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► To cite this version:

Franto Novico, David Menier, Manoj Mathew, Mu Ramkumar, M. Santosh, et al.. Impact of Late Quaternary climatic fluctuations on coastal systems: Evidence from high-resolution geophysical, sedimentological and geochronological data from the Java Island. *Marine and Petroleum Geology*, 2022, &”- (Article number 105399), pp.105399. 10.1016/j.marpetgeo.2021.105399 . hal-03485730

HAL Id: hal-03485730

<https://hal.univ-brest.fr/hal-03485730v1>

Submitted on 8 Jan 2024

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1 **Impact of Late Quaternary climatic fluctuations on coastal systems:**

2 **Evidence from high-resolution geophysical, sedimentological and**

3 **geochronological data from the Java Island**

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23 **Abstract**

24 The major climatic oscillations during the Quaternary Period significantly influenced the
25 evolution and distribution of ancient and modern coastal systems. Here we investigate the
26 morphology and sedimentary infilling of submerged Late Quaternary incised valleys along the
27 northern coast of Java Island (Indonesia) using high-resolution geophysical, sedimentological
28 and geochronological data. Our results indicate that the spatial development and morphology
29 of the incised valleys are predominantly controlled by Quaternary glacial–interglacial eustatic
30 fluctuations, within a marked subsiding setting. The valleys were incised during prominent
31 Quaternary lowstands and most of the valley fill was emplaced during the last postglacial sea
32 level rise. The valley fill forms a transgressive succession, consisting mainly of fluvial
33 deposits at the base (possibly amalgamated from older sequences) overlain by shallow marine
34 sediments and capped by hemipelagic deposits. The valley-fill architecture is strongly
35 dependent on the valley morphology (depth of incision, width of the valleys, and extent of the
36 intertidal zone). The shallow marine deposits contained within the narrow and linear valleys
37 are mostly aggrading muds. The vertical incision and valley formation was chiefly controlled
38 by the extent of glacial sea-level fluctuations. The studied sections represent the continental-
39 offshore extension of a paleodeltaic system. The implication of our work is that even in
40 predominantly enclosed shallow marine systems that are located distal to the shelf break, the
41 response of the sedimentary system and ensuing stratigraphic configuration can be effectively
42 impacted by the rapid and abrupt Quaternary global climatic transition and eustatic sea-level
43 fluctuations.

44

45 **Keywords:** Last Glacial Maximum; Java Sea; Incised Valleys; depositional controls; stratal
46 morphology

47 **1. Introduction**

48 The Quaternary Period is characterized by rapid, large-scale and abrupt climatic oscillations
49 that strongly influenced the evolution and distribution of ancient coastal systems around the
50 world and continue to exert control until present-day (Adams et al., 1999; Elias, 2013;
51 Gornitz, 2021). The associated eustatic fluctuations predominantly generated arrays of incised
52 valleys during relative sea level lowstands which were inundated and filled during subsequent
53 relative sea level rise, inundated and infilled the incised valleys. Over the last 40 years, owing
54 to its scientific and economic significance, extensive research has been focused on the
55 stratigraphy and infilling of such incised valleys or paleochannels (Puchala et al., 2011; Wang
56 et al., 2020). Research conducted elsewhere has provided important geomorphologic as well
57 as stratigraphic information from regions such as the North and South American shelf (e.g.,
58 Dalrymple et al., 1994; Nordfjord et al., 2006; Moreira et al., 2019), northwest European shelf
59 (e.g., Allen and Posamentier, 1993 and 1994; Tesson et al., 2000; Chaumillon et al., 2010;
60 Menier et al., 2010; Martinez-Carreno and Garcia-Gil, 2017), northeastern Australian shelf
61 (e.g., Fielding et al., 2005), southwestern Huanghai shelf (e.g., Kong et al., 2011), South
62 African shelf (e.g., Green, 2009), eastern Indian coast (e.g., Dubey et al., 2019), Sunda shelf
63 in Southeast Asia (e.g., Hanebuth et al., 2009; Puchala et al., 2011; Horozal et al., 2021),
64 among others.

65 In Southeast Asia, the Sunda Shelf or Sundaland is an extension of the continental shelf and
66 includes the island of Java, the Malay peninsula, Sumatra, Borneo, Madura, Bali and their
67 surrounding smaller islands. It covers an area of approximately 1.85 million km². Its seas are
68 relatively shallow and was exposed several times during the Pleistocene (e.g., Emery et al.,
69 1972; Hanebuth et al., 2009) when Sumatra, Java, Borneo and the Malay peninsula were
70 connected and formed a single large landmass (Heaney et al., 1991; Voris, 2000; Bird et al.,
71 2005) (Fig. 1A). During the Last Glacial Maximum (LGM), ~26.5–19 ka BP, much of the
72 remaining Sundaland area was covered by savanna, grassland, lowland evergreen forests,

73 marshy grounds and crossed axially by the deeply incised ‘rivers’ feeding the late falling-
74 stage deltas that debouched close to the present-day shelf break of the Sundaland (Hanebuth
75 et al., 2009; Hanebuth et al., 2011; Puchala et al., 2011; Sathiamurthy and Rahman, 2017;
76 Irwanto, 2019). The Java Sea that today corresponds to a large and shallow sea of the Sunda
77 Shelf, which lies between the islands of Borneo to the north, Java to the south, Sumatra to the
78 west and Sulawesi to the east, was entirely exposed during the LGM (Clark et al., 2009). The
79 Java Sea was occupied by river valleys and channels that coursed to the shelf break located
80 toward the eastern part of Java. Currently, the northwestern region of the Java Sea hosts a
81 poorly-documented offshore sedimentary prism dominated by argillaceous deposits within a
82 rapidly subsiding geodynamic setting (Abidin et al., 2008, 2013 and 2015, Chaussard et al.,
83 2013; Husson et al., 2019). While it is recognized that this region has undergone various
84 phases of tectonic and eustatic fluctuations until recent-times (e.g., Zahirovic et al., 2016), a
85 detailed analysis of the sedimentary architecture and stratigraphic archive, which can
86 potentially encapsulate evidences of important environmental changes in response to
87 endogenic and exogenic forcing, remain less understood.

88 Here, we present a detailed description of the shallow sub-bottom stratigraphy of the offshore
89 section of northwest Java (Fig. 1B) using results obtained from shallow seismic surveys and
90 cores collected in 2015. These results, aided with radiocarbon ages provide insights into the
91 Pleistocene to Holocene transition events and the major climatic and eustatic controls on the
92 sedimentary organization within a subsiding shelf setting.

93 **2. Geological characteristics of Java and Java Sea**

94 **2.1. Structural setting**

95 Sundaland consists of a stable core of Paleozoic continental crust that was augmented in size
96 by tectonism and volcanism associated with subduction along the southern margin of the

97 continent, with episodes of uplift and subsidence affecting the entire Sunda Shelf (Bird et al.,
98 2005; Metcalfe, 2011). Java represents a volcanic arc built on the southernmost margin of the
99 continental Sunda Plate, due to the subduction of the oceanic Australia-Indian plate (Fig. 2A;
100 Hamilton, 1979). It is a structurally complex island attributable to a long history of accretion
101 of Gondwana-derived crustal blocks that led to a configuration of alternating highs and
102 transverse depressions (Haberland et al. 2014). The northern part of the Northwest Java Basin,
103 including the coastal area, is dominated by extensional faulting with minimal compressional
104 structures (Darman and Sidi, 2000; Sathiamurthy et al., 2006). It was formed by continuous
105 subsidence and southward tilting of the Sunda Plate since the Paleogene (Hamilton, 1979).
106 The subsidence is documented to have resulted in the development of the Pulau Seribu
107 carbonate platforms (Fig. 1B) and the NE-SW trending asymmetrical northwest Java basinal
108 area (Suyanto et al., 1977). Subsequent development of several sub-basins and basement
109 highs within the basin (Patmosukismo et al., 1974) was associated with N-S trending block
110 faulting (Adriansyah et al., 2002).

111 **2.2. Geomorphology and seafloor sedimentary cover**

112 Morphologically, the Java Sea is roughly rectangular in shape, located between Sumatra to the
113 west and Bali to the east. In the west, it is open to the Indian Ocean through the Sunda Strait
114 and the Karimata Strait, respectively. In the east, it has an open connection to the Flores Sea
115 and the Sulawesi Sea through the Makassar Strait (Durand & Petit, 1995; Genia et al., 2007).
116 The Java Sea including Jakarta Bay is a large (~310,000 km²), shallow sea (40–100 m water
117 depth) and the slope is toward the east at the edge of the Sunda Shelf. Seafloor surface
118 sediment of Indonesian waters including the Java Sea generally consists of cohesive fine-
119 grained sediments (Fig. 2).

