Multi-approach Characterization of Shallow-water Carbonates off Minamitorishima and in Bengal Basin and their Depositional Settings/History

博士論文

Multi-approach Characterization of Shallow-water Carbonates off Minamitorishima and in Bengal Basin and their Depositional Settings/History
(南鳥島およびベンガル堆積盆の浅海性炭酸塩岩の特性評価とそれらの堆積環境・歴史の解明)

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博士論文要約

Shallow-water carbonates are formed in complex depositional settings whose biota represents the source of most of the sediment. Biotic communities in shallow-water carbonates and their production vary responding to various changes in sea level, climatic and oceanographic conditions, nutrient levels, and supply of terrigenous materials. Since the carbonate production depends on such factors, it can obtain paleoenvironmental information in shallow-water that are not recorded in deep sea sediments. Therefore, shallow-water carbonates are considered one of the best research targets of and are indispensable for understanding the Earth's surface environmental system.

The shallow-water carbonates at different locations, Minamitorishima and the Bengal Basin, are investigated in this study. The Minamitorishima is located in northwestern Pacific Ocean, composed of Cretaceous volcanic edifice covered with shallow-water and pelagic carbonates. In the Bengal Basin, Eocene shallow-water carbonates were recently collected from two boreholes drill in northwestern Bangladesh. However, no detailed research has been conducted on the carbonates at Minamitorishima and in northwestern Bangladesh, and their depositional history remains unknown.

Minamitorsihima

Sedimentological, geochemical, and chronological analyses were carried out on 18 carbonate rock samples collected at depths of 938, 1085, and 3352 m (Fig. 1) on the western slope of Minamitorishima, which is located near the western margin of the Pacific Plate.

