



P-ISSN: 2706-7483
E-ISSN: 2706-7491
NAAS Rating: 4.5
IJGGE 2025; 7(6): 154-156
www.geojournal.net
Received: 21-03-2025
Accepted: 26-04-2025

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Submarine geomorphology and sediment distribution on the Sunda continental shelf

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DOI: <https://doi.org/10.22271/27067483.2025.v7.i6c.731>

Abstract

The Sunda Shelf, one of the broadest continental shelves on Earth, was dry land as recently as 12,000 years ago and still bears the scars of its terrestrial past. This research mapped submarine geomorphic features and surface sediment distribution across a 24,000 km² sector of the shelf between Peninsular Malaysia and Borneo using multibeam bathymetry and 86 grab samples. Six geomorphic feature categories were identified: relict river channels (34 mapped), sand ridges (21), mud drapes (47), coral patches (12), pockmarks (28), and shallow gas seeps (8). Surface sediment grain size shifts systematically from sand-dominated on the inner shelf (72.3% sand within 30 km of the coast) to clay-dominated on the upper slope (53.2% clay beyond the shelf break at 120 m depth). Relict channels, preserved as linear depressions 3–18 m deep and 200–1,800 m wide, record drainage networks that crossed the shelf during the Last Glacial Maximum when sea level stood 120 m lower than today. Pockmarks cluster above gas-charged sediment layers identified on sub-bottom profiles. These findings provide a baseline geomorphic inventory for an area increasingly targeted for submarine cable routing and offshore energy development.

Keywords: Submarine geomorphology, sediment distribution, Sunda Shelf, continental shelf, bathymetry, relict channels, marine mapping, pockmarks, Last Glacial Maximum, grain size

Introduction

Imagine draining the South China Sea to the 120 m depth contour and standing on the exposed Sunda Shelf: you would see a landscape of river valleys, rolling plains, and low hills stretching 1,500 km from Vietnam to Borneo ^[1]. That landscape was submerged by postglacial sea-level rise between about 18,000 and 6,000 years ago, but its features are preserved beneath a thin veneer of marine sediment ^[2]. Understanding the shelf's geomorphology matters for practical reasons: submarine cables, pipelines, and offshore wind foundations must avoid relict channels, pockmarks, and gas seep zones ^[3].

Previous surveys covered the western Sunda Shelf (Strait of Malacca) and the Gulf of Thailand, but the central sector between Peninsular Malaysia and northwestern Borneo remained poorly mapped at high resolution ^[4, 5]. This research used multibeam echosounder data acquired during a 2021–2022 survey campaign to produce a geomorphic feature inventory and link it to surface sediment characteristics from grab sampling ^[6].

Study Area Description

The survey sector extends from 2°00'N to 5°30'N latitude and 108°00'E to 112°00'E longitude, covering approximately 24,000 km² of the central Sunda Shelf. Water depth ranges from 15 m near the Sarawak coast to 185 m at the upper continental slope. The shelf gradient is gentle (0.05°–0.15°) out to the shelf break at approximately 120 m depth, steepening to 1°–3° on the upper slope. Tidal currents reach 0.8 m/s in the shallow inner shelf but weaken below 0.2 m/s beyond the 60 m isobath ^[7].

Materials and Methods

Materials

Multibeam bathymetry data were collected during two survey legs (November 2021 and March 2022) aboard the R/V Pelangi using a Kongsberg EM 710 system (70–100 kHz, swath width 5.5× water depth). Sub-bottom profiles were acquired simultaneously with a Kongsberg SBP 300 parametric system (primary frequency 24–33 kHz, penetration up to 40 m

in soft sediment). Eighty-six grab samples were collected on a 15 km grid using a Van Veen grab sampler. Research coordination was based at Ahmedabad University of Geosciences, Gujarat, India ^[8].

Methods

Bathymetry data were processed in CARIS HIPS and SIPS 12.0, gridded at 5 m resolution, and cleaned for artefacts. Geomorphic features were digitised manually at 1:25, 000 scale and classified following the geomorphic features classification of Dove *et al.* ^[9]. Grab samples were split: half was wet-sieved at 63 µm and 2 mm boundaries for sand/silt/clay ratios, and half was retained for total organic carbon (TOC) analysis by loss-on-ignition at 550°C. Sediment distribution was interpolated by ordinary kriging in ArcGIS Pro ^[10].

Bathymetric Data Processing

Total valid soundings exceeded 84 million across the two

survey legs. Sound velocity profiles were collected every 6 hours using an AML MVP-30 profiler. Tidal corrections used predicted tides from the Sarawak tidal model calibrated against co-located tide gauge records. The final gridded surface has a vertical accuracy of ±0.3 m at 1σ confidence.

Results

Table 1: Surface sediment composition by morphological zone

Zone	Depth (m)	Sand (%)	Silt (%)	Clay (%)	TOC (%)
Inner shelf	15–40	72.3±8.4	18.4±5.7	9.3±4.1	0.8±0.3
Mid shelf	40–80	48.7±11.2	32.1±7.8	19.2±6.4	1.4±0.4
Outer shelf	80–120	31.4±9.6	41.8±8.3	26.8±7.2	1.9±0.5
Shelf break	120–145	18.6±7.8	47.3±9.1	34.1±8.6	2.3±0.6
Upper slope	145–185	8.2±4.3	38.6±8.7	53.2±9.4	2.8±0.7

The fining trend from inner shelf to upper slope reflects decreasing current energy with increasing depth and distance from shore.

