Proceedings of ISFOG 2025
5TH INTERNATIONAL SYMPOSIUM ON
FRONTIERS IN OFFSHORE GEOTECHNICS
Nantes, France | June 9-13 2025

ISBN 978-2-85782-758-0

Age dating integrated approach for geohazard study in transitional and structural complex environment in Moattama (Martaban) basin, Myanmar

R. E. Borella*
RINA Consulting, Genoa, Italy

F. Zolezzi
RINA Consulting, Genoa, Italy

* *riccardo.borella@rina.org*

ABSTRACT: Geophysical surveys (2D-UHR) have been conducted in the last decade in the Moattama Basin between Myanmar and Thailand, as well as geotechnical surveys (CPTs, Piston Cores, Vibrocores and Gravity Cores) to fine tune the amount of displacement occurring along the many faults pertaining to the Sagaing Fault System, dissecting the local stratigraphy. Age dating has an important role to address both sequence and timing issues, tying geological events within seismic sections to fault activity. The common ^{14}C isotope method used for age dating shows problems in many of the samples collected in the area of study, since the inputs from the Ayeyarwady and Thanlwin Delta funnel organic matter of terrestrial origin in the basin. To partially solve the problems related to Marine Reservoir Effect and Old Wood Effect, the ^{14}C dating has been integrated with biostratigraphic datasets coming mainly from planktonic foraminifera and pollen assemblages. Although the time-constraints of the biozones are wider than the ^{14}C ones, they can highlight horizons with reworked material, cross-validate stratigraphic units across fault boundaries and help build a sedimentation rate history for the Pleistocene – Holocene Moattama Basin. Seismostratigraphic facies so described have been correlated across the area of study, with the identification of Paleo-Ayeyarwady prograding delta units, alongwith tentative sedimentation rates for present-day deposition. The method described proved particularly useful in transitional settings, where high variability of sediments may prove a single age dating technique unreliable, presenting a case study with integrated, combined approach.

Keywords: Geohazard; seismostratigraphy; age dating; palynology; foraminifera

1 INTRODUCTION

Complex regions, with few publicly available data and intricate seismotectonic setting, always pose challenges for geohazard analysis. Gulf of Moattama falls within the description, with one of Earth's most active tectonic fault systems, the Sagaing fault, crossing both Myanmar eastern sector onshore and offshore down until the North Andaman Sea, and one of the biggest river systems, Ayeyarwady-Thanlwin, creating a vast delta draining waters from the Himalayas and the Burma Plateau. Distribution of sediments within the basin is further complicated by the seasonal monsoons and by the strong tidal currents that constantly reshape the delta and the basin deposits. Recent interest in the dynamics of this area has been spurred by hydrocarbon exploration; reservoirs are being exploited offshore (and onshore), with gas and condensate driven from deep sources up to paleo-deltaic reservoirs via migration pathways along the fault planes that dissect the stratigraphy (Kundu, 2010). To understand the activity of the faults, some of which seem to reach the seabed, an age dating campaign has been envisioned, coupled with geophysical survey and geotechnical sampling.

This study presents the integration between the different techniques used for age dating evaluation and its outcomes, and geophysical/geotechnical studies. In fact, radiocarbon dating encountered problems related to characteristics of sediments, such as high pyrite content and gas-charged sediments.