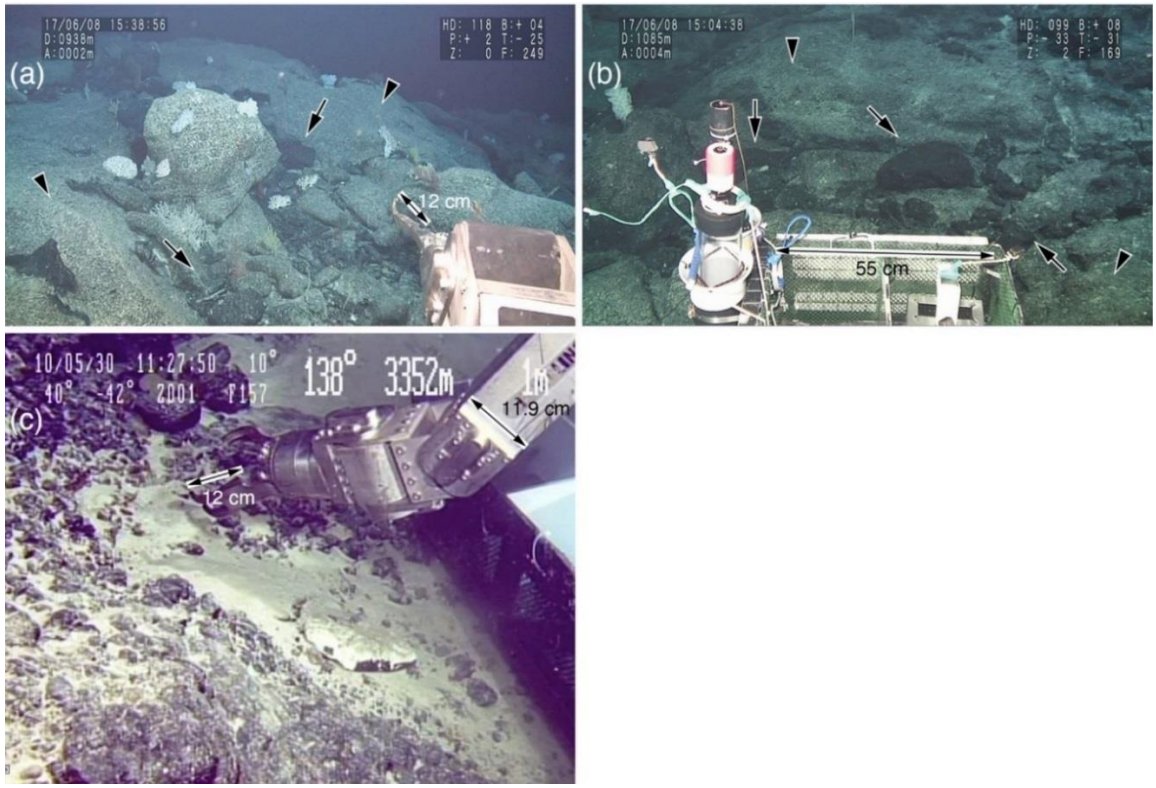

Fig. 1. Submarine occurrence of the carbonate samples. (a, b) Boulder-to cobble-sized gravels of shallow-water carbonates coated with Fe–Mn crusts (arrows) at water depths of (a) 938 and (b) 1085 m. These gravels accumulated in depressions on limestone outcrops (arrowheads). Black spots composed of Fe–Mn were abundant on the outcrop at a water depth of 938 m. (c) Limestone gravels, most of which are coated with Fe–Mn crusts at a water depth of 3352 m. The space between the gravels was filled with foraminiferal ooze.

Four groups of carbonate rocks were distinguished: a mollusk-rich limestone, a coral-rich dolomite, a foraminiferal-nannofossil packstone, and a phosphatized mudstone/wackestone. The mollusk-rich limestone is characterized by the dominance of bivalves (including rudists) and gastropod shells. Strontium isotope ratios ($^{87}Sr/^{86}Sr$) and occurrence of *Mesorbitolina* ex gr. *texana* (an age diagonostic large benthic foraminifer) indicate that the shallow-water carbonates were deposited during the late Aptian–early Albian (ca. 123–111 Ma; Fig. 2).

