

## RESEARCH ARTICLE

# Seabed Morphology and Geohazard Assessment for Subsea Pipeline Routing based on MBES and Seismic Data: A Case Study of Teluk Palabuhanratu, Indonesia

Chairunisyah Putri Salsabila<sup>1</sup>, Idarwati<sup>1</sup>, Muhammad Alfath Salvano Salni<sup>1\*</sup>, Faris Nauval Rasyid<sup>2</sup>

<sup>1</sup>Department of Geological Engineering, Faculty of Engineering, Universitas Sriwijaya, Indonesia

<sup>2</sup>Center for Marine Geological Survey and Mapping, Geological Agency, Ministry of Energy and Mineral Resources, Indonesia

\* Corresponding author : [muhammadalfathsalvanosalni@ft.unsri.ac.id](mailto:muhammadalfathsalvanosalni@ft.unsri.ac.id)

Tel.: +62 822-1427-8330

Received: Oct 1, 2016; Accepted: Nov 20, 2016.

DOI: 10.24273/jgeet.2016.1.2.001

## Abstract

To support the development of subsea pipeline infrastructure across Java, there is a need to assess geohazard potential in Teluk Palabuhanratu. The aim of this study is to characterize seabed morphology and evaluate its implications for geohazard potential for subsea pipeline routes. The method employed consists of morphometric analysis based on digital bathymetric model (DBM) that is derived from multibeam echosounder (MBES), delineation of seabed morphological units by integrating DBM with seismic interpretation, and geohazard assessment based on morphometric parameters and morphological units. Seabed morphology is predominantly characterized by very gentle to gentle slopes, near-planar curvature, and low roughness, while localized zones of steep slopes, complex curvature, and high roughness are associated with faults, submarine landslides, and mud volcanoes. Ten morphological units were identified, including slopes, ridges, knolls, channels, basin floors, sand ridges, mounds, valleys, gullies, and landslides. The geocost-based geohazard assessment indicates a spectrum of hazard potential ranging from low to high for subsea pipeline. High hazard levels are associated with steep slopes, high roughness, and morphological units influenced by erosion and mass-transport processes, such as gullies, valleys, and fault-associated ridges.

**Keywords:** Multibeam Echosounder, Seabed Morphology, Seismic, Submarine Geohazard, Teluk Palabuhanratu

## 1. Introduction

Subsea pipelines for hydrocarbon transportation of Java Island have expanded significantly in recent years. In West Java, pipelines extend from North Cirebon to the Seribu Islands, covering an area of approximately 8,300 km<sup>2</sup> (Putra et al., 2024). Additionally, in east Java, natural gas is transported through 370 km subsea pipelines connected to onshore pipelines (Dhina and Permana, 2021). Similar subsea pipeline developments have also been reported in the Northeast Java Sea (Silvianita et al., 2021). National development plans of Indonesia target a substantial expansion, with up to 17,300 km of subsea pipelines projected by 2024 (Puspasari et al., 2021). Taking together, these developments highlight the growing subsea pipeline development across Java.

Despite their strategic importance, subsea pipelines remain highly vulnerable to geohazards, particularly in tectonically active settings. Teluk Palabuhanratu is situated along the southern margin of the West Java Basin and in close proximity to a subduction zone (Martodjodjo, 1984). Multiple geological hazards, including soil movement, earthquakes, and tsunamis, pose significant threats to the region (Ar-Rouf, 2025). Moreover, the presence of shallow earthquake epicenters linked to the Cimandiri fault zone highlights the significant seismic risk in the area (Muslim et al., 2019). Altogether, these conditions present considerable challenges for planning subsea pipeline routes in Teluk Palabuhanratu.

Seabed morphological assessment plays a fundamental role in evaluating subsea geohazards. Active pockmarks threatening

port structures were identified through seabed morphology analysis in Katakolo, Greece, highlighting the necessity of integrating morphological assessment into port maintenance (Tsoukala et al., 2024). In Indonesia, seabed morphology characterization was applied to evaluate hazards along a submarine cable route, where clusters of pockmarks were recognized as high-hazard zones requiring route modification (Ardhyastuti et al., 2023).

Although geohazards of Teluk Palabuhanratu are well recognized, geohazard assessment based on seabed morphology in this area remains limited. Therefore, this study aims to characterize seabed morphology and evaluate its implications for geohazards for subsea pipeline routes in Teluk Palabuhanratu through the integration of Multibeam Echosounder (MBES) bathymetry and two-dimensional (2D) seismic reflection data.

## 2. Data and Methods

### 2.1 Data

The data used in this study consists of MBES bathymetry and 2D seismic reflection. Prior to analysis, the MBES data underwent standard preprocessing, including position, tidal, sound velocity, and vessel motion corrections, to enhance depth accuracy and spatial consistency (Lubis et al., 2017). The corrected data were then interpolated to generate a Digital Bathymetric Model (DBM) (Fig. 1). DBM is used as the primary basis for seabed morphology analysis in Teluk Palabuhanratu. Meanwhile, the 2D seismic reflection data were

utilized to characterize subsurface stratigraphy and structural features. This data provides essential support for the interpretation of morphological units determined by DBM.