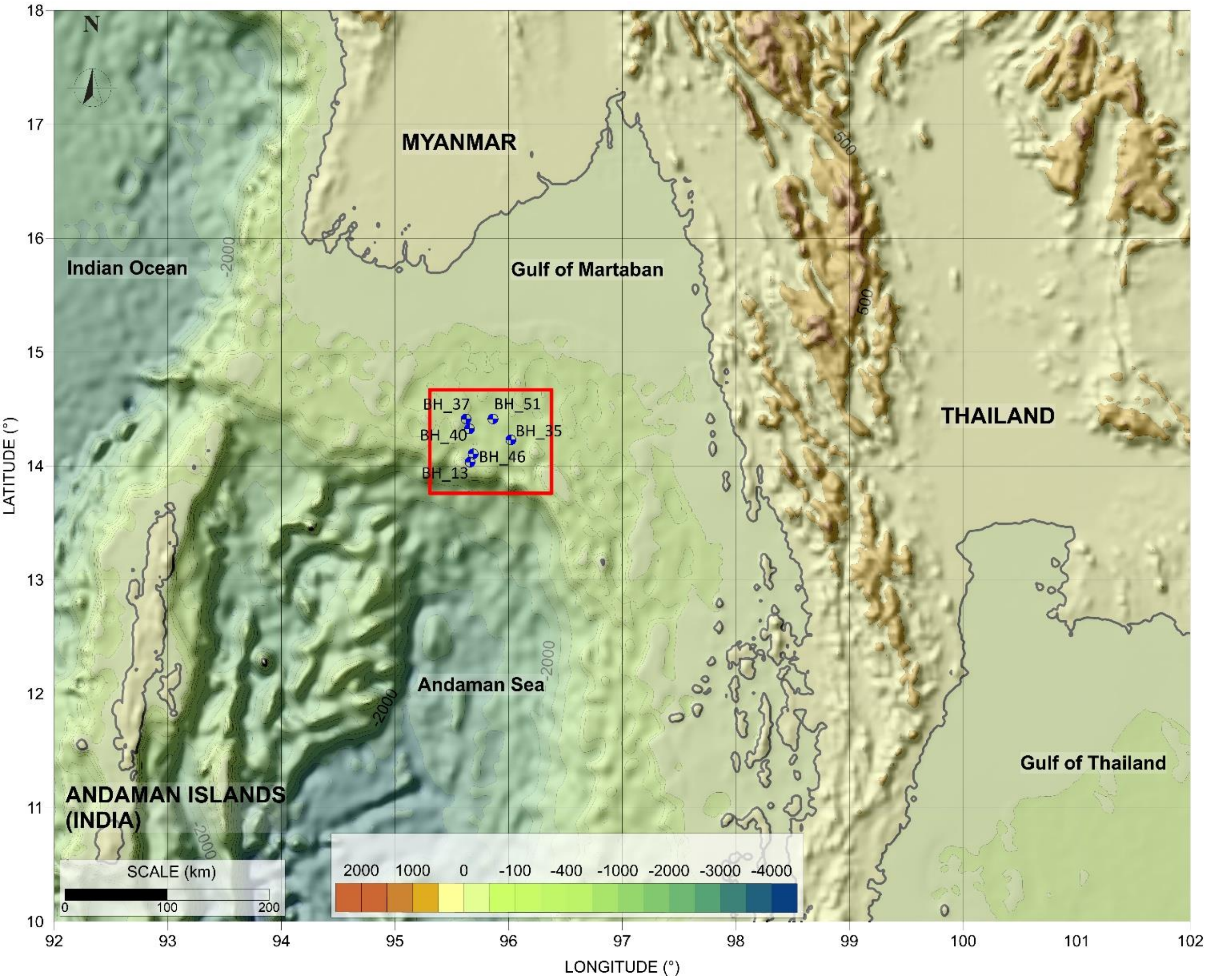

Figure 1: Morphobathymetric map of Gulf of Martaban and surrounding areas. Area of this study in red. Sample locations in blue.

2 REGIONAL SETTING

2.1 Depositional setting

The Holocene evolution of the Moattama Basin is mainly driven by the deltaic deposition of Ayeyarwady, Thanlwin and Sittang Rivers. The discharge of the Ayeyarwady, the biggest river system, has formed 35,000 km^2 delta plain, stretching from the Indo-Burman Range to the Bago-Yoma Range. The combination of the Irrawaddy and Thanlwin alone could contribute to the averages of 697 km^3 of water, 365 MT of suspended material, and 162 MT of dissolved material to the Gulf of Moattama and its surrounding area yearly (Robinson et al., 2007).

Some of the 2D-UHR seismic surveys conducted in the offshore section of basin, show a well layered seismostratigraphic unit at the seabed, with underlying somewhat chaotic, acoustic transparent, possibly corresponding to the regressive wedge, overlying well defined, although acoustic faint, unit with prograding clynoforms, possibly representing the LGM paleo-Ayeyarwady delta.

