Offshore Wind Infrastructure in Bunbury, Western Australia: Subsurface and Engineering Challenges

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and

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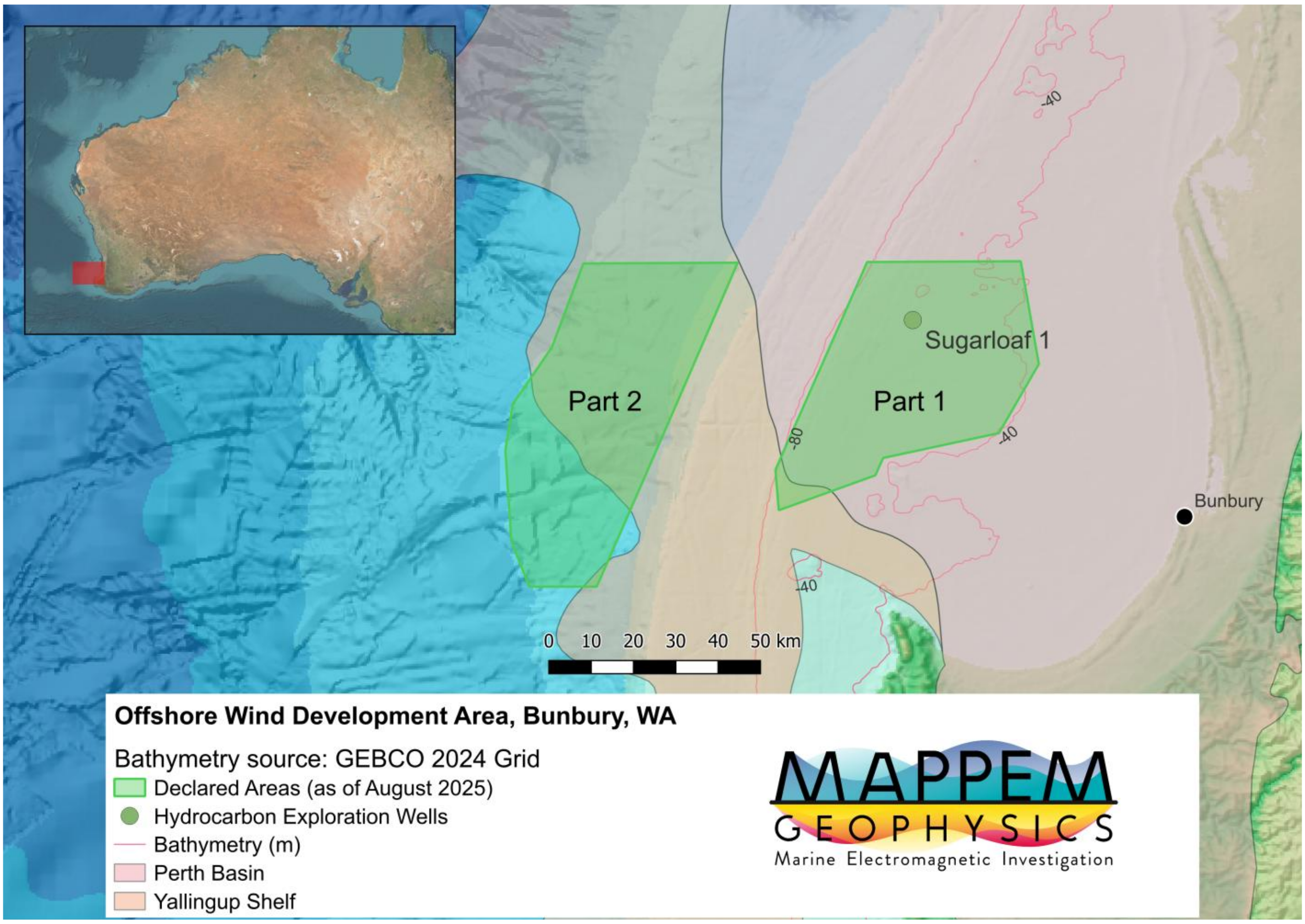
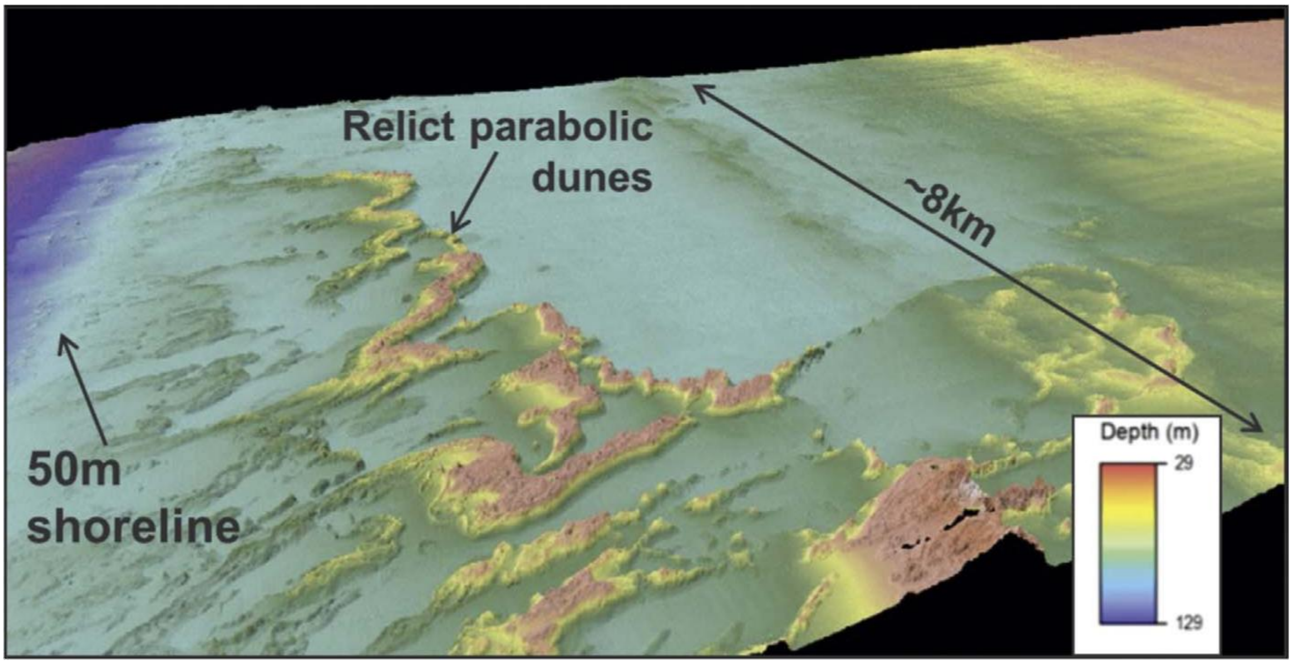
In August 2024, the Australian Government officially declared an offshore wind development area in the Indian Ocean off the coast of Bunbury, Western Australia (WA). The designated area spans approximately 4000 km², located at least 30 km offshore, between Dawesville and Cape Naturaliste. As of August 2025, preliminary feasibility licences have been offered for three offshore wind projects within Part 1 of the Declared Area (P1DA), covering a combined area of over 730 km² and situated in water depths ranging from about 40 to 80 m.