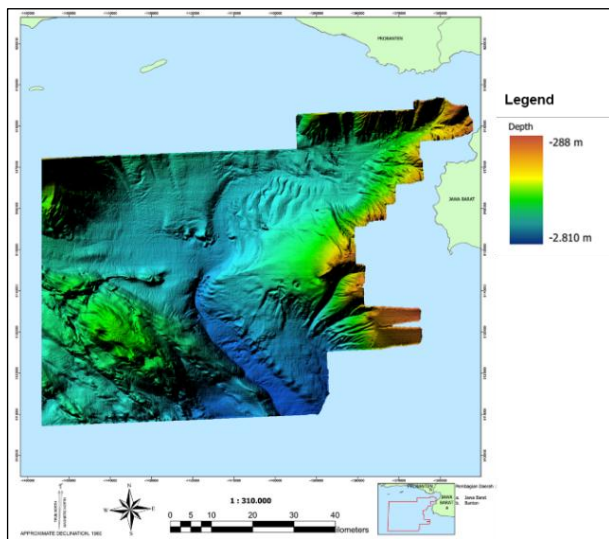


Fig 1. DBM of Teluk Palabuhanratu

## 2.2 Methods

### 2.2.1 Seabed Morphometric Analysis

Seabed morphometric analysis was conducted by calculating slope, curvature and roughness of Teluk Palabuhanratu seabed based on DBM using ArcGIS Pro. Slope was calculated as it represents potential gravitational instability (Kanamatsu et al., 2024). Curvature analysis was applied to identify concave and convex surface forms that may indicate erosional processes (Zulkifli et al., 2024). Surface roughness was derived as it could be associated to hazard of slope failure (Unterseh and Contet, 2015). These parameters were used collectively to as input to identify morphological units and geohazard assessment parameters.

### 2.2.2 Morphological Unit Delineation

The identification and delineation of seabed morphological units was based on a two-part seabed geomorphology classification scheme (Dove et al., 2020; Nanson et al., 2023). Initially, the area was classified solely based on their morphology, such as planar surfaces, inclined surfaces, lineaments, highs, or lows with further classification outlined in Part 1 (Fig. 2). Subsequently, interpretation of 2D seismic profiles was used to classify these features into Basic Geomorphic Units (BGU) and, where possible, more specific BGU Types (BGU-T), based on their inferred setting and governing processes as defined in Part 2 (Fig. 2).

### 2.2.3 Geohazard assessment

The assessment of geohazard for subsea pipeline routing at Teluk Palabuhanratu utilized the Geocost concept (American Bureau of Shipping, 2016). The assessment was performed by integrating the identified morphological unit type, slope, and roughness parameters through a weighted overlay analysis with ArcGIS Pro. Relative weights were assigned to each parameter, which reflects how significant the contribution is for hazard level. Each parameter was assigned a score based on its classification level, allowing the parameters to be combined (Table 1). The results, which range from 1 to 10, were

subsequently classified into hazard levels with each geohazard example and mitigation recommendation (Table 2).

Table 1. Parameter weighting for geohazard assessment

No.	Morphological unit (45%)	Score
1	Fault	10
2	Escarpment	10
3	Knoll	10
4	Mound	10
5	Sand Ridge	10
6	Gully	8
7	Valley	10
8	Floor	3
9	Channel	10
10	Slope	10
11	Ridge	10
No.	Slope (35%)	Score
1	0°–3°	1
2	3°–5°	2
3	5°–10°	4
4	10°–15°	8
5	>15°	10
No.	Roughness (20%)	Score
1	0 – 0.6 m	1
2	0.6 – 16 m	10

Table 2. Description of geohazard and mitigation based on Geocost

Geocost	Hazard Level	Geohazard Example	Mitigation
1	Negligible	Smooth surface, inferred to be geologically very old, radiometric age dates suggest no geological recent movement.	Avoidance unnecessary. Possible to mitigate using engineering solutions if necessary.
2 – 4	Low Hazard	Smooth surface, inferred to be geologically old, no radiometric data available.	Mitigation using engineering solutions depends on site specific details, avoidance should be considered but not necessary.
5 – 7	Moderate Hazard	Rough surface, inferred to be geologically young, geological evidence (scallop fractures) suggests movement in the past 11,000 years.	Mitigation using engineering solutions depends on site specific details, avoidance recommended.
8 – 10	High Hazard	Rough surface, inferred to be geologically very young, radiometric age dating suggests evidence of geological recent movement (numerous seafloor fractures).	Mitigation is not practical – avoidance strongly recommended.
N/A	Impassible Zone	Geological evidence suggests frequent occurrence of landslides, area deemed impassible.	Mitigation not applicable – complete avoidance.

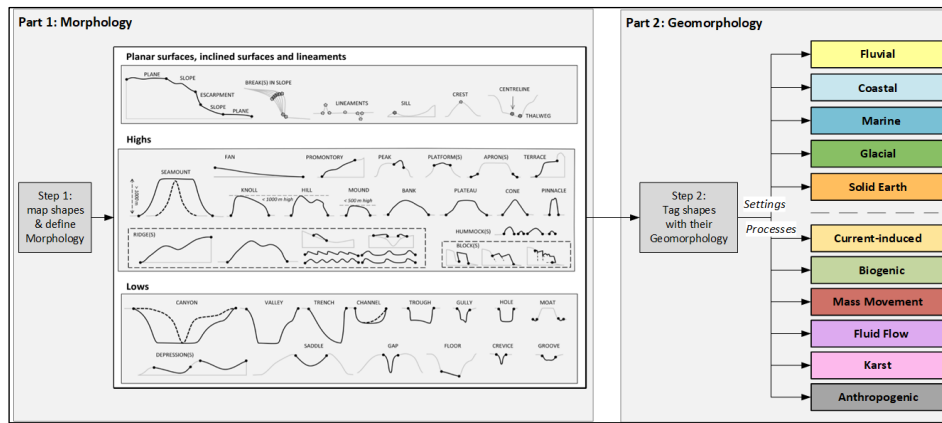


Fig 2. Classification framework used to classify seabed morphology (Nanson et al., 2023).