120 Java presents an elongated morphology with a surface area of ~130,000 km² (~1000 km in
121 length and ~210 km wide). The coastline is structurally controlled and shows an irregular

122 morphology. Northern Java including the Jakarta Bay is in a transition area between the
123 volcanic arc and the extensional back-arc zone. This area is characterized by the flat alluvial
124 plain of the coastal zone. The southern parts of Java are occupied by volcanic mountains
125 where Mount Semeru is the highest (~36576 m). Java is drained by multiple rivers, with large
126 drainage basins in the north and small drainage basins in the south (Figure 3). The drainage
127 pattern is predominantly controlled by the volcanic arc and recent uplift (Marliyani, 2016).

128 **2.3. Sea level changes**

129 On a global scale, the development of Quaternary stratigraphy of continental shelves was
130 predominantly controlled by glacio-eustatic fluctuations (Suter et al., 2012). Hence, an
131 understanding of relative sea-level change may help to explain critical interactions in earth
132 environmental systems throughout the Quaternary (Shennan, 2018).

133 The Sundaland core is considered to be tectonically quiescent, as evidenced by the lack of
134 noticeable seismic activity of the fault systems. However, a recent biographical study on
135 organism divergence time (Husson et al., 2019) shows that Sundaland was subaerially
136 exposed before 400 ka and subsequently experienced subsidence at a rate of 0.2–0.3 mm yr⁻¹
137 (Sarr et al., 2019). The insights gained from Sarr et al. (2019), resulted in an updated
138 framework of sea level changes for Sundaland by combining variations of both glacio-eustatic
139 and subsiding activity.

140 During the LGM, when ice sheets were at their maximum, the glacio-eustatic depression of
141 the sea level by ~120 m had fully exposed the Sunda Shelf. Several previous studies (e.g.,
142 Bird et al., 2005; Sathiamurthy et al., 2006; Cannon et al., 2009; Sathiamurthy et al., 2017),
143 using sedimentological, geophysical and palynological data records from the LGM stage,
144 reconstructed the paleogeography of Sundaland along the areas from the South China Sea and
145 Malacca Strait to the Java Sea. The area was dominated by large fluvial drainage systems with

146 savanna and lowland evergreen vegetation in their catchment areas (Fig.1A). Sea level
147 changes seem to play a critical role in variability of the sedimentary successions in these areas
148 including the Jakarta Bay and the Java Sea.

149 The last marine flood that initiated ~19 ka BP had significant consequences on the
150 remobilization of sediments of the paleolandscapes associated with the vast coastal plain,
151 which occupied most of the present-day Java Sea. During this sea level rise, the new
152 hydrodynamic conditions led to a reorganization of the sedimentary architecture that initiated
153 with continental sedimentary regime to a mixed sedimentary system (i.e., both marine and
154 continental) and then culminated in an exclusively marine-dominated stratigraphic
155 architecture, to reach the current coastline of northern Java.

156

157 **3. Material and methods**

158 **3.1. Geophysical data acquisition and processing**

159 Two high-resolution reflection seismic (HRRS) single channel data records were used. The
160 first set of seismic profiles correspond to refined HRRS campaigns that were carried out in
161 June to July 2015, covering nearly the entire Jakarta Bay. The second set of seismic profiles
162 were obtained from the HRRS data acquisition campaign that was conducted in March 1990
163 (unpublished report by Kurnio et al., 1991) for the Java Sea (Fig. 1B). Both seismic records
164 were acquired by deploying a sparker system that could penetrate up to 250 ms TWTT.
165 Cheaspeake Sonarwiz 5 software was used for processing the single channel data by
166 completing the sea bottom track by noise attenuation, seismic signal gaining by Automatic
167 Gain Control and User Define Gain/Attenuation, bandpass filtering through frequency
168 selection to have a better resolution of seismic reflectors at upper layers of sub-sea bottom and
169 seismic trace stacking by increasing the ratio of signal/noise to obtain a better quality of the

170 reflectors. The time-depth conversion for sediment unit boundaries was assumed using an
171 internal velocity of 1600 m/s beneath the seafloor (Puchala et al., 2011; Martínez-Carreño and
172 García-Gil, 2017). Thus, 200 m depth was reached with some approximately visible
173 reflectors. Survey positioning was achieved with a differential global positioning system
174 (DGPS) using CNAV 3050. The seismic reflectors were analyzed following the procedures
175 enlisted by Mitchum and Vail (1977), Brown and Fisher (1980), Posamentier et al. (1988),
176 Posamentier and Vail (1988), and Catuneanu (2019).

177 **3.2. Sediment cores**

178 Ten boreholes (BH-01–BH-10) were drilled (Figs. 1C and 2B) around the Jakarta Bay. The
179 borehole, BH-10, has the deepest water depth (22 m below Lowest Astronomical Tide -LAT),
180 while the others varied from 14 to 19 m water depth below LAT. Among the 10 boreholes, the
181 drilling depth of BH-02 and BH-07 reached 150 m below the sea bed and both boreholes were
182 located in the middle of the bay (Fig. 1C and Table 1). The other boreholes were drilled to a
183 depth of 60 m below the seafloor. The retrieved sediment cores were used to describe the
184 lithology, microfauna and organic matter (e.g., fragments of fossilized wood, rootlets,
185 charcoal, etc.) to decipher the depositional environments, which were interpreted based on
186 granulometric analyses (30 g dry samples were sieved for grain sizes 2 mm, 500 μm , 250 μm
187 and 63 μm) and microfossil analysis (using stereo zoom Zeiss Stemi SV 11) following
188 standard procedures.

189 **3.3. AMS ^{14}C dating**

190 The selected samples for radiocarbon dating were analyzed with Accelerator Mass
191 Spectrometry at the Radiocarbon Laboratory, University of Arizona, USA. Each age
192 measurement was conducted on shell fragments and organic matter extracted from the cores.
193 All radiocarbon dates are given in years before present/1950 (BP) (Smith et al., 2011; Reimer

194 et al., 2013). Radiocarbon dates with a “measured radiocarbon age” older than 46,400 yrs BP
195 are outside the detection limits and are not calibrated; thus, these ages are shown as > 46,400
196 yrs BP (Table. 2).

197 **4. Results**

198 **4.1. Interpretation of seismic reflection configuration patterns and seismic stratigraphy**

199 The seismic profiles were analyzed in terms of continuity, amplitude, configuration and
200 termination of reflectors following Mitchum et al. (1977) and Catuneanu (2019). This was
201 followed by the recognition of seismic units and description of the recognized units along
202 with their boundaries (unit boundary - UB). The characteristics of the acoustic facies are
203 summarized in Table 3 for the seismic units observed in the offshore zone and identified in
204 boreholes BH-02 and BH-07.

205 To illustrate the Holocene infilling of the incised valleys from the Jakarta Bay to the Java Sea,
206 we selected five seismic profiles that are located in the central part of the study zone.

207 In the five profiles (sparker profiles: L-42, CL-06B, L-C7, L-C8 and L-X), located at water
208 depths ranging from 5 to 50 m, seven seismic units, i.e., U1–U7, from the base towards the
209 top, were identified in the sedimentary infilling of the incised valleys (Fig. 4 and Table 3).

210 These units are illustrated on the selected profiles, except for Units 1, 2 and 3, which are only
211 adequately visible on L-42. Units 1 and 2 are characterized by discontinuous reflectors with
212 an acoustically opaque configuration.

213 Unit 1 (U1) is located in the basal part (Fig. 4A) and displays a thickness of >25 ms TWTT
214 (>20 m). The reflectors of U1 demonstrates very poor continuity, low frequency and low
215 amplitude (Table 3). The reflection configuration is aggrading sub-parallel with attenuated
216 zones (acoustically opaque) as a result of subsurface gas. It should be noted that this area has

217 been shown to contain acoustically turbid zones, which are related to the presence of gas in
218 organic-rich sediments (e.g., Schubel, 1974; Baltzer et al., 2005).

219 Unit 2 (U2) presents an acoustic thickness varying from 20 to 35 ms TWTT (~16 m to 28 m).
220 Continuity, amplitude and frequency in seismic facies range from low to medium and very
221 poor at some parts with acoustic turbidity (Table 3). Reflector configuration displays
222 aggrading sub-parallel to parallel patterns associated with a shallow marine environment, such
223 as a deltaic depositional system.

224 Unit 3 (U3) exhibits an acoustic thickness varying between 35 ms to 60 ms TWTT (~28 m to
225 48 m). U3 is characterized by aggrading reflectors in the sedimentary prism wedging
226 morphology systems towards the south and the north, particularly in the lower section of the
227 seismic line L42. This seismic facies is interpreted as a deltaic depositional system.

228 Unit 4 (U4) overlies U3 (Figs. 4 and 5) and has an acoustic thickness varying between 50 ms
229 and 70 ms TWTT (~40 m to 64 m). The reflectors show very poor to moderate continuity and
230 the amplitude and frequency are medium (Table 3). The top of the unit is bounded by an
231 erosional surface. The internal reflectors show corrugated reflector stacking pattern, probably
232 due to the prevalence of superimposed subaqueous lobes within a deltaic system, and some
233 erosional surfaces, which in turn are located at the southern and northern parts. The seismic
234 facies could suggest that U4 comprises an alluvial plain depositional environment (Reineck
235 and Singh, 1980; Catuneanu et al., 2009; Catuneanu, 2019).