2.2 Seismotectonic setting

The Moattama Basin is located within the northern Andaman Sea. The area has active tectonic conditions associated with the interaction of the main Eurasian, Indian and Sunda Plates, and with the Burma Microplate trapped between them. The area is also where the contact of the Myanmar/Burma Plate with the Eurasia and/or Sunda plates can be found. The Myanmar/Burma Plate is a small tectonic plate or microplate which includes the Andaman Islands, Nicobar Islands and northwestern Sumatra.

Immediately north of about 15°N latitude and as far north as about 18°N latitude, many researchers have noted the absence of instrumentally recorded subduction zone earthquakes with locations and focal mechanisms corresponding to slip on the interface between the India plate and the northern Burma plate (Le Dain, 1984, Socquet, 2006, among others).

Specifically, Kundu and Gahalaut (2010) postulate that the segment across from southern Myanmar is not capable of generating great earthquakes.

3 DATA AND METHODS

The data and studies described within this paper have been collected in several years from the early 2010s up to 2024 from different suppliers, with the aim to thoroughly analyse the interaction between sedimentary environment and neotectonic input.

3.1 Seismic surveys

Different geophysical cruises have been analysed, shot in 2024 back until 2016, mainly composed of sparker Sub-Bottom Profiler (SBP) and 2D-UHR 150 cu in airgun array. The surveys have covered an extensive area (tens of km^2) about 150 km SE of the Ayeyarwady delta.

3.2 Geotechnical surveys

For the most part, geotechnical surveys have been conducted alongside with geophysical surveys, generally sampling gravity cores or piston cores (5”), or boreholes samples through swivel drilling rigs and downhole PCPT systems.

3.3 Age dating samples

After collection and sedimentary log description, suitable sampling intervals have been located to thoroughly describe the stratigraphy available. Each core (borehole core sample) has been extruded and described; a 5 cm section for each age dating sample has been collected and trimmed to avoid possible cross-contamination from coring.
Samples collected for age dating have been analysed with a combination of palynology, microfossil analysis and radiocarbon (^{14}C) dating.

3.3.1 Palynology

Palynology samples were prepared using standard techniques, for each sample pollen and spores were counted across regularly spaced slide traverses until a total pollen sum of approximately 200 grains was achieved or until the whole slide was logged.

3.3.2 Microfossils

Each sample was washed through a 125µm sieve, and the residue dried at 100°C. The dried residue was then examined for microfossils. Individual foraminiferal species were recorded quantitatively.

3.3.3 Radiocarbon (^{14}C) dating

Using this method, the maximum detectable age is no greater than 50,000 years and over 40,000 years dates are unreliable. In addition, material from the last 300 years gives unreliable ages, mainly due to the widespread burning of fossil fuels and more recently the explosion of nuclear bombs, both of which have artificially increased the amount of ^{14}C in the atmosphere. Thus, it is not possible to accurately date organisms which have died since 1950.
Suitable material includes molluscs, microfossils and wood from terrestrial, non-marine and marine environments. the results of ^{14}C dating have traditionally been quoted in “conventional radiocarbon years”, typically in years BP (before present) where the “present” is 1950. The initial assumption that the concentration of atmospheric ^{14}C has been constant as measured in 1950 has been shown to be incorrect. Dating annual tree growth rings of known historical age has demonstrated that in the past there have been short term variations in atmospheric ^{14}C levels. The INTCAL98 calibration curve thus constructed has been accepted by international consent (Stuiver *et al.*, 1998). Suitable material was hand-picked from washed and dried microfossil sample residues.

4 RESULTS

The core locations were all between -123m and -155m water depth.

Table 1. Samples analysed in this study, their depths bsb and types of analysis performed.