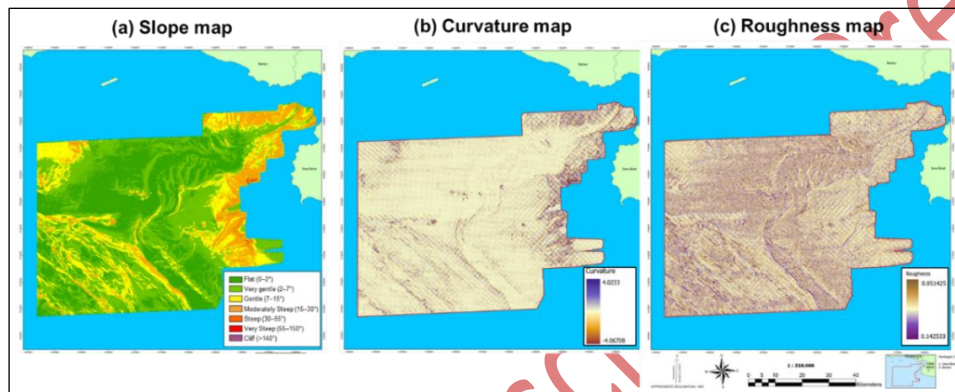


Fig 3. Spatial distribution maps of seabed morphometric parameters of (a) slope, (b) curvature, and (c) roughness

### 3. Results and Discussions

#### 3.1 Seabed Morphometry of Teluk Palabuhanratu

Slope reflects the intensity of submarine processes and the potential for gravitational instability (Cappadonia et al., 2016). The results indicate that the study area is predominantly characterized by very gentle to gentle slopes, suggesting relatively stable seabed conditions (Fig. 2a). Moderately steep slopes occur mainly within transitional zones between major morphological units, whereas steep to very steep slopes are confined to limited areas associated with pronounced relief and geological structures.

Curvature analysis is used to identify concave and convex morphological zones that may reflect processes such as erosion, sediment accumulation, and the influence of underlying geological structures (Hasenhündl and Blanckaert, 2022). The results show that low curvature values are developed in relatively flat seabed areas, whereas higher positive and negative values are concentrated along slopes, ridges, and valleys (Fig. 2b). The occurrence of complex curvature patterns in transitional morphological zones indicates more active geomorphological processes (Hart and Sagan, 2007).

The seabed roughness map was derived to represent the degree of surface irregularity of the seabed (Fig. 2c). Roughness values reflect variations in small-scale topography, where low values indicate relatively smooth surfaces and higher values represent more complex relief. In the study area, roughness values are generally low to moderate, locally elevated roughness values occur in zones of morphological transition, particularly along steep slopes, ridges, and submarine valleys.

#### 3.2. Seabed Morphological Unit of Teluk Palabuhanratu

Morphological unit identification of seabed was carried out through the interpretation of morphometric parameters and seismic. Eleven morphological units were identified, including

ridge, channel, basin floor, slope, sand ridge, mound, knoll, valley, gully, and landslide (Fig. 3).

##### 3.2.1 Ridge

A ridge is a seabed morphological unit characterized by an elongated positive relief with a relatively higher elevation than the surrounding seafloor (Dove et al., 2020). MBES bathymetric data identify the ridge as a linear protrusion with a distinct orientation and relatively steep slopes on both flanks, as also illustrated by the A–A' cross-section (Fig. 5A). Seismic data indicates uplift of sedimentary layers beneath the ridge crest, followed by subsidence on both sides, accompanied by deformed reflectors intersected by fault systems. These characteristics suggest that the ridge formation is structurally controlled by subsurface deformation and tectonic processes, while sedimentary layers outside the ridge zone appear more parallel and continuous, indicating relatively stable depositional conditions (Escartín and Olive, 2022).

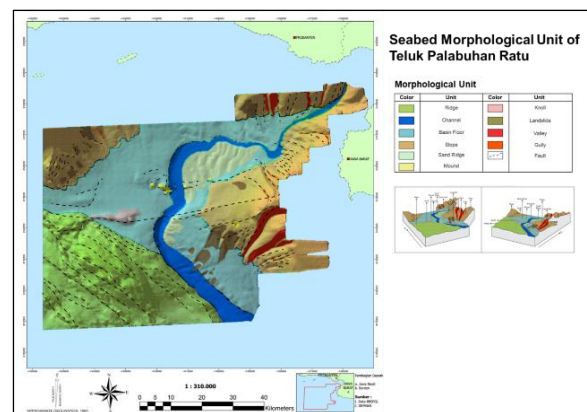


Fig 4. Seabed morphological unit map of Teluk Palabuhanratu

Ridges are included within the *Solid Earth Setting* system and categorized as Basic Geomorphic Units (BGU) of the tectonic high type. Within this framework, they may be further classified as compressional ridges (BGU\_T) and thrust ridges (BGU\_sT) (Nanson et al., 2023). The linear morphology observed in the bathymetric data and the presence of strongly deformed seismic reflectors indicate regional compressional stress associated with Java subduction zone.

#### 3.2.4. Slope

A slope is a seafloor morphological unit characterized by an inclined surface that forms a transition between shallower areas and deeper ocean basins and plays a vital role in directing sediment transport toward the basin floor (Dove et al., 2020). MBES bathymetry identifies slopes through significant depth gradients and consistently descending profiles (Fig. 5B). These areas commonly exhibit morphological features such as gullies, valleys, and channels, which indicate that the slope functions as a principal pathway for sediment transfer downslope. Seismic profile shows that sedimentary layers begin to tilt and are no longer parallel to those of the basin floor. Seismic reflectors appear wavy and locally discontinuous, and in several locations are intersected by fault structures. The presence of channels indicates ongoing sediment transport and localized slope instability.