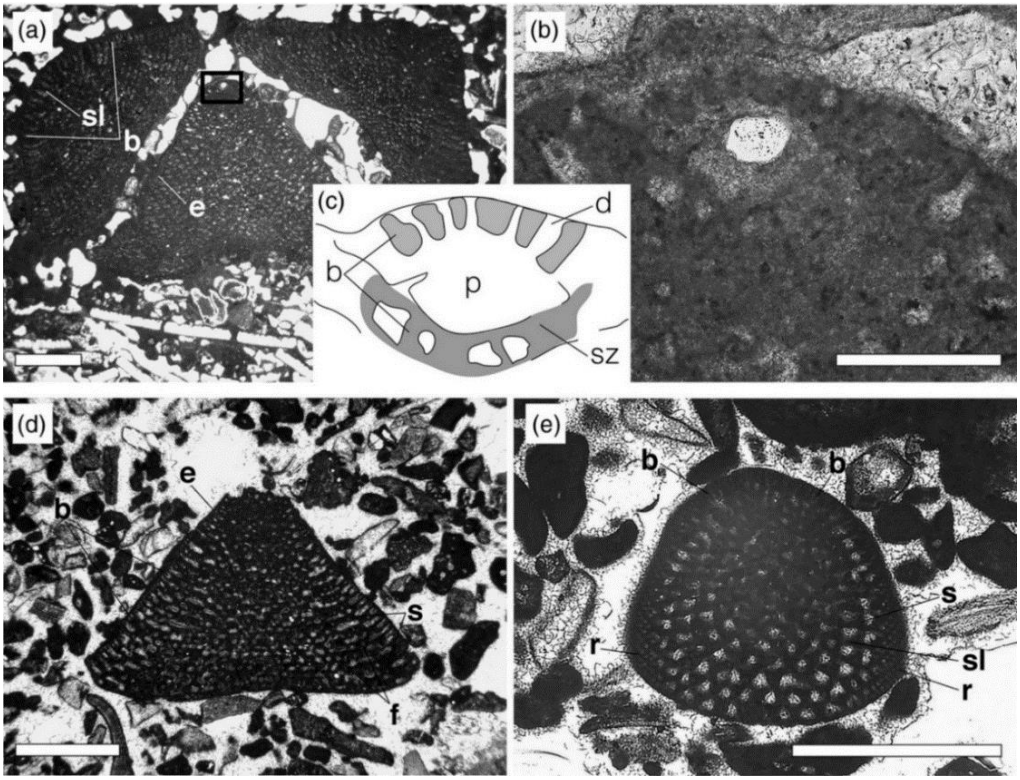

Fig. 2. Orbitolinid foraminifers in the Cretaceous mollusk-rich limestone collected off Minamitorishima. (a) Three sub-axial sections of *Mesorbitolina* ex gr. *texana* (Roemer, 1849); sample YK17-11C 6K#1502 N5-010. (b) Enlarged view of the specimen in (a) showing the tangential sub-axial section of the embryonic apparatus (c). (d) *Mesorbitolina* ex gr. *texana*, sub-axial section showing the septa and the complex exoskeleton with beams and rafters; sample YK17-11C 6K#1502 N5-005. (e) *Mesorbitolina* cf. *birmanica* (Sahni, 1937), oblique sub-axial section; sample YK17-11C 6K#1502 N5-005. b, beam; d, deuteroconch; e, epiderm; f, foramen; p, protoconch; r, rafter; s, septum; sl, septulum; sz, subembryonic zone. Scale bars, 1 mm in a, d–e, and 0.2 mm in b–c.

The coral-rich dolomite is characterized by abundant scleractinian corals and nongeniculate coralline algae associated with encrusting acervulinid foraminifers. The biotic composition is similar to that of the Oligocene–Pleistocene carbonates reported from other seamounts in the northwestern Pacific. Geochemical data show that the coral-rich carbonates were dolomitized at 9.5–6.8 Ma (Tortonian–Messinian) and that normal seawater was the most likely parent fluid. The foraminiferal-nannofossil packstone is a semi-consolidated foraminiferal-nannofossil ooze and was deposited during the Pleistocene (0.99–0.45 Ma). The phosphatized mudstone/wackestone is marked by the absence of macrofossils and the presence of traces of planktic foraminifers. Although its depositional age is not constrained, the Sr isotope ratios indicate that the phosphatization occurred at 33.2–28.9 Ma. After the deposition of the Cretaceous shallow-water carbonates, including the mollusk-rich limestone, Minamitorishima was drowned and its top was covered with a pelagic cap, represented by the mudstone/wackestone, and the late Eocene–early Oligocene volcanism (40.2–33.2 Ma) caused episodic uplift and returned the top of Minamitorishima to a shallow-water environment (Fig. 3). After the early Oligocene phosphatization of the pelagic cap, coral reefs flourished on the top of this island. The reef limestone was dolomitized during the Tortonian–Messinian.

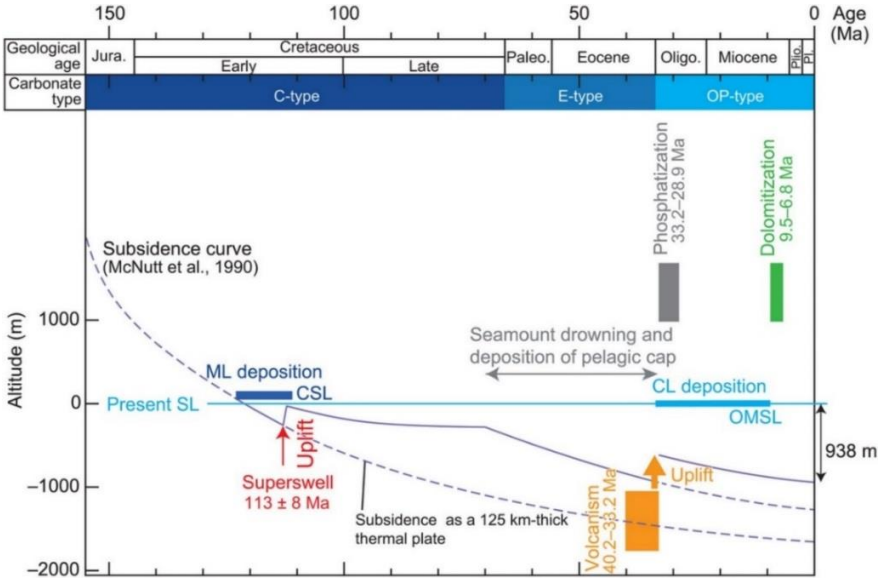

Fig. 3. Depositional history of reefs and carbonate platforms on Minamitorishima. The purple solid line denotes the vertical motion of the Cretaceous mollusk-rich limestone that formed at 123 Ma near sea level and is situated at a water depth of 938 m at present. This line follows McNutt et al. (1990) and the effect of episodic uplift by Eocene volcanism (Hirano et al., 2021) has been added. The Cretaceous limestone samples may be allochthonous and derived from outcrops located shallower than the presumed depth. In such a case, the purple solid line between 33.2 and 0 Ma should be placed above the present. CSL, Cretaceous sea level (Haq, 2014). OMSL, Oligocene–Miocene sea level (Miller et al., 2005); Jura., Jurassic; Paleo., Paleocene; Oligo., Oligocene; Plio., Pliocene; Pl., Pleistocene. Carbonate type follows Takayanagi et al. (2012).