236 Unit 5 (U5) overlies U4 with an acoustic thickness varying between 5 ms to 50 ms (~4 m to
237 40 m) and is bounded by erosional surfaces on the top and bottom (Figs. 4 and 5). The unit
238 extends laterally to a planar geometry. The continuity of seismic facies is very poor to poor
239 corresponding to acoustic attenuation and demonstrates an oblique-aggrading subparallel
240 geometry, while amplitude and frequency are low to high (Table 3). Aggrading subparallel

241 seismic reflector geometry is commonly found beside discontinuous reflectors that could
242 indicate existing gas pockets. This unit presents a general organization of horizontal reflectors
243 with some downlap and onlap in a few places. Using indications from the seismic facies, the
244 depositional environment of U5 is interpreted as a delta plain with some parts containing
245 alluvial channels and tidal flat sediments (Brown and Fisher, 1980; Reineck and Singh, 1980;
246 Catuneanu et al., 2009; Catuneanu, 2019).

247 The next unit, U6, presents an acoustic thickness of 5 ms to 40 ms TWTT (~4 m to 32 m)
248 (Figs. 4 and 5). This unit reveals acoustic facies that are characterized by aggrading parallel
249 and progradation pattern of poor continuity, and low to high frequency with very low to high
250 amplitude (Table 3). The base of U6 corresponds to a subaerial unconformity and
251 demonstrates flat upper layers that overlie clinoform deposits in some parts (Figs. 4 and 5),
252 which intersects U5 with a divergent filling pattern. The variation in thickness of this unit is
253 associated with incised channels and U6 is interpreted as delta front deposits within a shallow
254 marine setting (Reineck and Singh, 1980; Dalrymple et al., 2003; Catuneanu et al., 2009;
255 Catuneanu, 2019).

256 Unit 7 (U7) is the most recent seismic unit which overlies U6 (Figs. 4 and 5). The seismic
257 facies show medium to good continuity with good amplitude and medium frequency. Seismic
258 reflector configuration is predominantly aggrading parallel (Table 3). The acoustic thickness
259 ranges between 5 ms to 30 ms TWTT (~4 m to 24 m). The depositional environment of U7 is
260 interpreted as a subaqueous fan delta in the south-central and eastern parts that can be
261 associated with existing river mouths and a shoreface setting toward the north as seen in the
262 modern bathymetric map of the study area.

263 **4.2. Lithofacies description and correlation from sediment cores**

264 Lithofacies description of the recognized seismic units was conducted on selected cores, i.e.,
265 BH-02, BH-04, BH-05, BH-06, BH-07 and BH-09 (Figs. 2B and 6). It is evident from the
266 sparker profile L-42 (Fig. 4A) that these cores represent a complete and continuous record of
267 stratigraphic successions in units U2 to U7, and thus provide the optimal opportunity to
268 investigate the sedimentary infilling history of the study area. U2 was recognized at a depth of
269 130–150 m and consists of dark grey to olive grey silt and clay, and medium to dark grey
270 very-fine to fine-grained sand and the depositional environment indicated an inner shelf
271 setting. U3 comprises of sediments that correspond to grey clay and dark grey medium-
272 grained sand as seen in BH-02 and BH-07 and gathering information from the seismic facies,
273 this unit is interpreted as being deposited in a deltaic setting. The lithology of U4, as seen in
274 cores BH-04 to BH-09, and identified at a depth of 46–100 m below the seabed, is
275 characterized by dark grey to olive grey silt with traces of clay, medium to coarse grain
276 greyish brown sand and silt with traces of clay that indicate a shallow marine to alluvial plain
277 depositional environment. Core description of boreholes BH-04 and BH-09 (Fig. 6) reveal
278 that U5 consists predominantly of greyish brown to brown sand and brownish grey silt and
279 clay. Informed by the seismic facies and lithofacies, we interpret the depositional environment
280 of U5 as a delta plain with some parts containing alluvial channels and tidal flat sediments.
281 The sediments of U6, witnessed in the boreholes BH-05 and BH-07, reveal dark grey to black
282 sand, medium to coarse grained sand and dark grey mud with some medium grain sand. The
283 basal sequence boundary is overlain by yellowish-brown medium grain sand, reversed graded
284 bedding, containing shell fragments, which denote a shallow marine to deltaic depositional
285 environment. U7 occupies the stratigraphic succession between 0 to 12 m and consists of
286 yellowish-grey clay with medium grained sand containing visually $\pm 10\%$ of shell fragments
287 and depositional environment is interpreted as a shallow offshore environment

288 **4.3. Micropaleontological indices**

289 Microfossils were identified and described from cores BH-02, and BH-07 (Table 4).

290 The dominant benthic foraminifera taxa (i.e., *Ammonia* spp.; *Asterorotalia* spp.) (Fig. 7 and
291 Table 4) in U2 seem to indicate a coastal waters environment. *Ammonia tepida* is indeed
292 known to be tolerant to continental organic matter and freshwater inputs in the southwestern
293 Pacific region (Debenay, 2012). *Asterorotalia* spp. is a typical warm water epifaunal benthic
294 foraminifera well represented in riverine influx dominated coastal domain (Panchang and
295 Nigam, 2012; Saraswat et al., 2017). Microfossil barren zones are observed in U4 in both BH-
296 02 and BH-07. A gradual increase in benthic foraminifera, especially *Elphidium* spp.,
297 *Operculina* spp. and *Quinqueloculina* spp. is seen in the upper parts of U4 and in U5 within
298 BH-07, while ostracods are very rare in these two units (Table 4). Similarly, in BH-02, the
299 lack of ostracods is evident in U4 and U5, while rare occurrences of *Elphidium* spp.,
300 *Pseudorotalia* spp. and *Quinqueloculina* spp. is noticed in upper parts of U4. U6, similar to
301 U3, entails an abundance of various species of ostracods and benthic foraminifera and this
302 could be indicative of a shallow marine setting (Table 4). U7 reveals the presence of some
303 marine benthic foraminifera taxa found in modern warm marine waters of southwestern
304 Pacific Ocean (e.g. *Dendritina* spp., *Spiroloculina* spp., Hohenegger et al., 1999; Debenay,
305 2012). *Dendritina* spp. is indeed a full marine species frequently found abundant in regions
306 protected from extreme hydrodynamic forcing.

307

308 **4.4. Radiocarbon ages**

309 A total of 3 cores (i.e., BH-05, BH-06 and BH-07) were sampled for radiocarbon dating. The
310 dating analysis from a sample recovered at 134.5 m depth of BH-07 and pertaining to U2
311 revealed an age of > 49,900 ka BP.

312 In the same core, ^{14}C dating results (Table 2) of samples at 77 m depth and 56.2 m depth, and
313 within U4, presented ages of > 46.4 ka BP and 41.8 ± 1.5 cal ka BP, respectively.

314 The result of radiocarbon dating applied on shell materials of the sub-sample from 14.3 m
315 below the seabed from BH-06 revealed an age of 8461 ± 29 cal yrs BP (Table 2).

316 The dating applied on molluscan shell collected at 7 m depth below seafloor from BH-05
317 returned an age of $3,308 \pm 24$ cal yrs BP (Table 2).

318 **5. Discussion**

319 **5.1. Sequence stratigraphic framework**

320 While all the depositional units are not equally preserved in all the studied valleys, a general
321 stratigraphic scheme can be drawn that applies over the entire zone or system.

322 The chronology of the complete succession remains speculative for Units 1, 2 and 3 except
323 for the upper units (U4–7), wherein, the formations indicate ages ranging from the Pleistocene
324 to Holocene. U4 that signifies the falling stage systems tract shows a first stage of incision
325 and is characterized by alluvial deposits (Figs. 4 and 6), which indicate ages of > 46.4 ka BP
326 and 41.8 ± 1.5 cal ka BP (MIS 3) (Table 2) and we interpret this sequence to be associated
327 with the accumulation of regressional deposits following the persistent drop of relative sea
328 level since MIS 5e. The microfossil assemblages (benthic foraminifera and ostracods) within
329 U4 show a dramatic decline in BH-02 and BH-07 (Table 4) that further supports the
330 interpretation of relative sea level drop and subaerial exposure of the shelf. U5 incorporates
331 mixed fluvio-estuarine deposits that could have been emplaced initially under lowered relative
332 sea levels, during which, regressional alluvial channel deposits continued to accumulate and
333 sealed the first incisional features. Incision synchronously propagated across these deposits,
334 and later as relative sea level began to gradually increase there could have been reduced
335 incisional capacity with aggradation of sediments due to a rise in base level and some filling

336 of the incised system, and owing to these evidences, we deduce U5 to represent the lowstand
337 systems tract. The gradual rise in sea level and estuarine sedimentation is corroborated by the
338 increase in population of brackish and saline water favoring benthic foraminifera species such
339 as *Elphidium* spp., *Operculina* spp. and *Quinqueloculina* spp. in BH-07. U6, demonstrating an
340 age of 8461 ± 29 cal yrs BP (Table 2) in the intermediate part of the sequence and which lies
341 above the transgressive surface, consists of shallow marine sediments that may have been
342 deposited during rapid transgression after ~15 ka BP, which could efficiently preserve the
343 preceding fluvial deposits, and we posit that this unit elucidates the transgressive systems
344 tract. Lastly, the Holocene sediments forming the hemipelagic drape of U7 that overlie the
345 maximum flooding surface represent the highstand systems tract.

