagamanoc, northern Catanduanes is proposed to be included in the Yop Formation. Based on the occurrence of *Quadrum intermedium* and *Helenea chiastia*, the UC5c subzone, which is within the Cenomanian–Turonian boundary interval, is recognized. The results of the study necessitate the revision of the age of Codon Formation, which was previously identified to be late late Cretaceous in age. With the new nannofossil data available in Nagumbuaya Point, the age of the formation is proposed in the present study to be refined and extended to the Coniacian–Santonian. The recognition of the UC5c subzone in the black mudstone-fine-grained sandstone interbeds in northern Catanduanes is also significant as this may represent the possible occurrence of the oceanic anoxic event 2 (OAE2), which is within the Cenomanian-Turonian boundary interval. An ongoing detailed biostratigraphic work is being done in the area to confirm the assumption, which if proven, will represent one of the very few OAE2 sections in the western Pacific region.

Key words: Catanduanes, Cretaceous, calcareous nannofossils, oceanic anoxic event 2 (OAE2)

Introduction

The Western Pacific Region is a complex system of subduction zones, collision zones and marginal seas. Within this region lies the Philippines, an island arc system straddling the boundaries of the Eurasian and the Philippine Sea Plates, and an assemblage of allochthonous arcs, ophiolite complexes, continental rocks and oceanic materials welded together (Karig, 1983; Hall, 1997; David *et al.*, 1997; Galgana *et al.*, 2007; Yumul *et al.*, 2008; Fang *et al.*, 2011). The Cretaceous rocks in the Philippines are exposed in the form of metamorphic basement rocks, crust-mantle sequences, magmatic/volcanic arcs and their associated sedimentary carapace (Militante-Matias *et al.*, 1994; MGB, 2010). Confirmed Cretaceous localities in the Philippines

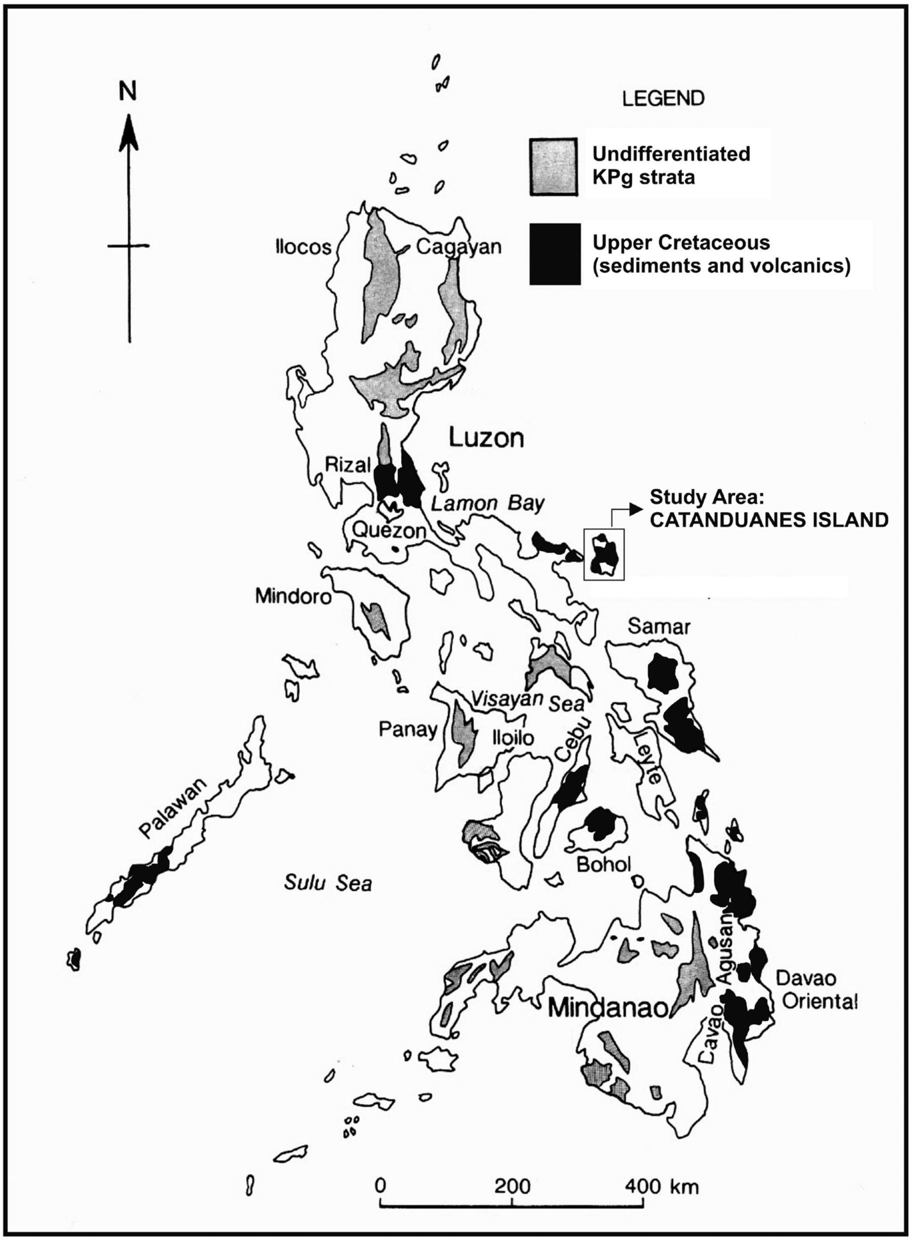

Fig. 1. Map showing the location of selected Cretaceous localities in the Philippines. The Cretaceous units include metamorphic basement rocks, crust-mantle sequences, magmatic/volcanic arcs and their associated sedimentary carapace. Map adapted and modified from Militante-Matias *et al.* (1994).

include the Provinces of Rizal, Quezon, Camarines Norte and Sur, Marinduque, Samar, Leyte, Cebu, Palawan, Davao Oriental and Catanduanes (Fig. 1). The Cretaceous units in these areas were studied using ammonites, radiolarians, foraminifera, palynomorphs and, to a lesser extent, calcareous nannofossils.