Bengal Basin

During the early Eocene to the early Oligocene, various genera of large benthic foraminifers (LBFs), i.e., *Alveolina, Glomalveolina, Nummulites, Assilina, Operculina*, orthopharagminids (*Discocyclina*), and coralline algae were dominating components of shallow-water carbonates and mixed carbonate-siliciclastic platforms that extended from western Tethys through Indo-Pacific to western Pacific. The LBFs and coralline algae were important sediment producers in shallow, oligotrophic conditions at that time. During the Eocene, the climate shifted from warm phase to ice phase, resulting in long-term high latitude and deep-water cooling, which continued throughout the middle and late Eocene. The long transition to secular cooling trend was interrupted by a short-time global warming event called the middle Eocene climatic optimum (MECO). This warming peak is not reflected by a large negative carbon isotope excursion (CIE) observed during other hyperthermal events; rather it was possibly related with high-grade metamorphic decarbonation in the Himalayan Orogeny (Bohaty and Zachos, 2003). Many studies have documented significant changes in benthic and planktonic foraminiferal assemblages in MECO. Despite such a significant progress, the response of LBFs in the shallow Tethyan Ocean to the MECO remains poorly explored. Therefore, Eocene shallow-water carbonates of the Bengal Basin (northwestern Bangladesh) was analyzed and the characteristics features of shallow-water carbonates and their biotic compositions were delineated to and their response to the MECO was revealed based on biostratigraphic, sedimentologic, and chemostratigraphic analyses.

The shallow-water carbonate platform of the Bengal Basin is particularly rich in LBFs. The unit consists of various species of *Alveolina*, *Nummulites* (A and B forms), Orthophragminids (*Discocyclina*). Planktonic and small benthic foraminifera are also present but fewer in number. Presence of *Nummulite ptukhiani* Kacharava, 1969 (A form) and *N. variolarius/incrassatus* (A form) in the Bengal Basin indicate that the shallow-water carbonates were deposited at SBZ 15–SBZ 18 in 'Khirthar' transgression event. Occurrence of *Nummulites ptukhiani* (A form) indicates that the Sylhet Limestone Formation of the Bengal Basin was deposited during the late middle Eocene and corresponds to shallow benthic zones SBZ 15–SBZ 17 (Fig. 4).

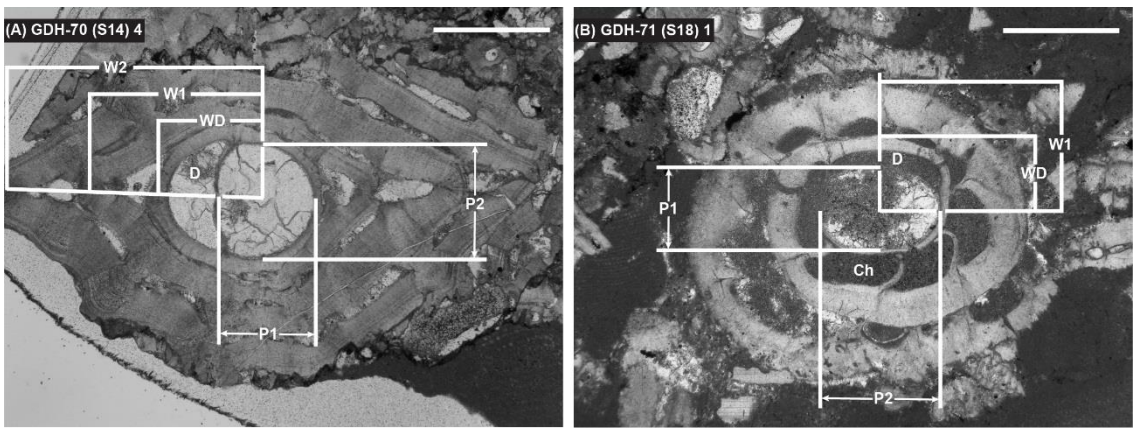

Fig. 4. (A) Axial section of *Nummulites ptukhiani* Kacharava, 1969 (A form) of drill hole GDH–70, Sample no. GDH–70 (S–14), specimen no. 4, depth, 679.70 m mean sea level (msl) and (B) equatorial section of *N. ptukhiani* Kacharava, 1969 (A form) of drill hole GDH–71, Sample no. GDH–70 (S–18), specimen no. 1, depth,

659.89 m msl of Sylhet Limestone Formation, Bengal Basin (northwestern Bangladesh) showing measurements taken carried out in this study. D, deuteroconch; P1, vertical protoconch height; P2, horizontal protoconch height; P1 and P2 are right angles to each other; Ch, chamber; WD, distance from center of protoconch to edge of deuteroconch including wall; W1, W2, successive whorl radius. Scale bars, 0.5 mm.