346 **5.2. Valley morphology**

347 As defined by the seismic data shown in figure 5 (Fig. 1B for location), the valleys run
348 parallel to the coast and are between 1 and 10 km long. They follow a regional slope towards
349 the shelf break and reach maximum depths of ~30 to 40 m. These valleys are increasingly
350 wide towards the east, particularly where several valleys converge, and are linked to the
351 confluence of fluvial channels. Indeed, there could have been high rates of sedimentation,
352 channel flow and drainage discharge which could possibly explain the processes of alluviation
353 and incisional dynamics that promoted the notable widening of the emerging valleys in the
354 Java Sea (Fig. 8), that are mainly controlled by global sea level changes during the LGM
355 (Voris et al, 2000; Hanebuth et al., 2004; Clark et al, 2009; Sar et al, 2019).

356 These valleys, filled by marine transgressive deposits (U6–shallow marine), are underlain by
357 mixed fluviio-estuarine formations of weakly consolidated origin (U5–lowstand channel fill),
358 the facies of which are mainly fine to medium grained.

359 The morphology of the valleys demonstrates generally a flat bottom and markedly steep edges
360 (Fig. 5).

361 The morphology with a flat bottom and marked edge can be explained by the lithological
362 nature of the incised unit (U5), consisting of weakly consolidated and easily remobilized
363 alluvial plain deposits, and conversely as a zone where the potential for incision is very low
364 given the low to medium slopes in a region very far from the continental slope (Fig. 8A).
365 The incision depths of ~8 m to 32 m, (Fig. 5) are of the same order as those documented from
366 other parts of the world, for example, on the platforms of the American east coast (Thomas
367 and Anderson, 1994; Foyle and Oertel, 1997), the Bay of Biscay (Lericolais et al., 2001;
368 Chaumillon et al., 2008; Chaumillon et al. 2010; Menier et al., 2010; Estournès et al., 2012;
369 Menier et al., 2014; Martínez-Carreño and García-Gil, 2017), the Mediterranean (Tesson et
370 al., 2010; Tesson et al., 2015), India (Dubey et al., 2019) and also in Southeast Asia
371 (Hanebuth, et al., 2009; Puchala et al., 2011; Alqahtani, et al., 2015; Wang et al., 2020;
372 Horozal et al., 2021).

373 **5.3. Depositional evolution**

374 The main stratigraphic units recognized across the study area are composed of continental
375 formations (U4 and U5) that transitions upward to shallow marine deposits (U6 and U7). This
376 interpretation is also confirmed by the succession of fossil foraminifera faunas, from taxa that
377 are indicative of environments under continental influence (*e.g. Asterorotalia* spp.) to those
378 that are indicators of shallow coastal waters (*e.g. Dendritina* spp., *Spiroloculina* spp.,
379 *Operculina* spp.) (Fig. 7 and Table 4). The core and the major parts of the valley fills are
380 composed of alluvial deposits (U5) and shallow marine deposits (U6 and U7), and the vertical
381 facies succession is predominantly deposited within a transgressive setting.

382 In our proposed model of valley morphogenesis, the supposed thalweg, which overlays the
383 erosional surface UB-4, is dated at 41800 +/- 1500 cal. age BP, which corresponds to the last
384 and deepest incision (pre-LGM incision), and therefore, the overlaying fluvial deposits (U5)
385 could be younger than 25 ka. Based on deductions implied in previous studies (*e.g.*,

386 Posamentier and Allen, 1999; Posamentier, 2001), the alluvial channels more than likely
387 formed when the shelf was not fully subaerially exposed and the lowstand fluvial system was
388 incapable of substantially efficient downcutting, both laterally and vertically.

389 On the seismic records (Fig. 3B and Table 3) U4 seem to illustrate an irregular and oblique
390 aggrading subparallel or wavy reflector geometry and we interpret it as interfluves or bars,
391 dominated by sandy to silt-argillaceous facies established during the marine isotopic stage 3
392 (Fig. 9).

393 Unit 5 is interpreted to consist of lowstand channel fill deposits that accumulated during
394 periods of significant drops in sea level but the majority during the post lowstand system tract
395 (LST), which was lower than present-day in this zone (Fig. 9). Our results clearly highlight
396 the occurrence of alluvial channel deposits and nearshore tidal flat sediments that are
397 explicitly indicative of a shift from a relatively sand-rich lowstand system to a clay-rich
398 nearshore sediment as mention in Table 4. Gathering consensus from the global and Sunda
399 shelf sea level curves (Fig. 9), the transition from a fluvial to a shallow marine setting in our
400 data could correspond to the post-LGM abrupt and rapid sea level rise induced by
401 deglaciation. Furthermore, our inference of an abrupt and rapid rise in sea level is congruent
402 with previous findings (Hanebuth et al., 2000) of an accelerated increase in eustatic levels in
403 the northern Sunda Shelf during the MWP 1A (meltwater pulse) event that commenced at
404 ~14.7 ka and terminated before ~13.8 ka, including an abrupt rise of up to ~16 m within a
405 span of 300 years that occurred between 14.6–14.3 ka cal BP (Hanebuth et al., 2000).

406 Unit 6, dated at ~8461 +/- 29 cal. age BP, which mainly rests above Unit 5, is interpreted as
407 deposited in the course of the last sea level rise over the area (Fig. 8). As the fluvial valleys
408 were flooded by the rising sea levels, sediment supply could not keep pace with the increase
409 of accommodation space, and this would explain the aggrading nature of Unit 6. The very
410 homogeneous structure of Unit 6 and the inferred fine-grained sedimentation would point to a

411 wave-dominated bay (Dalrymple et al., 1994). While there is an inexistence of sandy barriers
412 in the seismic record, the Java Sea seems to be a sector that was very calm, favoring low-
413 energy sedimentation comparable to that in estuarine central basins (lagoonal basins). Further
414 expanding on our sedimentological and seismic data, we favor the interpretation of very calm
415 and low-energy conditions in the Java Sea during the deposition of Unit 6. We base this on an
416 additional line of evidence, viz. the preservation of Unit 5 could be plausible only under rapid
417 transgression and placid hydrodynamic environments. This can effectively weaken potential
418 erosional processes, given that ubiquitously, the efficient preservation of lowstand fluvial
419 deposits, subsequent to erosion during transgression and reworking by inclement
420 hydrodynamic conditions, would be, at best, in patches (Allen, 1991; Allen and Posamentier,
421 1993; Posamentier, 2001).

422 Unit 7 is interpreted as offshore muds aggrading above the estuarine valley fills as the first
423 succession overlaying UB-6. It rests above the maximum flooding surface that truncates all
424 the units below (Figs. 4 and 10). The unit is dated at $\sim 3308 \pm 24$ yr BP, and is composed of
425 Holocene-age hemipelagic drape. U7 was emplaced during a full transgression over the area,
426 inasmuch as it overlaps most of the valley interfluves.

427 **6. Conclusions**

428 Two remarkable incisions are identified in the Java Sea shelf. The first incision occurred
429 during the sea level drop of the marine isotopic stage 3, which was later sealed by
430 lowstand alluvial channel deposits. These deposits were re-incised during the LGM,
431 creating the second incisional surface. This discontinuity does not intersect the Upper
432 Pleistocene incision, indicating a relatively low incision potential, in a context of rapid sea
433 level rise within very sheltered hydrodynamic conditions.

434 The incised valleys demonstrate a wide and flat bottom morphology along with very steep
435 edges owing to low velocity channel flow and shallow paleo-topographic gradients. The

436 sedimentary infill of the incised valleys indicates the continent-offshore extension of the
437 paleodeltaic system, complete with variable facies characteristics and variable rates of
438 deposition. Influences of regional slope and hydrodynamics are recognized to have
439 exercised control over the spatial distribution of facies types as well as grain sizes of the
440 facies types.

441 Prevalence of major river systems that drained the Sundaland Craton that advanced over
442 former offshore regions during LGM created an extensive incised valley and associated
443 geomorphic-sedimentary infill.

444 **Author Contributions**

445 Author Contributions: Conceptualisation: F.N., D.M., M.M., H. and C.E.; methodology: F.N.,
446 D.M., R.K. and M.S.; field investigation: F.N. and I.K.; manuscript preparation: F.N., D.M.,
447 M.M., M.R. and H.; review and editing: F.N., D.M., M.M., M.R., M.S. and C.E.; figures:
448 D.M., M.M., F.N., and C.E.; microfossil analysis: F.N. and K.T.D.