Slopes are included within the Solid Earth Setting system and categorized as BGU of the scarp slope type (Nanson et al., 2023). This slope type is primarily formed by tectonic deformation and subsequently modified by gravity-driven sedimentary processes (Naranjo-Vesga et al., 2020). The subsurface indicates that the slope initially developed from reverse faulting caused by compressional stress related to southern Java subduction. Subsequently, erosion followed by gravity-driven sediment transport downward the slope base

#### 3.2.2 Channel

According to Dove et al. (2020), a channel is characterized by an elongated depression with a lower elevation than the surrounding seafloor. The unit is identified by the shape of elongated valleys with distinct elevation contrasts and U- to V-shaped cross-sections (Fig. 5C). Similarly, seismic profiles show downward-curving sedimentary layers forming channel geometry. This geometry serves as a primary pathway for sediment transport driven by gravity (Normandeau et al., 2019). The seismic profile of channel shows a less continuous to chaotic pattern, indicating repeated erosion and deposition processes. In contrast, reflectors outside the channel appear more parallel and continuous, suggesting relatively stable depositional conditions.

Channels are included within the Marine system and categorized BGU in the form of submarine channels (Nanson et al., 2023). Their presence in Teluk Pelabuhanratu is associated with sediment transport concentrated along steep slopes, which are influenced by the active tectonic regime of the southern Java subduction zone. The accumulation of unconsolidated and heterogeneous sediments within the channel, combined with steep channel margins, increases susceptibility to submarine landslides (Heijnen et al., 2022).

#### 3.2.3. Basin Floor

The basin floor is the deepest part of the seabed with a relatively flat surface (Dove et al., 2020). This unit is typically surrounded by adjacent slopes and ridges (Fig. 5D). Seismic profiles show layers within the basin floor are generally parallel and continuous, reflecting relatively calm and stable depositional conditions. In the seismic profiles, the basin floor is intersected by channels identified by downward-curving reflectors, while the transition between the basin floor and

surrounding slopes is marked by changes in gradient and localized deformation of reflectors.

Basin floor is included within the *Current-Induced Processes* system and categorized as a BGU of the bedform type, specifically classified as BGU\_T planebed (Nanson et al., 2023). This classification reflects a seabed morphology dominated by relatively low-energy sedimentary processes that produce flat depositional surfaces. However, the presence of unconsolidated sediments and variations in sediment thickness indicates the potential for sediment remobilization if triggered by external factors such as seismic activity (Camerlenghi, 2018).

#### 3.2.8. Valley

A valley is characterized by an elongated depression with negative relief, flanked by slopes on both sides (Dove et al., 2020) (Fig. 5E). A valley is distinguished from a channel based on the broader negative relief. As opposed to sediment transport pathways of channels, valleys develop through a combination of structural control and erosional processes. Seismic data shows that reflectors within the valley floor are discontinuous, irregular, and locally eroded, whereas layers along the valley flanks remain relatively parallel and intact. This pattern indicates that the valley developed through post-depositional erosion and sediment shearing associated with mass-flow (Gee et al., 2007).

Valleys are categorized as BGU of the submarine valley type. It reflects large-scale seafloor depressions shaped by a combination of tectonic, erosion, and gravity-driven sediment transport. The occurrence of relatively unconsolidated sediments and disturbed seismic reflectors indicates potential for sediment remobilization and mass-flow activity (Aiden-Lee Jackson, 2012).

#### 3.2.9. Gully

Gullies consist of narrow channels with negative relief that develop on slope surfaces and are commonly arranged in parallel or branching patterns following the slope direction (Dove et al., 2020). In the study area, gullies are characterized as narrow, linear depressions forming dense networks that extend downslope and display clear contrasts with the surrounding terrain (Fig. 5F).

Cross-section A–A' illustrates shallow channels incised directly into the slope surface. Correlation with seismic data from profiles A–A' and B–B' shows shallow dissection of the upper sedimentary layers at the gully locations, while deeper layers remain relatively parallel and undisturbed. This pattern indicates that gullies formed primarily through surface erosion. The feature reflects the function of gully as sediment collection channels that transport material downslope toward larger valleys (Post et al., 2020).

#### 3.2.5. Sand Ridge

A sand ridge is an elongated seafloor ridge composed of accumulated sandy sediments formed through the interaction between bottom currents and sediment supply (Dove et al., 2020). Sand ridge is characterized as low-relief ridges with relatively smooth surfaces and orientations that are generally parallel to, or slightly oblique to, the dominant current direction (Fig. 5G). Cross-sectional profiles show gently undulating forms with rounded crests and relatively symmetrical slopes. Seismic cross-section indicates that sedimentary layers thicken toward the ridge crest and thin laterally outward. The reflectors remain parallel to the ridge geometry and show minimal structural disturbance, indicating that the ridge developed primarily through depositional processes rather than tectonic deformation. In addition, the presence of channels along the

ridge margins suggests that sediment transport processes influence the distribution and accumulation of sandy material. Sand ridges are included within the Current-Induced Processes system and categorized as BGU of the bedform type, including dune (BGU\_T) and very large dune (BGU\_sT (Nanson et al., 2023)). The unit is generated by bottom-current dynamics that

reorganize sandy sediments into elongated ridges. The relatively unconsolidated sandy sediments and variations in sediment thickness are a hazard risk for shallow sediment remobilization under changing hydrodynamic conditions (Moore et al., 2018).