The present study is part of an ongoing project in refining the ages of Cretaceous sedimentary units in the Philippines. Initial phase of the project included the Provinces of Palawan, Rizal and Catanduanes, which will be main focus of this paper. A recent field mapping in Catanduanes done by the Geology 215 (Advanced Field Geology) Class of the National Institute of Geological Sciences, University of the Philippines (UP NIGS) confirmed the distribution of the Cretaceous units in the study area: Yop Formation and Codon Formation. Preliminary calcareous nannofossil analysis of the samples also confirmed the age of the Cretaceous units and, at the same time, reported previously unmapped Cretaceous rocks in the northeastern part of the island, which is tentatively included in the Yop Formation (Fernando *et al.*, 2014; Guballa *et al.*, 2015; Magtoto *et al.*, 2015).

The paper will discuss and present the calcareous nannofossil assemblages observed in the Yop and Codon Formations, and discuss their implications with regards to the ages of the units and the geologic history of Catanduanes during the Cretaceous.

Study Area

Catanduanes Island lies at the eastern end of the northwest-trending Eastern Luzon Metamorphic Belt (Karig, 1983). It is considered as a sliver of a continental margin or older arc crust that rifted away during the late Cretaceous due to back-arc spreading. The stratigraphy of the island consists of late Cretaceous volcanic, volcaniclastic rocks and limestones, overlain by Paleogene to Quaternary sedimentary sequences. The Batalay Diorite intruded the older units in the island during the Oligocene (MGB, 2010). Paleontological studies of Cretaceous sedimentary formations in the island include the foraminifera studies of Tan (1986), Fernandez *et al.* (1994) and Militante-Matias *et al.* (1994); the ammonite studies of Miranda and Vargas (1967) and Matsukawa *et al.* (2012); and the nannofossil studies of Militante-Matias *et al.* (1994) and Tangunan *et al.* (2013).

A number of field mapping activities in the island have already been conducted by BS and MS Geology students of UP NIGS. The most recent was in 2014, when the Geology 215 Class mapped exposures in accessible areas around the island. This mapping led to the confirmation of the Cretaceous age (based on calcareous nannofossils) of the exposures of Codon Formation in the southeast (Nagumbuaya Point; Fernando *et al.*, 2014; Guballa *et al.*, 2015; Magtoto *et al.*, 2015), and the recognition of previously unreported Cretaceous sedimentary sequences in the northern part of the island (Guballa *et al.*, 2015; Magtoto *et al.*, 2015). Figure 2 shows the revised geologic map and stratigraphic column of Catanduanes Island by the 2014 Geology 215 Class of UP NIGS.

General Geology and Stratigraphy of the Study Area

The basement of Catanduanes Island was previously identified as the pre-Cretaceous Catanduanes Formation (Miranda and Vargas, 1967), which was disregarded by David (1994) based on its observed intercalation with the Cretaceous Yop Formation, which is now widely accepted as the basement of the island. The Yop Formation consists of basalts, andesites, volcaniclastic rocks, limestones and pyroclastic breccias (Peña, 2008; MGB, 2010). The chaotic limestone units in the southern part of Catanduanes, dated Cretaceous, were designated by David (1994) as part of the Codon Formation, which are olistostrome sequences consisting of volcanic blocks and reworked limestones in a volcaniclastic matrix and showing synsedimentary faulting and deformation features. The Codon Formation is unconformably overlain by the Eocene Payo Formation, which consists of the (a) Manamrag volcanic and volcaniclastic facies consisting of sandstones, conglomerates, siltstones and volcanic flows and the (b) Hilawan Limestone (Peña, 2008; MGB, 2010).

The Yop and Codon Formations are intruded by the Oligocene Batalay Diorite (previously referred to as the Batalay Intrusives; Miranda and Vargas [1967]; MGB [2010]). Based on the recent mapping by UP NIGS, the diorites and andesites that were mapped as part of the Batalay