449 **Acknowledgements**

450 The field activities were fully supported by the Ministry of Public Works and Housing, the
451 Republic of Indonesia, under the grant bearing the contract number HK.02.03/PPK-
452 PP/SBBWSCC/1311.2 and also by the Ministry of Energy and Mineral Resources, the
453 Republic of Indonesia, under the contract number P.P.G.L. G.F. 030.90. We also
454 acknowledge the Embassy of France in the Republic of Indonesia and M. Jean-Charles
455 BERTHONNET for providing the funding for the AMS analysis through the ‘Programme
456 Science and Impact’ (March 2017) initiative. M.M. was supported by the ISblue project,
457 Interdisciplinary Graduate School for the blue planet (ANR-17-EURE-0015) and by a grant

458 from the French Government under the program “Investissements d’Avenir”. We express our
459 gratitude to Ir. Duddy Ranawijaya for significantly contributing to improve the manuscript.

460

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682

683 **Caption Figures**

684 **Figure 1. A:** Map showing the spatial distribution and type of vegetation cover in Sundaland
685 during the LGM. Figure adapted from Heaney (1991), Voris (2000) and Bird et al. (2005). **B:**
686 Location of seismic lines in the Java Sea and also shown are the bathymetry contours. **C:**
687 Location of seismic lines and boreholes used in this study from the Jakarta Bay.

688 **Figure 2. A.** Map of the Java Sea seafloor sediments. **B.** Map of seafloor sediments of the
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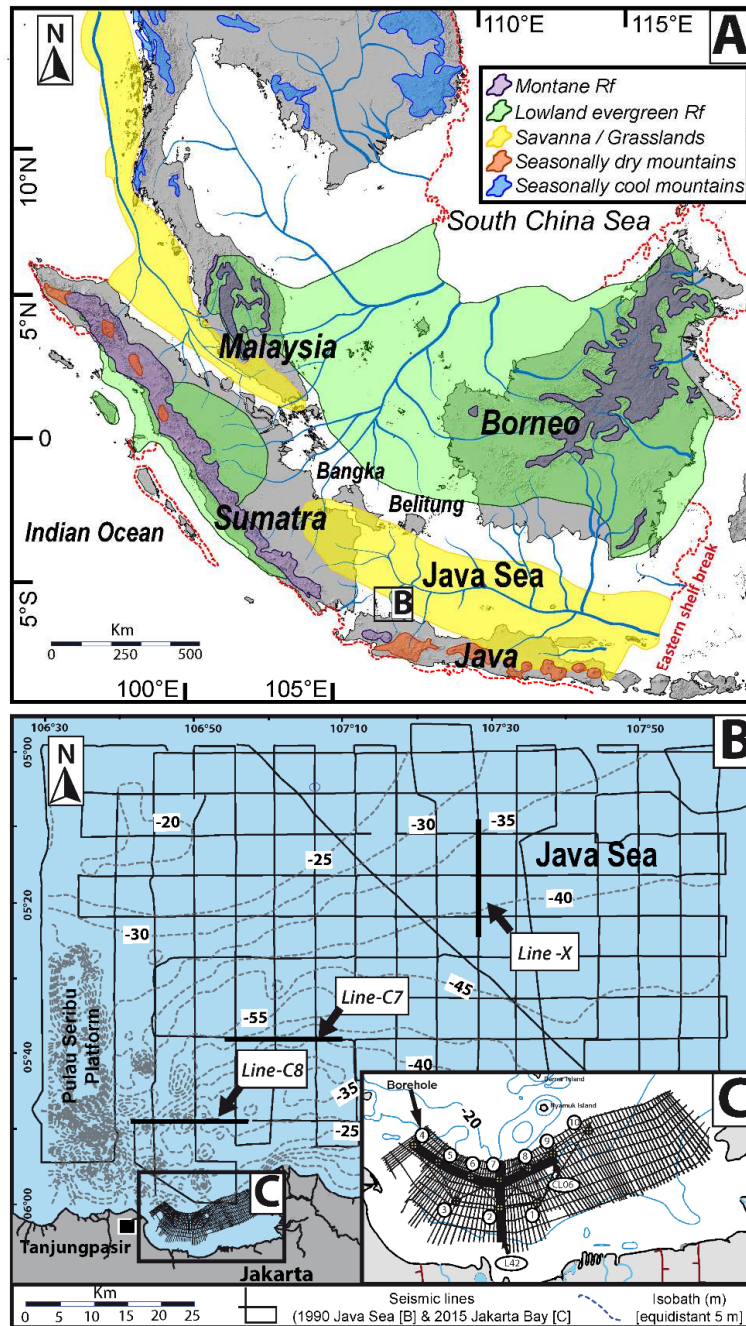
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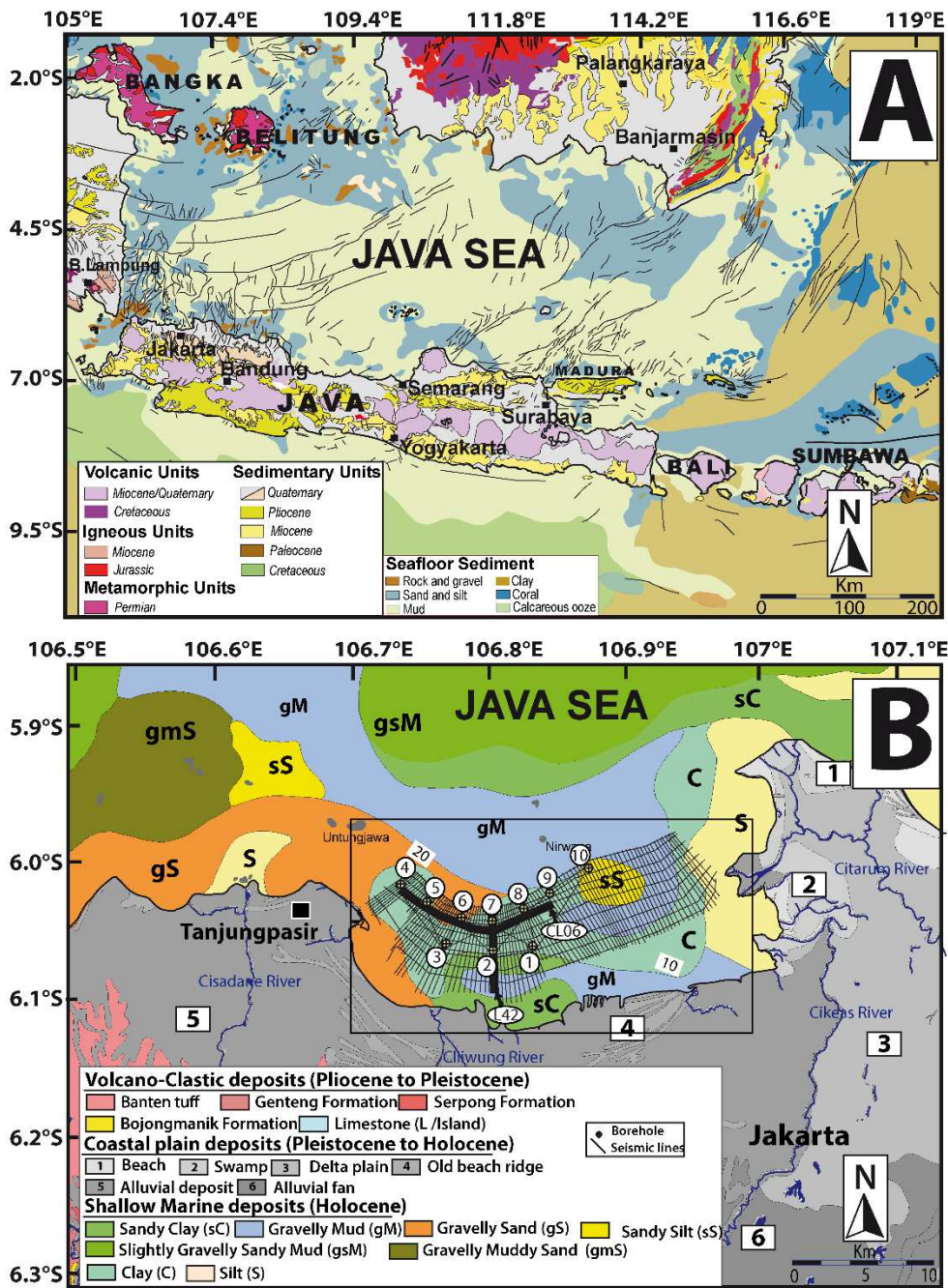
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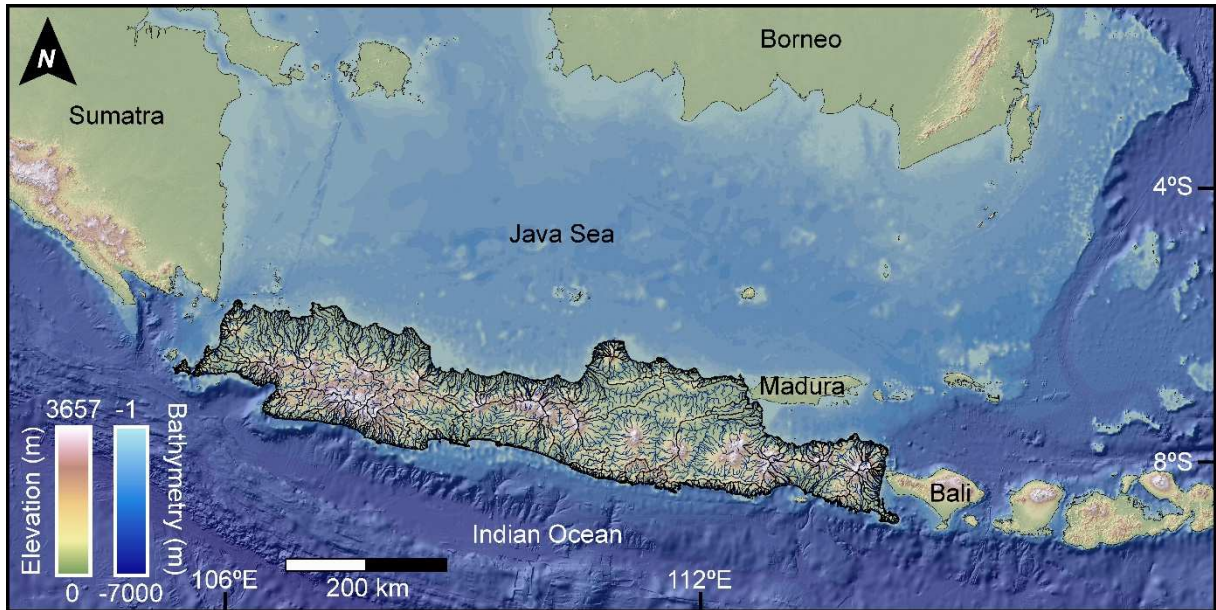