Due to limited direct data, understanding the near-surface conditions in P1DA requires reliance on nearby geological proxies, published literature, and publicly available datasets. These sources indicate the presence of several engineering risks that must be carefully considered during the design and construction phases. This article examines the anticipated engineering challenges and highlights how alternative geophysical methods can be employed to mitigate them effectively.

Geological History

P1DA is located within the southern Perth Basin, a sedimentary basin formed during the breakup of Gondwana. The basin exhibits a complex stratigraphy of sandstones, siltstones, and claystones, interbedded with carbonates and occasional volcanic intrusions, and is also prospective for hydrocarbons, which may present as shallow gas accumulations in near-surface sediments (Nicholas et al., 2014). To the west of the basin is the Yallingup Shelf, a relatively shallow basement high composed of older, more stable crystalline and sedimentary rocks, with a thinner sedimentary cover compared to the surrounding basins.



Relict dunes on the Rottnest Shelf, located near the offshore Bunbury wind area (from Brooke et al., 2014).

Shallow Geology

The continental shelf off Bunbury is a broad, relatively shallow, wave-dominated shelf along the passive margin of southwestern Australia (Bufarale et al., 2019; Collins, 1988). It gently slopes to ~75 m depth before a marked increase in gradient occurs (Brooke et al., 2014). The seabed receives minimal terrestrial sediment input and is primarily composed of marine biogenic carbonate sediments, including moderately sorted carbonate sands with minor detrital quartz, largely derived from the (Pleistocene) Tamala Limestone (Collins, 1988; Commander, 2003). A petroleum exploration well, Sugarloaf 1, drilled in ~45 m of water, encountered ~175 m of highly porous and permeable “Unnamed Carbonates” (Bird & Moyes, 1971).

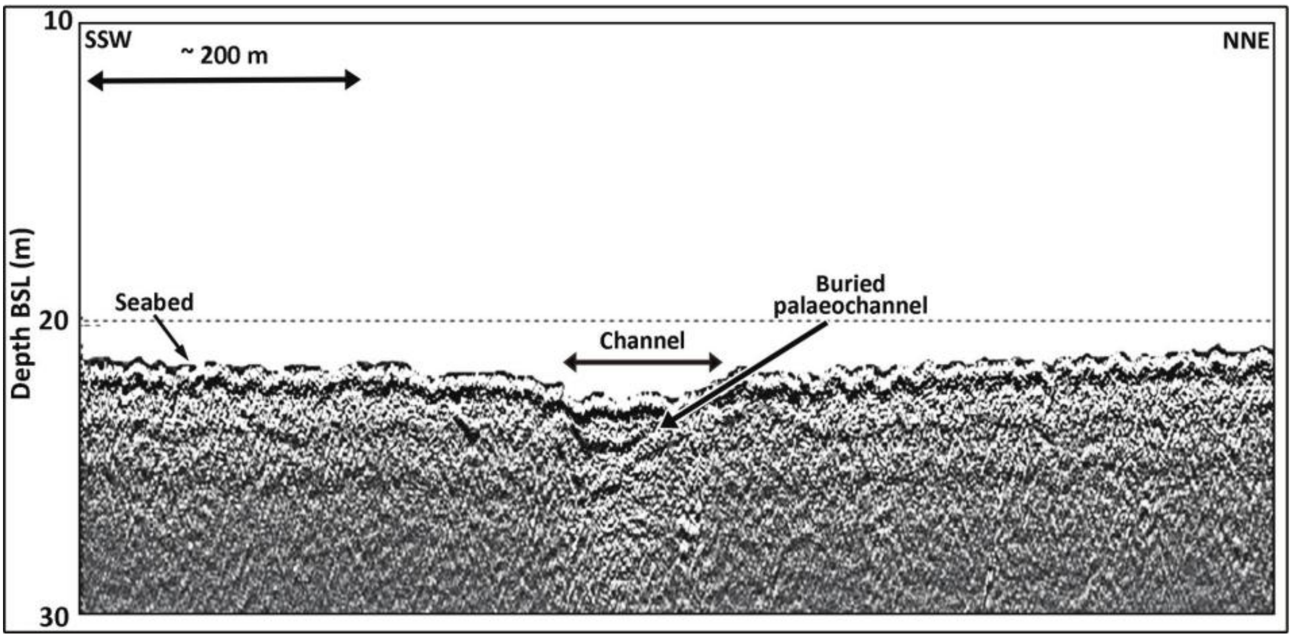
Although tectonically stable since the Mid-Pleistocene (Bufarale, 2019), the region’s sedimentary history reflects repeated glacial-interglacial cycles, producing a mix of marine, estuarine, alluvial, aeolian, and swamp deposits (Commander, 2003). Relict features such as submerged terraces, ridges, palaeochannels, reefs, and barrier dunes are well preserved, indicating past sea-level fluctuations.

The stratigraphy includes limestones (calcarenite), sands, clays, and gravels (Commander, 2003; Iasky, 1993), many of which are unconsolidated and exhibit spatial variability in thickness and composition (Nicholas et al., 2014). These materials may exhibit low shear strength, variable density, and potential for liquefaction under cyclic loading, posing engineering challenges for offshore infrastructure.

Subsurface Conditions for Offshore Wind Development

Understanding near-surface conditions in P1DA is essential due to the area's sedimentary heterogeneity, reliance on geological proxies, and limited public data. These factors introduce uncertainty and potential engineering risks that must be addressed through targeted subsurface investigations to identify geohazards and support safe, effective offshore wind infrastructure design.

P1DA is primarily underlain by Quaternary superficial sediments, ranging from 20 to 100 m thick, which rest unconformably atop an older Mesozoic sequence (Iasky, 1993). The following sections summarize the key lithologies and their engineering implications.