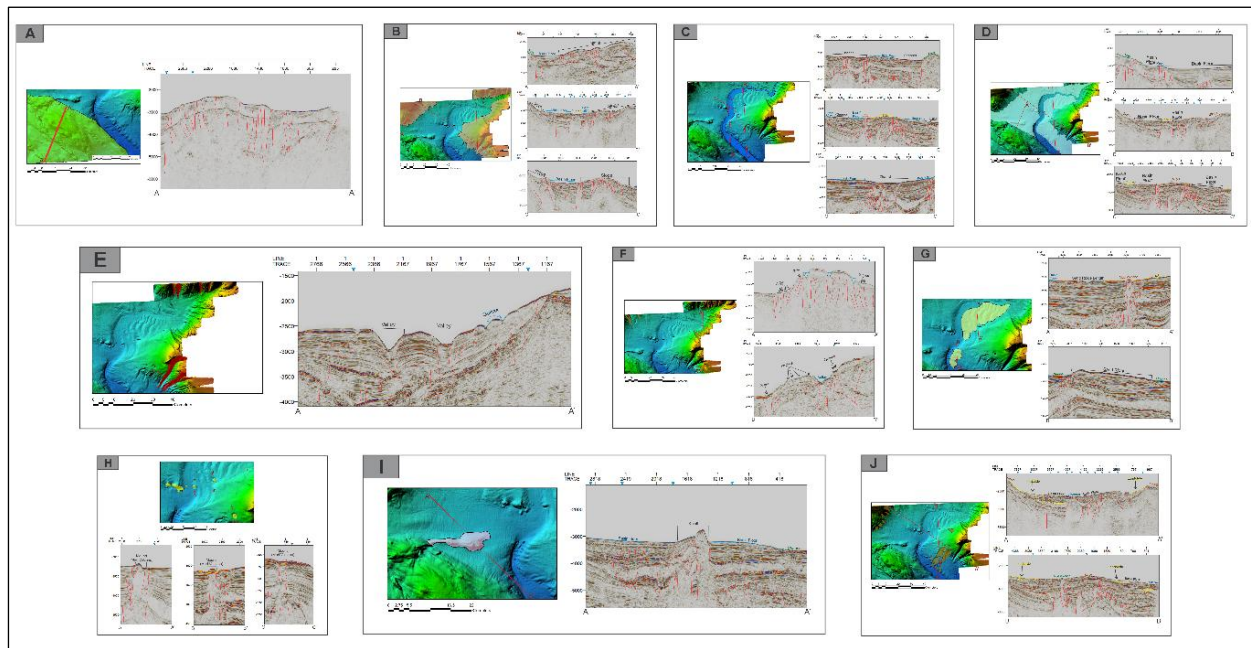


Fig 5. Morphology and seismic cross section of (A) Ridge, (B) Slope, (C) Channel, (D) Basin Floor, (E) Valley, (F) Gully, (G) Sand Ridges, (H) Mound, (I) Knoll, and (J) Landslide

### 3.2.6. Mound

A mound is characterized by a localized protrusion with positive relief, typically rounded to oval and relatively isolated (Dove et al., 2020). This unit displays an upward-convex profile in cross-section (Fig. 5H). Seismic data reveals disturbance to chaotic reflectors, uplifted sediment layers of small dome-shaped structures, and indications of vertical fluid migration pathways. Seismic reflectors surrounding the mound tend to bend upward and locally thin toward the summit. These characteristics suggest the unit was formed by a bottom-up mechanism associated with submarine fluid expulsion (Burhannuddinur and Noeradi, 2021).

Mounds are included within the Fluid Flow Processes system and categorized as BGU of mud volcano, specifically classified as mud domes (BGU\_T). This unit reflects a seabed formed by the upward migration and extrusion of fluid-rich sediments (Ge et al., 2022). The presence of fluid activity and relatively unconsolidated sediments is causing localized instability due to elevated pore-fluid pressure (Saroni et al., 2025).

### 3.2.7. Knoll

A knoll is characterized by an isolated protrusion with positive relief, typically rounded to oval and surrounded by radial slopes (Dove et al., 2020). The unit shows localized elevations occurring on the basin floor, generally with a relatively narrow summit (Fig. 5I). Unlike mounds, knolls show no indications of fluid-related activity, which distinguishes them from features associated with submarine fluid expulsion. Seismic profiles reveal weak to irregular reflectors within the knoll body, while surrounding sedimentary layers appear uplifted and locally thinned following the protrusion. Outside the knoll, seismic reflectors are generally parallel and continuous, indicating more stable depositional conditions.

Knolls are included within the *Solid Earth Setting* system and categorized as BGU of the tectonic high type, including BGU\_T tectonic dome and BGU\_sT diapir dome. Knoll features formed primarily by tectonic uplift or subsurface structural processes. The occurrence of knolls in the area is associated with nearby ridges and with the structural continuity of the Cimandiri Fault (Meredyk et al., 2020).

### 3.2.10. Landslide

A landslide is characterized by a steep slope or escarpment formed by slope failure and the downslope movement of sediment masses under gravitational forces (Dove et al., 2020). This unit was identified as a very steep slope with pronounced depth contrasts and irregular surface morphology, commonly accompanied by a zone of accumulated material at the slope toe (Fig. 5J).

Seismic cross-section reveals disturbed, discontinuous, folded, and chaotic sediment reflectors within the landslide zone, contrasting with the relatively parallel and continuous layers observed outside the affected area (Bhattacharya et al., 2020). The upper part of the escarpment represents an evacuation or source zone, while the lower section contains mass-flow deposits, confirming the downslope transport of material toward deeper areas (Scarselli, 2020).