Four groups of microfacies were identified based on sedimentary characteristics and biotic composition (Fig. 5). The Orthopharagminids (*Discocyclina*) packstone/wackestone microfacies (MF 1) is characterized by Orthopharagminids (*Discocyclina* B form) with highly damaged outer whorl, indicating the deposition in distal middle ramp with high–energy water conditions. The coralline algae–larger *Nummulites* packstone/wackestone microfacies (MF 2) is delineated by abundant of nongeniculate coralline algae (melobesioids) with fruticose growth forms and larger *Nummulites* (A form) with damaged, thick outer spiral lamina, which is considered to have been deposited below fair weather wave base (FWWB) with high energy water conditions. The larger *Nummulites*–alveolinids grainstone/packstone microfacie (MF 3) is circumscribed by abundance of alveolinids, miliolids, soritids, larger *Nummulites* (A and B form), larger rotaliids and nongeniculate coralline algae, indicating a highly illuminated, inner shelf depositional environment. Larger *Nummulites*–orthopharagminids packstone/wackestone microfacies (MF 4), dominated by larger *Nummulites* (A form) having smooth outer whorl surface associated with orthopharagminids (*Discocyclina* A form), suggests a distal middle ramp depositional environment. The microfacies analysis of the shallow-water carbonates indicates that warming of the climate associated with 'Khirthar' transgressive event promoted highly oligotrophic environment in the Bengal Basin.

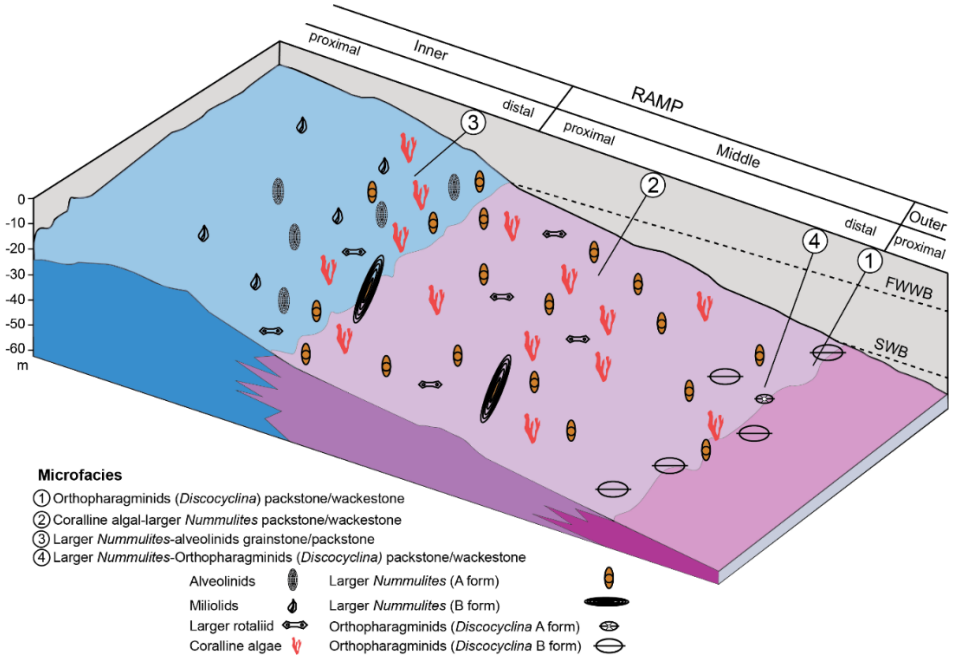

Fig. 5. Depositional model for the Eocene *Nummulites* banks showing depositional environments of the identified microfacies in the Sylhet Limestone and the Kopili Shale Formation of the Bengal Basin

(northwestern Bangladesh). The distinguished microfacies are distributed with respect to their position within the distal inner to distal middle ramp. FWWB, fair weather wave base; SWB, storm weather base.