Buried palaeochannel in Geographe Bay, located on the shelf near P1DA (from Bufarale et al., 2019). BSL: Below Sea Level. Note the generally noisy appearance of the seismic data.

Limestone

The Tamala Limestone is a widespread Pleistocene aeolianite composed mainly of coarse- to medium-grained calcarenite, formed from wind-blown shell fragments and quartz sand (Brooke et al., 2014; Department of Water, 2017; Iasky, 1993). Its heterogeneous, with quartz, minor clays, feldspar, glauconite, and phosphate nodules (near its base), and calcium carbonate content ranging from 30% to 96%. The quartz grains are mostly well-rounded, indicating prolonged mobility and reworking in high-energy environments. Cementation ranges from friable to well-lithified, with surface capstones and indurated subsurface layers forming pinnacles and dipping strata (Commander, 2003; Nicholas et al., 2014).

From an engineering perspective, the Tamala Limestone is notable for its high porosity, permeability, and extensive karstic features, including solution channels, cavities, and sinkholes often filled with sand (Commander, 2003; Department of Water, 2017). These structures create complex fluid pathways and contribute to high hydraulic conductivity, even without visible karst (Nicholas et al., 2014).

Such heterogeneity poses challenges for offshore infrastructure: foundation stability may be compromised by voids and variable cementation; seismic imaging is often ineffective due to signal attenuation (Bufarale et al., 2019); and sediment sampling in indurated zones requires specialized techniques (Bufarale et al., 2019). The formation likely corresponds to the “Unnamed Carbonates” encountered in the Sugarloaf 1 well (Bird & Moyes, 1971), underscoring its regional significance. Site-specific investigations are essential to assess and mitigate these risks.

Clastics (Sands, Clays, Gravels)

The Fremantle Blanket is a thin (<0.5 m), mobile sediment layer found in water depths of 20-90 m, composed of well-sorted, medium- to coarse-grained calcareous and quartzose sands (Collins, 1988; Heap et al., 2008). Derived primarily from biogenic shelf production, it includes minor fractions of very coarse sand to gravel-sized material, especially near offshore ridges (Glenn et al., 2008). In depths <50 m, it is estimated to be mobile about 50% of the time due to storm and swell activity. Its loose, unconsolidated nature and frequent movement under wave action result in low shear strength, high porosity, and high compressibility, posing risks to infrastructure stability.

The Safety Bay Sand is a Holocene aeolian deposit that continues to accumulate along the WA coast (Department of Water, 2017; Semeniuk & Searle, 1985). It consists mainly of calcareous or carbonate-quartz sands with >50% calcium carbonate, along with shell fragments, minor feldspar, and traces of heavy minerals (Commander, 2003). Typically, fine- to medium-grained and moderately to well sorted, the sand shows crossbedding and lamination, with grains ranging from angular to rounded. It is generally loose to moderately cemented, forming an unconsolidated unit with high porosity and typical superficial sand density. Similar materials have been identified in Holocene offshore cores (Glenn et al., 2008).

Extreme karstification in the Tamala Limestone, exemplified by the Pinnacles of Nambung National Park, WA. The left foreground pinnacle is ~1.5 m high. Image © Andrew Weller.

The Becher Sand is a Holocene nearshore marine deposit found along the southern WA coast, associated with sandbanks, beach-dune ridges, and seagrass beds (Department of Water, 2017; Semeniuk & Searle, 1985). It consists of fine to medium, well-sorted, subrounded to rounded quartz and skeletal sands, with calcareous mudstone, shell gravel, coarse sand layers, and laminated calcareous muds. Organic-rich horizons, such as seagrass rhizomes, are also present. The deposit is generally unconsolidated and bioturbated, with low strength and stiffness (Commander, 2003). Its thickness can reach up to 20 m, and it often underlies the Safety Bay Sand. The presence of organic material, lack of cementation, and fine grain size contribute to high porosity, moderate to low bulk density, and high compressibility. Due to its saturated condition and depositional setting, Becher Sand may be sensitive to groundwater fluctuations and requires careful engineering evaluation.