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745 **Figure 1. A:** Map showing the spatial distribution and type of vegetation cover in Sundaland
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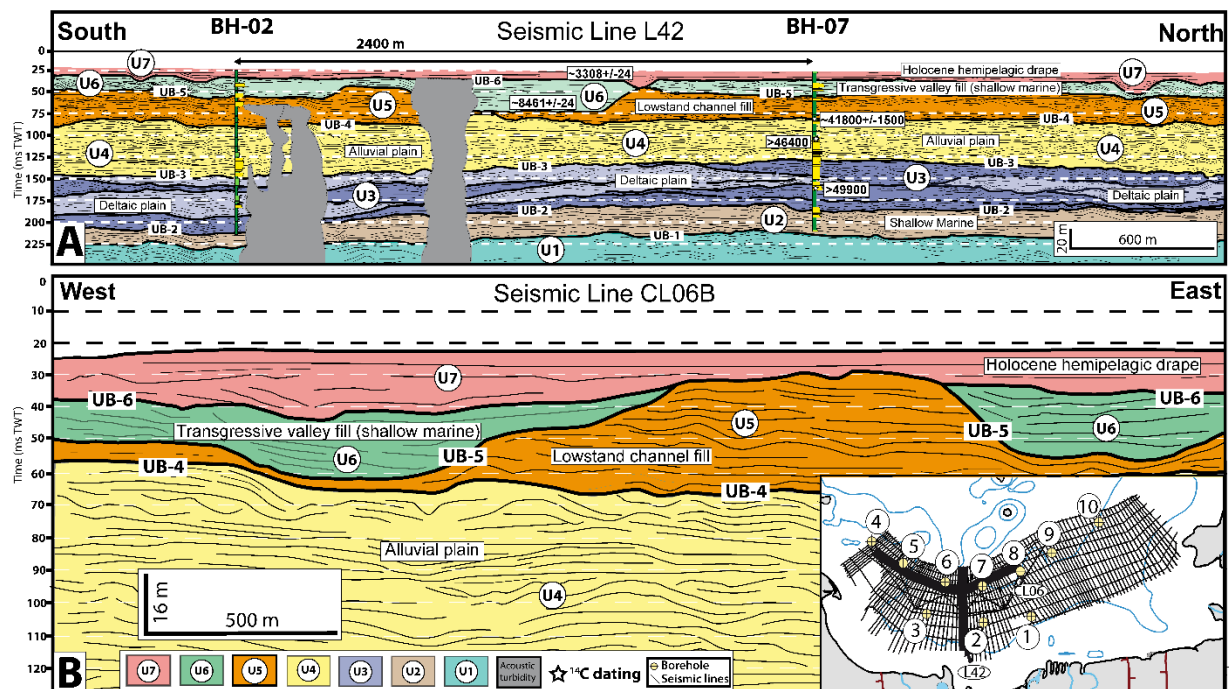