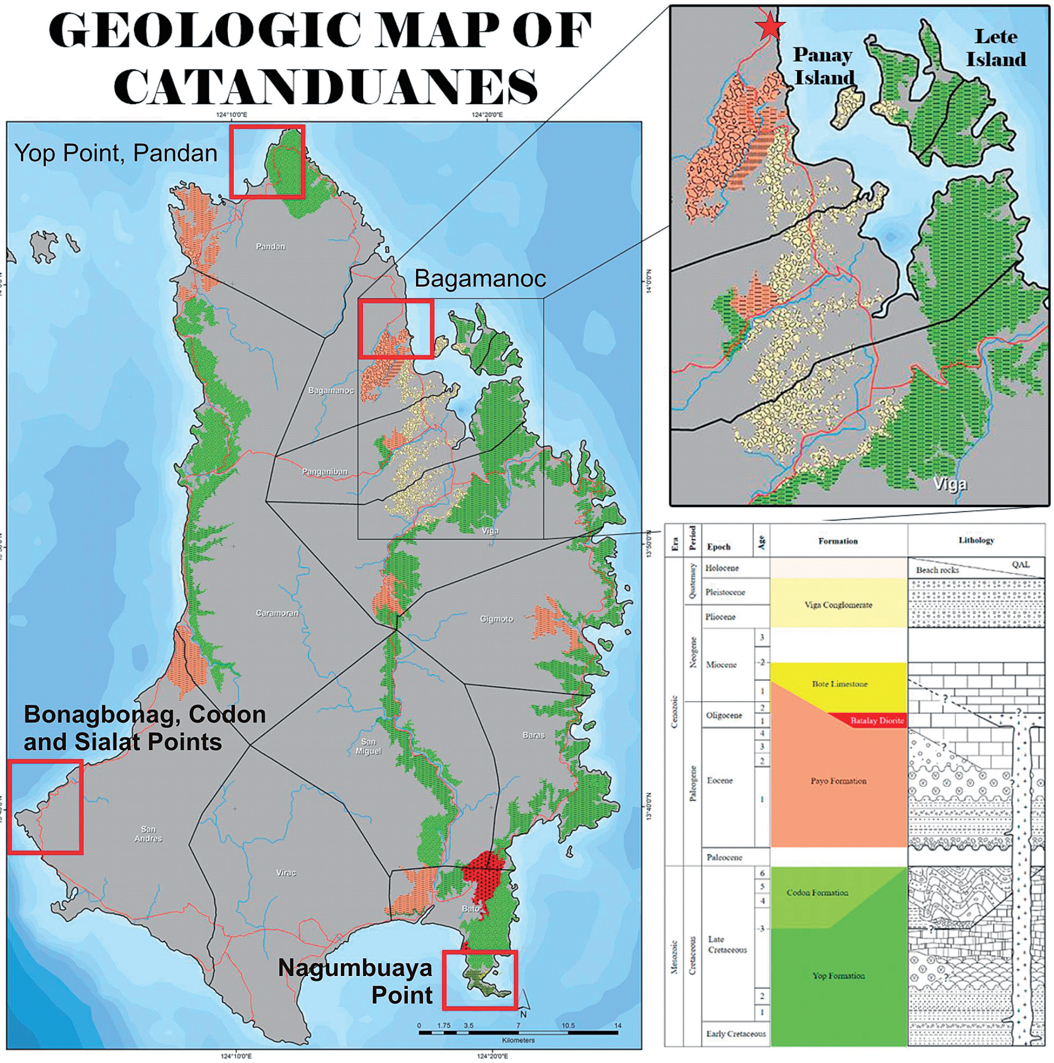

Fig. 2. Geologic map and stratigraphy of the area mapped by the Geology 215 Class 2014 in Catanduanes (Guballa *et al.*, 2014). The red boxes correspond to the areas where the samples investigated for calcareous nannofossils were collected: Bonagbonag, Codon and Sialat Points in the southwest, Nagumbuaya Point in the southeast, Yop Point in the northern and Bagamanoc in the northeastern part of the island. The red star in Bagamanoc indicates the locality of the previously unmapped interbedded black mudstone-fine-grained sandstone outcrop.

Diorite were also observed to intrude the sandstones of Payo Formation (Guballa *et al.*, 2014). The Yop Formation is unconformably overlain in the southeastern part of the island by Bote Limestone, which consists of fossiliferous neritic limestones and calcarenites (David, 1994). Based on foraminifera, the Bote Limestone was dated as late Oligocene to early Miocene (Peña, 2008; MGB, 2010). The middle Miocene San Vicente Conglomerate and the middle to late Miocene Sto. Domingo Limestone were not observed in the area mapped by UP NIGS, although both units were observed in previous studies to unconformably overlie the Codon Formation and other older units (Miranda and Vargas, 1967; MGB, 2010). The youngest formation in Catanduanes

Island is the Viga Conglomerate, which is widely distributed in the northeastern part of the island. The conglomerates are polymictic and range from clast- to matrix-supported. Based on its stratigraphic position, Miranda and Vargas (1967) and JICA-MMAJ (1996) suggested that it is late Pleistocene to Recent in age. A Pliocene-Pleistocene age, on the other hand, was suggested by Peña (2008) and MGB (2010).

Micro- and Macropaleontological Studies in Catanduanes

Paleontological investigation of carbonate rocks in Catanduanes revealed micro- and macrofossil assemblages indicative of Cretaceous age. Foraminifera studies include the works of Tan (1986), Fernandez *et al.* (1994) and Militante-Matias *et al.* (1994; in Okada and Mateer, 2000), while Tumanda (1986) and Matsukawa *et al.* (2012) reported the occurrence of ammonites in the Yop Formation. Prior to this paper, there were very few studies on calcareous nannofossils in the island: Militante-Matias *et al.* (1994), David *et al.* (1997) and more recently Tangunan *et al.* (2013) who reported late Maastrichtian nannofossils in the olistostromic Codon Formation in its type locality in Codon Point (southwest Catanduanes Island). The chaotic (olistostromic) nature of the Codon Formation has prevented earlier studies from conducting biostratigraphic studies due to the rarity of fossils (David, 1994 as cited in MGB, 2010).

The present paper reports the results of calcareous nannofossil analysis of samples collected from Bonagbonag, Codon and Sialat Points in southwest Catanduanes, Nagumbuaya Point in the southeast, and Bagamanoc and Pandan in the north (Fig. 2). The preliminary results have been reported in Fernando *et al.* (2014), Guballa *et al.* (2015) and Magtoto *et al.* (2015).

Materials and Methods

A total of 37 samples were collected from the different exposures of Yop and Codon Formations in the island (Table 1). Smear slides from the samples were prepared following standard sample preparation techniques (Bown and Young, 1998). The slides were examined under an Olympus BX51 polarizing microscope at 1000× magnification. Calcareous nannofossil taxa, particularly the index markers, were tallied and photo-documented. Relative abundances of calcareous nannofossil taxa were estimated using the following categories: abundant (A)—≥25 coccoliths/field of view (FOV); very common (VC)—2–24 coccoliths/FOV; common (C)—1 coccolith/1–5 FOVs; few (F)—1 coccolith/6–10 FOVs; rare (R)—1 coccolith/10–24 FOVs; very rare (VR)—1 coccolith/≥25 FOVs.

The zonation scheme used in this study is the UC zonation scheme of Burnett *et al.* (1998). Identification of nannofossils and biostrati-

Table 1. Number of samples collected from the Cretaceous units in Catanduanes Island. The possible formational unit where the samples belong to are also indicated (see Fig. 2 for location).

Locality	GPS data	# of samples	# of barren samples	Formational assignment	Age	Nannofossil Zone
Bagamanoc, northeast Catanduanes	N 13.960, E 124.268	4	2	Unknown	Unknown	Unknown
Pandan, northern Catanduanes	N 14.094, E 124.198	1	0	Yop Formation	late Cretaceous, probably Turonian (David, 1994)	Unknown
Nagumbuaya Point, southeast Catanduanes	N 13.548, E 124.336	15	4	Codon Formation	late Maastrichtian	UC20d Nannofossil Zone; Tangunan *et al.* (2013)
Bonagbonag Point, southwest Catanduanes	N 13.676, E 124.046	5	0	Codon Formation	late Maastrichtian	UC20d Nannofossil Zone; Tangunan *et al.* (2013)
Codon Point, southwest Catanduanes	N 13.665, E 124.036	12	7	Codon Formation	late Maastrichtian	UC20d Nannofossil Zone; Tangunan *et al.* (2013)

graphic ranges of the marker taxa were based on Perch-Nielsen (1985), Bown (1998) and more recent works on Cretaceous nannofossil taxa. Rock samples, smear slides and original microphotographs are stored at the Nannoworks Laboratory of the National Institute of Geological Sciences, University of the Philippines, Diliman, Quezon City (UP NIGS) and the Micropaleontology Section, the National Museum of Nature and Science, Tsukuba.