The Leederville Formation (Early Cretaceous) comprises interbedded siliciclastic sediments deposited in a fluvio-deltaic setting with shallow marine intervals. It includes sand, shale, claystone, and siltstone, with minor conglomerate, coal/lignite seams, and glauconite (Bufarale et al., 2019; Department of Water, 2017). The sandstones are weakly to moderately consolidated, poorly sorted, and range from very fine to coarse and angular to subangular grains, often containing clay and angular feldspar. Finer silt and clay layers are laminated, slightly micaceous, and variably consolidated, with carbonaceous shales also present. These characteristics suggest modest strength and stiffness, high compressibility, and low shear strength, primarily due to the clay-rich matrix. Lenticular bedding complicates borehole correlation, and non-marine beds may contain pyrite and heavy minerals, affecting bulk density and geochemical reactivity. Averaging 235 m in thickness, the formation also serves as a significant aquifer, indicating notable porosity and permeability.

Fossilised aeolian dune ridge of the Tamala Limestone near Neerabup National Park, WA. Note the dipping strata, which may act as conduits for fluid migration and influence engineering properties. No scale provided. Image © Paul Morris (Flickr), distributed under the "CC BY-SA 2.0" licence.

Swamp Deposits

Swamp deposits are Holocene superficial sediments found in interdunal areas, recording past sea-level fluctuations (Department of Water, 2017; Nicholas et al., 2014). They consist of fine-grained, organic-rich materials such as clay, silt, sand, and peat, formed in low-energy environments. These deposits are generally unconsolidated (Commander, 2003), with very low shear strength and stiffness, resulting in poor bearing capacity. Peat and organic clays exhibit high porosity, low bulk density, and significant compressibility under static loading. While liquefaction is unlikely due to their plasticity, failure modes may include bearing capacity failure or lateral spreading. Their saturated condition and variability require careful engineering evaluation for infrastructure development.

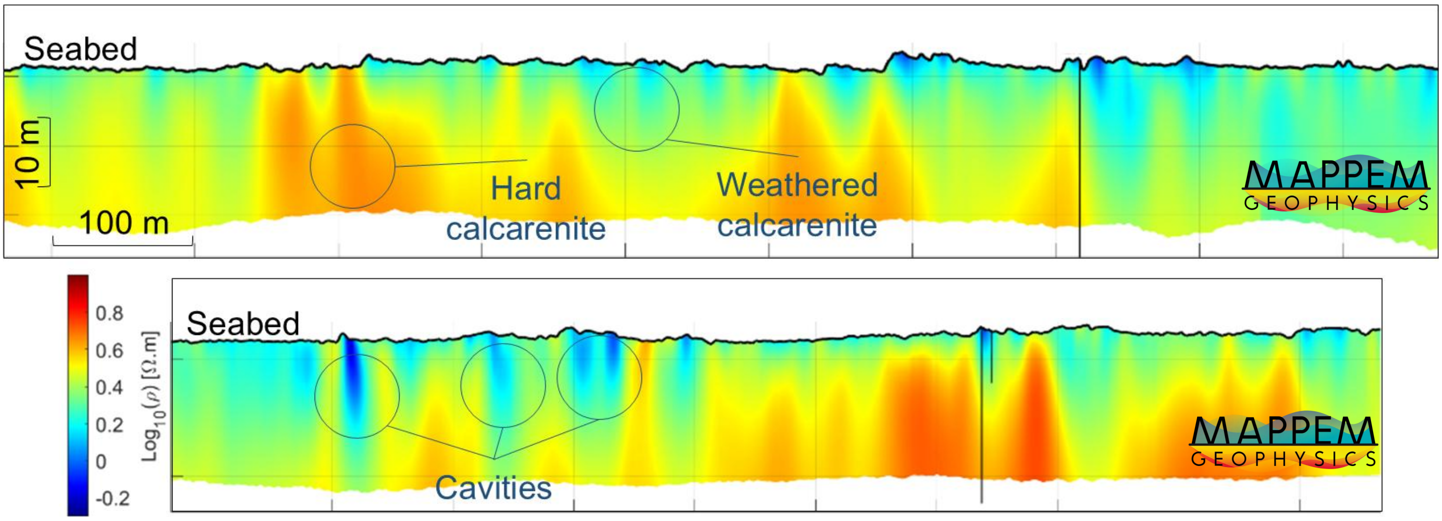
View towards P1DA from Back Beach, Bunbury, WA.