Sample ID	Depth (m)	Biostratigraphy	Palynology	^{14}C
BH_13	29.05	Y	N	N
	29.75	Y	N	N
	51.70	Y	N	N
	51.80	Y	N	N
	104.2	Y	N	N
BH_35	04.30	Y	N	N
	51.80	Y	N	N
	59.10	Y	N	N
BH_37	04.05	Y	N	N
	04.57	Y	N	N
	09.50	Y	N	N
	14.10	N	Y	N
	14.65	Y	N	N
	67.15	Y	N	N
	74.20	Y	N	N
BH_40	24.37	Y	N	N
	44.40	Y	Y	Y
	44.60	Y	N	Y
	59.20	N	Y	N

BH_46	04.15	Y	N	Y
	19.20	N	Y	N
	19.35	Y	N	Y
	59.24	Y	N	Y
BH_51	04.75	Y	N	N
	09.60	Y	N	N
	89.70	Y	N	N
	119.2	Y	N	Y

Most of the samples with "N" for ^{14}C in TABLE 1 show high pyrite concentrations.

4.1 Palynology

The assemblages are characterised by commonly occurring plant debris, including structured and unstructured plant material, brown and black woody debris and rare charred plant cuticle. The assemblages are similar and contain relatively poorly diverse palynofloral assemblages which, nevertheless, provide evidence of mangrove swamps, savannah grasslands, freshwater environments and upland forests. There are no age-restricted taxa, however the assemblages would be consistent with a Pleistocene to Holocene age.
The interpretative value of the palynomorph assemblages is in providing broad environmental data. It is likely that the samples reflect pollen deposition following possible river discharge, accounting for the abundance of fern spores, along with pollen from coastal plants as well as long-distance transported pollen (for example, pine pollen, from upland forest sources).

BH_40
44.40-44.45m
Palynomorph assemblage is relatively rich but poorly diverse – dominated by long ranging fern spores with evidence of mangrove or swamp environments.
59.20-59.25m
Abundance of fern spores suggest fern-dominated swamps. This sample contained a single algal type, *Concentricystes circulus*, indicative of freshwater or brackish water conditions. Pollen and spores from a range of forest and mangrove plants include occurrences of pollen of *Casuarina*, a tree/shrub which commonly occurs along sandy beaches (Morley *et al.*, 2019).

BH_46
19.20-19.25m
The assemblage is dominated by fern spores and grass pollen, providing evidence for swamp environments and savannah grasslands. Abundance of spores may be indicative of disturbed mangroves or floodplain settings (Morley *et al.*, 2019). The occurrence of taxa such as Ephedra spp., which may be in-situ and may be indicative of dry and warm scrub or braided river may potentially represent reworking from Tertiary sediments.

BH_37
14.10-14.15m
The sample yielded a poorly diverse assemblage of terrestrially derived palynomorphs dominated by fern spores and fungal spores. Pollen grains from mangrove or swamp environments are present. Plant debris, including structured and unstructured plant material, brown and black woody debris and rare charred plant cuticle was common. There are no age-restricted taxa, however the assemblages would be consistent with a Pleistocene to Holocene age.

4.2 Microfossils

A detailed analysis of the microfauna (benthonic and planktonic foraminifera) was undertaken to provide information about the depositional environment and to provide a context for radiocarbon dating.

Planktonic foraminifera
Planktonic foraminifera are very rare and only present in four samples (BH_35, 51.80m, BH_37, 74.20m, BH_40, 24.37m and BH_51, 119.20m). no stratigraphic markers were observed, and the few species present are long-ranging taxa (i.e. no species inceptions and extinctions). Furthermore, due to the rarity of planktonic foraminifera, age interpretations which rely on ratios of cold vs warm taxa, for example, are not possible.

Benthic foraminifera
There is no published benthonic foraminiferal zonation applicable to the Gulf of Martaban and no inferences of age can be made from the species present. Benthic foraminifera were found in samples BH_13, 29.75m and 51.70m, 51.80m, BH_35, 04.30m and 59.10m, BH_51, 89.70m, and 119.20m. The species present are typical of shallow waters and consistent with a neritic environment, as is the accompanying shell debris. The shallow water species Ammonia beccarii tends to be a sand-gravel dweller and the large number seen in sample BH_51 119.20m-119.25m may indicate a coarser substrate present compared to the other samples. *Ammonia tepida*, which is tolerant of hyposaline conditions (Todd and Bronnimann, 1957) in the same sample would suggest a fluvial component and a river dominated shelf environment; also, in BH_35, 04.30m. the abundance of plant material and pyritised content in some samples would also support the suggestion of a river dominated

shallow marine environment (Lee *et al.* 2020). This organic material which dominates some samples may also reflect seasonal monsoonal rains in the region.