Results and Discussion

Table 2 lists all calcareous nannofossil taxa observed in the samples. A total of 41 species belonging to 21 genera were observed in the samples. Preservation of calcareous nannofossils range from poor to moderate, with better preservation in mudstone/fine-grained sandstones and poor to moderate preservation in limestones. Species richness (# of species) is generally <25, although several samples were observed to be barren of nannofossils (Table 1). The most common taxa in the samples belong to the genus *Watznaueria* (*W. barnesiae*, *W. fossacincta*, *W. ovata*). Marker taxa used for determining the age of the samples include *Micula* spp. (*M. cubiformis*, *M. murus*, *M. praemurus*, *M. swastica* and *M. staurophora*), *Eprolithus* spp. (*E. moratus* and *E. floralis*), *Quadrum* spp. (*Q. intermedium* and *Q. gartneri*) and *Helenea chiastia*. Selected calcareous nannofossil taxa are illustrated in Fig. 3. The calcareous nannofossil assemblages, abundance and preservation per locality are discussed below.

Northern Catanduanes

Samples collected in northern Catanduanes include samples from Bagamanoc and Pandan (Tables 1 and 2). The sample from Pandan was collected from mudstones intercalated with pillow basalts previously mapped as part of the Yop Formation. The samples from Bagamanoc, on the other hand, were collected from a previously unmapped interbedded black mudstone-fine-grained sandstone outcrop (Fig. 4; Table 1).

The sample collected in Pandan yielded poorly-preserved specimens of long ranging taxa belonging to *Watznaueria* and *Zeugrhabdotus* and, therefore, cannot be used to determine the age of the sample. An earlier study by David (1994), however, revealed the presence of *Micula staurophora* and *Eprolithus floralis*, suggesting a late early to late Cretaceous age (Turonian) for the Yop Formation. Fernandez *et al.* (1994) also suggested an Aptian to Albian age based on the presence of *Orbitolina*.

The two samples collected from the black mudstone-fine-grained sandstone interbeds in Bagamanoc were found to contain calcareous nannofossils. Sample CAT-G14-OL-009A contains moderate to well-preserved specimens and the highest species richness (25 species in 19 genera) among all the samples investigated in Catanduanes (Table 2). Based on the occurrence of *Quadrum intermedium* (first occurrence [FO] within the UC5c subzone; Burnet *et al.*, 1998) and *Helenea chiastia* (last occurrence [LO] at the top of the UC5c subzone; Burnett *et al.*, 1998), the sample can be assigned to the UC5c subzone which straddles the Cenomanian-Turonian boundary. Another taxon, *Rhagodiscus asper*, also occurs within the sample. In Burnett *et al.* (1998), the LO of *R. asper* was placed within the UC5b subzone. In the Vocontian Basin (southeast France; Fernando *et al.*, 2010) and northern Spain (Lamolda *et al.*, 1997), however, the LO of *R. asper* occurs within the Turonian.

Based on the age of the samples from Bagamanoc, the black mudstone-fine grained sandstone interbeds were tentatively assigned to the Yop Formation (Guballa *et al.*, 2015; Magtoto *et al.*, 2015). The age of the sample, in addition to the dominant lithology (i.e., black mudstones), suggests the possible occurrence of the Cenomanian-Turonian oceanic anoxic event 2 (OAE2), which is characterized by the worldwide deposition of black shales during the middle Cretaceous (Tsikos *et al.*, 2004; Bowman and Bralower, 2005; Takashima *et al.*, 2006; Wagreich *et al.*, 2008; Damste *et al.*, 2010; El-Sabbagh *et al.*,

Table 2. Calcareous nannofossil assemblages and abundance in samples collected from exposures of Cretaceous units in northern, southeastern and southwestern Catanduanes. Abbreviations listed: Preservation – P = poor, M = moderate, G = good; Abundance – VR = very rare, R = rare, F = few, C = common, VC = very common.

Locality	Sample Number	Preservation	*Assipetra* spp.	*Biscutum ellipticum*	*Calculites* sp.	*Cribrosphaerella ehrenbergii*	*Eprolithus floralis*	*Eprolithus moratus*	*Eprolithus* cf. *E. rarus*	*Eprolithus* spp.	*Hayesites irregularis*	*Helenea chiastia*	*Manivitella pemmatoidea*	*Micula cubiformis*	*Micula murus*	*Micula* cf. *M. praemurus*	*Micula staurophora*	*Micula swastica*	*Micula* spp.	*Owenia hillii*	*Retecapsa crenulata*	*Rhagodiscus asper*	*Prediscosphaera* spp.	*Quadrum gartneri*	*Quadrum intermedium*	*Staurolithites* sp.	*Uniplanarius trifidus*	*Watznaueria* spp.	*Zeugrhabdotus* spp.
Northern Catanduanes	CAT-G14-OL-009A	M–G	VR	VR	R	—	VR	—	—	VR	VR	R	VR	—	—	—	—	—	—	VR	—	VR	VR	—	VR	VR	—	C–VC	VR
	CAT-G14-OL-014	P	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	F	—
	CAT-G14-FBN 002	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	VR	VR
Southeast Catanduanes (Nagumbuaya Point)	CAT-G14-FIC-002b	P	—	—	—	—	—	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	VR
	CAT-G14-FIC-003.1	P	—	—	VR	—	—	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—
	CAT-G14-FIC-003.2	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	VR	—
	CAT-G14-FIC-003b	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	VR
	CAT-G14-FIC-003d	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	VR	—
	CAT-G14-FIC-004c	P–M	VR	—	VR	—	VR	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	CAT-G14-FIC-004d	P	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	CAT-G14-KE-004b	P–M	—	—	—	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	VR	—
	CAT-G14-IQ-003B	P	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	VR	—
	CAT-G14-QFIC-003b	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	R	R
	CAT-G14-QFIC-004c	M	VR	—	—	—	—	F	R	F	—	—	—	—	—	—	R	—	—	—	—	—	—	—	—	—	—	F	VR
Southwest Catanduanes — Bonag-Bonag Point	CAT-G14-QFI-001	P–M	—	—	R	—	—	—	—	—	—	—	—	R	—	—	—	R	—	—	—	—	—	—	—	—	—	—	—
	CAT-G14-QFI-002	P–M	—	—	—	—	—	—	—	—	—	—	—	—	—	VR	—	—	—	—	—	—	—	—	—	—	—	—	—
	CAT-G14-QFI-003	M	—	—	—	—	—	—	—	—	—	—	—	—	—	R	R	R	R	—	—	—	—	R	—	—	—	—	—
	CAT-G14-QFI-004	P–M	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—	—	—	—	—	—	—	—	—
	CAT-G14-QFI-005	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—	—	R	—	—	—	—	—
Southwest Catanduanes — Codon Point	CAT-G14-FI-006	P–M	—	VR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	VR	R	—
	CAT-G14-FI-010	P	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—
	CAT-G14-FI-014a	M	—	—	R	—	—	—	—	—	—	—	—	—	R	—	—	—	R	—	—	—	—	—	—	—	—	F–C	—
	CAT-G14-FI-015	M	—	—	—	—	—	—	—	—	—	—	—	VR	VR	—	VR	—	—	—	—	—	—	—	—	—	VR	R	—
	GAT-G14-FI-027B	M	—	—	—	R	—	—	—	—	—	—	—	VR	—	VR	—	VR	VR	VR	VR	—	—	—	—	—	VR	F	—