The MECO is thought to have occurred in the early Bartonian based on the CIE record (Fig. 6) and presence of *N. ptukhiani* Kacharava, 1969 (A form) and other LBFs in the shallow-water carbonate platform of the Bengal Basin. The continuous dominance of the LBF genera may be due to the biotic response of events such as the MECO that triggered warming episodes, which in turn increased the abundance of LBF. A distinct positive $\delta^{13}C$ shift marks the stratigraphic position of the MECO in the Sylhet Limestone Formation in the Bengal Basin (Fig. 6). The CIE interval that would represent the warming peak of the MECO at the Bengal Basin is also marked by changes in LBF. At the Bengal Basin, a shift towards humid and warm conditions is inferred during the MECO interval as suggested by the last occurrence of *Alveolina*, orthopharagminids (*Discocyclina*) and proliferation of larger *Nummulites* (B form) (Kamran et al., 2021), although the global extinction of *Alveolina*, and larger foraminifera (B form) occur in the late middle Eocene is not directly associated with the MECO event (Hallock, 1991; Cotton et al., 2012). A comparison of carbon isotope records from the Bengal Basin and other middle Eocene sections is provided in Figure 6. The Bengal Basin section displays gentle fluctuations and difference in amplitude of $\delta^{13}C$ values than those in the other sections formed in different depositional settings (Edgar et al., 2010).

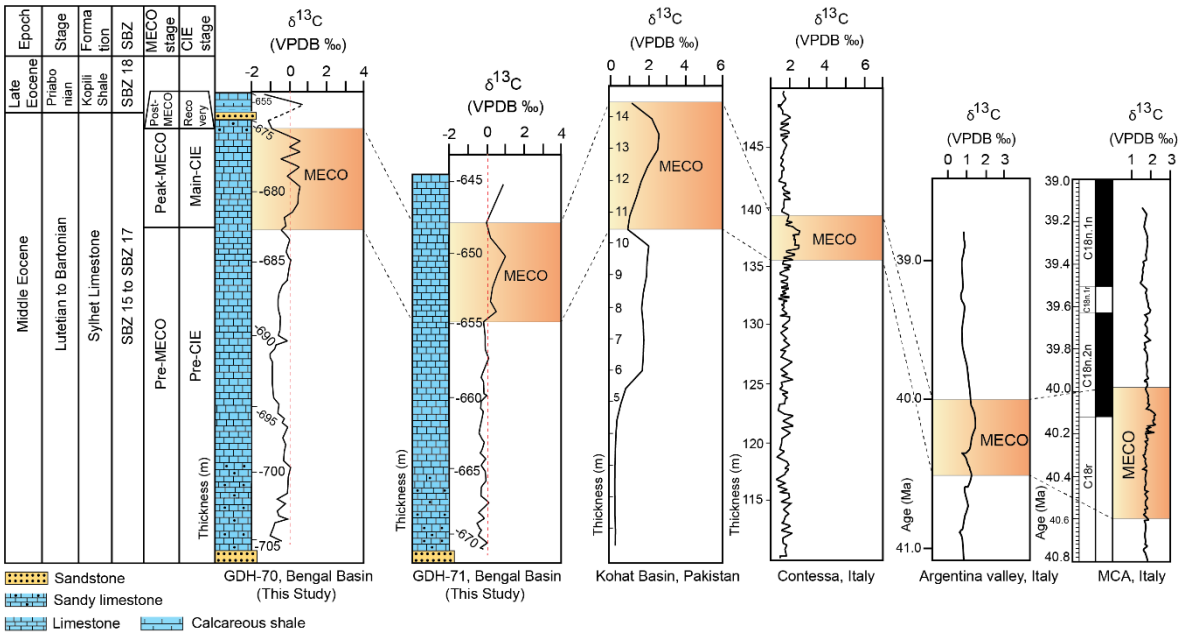

Fig. 6. Detailed bulk carbonate carbon isotope data from the drill holes GDH–70 and GDH–71, the Bengal Basin, compared with drill hole MCA, Italy (Savian et al., 2013), Argentina Valley (Ligurian Alps, Italy; Brandano and Tomassetti, 2020), Contessa, Italy (Jovane et al., 2007), Kohat Basin, Pakistan (Kamran et al., 2021) for the comparison of carbon isotope excursion (CIE) of the middle Eocene climatic optimum (MECO) event.