4.3 Radiocarbon age dating

Results presented in Table 2 are all achieved sampling plant-derived organic matter.

Both conventional and calibrated ages fall within three age groups; the most recent one spanning between 15kyrs and 17kyrs, with samples collected between 4m and 20m below mud line; the group collected at 40m below mud line shows ages in the 30kyrs range; whilst the oldest group collected just shy of 60m below mud line and below shows ages at the limit of the radiocarbon dating or below.

Table 2. Age dating results.

ID Sample	Depth (m)	Conventional age (yrs BP)	Calibrated age (cal yrs BP)	$\delta^{13}C$
BH_40	44.40	26,520 ± 130	31,064-30,397	-27.4
	44.60	27,210 ± 150	31,572-31,070	-27.0
BH_46	04.15	13,050 ± 40	15,795-15,474	-29.1
	19.35	14,460 ± 40	17,845-17,419	-28.9
	59.24	37,430 ± 420	42,380-41,441	-27.9
BH_51	119.20	>43,500	n/a	-26.7

5 DISCUSSION

Sampling strategy for the locations surveyed was firstly established with radiocarbon dating in mind. However, knowing from previous runs in the same area that sampling can be difficult due to the limited penetration of piston and/or gravity cores, and due to limited availability of material due to in-situ testing, additional analyses (palynology and microfossils) had been foreseen in case ^{14}C would run into problems (lack of suitable material, etc.).

As can be seen in Table 1, the integration between different dating techniques proved essential, since so many samples were consistently bearing high pyrite content and/or scarce organic content.

However, although no distinctive marker has been found within the palynology and the microfossil record, the coupling with ^{14}C and seismostratigraphy has proven useful to pinpoint the time frames for the different units.

For example, mangroves and ferns indicative of coastal and brackish water environments, when found within deposits pertaining to the paleo-delta sequence, at a water depth compatible with the LGM sea level drop are coupled with a radiocarbon age dating taken few kilometres to the NW, at related seismic horizons, reading close to 18,000 yrs BP.

5.1 High pyrite content

Most of the sample selected for age dating analysis returned the note “insufficient material” along with “sand and pyrite”. Whenever a sample has been discharged for not having enough material to test, the pyrite was present and abundant. As Rickard described in his paper (2012), the presence of H_2S combined with organic matter (occasionally with sulphates and iron), spurs the formation of pyrite, with the contemporary depletion of organic carbon. Thus, the presence of gas in the sediment at shallow depths (even at seabed) is probably the reason why so many samples display such a low carbon content.

5.2 Sedimentation rate

Previous studies on the area, when present, focus mainly on the nearshore Ayeyarwady delta and on the inner part of the Gulf of Moattama, as well as on the Martaban Depression. The sedimentation rate suggested for these sectors of the gulf reflect the predominant delta-driven inputs, with actual sedimentation rate in the order of cm/yr.

Establishing a representative sedimentation rate is key for geohazard risk analysis; particularly so dealing with fault movement rate assessment, like in this case history where multiple faults dissect the stratigraphy.

Even accounting for the scarcity of material available for robust radiocarbon dating, the samples collected have shown a much lower sedimentation rate in the outer part of the basin, close to the slope.

The presence of delta-related vegetal remains, such as mangroves, in samples close to or at the surface, suggest that flooding events from the Ayeyarwady (and possibly Thanlwin as well) do reach the outer rim of the shelf, but the frequency of those events appears very limited.

Foraminifera assemblages seem to confirm this view, since mostly species relative to shallow, deltaic conditions are present.
Grouping the radiocarbon age dating not only by age groups, but also by depth intervals, the results indicate a fairly consistent (1.4 mm/yr) sedimentation rate for most of the Upper Pleistocene, from 43kyr (BH_51, BH_46 and BH_40) to ~18kyr, covering the portion of stratigraphy from ~120m bml, to ~20m bml.
The most recent fraction examined (BH_46), at 4.15m bml, shows an even lower sedimentation rate (0.2 mm/yr) for the last ~15kyr.
This decrease is probably related to the increase of global sea level at the end of the last ice age, and the flooding events from the delta capable of reach this area of the gulf becoming fewer and far apart.