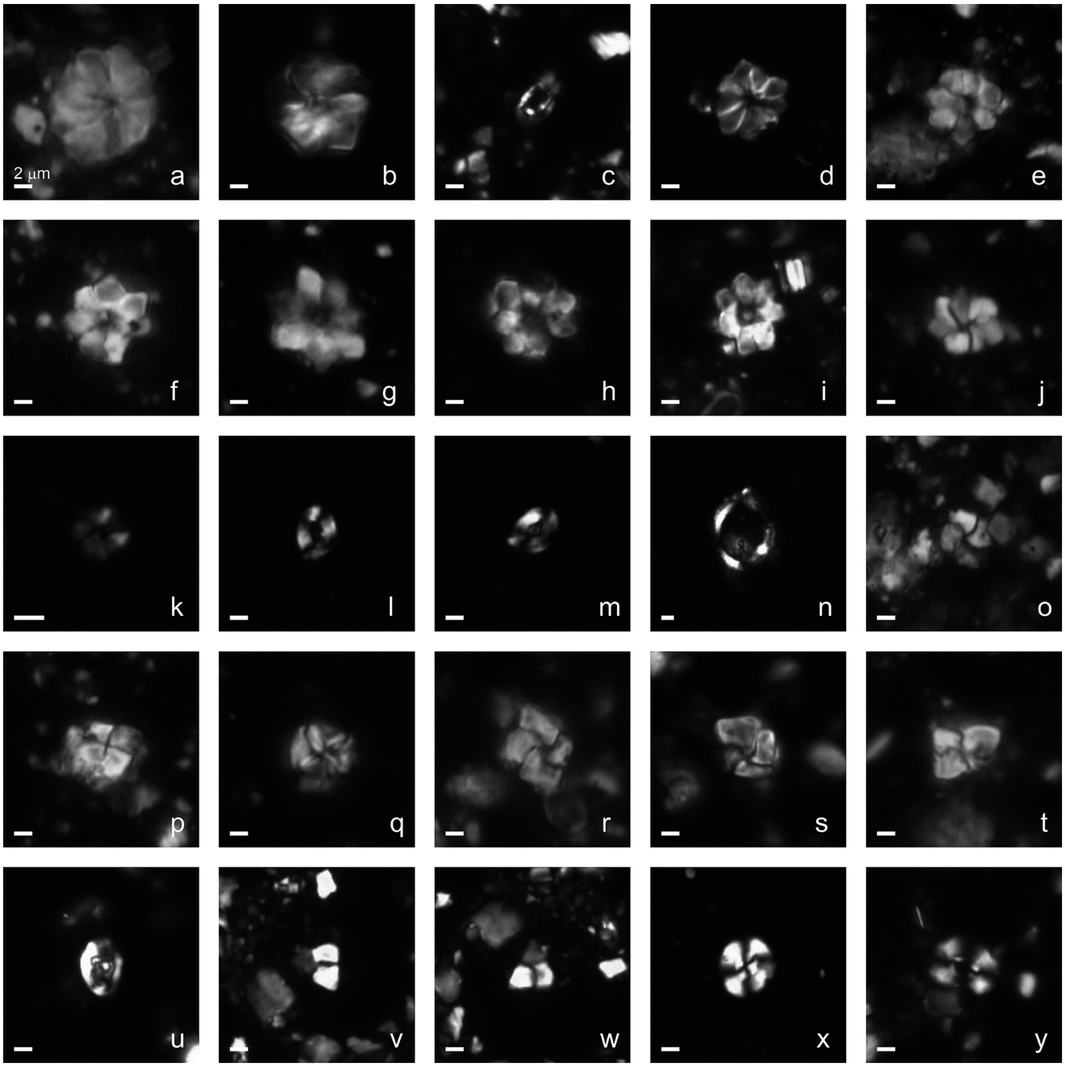

Fig. 3. Selected photomicrographs of calcareous nannofossils observed from Yop and Codon Formations in Catanduanes Island. All images are cross-polarized images (scale bar = 2 μm). **a**, **b**, *Assipetra terebrodentarius*; **c**, *Cribrosphaerella ehrenbergii*; **d**, *Eprolithus floralis*; **e–i**, *Eprolithus moratus*; **j**, *Eprolithus rarus*; **k**, *Hayesites irregularis*; **l**, **m**, *Helenea chiastia*; **n**, *Manivitella pemmatoidea*; **o**, **p**, *Micula praemurus*; **q**, *Micula staurophora*; **r**, **s**, *Micula swastika*; **t**, *Quadrum* sp.; **u**, *Rhagodiscus asper*; **v**, **w**, *Uniplanarius trifidus*; **x**, *Watznaueria barnesiae*; **y**, *Watznaueria fossacincta*.

2011; Takashima *et al.*, 2011). A more detailed nannofossil analysis of the section is currently being undertaken by AGS Fernando.

Southeast Catanduanes

Of the fifteen (15) samples collected from exposures of Codon Formation in Nagumbuaya Point, 4 were barren of nannofossils. Species richness is low (<10 species) and preservation is poor to moderate. Due to the olistostromic (i.e., chaotic) nature of the outcrops in southeast Catanduanes (Fig. 5), the stratigraphic relationships of the sections investigated were not established. Commonly-occurring taxa in the samples include *Calculites* sp., *Eprolithus* spp., *Watznaueria* spp.