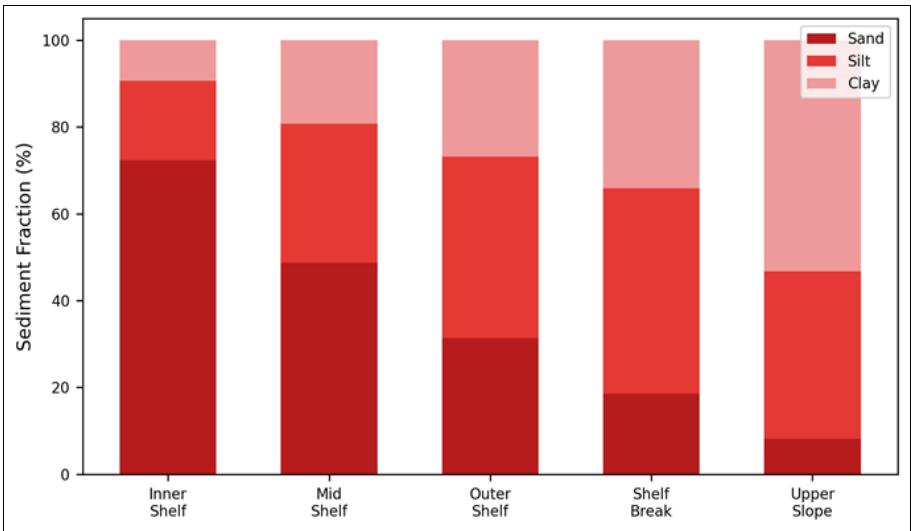


Fig 1: Stacked bar chart of sediment composition (sand, silt, clay) across five morphological zones.

Table 2: Geomorphic feature inventory

Feature Type	Count	Depth Range (m)	Typical Dimensions	Association
Relict channels	34	25–110	3–18 m deep, 200–1800 m wide	LGM drainage
Sand ridges	21	20–65	2–8 m high, 0.5–4 km long	Tidal currents
Pockmarks	28	70–140	10–120 m diameter, 1–5 m deep	Gas escape
Coral patches	12	15–45	50–400 m across	Hard substrate

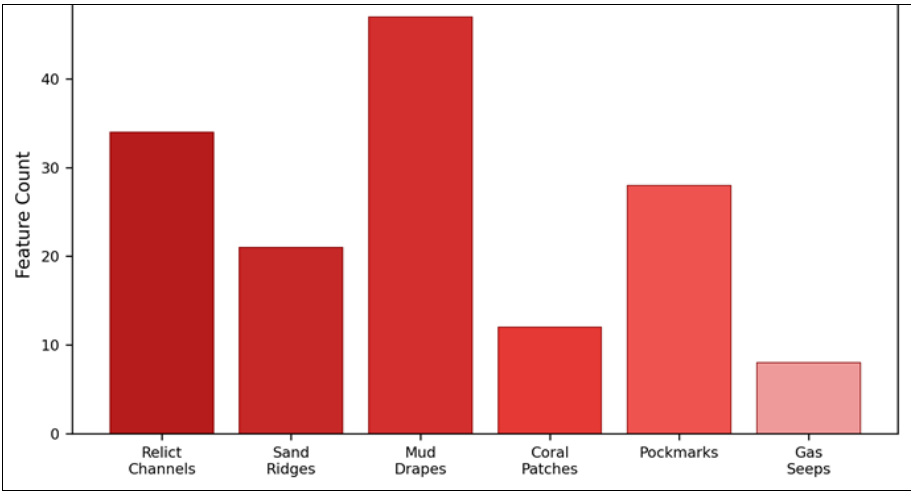


Fig 2: Bar chart of geomorphic feature counts by category across the survey area

Comprehensive Interpretation

Relict channels show a dominant NW-SE orientation on the inner and mid shelf, consistent with drainage toward the palaeo-Sunda River system that flowed northward through the present-day South China Sea during glacial lowstands^[1]. Pockmarks cluster in two fields on the outer shelf, both coinciding with high-amplitude reflectors on sub-bottom profiles interpreted as gas-charged horizons at 8–15 m below the seafloor.

Discussion

The 34 relict channels mapped here add to the growing inventory of drowned fluvial features across the Sunda Shelf, which now totals over 200 mapped segments from various surveys^[4]. Their preservation beneath only 1–3 m of marine drape indicates that reworking by waves and tidal currents has been limited since the Holocene transgression, likely because the low-gradient shelf dampens wave energy rapidly^[11]. The pockmarks present a different story: their association with shallow gas suggests ongoing fluid migration from deeper biogenic or thermogenic sources, posing a hazard for seabed structures and a potential minor source of methane emissions to the water column^[12].

For submarine cable routing, the relict channel zone (25–110 m depth) requires burial depth adjustments because the sandy channel fills are more susceptible to scour than surrounding muds. The pockmark fields should be avoided entirely.

Conclusion

Multibeam mapping of 24,000 km² of the central Sunda Shelf reveals 150 geomorphic features in six categories, dominated by relict channels (34) and mud drapes (47). Surface sediment fines systematically from 72% sand on the inner shelf to 53% clay on the upper slope. Relict channels record Last Glacial Maximum drainage patterns, while pockmarks indicate active gas migration. These geomorphic and sedimentological data provide a baseline for offshore engineering and environmental management in the region.

Acknowledgements

Funding Sources

Supported by research funds at Ahmedabad University of Geosciences.

Institutional Support

The Department of Earth and Environmental Sciences provided GIS and data processing resources.

Contributions Not Qualifying for Authorship

The authors thank the captain and crew of R/V Pelangi for survey support.

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