Other Features and Geohazards

Beyond the immediate superficial formations, several subsurface and geomorphological features present significant engineering challenges across P1DA.

- **Palaeochannels**, formed during previous sea-level lowstands, are typically oriented perpendicular to the coastline (Bufarale et al., 2019). These buried channels are infilled with variable sediments such as sand, clay, and silt, which often exhibit poor engineering properties. The soft and heterogeneous nature of the infill poses substantial risks to foundation stability and load-bearing performance.
- **Limestone ridges and reefs**, both exposed and shallowly buried, further complicate foundation design. These coast-parallel, jagged rock structures can reach heights of up to 15 m and are often discontinuous (Glenn et al., 2008). On the outer shelf, seismic data reveals hard-bottom conditions with local outcrops of rocky reef, including both low- and high-relief features in the area (Glenn et al., 2008; Heap et al., 2008). These hard substrates may obstruct pile installation and require specialized excavation techniques.

- **Shallow gas hazards** are indicated by seabed pockmarks and disrupted sub-bottom reflectors, interpreted as fluid escape features (Glenn et al., 2008). Deeper seismic profiles in the Vlaming Sub-basin have identified gas chimneys and hydrocarbon-related diagenetic zones (HRDZs) that may intersect Quaternary formations (Nicholas et al., 2014). The presence of proven hydrocarbon provinces in the region increases the risk of encountering pressurized fluids during drilling or piling operations (Heap et al., 2008; Thomas, 2018).
- **Mobile sand waves** are prevalent across the continental shelf and pose dynamic loading risks to infrastructure (Glenn et al., 2008). These features can bury or expose foundation elements and cables, leading to fluctuating mechanical stresses and potential structural instability.
- Although the region is generally considered tectonically stable since the Mid-Pleistocene, the subsurface framework is intensely faulted. **Seabed faulting** observed in some areas suggests possible neo-tectonic activity, with implications for engineering hazard assessments (Nicholas et al., 2014; Thomas, 2018).
- **Submarine canyons**, including several blind systems, are associated with widespread slope instability. Mass movement features such as slumps, scars, and rotational slides have been interpreted from geophysical profiles in canyon areas. Tension cracks trending along the lower continental slope and debris deposits of boulder-sized material on canyon floors further indicate active slope processes and potential geohazards (Glenn et al., 2008; Heap et al., 2008).



Resistivity imaging of marine karst (calcarenite), illustrating contrasts between hard and weathered zones, as well as the presence of cavities and differential dissolution across the area.