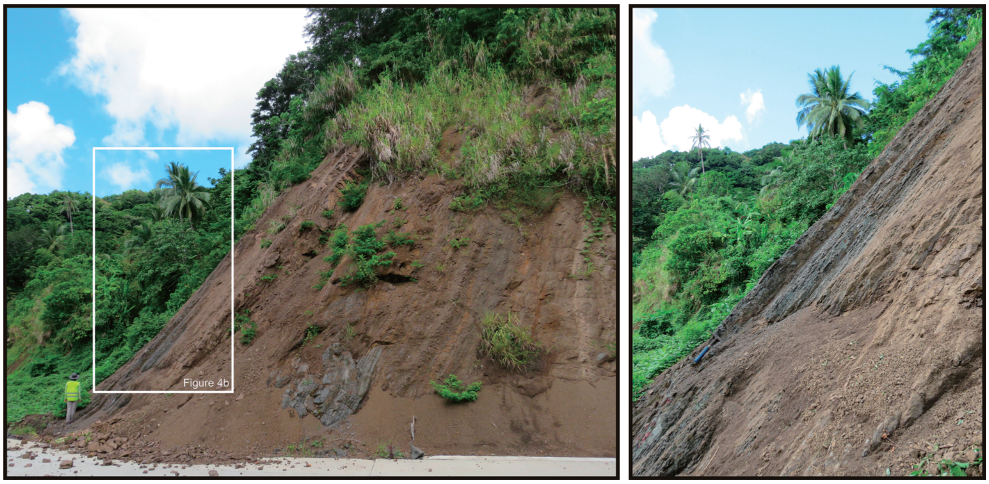

Fig. 4. Black mudstone-fine-grained sandstone interbeds in Bagamanoc, northeastern Catanduanes (**4a**, left). Detail of the section enclosed in Fig. 4a showing the steeply-dipping interbeds (**4b**, right).

Fig. 5. Exposures of Codon Formation in Nagumbuaya Point, southeast Catanduanes. Folded limestone beds where the samples for nannofossil analysis were collected (left). An outcrop of Codon Formation showing the olistostromic nature of the limestone units (right). Evidence of slump features/folds associated with synsedimentary gravity mass transport attributed to gravity slide and slump depositions can be observed in outcrops along the coast of Nagumbuaya Point (Nogot *et al.*, 2015).

and *Zeugrhabdotus* spp. (Table 2).

Based on the occurrence of *Eprolithus moratus* (UC6b to UC12 [Turonian–Santonian]; Burnett *et al.*, 1998) and *Micula staurophora* (UC10 [Coniacian] to Late Maastrichtian; Burnett *et al.*, 1998) in one sample (CAT-G14-QFIC-004c; Table 2), the exposures of Codon Formation in southeast Catanduanes can be assigned to the UC10–UC12 zones (Coniacian–Santonian). This age is different from the currently accepted age of Codon Formation (mostly in southwest Catanduanes) determined in earlier studies using either foraminifera or calcareous nannofossils: (a) late late Cretaceous (MGB, 2010), (b) late Cretaceous and Aptian to Albian (based on foraminifera; Fernandez *et al.*, 1994), (c) late Campanian to early Maastrichtian (based on calcareous nannofossils; Militante-Matias *et al.*, 1994) and (d) late Maastrichtian (based on calcareous nannofossils; Tangunan *et al.*, 2013). Fernandez *et al.* (1994) also collected samples from Nagumbuaya Point but unfortunately no dates were given for the samples. The present study, therefore, represents the first report of nannofossils from the southeastern part of Catanduanes (Nagumbuaya Point), the implications of which will be discussed in the next section.

Southwest Catanduanes

The samples from Bonag-bonag and Codon Points contain poor to moderately-preserved calcareous nannofossils. Similar to southeast Catanduanes, species richness is low (<10 species) but the assemblage is dominated by polycycloliths (i.e., *Micula*, *Quadrum* and *Uniplanarius*). Of the 17 samples collected from southwest Catanduanes, seven samples are barren of nannofossils (Table 1). Due to the olistostromic nature of the outcrops in southwest Catanduanes (although not as chaotic as the outcrops in southeast Catanduanes; Fig. 6), the stratigraphic relationships of the sections investigated were also not established.

The samples from Bonag-bonag Point contain the marker taxa *Micula cubiformis* (Coniacian to Maastrichtian), *Micula praemurus* (Campanian to Maastrichtian), *Micula staurophora*, *Micula swastica* (Coniacian to Late Maastrichtian) and *Quadrum gartneri* (Turonian to Maastrichtian). Based on the stratigraphic ranges of the marker taxa (Burnett *et al.*, 1998), therefore, the limestones from Bonag-bonag Point are Campanian to Maastrichtian in age. The samples from Codon Point, on the other hand, contain the same assemblage as Bonag-bonag Point, with the addition of *Micula murus* (UC20b subzone to late Maastrichtian; Burnett *et al.*, 1998) and *Uniplanarius trifidus* (Campanian to Maastrichtian; Burnett *et al.*, 1998). The samples, therefore, can be assigned to the UC20b subzone (late Maastrichtian).

The age of the limestones in southwest Catanduanes (i.e., Campanian to Maastrichtian and late Maastrichtian [UC20b subzone]) is comparable to the results of earlier studies in the area (Fernandez *et al.*, 1994; Militante-Matias *et al.*, 1994; Tangunan *et al.*, 2013). Militante-Matias *et al.* (1994) reported late Campanian to early Maastrichtian nannofossils in Bonag-bonag Point

Fig. 6. Exposures of Codon Formation in southwest Catanduanes: Bonag-bonag Point (left and middle) and Codon Point (right). The outcrops in southwest Catanduanes show steeply dipping and slightly folded limestones (marly/calcilutite) interbedded with red siltstone/mudstone units. In some places, the limestones contain chert nodules.

but a list of the observed taxa was not provided. Tangunan *et al.* (2013) recognized the UC20d subzone (late Maastrichtian) in Codon Point based on the occurrence of *Micula prinsii*.

Conclusions

1. The results of the present study represent the first report of calcareous nannofossils in the southeastern part of Catanduanes, represented by sections investigated in Nagumbuaya Point. Based on the occurrence of the marker taxa *E. moratus* and *M. staurophora*, the UC10-UC12 zones are recognized, suggesting a Coniacian to Santonian age for the Codon Formation in this part of the island. This result implies the necessary revision of the currently accepted late late Cretaceous age of Codon Formation (MGB, 2010).