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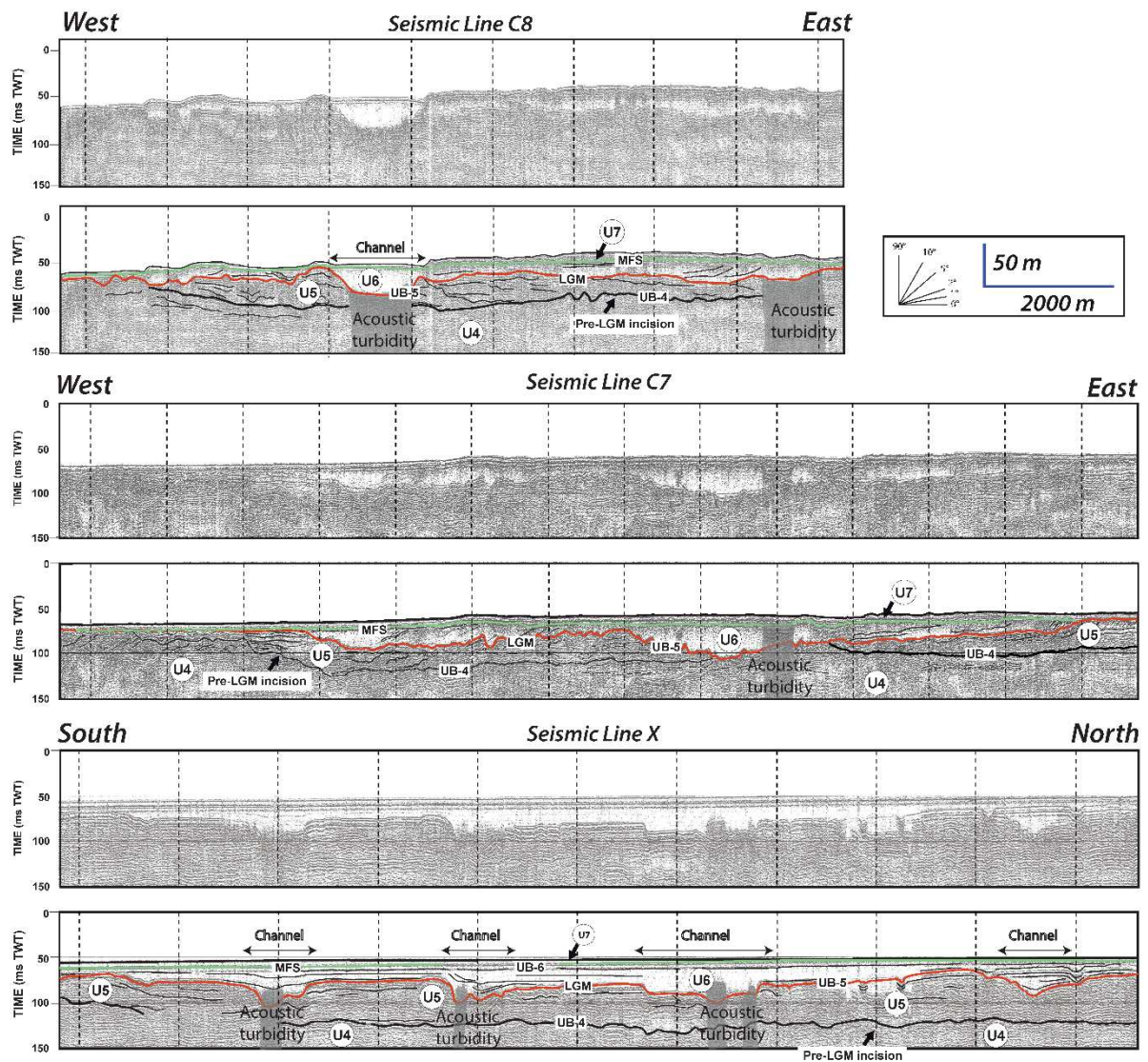
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 765 of 1600 m/sec. Note that the light blue coloured packages within U3 indicate the head of several
 766 deltaic lobes that are stacked and extends laterally. **B:** Sparker 2D High Resolution Seismic
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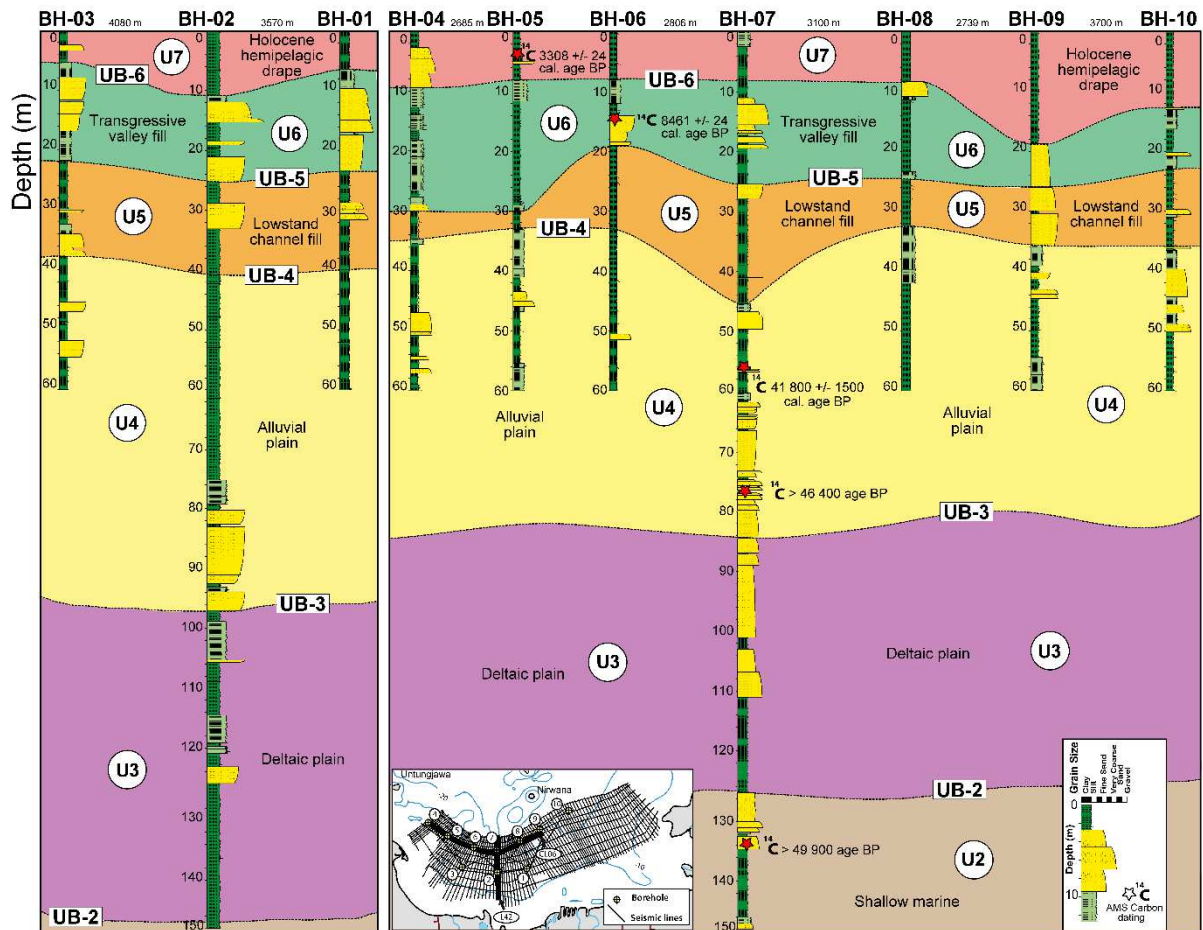
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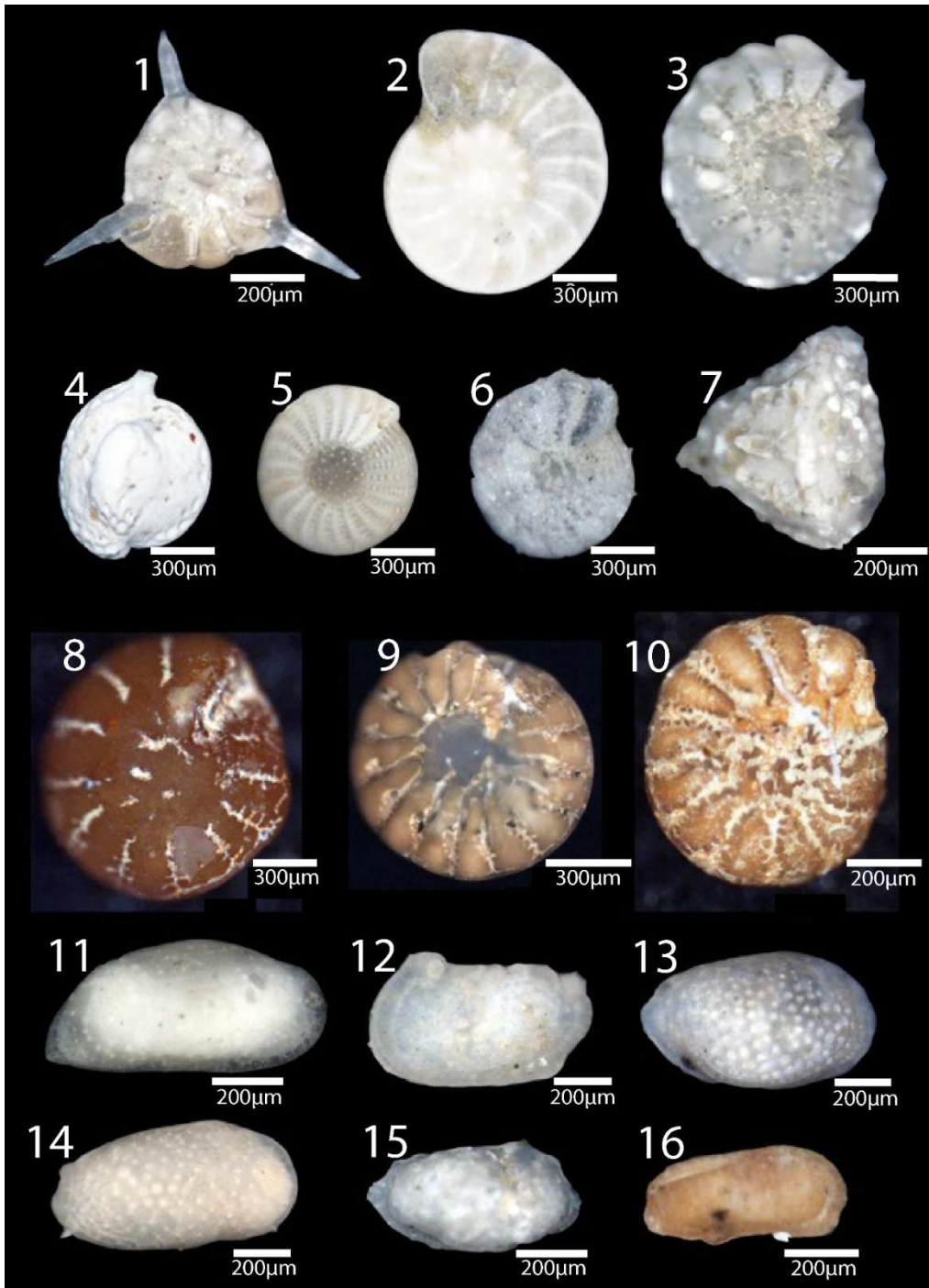
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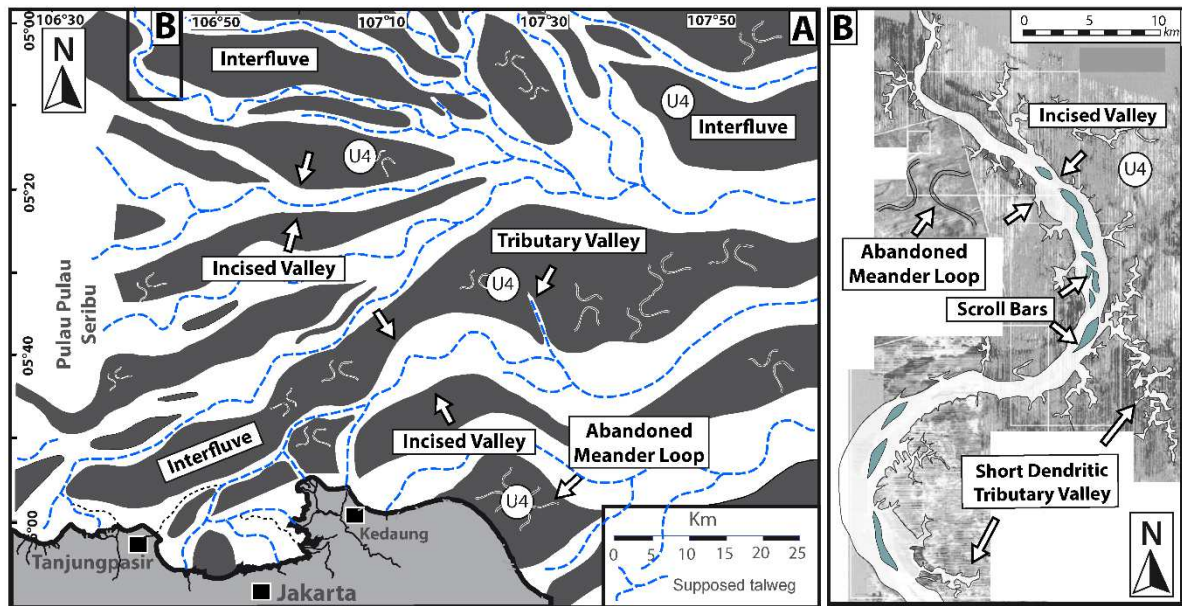
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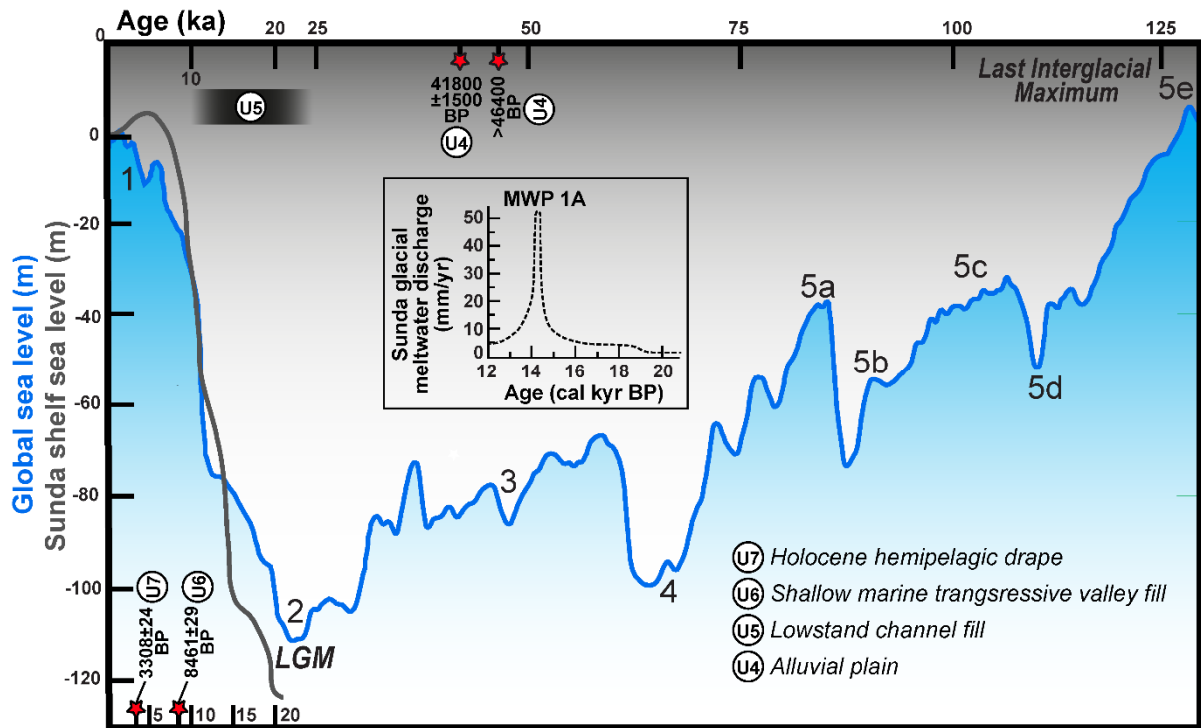
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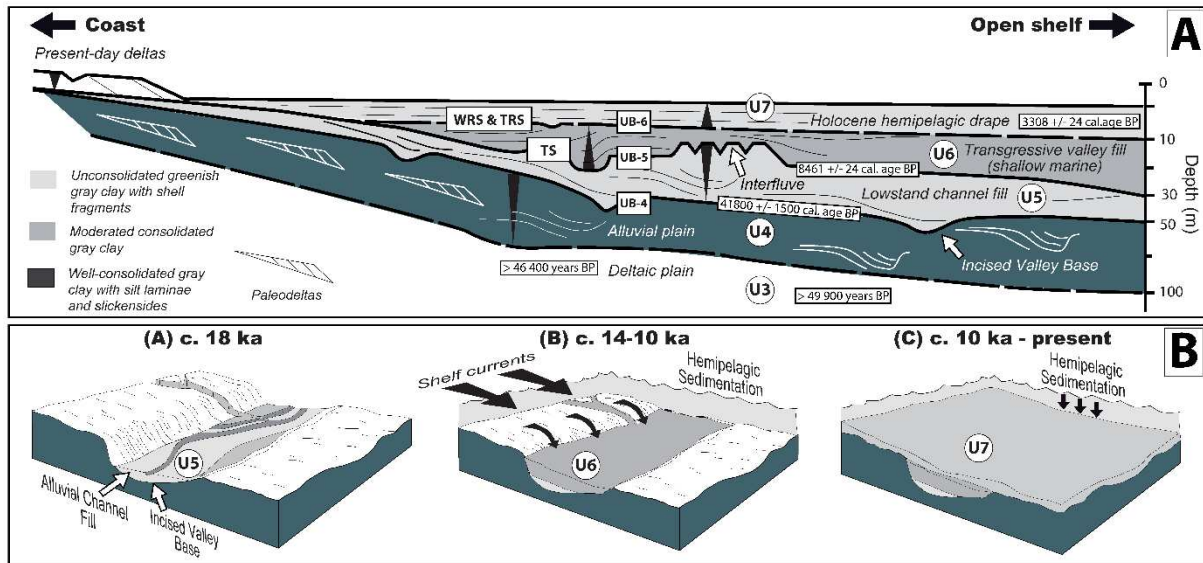
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 831 **Jakarta Bay and analysed in this study**