6 CONCLUSIONS

To define fault hazards and construction parameters in seismically active areas, sedimentation rate and accurate seismostratigraphy analyses are keys. The area of this study somewhat lacked precise sedimentation rate values, relying on general rates from the inner shelf section of Gulf of Moattama and Martaban Depression, where sedimentation rates of 1.4 mm/yr have been proposed in this study for most of the Upper Pleistocene deposits, up to ~20m below mudline. Lower sedimentation rate of 0.2 mm/yr is proposed for the shallow stratigraphy, from ~5m below mudline to the surface.
Transition zones like the one in the Gulf of Moattama often pose challenges to age dating techniques. Changes in organic carbon distribution and degradation, may result in lack of suitable material for classic ^{14}C dating method. Case history like the one presented, calls for differentiating dating techniques, like palynology and biostratigraphy, to cross-correlate datasets with overlapping age ranges, some of which can even tap on basin scale, thus being tied with seismostratigraphy.

AUTHOR CONTRIBUTION STATEMENT

Riccardo Eugenio Borella: Data curation, Interpretation, Writing-Original draft.
Francesca Zolezzi: Supervision, Interpretation, Reviewing and Editing.

ACKNOWLEDGEMENTS

The project presented in this article is supported by RINA Consulting S.p.A..

REFERENCES

Kundu, B. and V.K. Gahalaut, 2010, Short Note, An Investigation into the Seismic Potential of the Irrawaddy Region, Northern Sunda Arc. *Bulletin of the Seismological Society of America*, Vol. 100, No. 2, pp. 891–895. https://doi.org/10.1785/0120090081

Le Dain, A.Y., P. Tapponnier, and P. Molnar, 1984. Active Faulting and Tectonics of Burma and Surrounding Regions, *Journal of Geophysical Research*, Vol. 89, pp. 453–472. https://doi.org/10.1029/JB089iB01p00453

Lee, S.-A., Kim, T.-H., and Kim, G., 2020. Tracing terrestrial versus marine sources of dissolved organic carbon in a coastal bay using stable carbon isotopes. *Biogeosciences*, 17, 135–144. https://doi.org/10.5194/bg-17-135-2020

Morley, Robert J., Viet Dung Bui, Thanh Tung Nguyen, A.J. Kullman, Robert T. Bird, Van Kieu Nguyen, Hoai Chung Nguyen, 2019. High-resolution Palaeogene sequence stratigraphic framework for the Cuu Long Basin, offshore Vietnam, driven by climate change and tectonics, established from sequence biostratigraphy, *Palaeogeography, Palaeoclimatology, Palaeoecology*, Volume 530, 2019, Pages 113-135. https://doi.org/10.1016/j.palaeo.2019.05.010

Rickard, D., 2012. Chapter 6—Sedimentary Pyrite. In *Developments in Sedimentology*; Elsevier: Amsterdam, TheNetherlands, 2012; Volume 65, pp. 233–285. https://doi.org/10.1016/B978-0-444-52989-3.00006-4

Socquet, A., C. Vigny, N. Chamot-Rooke, W. Simons, C. Rangin, and B. Ambrosius, 2006. India and Sunda Plates Motion and Deformation along their Boundary in Myanmar determined by GPS, *Journal of Geophysical Research*, Vol. 111, B05406, pp. 11. https://doi.org/10.1029/2005JB003877

Stuiver, M. & Minze, & Reimer, Paula & J., Paula & Bard, Edouard & Edouard, & Beck, & Warren, J. & Burr, George & Hughen, & A., Konrad & Kromer, & Bernd, & McCormac, Gerry & Gerry, & Plicht, van & Johannes, & Spurk, Marco & Marco, 1998. INTCAL98 radiocarbon age calibration, 24,000--0\,cal\,BP. rc. 40. 1041. https://doi.org/10.1017/S0033822200019123

Todd, R.; Brönnimann, P., 1957. Recent foraminifera and thecamoebina from the eastern Gulf of Paria, Trinidad. *Cushman Foundation for Foraminiferal Research*. 3: 1-43.