## 3.3. Subsea Pipeline Routing Geohazard Assessment

Geohazard level zonation was identified through the integration of morphological units, slope, and roughness (Fig. 5). Faults, escarpments, sand ridges, channels, and steep slopes were assigned to the highest weight (10) due to their association with tectonic deformation and mass movement (Ceramicola et al., 2024). Gullies were assigned a high-moderate weight (8) due to their role as initial pathways for erosion and sediment transport (Post et al., 2020). In contrast, relatively flat morphological features of basin floors were assigned to lower

weights (3), reflecting stable environments. The weight score of a slope increases proportionally with slope angle, with a maximum of 10 for a slope greater than 15°. As for roughness, low values indicating smooth and stable surfaces were assigned a weight of 1, whereas high roughness values representing irregular and potentially unstable seabed conditions were assigned a weight of 10 (American Bureau of Shipping, 2016). The sum of each parameter subsequently classified the region into three hazard levels, namely low, moderate, and high (Fig. 6).

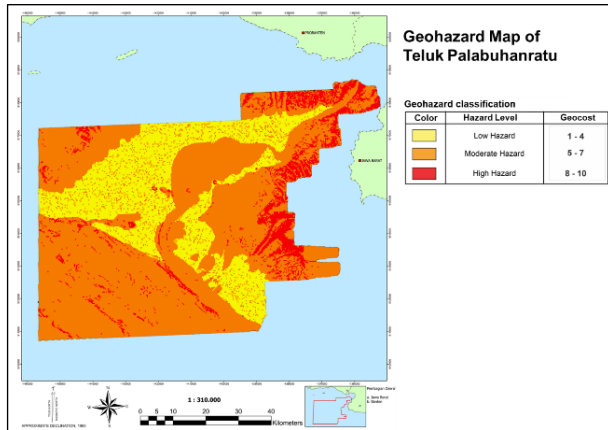


Fig 6. Geocost hazard level map of Teluk Palabuhanratu

Low hazard zones are predominantly associated with basin floor morphological units. These environments are characterized by low-energy depositional conditions, minimal sediment reworking, and limited evidence of recent geological activity (Nanson et al., 2023). The mechanical interaction between pipeline and seabed in such areas is generally stable, with continuous support and low risk of free-span formation. From an engineering perspective, these zones are the most suitable for pipeline placement, requiring minimal mitigation. Standard installation practices are typically sufficient, although localized site verification and minor adjustments may still be necessary (American Bureau of Shipping, 2016).

Moderate hazard zones are associated with channels, slopes, sand ridges, ridges, mounds, knolls, and landslides. These units are influenced by active sedimentary processes such as erosion, deposition, and sediment transport (Nanson et al., 2023). Channels for example act as pathways for sediment flow, increasing the risk of scouring and pipeline exposure (Normandeau et al., 2019). Sand ridges and mounds indicate mobile bedforms, which may migrate over time and affect pipeline burial conditions (Moore et al., 2018). Slopes areas introduce additional risks related to sediment instability (Naranjo-Vesga et al., 2020). In these zones, pipeline installation remains feasible but requires targeted mitigation measures. These may include trenching to improve stability, use of support or anchors to reduce free spans, route micro-adjustment to avoid localized hazards, and detailed geotechnical investigation prior to installation (American Bureau of Shipping, 2016). High hazard zones are associated with valleys, gullies, and part of ridges that are affected by fault. These areas are characterized by steep slopes, high roughness, and prominent geological control, indicating either sediment transport or tectonic deformation. Gullies and valleys represent zones of concentrated sediment movement, where sediment flows can affect pipeline stability (Clukey et al., 2007). Fault-associated ridges further introduce the risk of seabed displacement due to tectonic activity (Triantafyllaki et al., 2023). In such environments, the likelihood of pipeline failure is significantly elevated, and mitigation measures are often impractical or economically unviable. Therefore, these zones

are considered unsuitable for pipeline routing, and avoidance is strongly recommended (American Bureau of Shipping, 2016).

#### 4. Conclusions

Morphometric analysis of DBM indicates that Teluk Palabuhanratu is predominantly characterized by very gentle to gentle slopes, near-planar curvature, and low roughness, suggesting a stable seabed across most of the region. However, localized zones exhibiting steep slopes, complex curvature, and high roughness are found associated with faults, submarine landslides, and mud volcanoes, which indicate areas of potential instability. Ten morphological units were identified, including slopes, ridges, knolls, channels, basin floors, sand ridges, mounds, valleys, gullies, and landslide units. The geocost hazard assessment indicates hazard levels ranging from low to high. High hazard levels are associated with steep slopes, high roughness, and morphological units influenced by mass-transport processes and tectonic deformation, such as gullies, valleys, and fault-associated ridges.

#### Acknowledgements

We would like to express our gratitude to *Kementerian Energi dan Sumber Daya Mineral* (Ministry of Energy and Mineral Resources) for granting access to the marine survey data.