Core	Core length (m)	Water depth (m)	Coordinates		
			WGS_1984_UTM_Zone_48S X (m)	Y (m)	Latitude (S) Longitude (N)
1	60	15.31	704259.24	9330033.60	6°3'28.92" 106°50'43.98"
2	150	14.72	700755.12	9329627.65	6°3'42.52" 106°48'50.09"
3	60	13.76	696699.08	9330108.06	6°3'27.30" 106°46'38.15"
4	60	14.46	692826.95	9335232.98	6°0'40.92" 106°44'31.67"
5	60	15.27	695034.37	9333810.38	6°1'26.97" 106°45'43.62"
6	60	16.54	697886.62	9332414.95	6°2'12.11" 106°47'16.50"
7	150	17.36	700646.47	9332020.42	6°2'24.64" 106°48'46.28"
8	60	18.23	703556.3	9334974.58	6°1'49.40" 106°50'20.78"
9	60	19.59	705541.07	9334974.41	6°0'47.30" 106°51'25.11"
10	60	20.49	708651.68	9336919.69	5°59'44.30" 106°53'6.01"

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833 **Table 2. AMS ¹⁴C dating of shells, shell fragments and sediments retrieved from the**
 834 **cores**



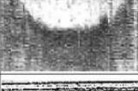
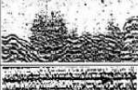
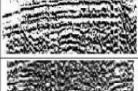
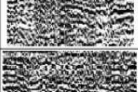

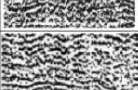
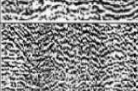








Core	Lab number	Depth (mbss)	Seismic Unit	$\delta^{13}C$ value	Age (¹⁴ C years BP)	Material
BH-05	X32132	7	U7	3.5	3308±24	Shell
BH-06	X32133	14.3	U6	-4.0	8461±29	Shell
	X31404	56.2	U4	-29.1	41800±1500	Sediment and shell fragments
BH-07	X31405	77.00	U4	-19.2	>46400	Sediment and shell fragments
	X31406	134.45	U2	0.8	>49900	Sediment and shell fragments

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Unit	Facies	Illustration	Continuity	Amplitude	Frequency	Reflector Configuration	Interpretation
U-7	F-7A		Good	Good	Medium	Aggrading parallel	Marine muds
	F-7B		Medium	Good	Medium	Aggrading parallel	Channel fill
U-6	F-6A		Poor	Very poor	Low	Transparent	Channel infill polymix
	F-6B		Poor	High	Low	Acoustic turbidity	Gas-charged sediments
	F-6C		Poor	Medium	High	Aggrading parallel	Bars associated to channel migration
U-5	F-5A		Very poor	Medium	Low	Acoustic turbidity	Gas-charged sediments
	F-5B		Poor	Medium	High	Oblique-aggrading subparallel	Channel bars system
	F-5C		Poor	High	High	Oblique-aggrading subparallel	Channel bars system
U-4	F-4A		Medium	Medium	High	Aggrading subparallel	Bars associated to channeling drainage system
	F-4B		Poor	Medium	Medium	Acoustic turbidity	Gas-charged sediments
	F-4C		Poor	Poor	Medium	Irregular Oblique-aggrading subparallel	Bars associated to channeling drainage system
U-3	F-3A		Medium	Medium	Medium	Aggrading subparallel	Marine muds and sandy intercalation
	F-3B		Very poor	Medium	Medium	Acoustic turbidity	Gas-charged sediments
U-2	F-2A		Medium	Medium	Low	Aggrading folded parallel	Marine muds
	F-2B		Very poor	Medium	Low	Acoustic turbidity	Gas-charged sediments
U-1	F-1A		Low	Medium	Low	Aggrading subparallel	Marine sediments
	F-1B		Very poor	Low	Low	Acoustic turbidity	Gas-charged sediments