2. The late Cretaceous age of the Codon Formation in southwest Catanduanes is confirmed in the present study. The nannofossil assemblage in Bonag-bonag and Codon Points are distinct from the Nagumbuaya Point nannofossil assemblage, with the former containing several marker taxa from the genus *Micula*, which were used to establish the Campanian to Maastrichtian age of limestones in Bonag-bonag Point and late Maastrichtian age for the Codon Point exposures.

3. The previously unmapped black mudstone-fine grained sandstone outcrop in Bagamanoc is assigned to the UC5c subzone which is within the Cenomanian–Turonian boundary interval. The outcrop is, therefore, tentatively included in the Yop Formation (Table 1). The age of the section, along with lithological characteristics, suggest the possible occurrence of the oceanic anoxic event 2 (OAE2) in Catanduanes. If this will be proven in succeeding studies (i.e., detailed biostratigraphic work), the section will represent one of the very few OAE2 sections in the western Pacific region, along with the Oyubari, Tappu, Mikasa and Obira Sections in Hokkaido, Japan (Hasegawa *et al.*, 2010; Nemoto and Hasegawa, 2011; Takashima *et al.*, 2011; Kurihara *et al.*, 2012).

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References

Bowman, A. R. and Bralower, T. J. (2005). Paleoceanographic significance of high-resolution carbon isotope records across the Cenomanian–Turonian boundary in the Western Interior and New Jersey coastal plain, USA. *Marine Geology*, **217**: 305–321.

Bown, P. R. and Young, J. R. (1998). Techniques. In: Bown, P. R. (Ed.), Calcareous Nannofossil Biostratigraphy. British Micropalaeontological Society Publications Series, Chapman and Hall/Kluwer Academic Publishers, pp. 16–28.

Bown, P. R. (1998). Calcareous Nannofossil Biostratigraphy. 314 pp. British Micropalaeontological Society Publications Series, Chapman and Hall/Kluwer Academic Publishers, London.

Burnett, J. A., Gallagher, L. T. and Hampton, M. J. (1998). Upper Cretaceous. In: Bown, P. R. (Ed.), Calcareous Nannofossil Biostratigraphy. British Micropalaeontological Society Publications Series, Chapman and Hall/Kluwer Academic Publishers, pp. 132–199.

Damste, J. S. S., Bentum, E. C. V., Reichart, G. J., Pross, J. and Schouten, S. (2010). A CO_2 decrease-driven cooling and increased latitudinal temperature gradient during the mid-Cretaceous Oceanic Anoxic Event 2. *Earth and Planetary Science Letters*, **293**: 7–103.

David, S., Jr. (1994). Geologie du Sud-Est de Luzon: Contributions a l'etude geodynamique ante-Neogene de la Ceinture Mobile Est Philippine. 352 pp. These de doctorat de l'Universite de Nice-Sophia Antipolis. Documents et Travaux 21, Nice.

David, S., Jr., Stephan, J. F., Delteil, J., Muller, C. and Butterlin, J. (1994). The Tabgon Flysch and Ragas Point Olistostrome in the Caramoan Peninsula: Nature, age, structures and their tectonic implications. *Journal of the Geological Society of the Philippines*, **49**: 41–63.

David, S., Jr., Stephan, J. F., Delteil, J., Muller, C., Butterlin, J., Bellon, H. and Billedo, E. (1997). Geology and tectonic history of southeastern Luzon, Philippines. *Journal of Asian Earth Sciences*, **15**(45): 435–452.

El-Sabbagh, A., Tantawy, A. A., Keller, G., Khozyem, H., Spangenberg, J., Adatte, T. and Gertsch, B. (2011). Stratigraphy of the Cenomanian–Turonian Oceanic Anoxic Event OAE2 in shallow shelf sequences of NE Egypt. *Cretaceous Research*, **32**(6): 1–18.

Fang, Y., Li, J. B., Ding, W. W. and Zhang, J. (2011). The formation and tectonic evolution of Philippine Sea Plate and KPR. *Acta Oceanologica Sinica*, **30** (4): 75–88.

Fernandez, M. V., Revilla, A. P. and David, S. J. (1994). Notes on the Cretaceous carbonates in Catanduanes Island and Caramoan Peninsula. *Journal of the Geological Society of the Philippines*, **49**: 241–261.

Fernando, A. G. S., Takashima, R., Nishi, H. and Okada, H. (2010). Calcareous nannofossil biostratigraphy of the Thomel Level (OAE2) in the Lambruisse section, Vocontian Basin, southeast France. *Geobios*, **43** (1): 45–57.

Fernando, A. G. S., Magtoto, C. Y., Guballa, J. D. S., Marquez-Ardiente, D. J., Nogot, J. R. C. P. and Uy, M. A. C. (2014). Updates on Philippine Cretaceous system: recent calcareous nannofossil biostratigraphic studies on selected Cretaceous localities in the Philippines. In: Organizing Committee of the 2nd International Symposium of IGCP608 (Ed.), Abstract volume of the 2nd IGCP608 Symposium, Waseda University, Tokyo, Japan, pp. 35.

Galgana, G., Hamburger, M., McCaffrey, R., Corpuz, E. and Chen, Q. (2007). Analysis of crustal deformation in Luzon, Philippines using geodetic observations and earthquake focal mechanisms. *Tectonophysics*, **432**: 63–87.

Guballa, J. D. S., Callejo, G. P., Castro, A. L., Crisologo, I. A., Geronia, M. M., Grajo, M. P. A., Lagura, M. L. H., Llanes, F. V., Magtoto, C. Y., Marquez-Ardiente, D. J. D., Nogot, J. R. C. P., Pena, M. A. Z., Rosario, D. J. G., Sabado, J. M. J., Supnet, K. M., Tupaz, C. A. J., Peleo-Alampay, A. M. and Fernando, A. G. S. (2014). The geology of Catanduanes: Revisited. In: Abstract volume of the 2014 Geological Convention of the Geological Society of the Philippines, Makati City, Philippines, pp. 31.

Guballa, J. D. S., Magtoto, C. Y., Peleo-Alampay, A. M. and Fernando, A. G. S. (2015). Biostratigraphic analysis of selected Cretaceous units in Catanduanes Island (eastern Philippines) using calcareous nannofossils. In: Abstract volume of the 12th Symposium on Mesozoic Terrestrial Ecosystems, Shenyang, China, pp. 35–36.

Hall, R. (1997). Cenozoic plate tectonic reconstructions of SE Asia. In: Fraser, A. J., Matthews, S. J. and Murphy, R. W. (Eds.), *Petroleum Geology of Southeast Asia*. Geological Society of London Special Publication, **126**: 11–23.