#### References

- Aiden-Lee Jackson, C., 2012. The initiation of submarine slope failure and the emplacement of mass transport complexes in salt-related minibasins: A three-dimensional seismic-reflection case study from the Santos Basin, offshore Brazil. *Geol. Soc. Am. Bull.* 124, 746–761. <https://doi.org/10.1130/B30554.1>
- American Bureau of Shipping, 2016. *Guidance Notes on Subsea Pipeline Route Determination*. Houston.
- Ardhyastuti, S., Husein, S., Muljawan, D., Haryadi, Y., Wiguna, T., Febriawan, H.K., Putra, A.P., Tohari, A., Marcino, A.R.R.I., Nugroho, A.B., Sudaryanto, A., 2023. Seabed morphology characterization for Indonesian cable-based tsunameter route in Cilacap Segment, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 1148, 012009. <https://doi.org/10.1088/1755-1315/1148/1/012009>
- Ar-Rouf, F.B., 2025. Identifikasi Multi Bencana Geologi di Kawasan Geopark Ciletuh Palabuhanratu. *Syntax Idea* 7, 1134–1150. <https://doi.org/10.46799/syntaxidea.v7i9.13560>
- Bhattacharya, S., Verma, S., Rotzien, J.R., 2020. 3D seismic imaging of the submarine slide blocks on the North Slope, Alaska. *Interpretation* 8, SR37–SR44. <https://doi.org/10.1190/INT-2020-0038.1>
- Burhannudinur, M., Noeradi, D., 2021. Understanding Mud Volcano System Using Hele-Shaw (H-S) Experiment: Seismic Confirmation at East Java Mud Volcano. *Journal of Geoscience, Engineering, Environment, and Technology* 6, 206–216. <https://doi.org/10.25299/jgeet.2021.6.4.7889>
- Camerlenghi, A., 2018. Drivers of Seafloor Geomorphic Change. pp. 135–159. [https://doi.org/10.1007/978-3-319-57852-1\\_9](https://doi.org/10.1007/978-3-319-57852-1_9)
- Cappadonia, C., Coco, L., Buccolini, M., Rotigliano, E., 2016. From Slope Morphometry to Morphogenetic Processes: An Integrated Approach of Field Survey, Geographic Information System Morphometric Analysis and Statistics in Italian Badlands. *Land Degrad. Dev.* 27, 851–862. <https://doi.org/10.1002/ldr.2449>
- Ceramicola, S., Senatore, M.R., Cova, A., Meo, A., Forlin, E., Critelli, S., Markežic, N., Zecchin, M., Civile, D.,

- Bosman, A., Candoni, O., Casalbore, D., Coste, M., Cotterle, D., Deponte, M., Dominici, R., Facchin, L., Gordini, E., Morelli, E., Muto, F., Praeg, D., Romeo, R., Chiocci, F.L., 2024. Geohazard features of the Gulf of Taranto. *J. Maps* 20. <https://doi.org/10.1080/17445647.2024.2431073>
- Clukey, E., Israel, K., Jones, C., Ziegler, C.K., 2007. Pipeline Risk Assessment in Deep-Sea Furrow Regions, in: *Offshore Technology Conference. OTC*. <https://doi.org/10.4043/18939-MS>
- Dhina, N., Permana, T., 2021. Natural gas transportation business contribution to Indonesia's national energy policy and carbon emission offset by on-grid solar PV utilization: Surabaya, East Java, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 753, 012022. <https://doi.org/10.1088/1755-1315/753/1/012022>
- Dove, D., Nanson, R., Bjarnadóttir, L.R., Guinan, J., Gafeira, J., Post, A., Dolan, M.F.J., Stewart, H., Arosio, R., Scott, G., 2020. A two-part seabed geomorphology classification scheme: (v.2). Part 1: morphology features glossary. British Geological Survey, Nottingham. <https://doi.org/10.5281/ZENODO.4075248>
- Escartín, J., Olive, J.-A., 2022. Mid-Ocean Ridges and Their Geomorphological Features, in: *Treatise on Geomorphology*. Elsevier, pp. 847–881. <https://doi.org/10.1016/B978-0-12-818234-5.00193-0>
- Ge, Y., Cao, C., Chen, J., Wang, H., Zhang, P., He, J., Lin, Y., 2022. Monitoring and Research on Submarine Hydrate Mound: Review and Future Perspective. *Mar. Technol. Soc. J.* 56, 140–162. <https://doi.org/10.4031/MTSJ.56.4.14>
- Gee, M.J.R., Gawthorpe, R.L., Bakke, K., Friedmann, S.J., 2007. Seismic Geomorphology and Evolution of Submarine Channels from the Angolan Continental Margin. *Journal of Sedimentary Research* 77, 433–446. <https://doi.org/10.2110/jsr.2007.042>
- Hart, B.S., Sagan, J.A., 2007. Curvature for visualization of seismic geomorphology. Geological Society, London, Special Publications 277, 139–149. <https://doi.org/10.1144/GSL.SP.2007.277.01.08>
- Hasenhüendl, M., Blanckaert, K., 2022. A Matlab script for the morphometric analysis of subaerial, subaquatic and extra-terrestrial rivers, channels and canyons. *Comput. Geosci.* 162, 105080. <https://doi.org/10.1016/j.cageo.2022.105080>
- Heijnen, M.S., Clare, M.A., Cartigny, M.J.B., Talling, P.J., Hage, S., Pope, E.L., Bailey, L., Sumner, E., Lintern, D.G., Stacey, C., Parsons, D.R., Simmons, S.M., Chen, Y., Hubbard, S.M., Eggenhuisen, J.T., Kane, I., Hughes Clarke, J.E., 2022. Fill, flush or shuffle: How is sediment carried through submarine channels to build lobes? *Earth Planet. Sci. Lett.* 584, 117481. <https://doi.org/10.1016/j.epsl.2022.117481>
- Kanamatsu, T., Ashi, J., Shiraiishi, K., 2024. Controlling factors of a submarine landslide on the Kumano-nada continental slope, West Japan. *Tectonophysics* 883, 230370. <https://doi.org/10.1016/j.tecto.2024.230370>
- Martodjodjo, S., 1984. Bogor Basin Evaluation, West Java (Evolusi Cekungan Bogor, Jawa Barat). Institut Teknologi Bandung, Bandung.
- Meredyk, S.P., Edinger, E., Piper, D.J.W., Huvenne, V.A.I., Hoy, S., Ruffman, A., 2020. Enigmatic Deep-Water Mounds on the Orphan Knoll, Labrador Sea. *Front. Mar. Sci.* 6. <https://doi.org/10.3389/fmars.2019.00744>
- Moore, R., Davis, G., Dabson, O., 2018. Applied Geomorphology and Geohazard Assessment for Deepwater Development. pp. 459–479. [https://doi.org/10.1007/978-3-319-57852-1\\_23](https://doi.org/10.1007/978-3-319-57852-1_23)
- Muslim, D., Haerani, E., Muslim, F.N., Muslim, G.O., 2019. Toward the Safe Live-able Built Environment around Ciletuh-Palabuhanratu Geopark Area in Sukabumi Regency, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* 248, 012036. <https://doi.org/10.1088/1755-1315/248/1/012036>
- Nanson, R., Arosio, R., Gafeira, J., McNeil, M., Dove, D., Bjarnadóttir, L., Dolan, M., Guinan, J., Post, A., Webb, J., Nichol, S., 2023. A two-part seabed geomorphology classification scheme; Part 2: Geomorphology classification framework and glossary (Version 1.0). Nottingham. <https://doi.org/10.5281/ZENODO.7804019>
- Naranjo-Vesga, J., Ortiz-Karpp, A., Wood, L., Jobe, Z., Paniagua-Arroyave, J.F., Shumaker, L., Mateus-Tarazona, D., Galindo, P., 2020. Regional controls in the distribution and morphometry of deep-water gravitational deposits along a convergent tectonic margin. Southern Caribbean of Colombia. *Mar. Pet. Geol.* 121, 104639. <https://doi.org/10.1016/j.marpetgeo.2020.104639>
- Normandeau, A., Campbell, D.C., Cartigny, M.J.B., 2019. The influence of turbidity currents and contour currents on the distribution of deep-water sediment waves offshore eastern Canada. *Sedimentology* 66, 1746–1767. <https://doi.org/10.1111/sed.12557>
- Post, A.L., O'Brien, P.E., Edwards, S., Carroll, A.G., Malakoff, K., Armand, L.K., 2020. Upper slope processes and seafloor ecosystems on the Sabrina continental slope, East Antarctica. *Mar. Geol.* 422, 106091. <https://doi.org/10.1016/j.margeo.2019.106091>
- Puspasari, T.J., Yordan, A., Suherman, I., 2021. Geoscience Application for Marine Pipe Line Identification and Validation, in: *2021 IEEE Ocean Engineering Technology and Innovation Conference: Ocean Observation, Technology and Innovation in Support of Ocean Decade of Science (OETIC)*. IEEE, pp. 1–5. <https://doi.org/10.1109/OETIC53770.2021.9733744>
- Putra, M.B.P., Soedarsono, J.W., Ferdian, D., Riastuti, R., Mahendra, M., Wibowo, J.H., 2024. Determination of the Risk of Oil and Gas Offshore Pipelines in Indonesia: A Risk-Based Analysis Approach for Developing Inspection Strategy Policy. *Journal of Advanced Zoology*. <https://doi.org/10.53555/jaz.v45i1.397>
- Saroni, A., Maurantonio, F., Casalbore, D., Chiocci, F.L., Cimenti, E., Coltorti, M., Demarte, M., Pierdomenico, M., Spatola, D., Ivaldi, R., 2025. Seafloor morphology and recent dynamics in the Scoglio d'Affrica (Northern Tyrrhenian Sea). *Mar. Geol.* 484, 107518. <https://doi.org/10.1016/j.margeo.2025.107518>
- Scarselli, N., 2020. Submarine landslides – architecture, controlling factors and environments. A summary, in: *Regional Geology and Tectonics: Principles of Geologic Analysis*. Elsevier, pp. 417–439. <https://doi.org/10.1016/B978-0-444-64134-2.00015-8>
- Silvianita, Fahreza Inzaghi, M., Rosyid, D.M., Dhanistha, W.L., 2021. Safety Case Development For Risk Management Of Offshore Pipeline. *IOP Conf. Ser. Earth Environ. Sci.* 698, 012043. <https://doi.org/10.1088/1755-1315/698/1/012043>
- Triantafyllaki, A., Loukidis, D., Papanastasiou, P., 2023. Design of offshore gas pipelines against active tectonic fault movement. *Soil Dynamics and Earthquake Engineering* 166, 107702. <https://doi.org/10.1016/j.soildyn.2022.107702>
- Tsoukala, V., Kioussi, D., Sartampakos, P., 2024. Seabed Morphology Assessment and Pockmark Detection for Port Construction and Maintenance, Using a Multibeam Echo-sounder: A Case study in Katakolo Port, Western

Peloponnese, Greece. Technical Annals 1.  
<https://doi.org/10.12681/ta.39589>  
Untersch, S., Contet, J., 2015. Integrated Geohazards  
Assessments offshore Azerbaijan, Caspian Sea, in:  
Offshore Technology Conference. OTC.  
<https://doi.org/10.4043/25911-MS>  
Zulkifli, Z., Clare, M.A., Heijnen, M., Lintern, D., Stacey, C.,  
Talling, P.J., Cartigny, M.J.B., Minshull, T.A., Moreno,

H.M., Peakall, J., Darby, S., 2024. A threshold in  
submarine channel curvature explains erosion rate and  
type. Earth Planet. Sci. Lett. 646, 118953.  
<https://doi.org/10.1016/j.epsl.2024.118953>



© 2026 Journal of Geoscience, Engineering,  
Environment and Technology. All rights reserved. This  
is an open access article distributed under the terms of  
the CC BY-SA License (<http://creativecommons.org/licenses/by-sa/4.0/>).

Accepted Manuscript in Press