Hasegawa, T., Seo, S., Moriya, K., Tominaga, Y., Nemoto, T. and Naruse, T. (2010). High resolution carbon isotope stratigraphy across the Cenomanian/Turonian boundary in the Tappu area, Hokkaido, Japan: Correlation with world reference sections. *Science Reports of Kanazawa University*, **54**: 49–62.

JICA-MMAJ (1996). Report on the cooperative mineral exploration in the Catanduanes area, the Republic of the Philippines, Consolidated Report. 87 pp. Japan International Cooperation Agency: Metal Mining Agency of Japan, Tokyo.

Karig, D. E. (1983). Accreted terranes in the northern part of the Philippine archipelago. *Tectonics*, **2:** 211–236.

Kurihara, K., Toshimitsu, S. and Hirano, H. (2012). Ammonoid diversity changes across the Cenomanian-Turonian boundary in the Yezo Group, Hokkaido, Japan. *Acta Palaeontologica Polonica*, **57** (4): 749–757.

Lamolda, M. A., Gorostidi, A., Martinez, R., Lopez, G. and Peryt, D. (1997). Fossil occurrence in the Upper Cenomanian–Lower Turonian at Ganuza section, northern Spain: an approach to Cenomanian–Turonian boundary chronostratigraphy. *Cretaceous Research*, **18**: 334–353.

Magtoto, C. Y., Guballa, J. D. S., Peleo-Alampay, A. M. and Fernando, A. G. S. (2015). Age refinement of Cretaceous units in Catanduanes Island (eastern Philippines) based on calcareous nannofossils. *Journal of Nannoplankton Research (INA 15 Abstracts)*, **35**: 54.

Matsukawa, M., Sendon, S. V., Mateer, F. P. T., Sato, T. and Obata, I. (2012). Early Cretaceous ammonite fauna of Catanduanes Island, Philippines. *Cretaceous Research*, **37**: 261–271.

Militante-Matias, P. J., de Leon, M. M. and Denoga, J. A. V. (1994). Philippine Cretaceous System. In: IGCP350 National Working Group of Japan (Ed.), The Cretaceous System in East and South Asia, Research Summary 1994 (Newsletter Special Issue, IGCP 350). Shunpousha, Fukuoka, pp. 39–52.

Mines and Geosciences Bureau (MGB) (2010). Geology of the Philippines, 2nd edition. 532 pp. Aurelio and Pena, Eds., Quezon City.

Miranda, F. E. and Vargas, B. S. (1967). The geology and mineral resources of Catanduanes Province. *Philippine Bureau of Mines*, *Report of Investigation*, **62**: 8–66.

Nemoto, T. and Hasegawa, T. (2011). Submillenial resolution carbon isotope stratigraphy across the Oceanic

Anoxic Event 2 horizon in the Tappu section, Hokkaido, Japan. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, **309**: 271–280.

Nogot, J. R. C. P., Grajo, M. P. A., Tupaz, C. A. J., Crisologo, I. A., Rosario, D. J. G., Guballa, J. D. S., Magtoto, C. Y., Peleo-Alampay, A. M. and Fernando, A. G. S. (2015). Paleoslope Analysis of Slump Folds in the Cretaceous Codon Formation, Catanduanes, Philippines. In: Abstract volume of the 12th Symposium on Mesozoic Terrestrial Ecosystems, Shenyang, China, pp. 51–52.

Okada, H. and Mateer, N. J. (2000). Developments in Palaeontology and Stratigraphy: Cretaceous Environments of Asia, 17. 255 pp. Elsevier, Amsterdam.

Peña, R. E. (2008). Lexicon of Philippine Stratigraphy 2008. 364 pp. The Geological Society of the Philippines, Inc., Mandaluyong City, Philippines.

Perch-Nielsen, K. (1985). Mesozoic calcareous nannofossils. In: Bolli, H. M., Saunders, J. B. and Perch-Nielsen, K. (Eds.), Plankton Stratigraphy. Cambridge University Press, Cambridge, pp. 329–426.

Takashima, R., Nishi, H., Huber, B. T. and Leckie, R. M. (2006). Greenhouse world and the Mesozoic ocean. *Oceanography*, **19** (4): 64–74.

Takashima, R., Nishi, H., Yamanaka, T., Tomosugi, T., Fernando, A. G., Tanabe, K., Moriya, K., Kawabe, F. and Hayashi K. (2011). Prevailing oxic environments in the Pacific Ocean during the mid-Cretaceous oceanic Anoxic Event 2. *Nature Communications*, **2**(234): 1–5.

Tan, M. N. (1986). Distribution of Cretaceous foraminifera. *Bureau of Mines and Geo-sciences Research Work*, **1**: 6–7.

Tangunan, D. N., Fernando, A. G. S. and Arcilla, C. A. (2013). Notes on the occurrence of late Cretaceous nannofossils from Codon Point, San Andres, Catanduanes. *Journal of the Geological Society of the Philippines*, **64**: 35–47.

Tsikos, H., Jenkyns, H. C., Walsworth-Bell, B., Petrizzo, M. R., Forster, A., Kolonic, S., Erba, E., Premoli Silva, I., Baas, M., Wagner, T. and Sinninghe Damste, J. S. (2004). Carbon-isotope stratigraphy recorded by the Cenomanian–Turonian Oceanic Anoxic Event: Correlation and implications based on three key localities. *Journal of the Geological Society*, **161**: 711–719.

Tumanda, F. P. (1986). Preliminary Report of the Fossil Findings in Comagaycay River, Alibuag, San Andres (Calolbon), Catanduanes. In: Technical Information Series, Geology, Publication No. 71–86. Bureau of Mines and Geosciences, Manila.

Wagreich, M., Bojar, A., V., Sachsenhofer, R. F., Neuhuber, S. and Egger, H. (2008). Calcareous nannoplankton, planktonic foraminiferal, and carbonate carbon isotope stratigraphy of the Cenomanian–Turonian boundary section in the Ultrahelvetic Zone (Eastern Alps, Upper Austria). *Cretaceous Research*, **29**: 965–975.

Yumul, G. P., Jr., Dimalanta, C. B., Maglambayan, V. B. and Marquez, E. J. (2008). Tectonic setting of a composite terrane: A review of the Philippine island arc system. *Geosciences Journal*, **12**(1): 7–17.