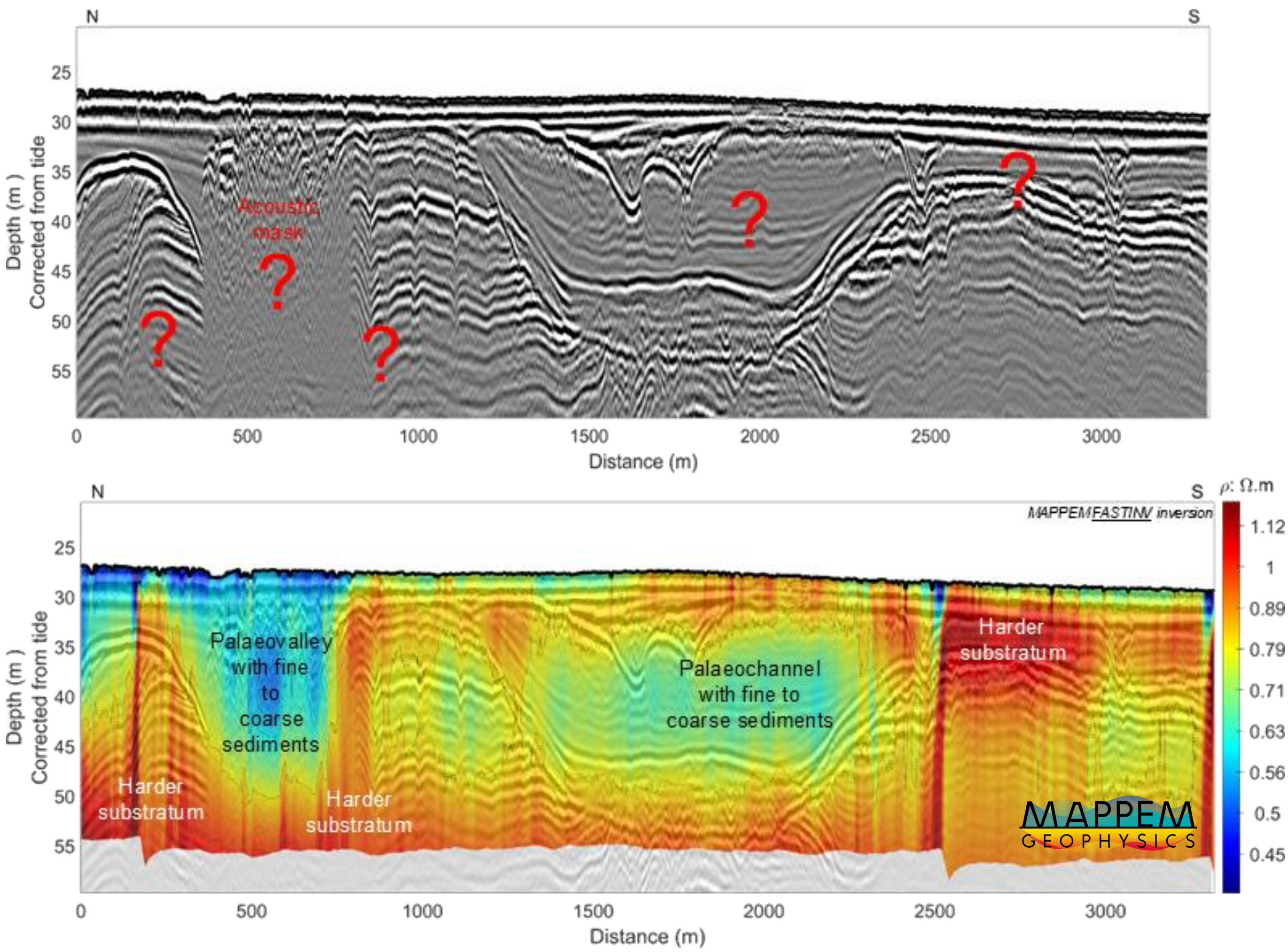
Mitigating Subsurface Risk with Alternative Geophysical Methods: Resistivity Imaging

Resistivity imaging offers a powerful alternative to traditional geophysical methods, particularly in geologically complex marine environments where seismic techniques often fall short. Unlike seismic data, which can be disrupted by voids, fractures, and abrupt changes in density (Whiteley, 2012), resistivity imaging is less affected by such heterogeneities (Palacky, 1988; Tarits et al., 2012). Its sensitivity to fluid content and mineralogy enables more reliable subsurface characterization, supporting robust ground models and better-informed engineering decisions.

The technique involves injecting electrical current into the ground via source electrodes and measuring voltage differences at receiver electrodes (Loke et al., 2020). These measurements yield apparent resistivity values, which are processed through inversion algorithms to estimate the true resistivity distribution. Because electric current flow is influenced by subsurface properties such as porosity and mineralogy, resistivity imaging provides valuable insights that complement other geophysical data.

MAPPEM Geophysics has developed purpose-built non-invasive resistivity systems designed to perform reliably in the challenging marine environment. These systems have demonstrated clear advantages in environments where seismic methods are limited.

In marine karst settings, seismic imaging often struggles due to the irregular and heterogeneous nature of the subsurface. Features such as voids, fractures, and abrupt changes in acoustic impedance scatter seismic waves, resulting in poor velocity models and ambiguous interpretations. MAPPEM's deep-towed dipole-dipole resistivity system has proven effective in such environments. Applied to a submarine karstic plateau composed of calcarenite and sandy pockets (like the Tamala Limestone), the system revealed a strong correlation between resistivity values and porosity estimates derived from gamma density measurements (Dusart et al., 2022a). This capability to resolve metre-scale heterogeneity makes resistivity imaging particularly valuable for delineating subsurface irregularities and identifying zones of dissolution and fracturing.



Top: 2D seismic image showing layered structure, acoustic masking (zones lacking velocity data), and uncertain lithology ("?"). Bottom: Resistivity image clarifying subsurface composition, including within masked areas. Note: Vertical resistivity artefacts are attributed to rapid changes in sensor tow depth (vessel motion).

Resistivity imaging also excels in areas affected by acoustic masking, such as shallow gas zones (Dusart et al., 2022b), like those identified in P1DA. MAPPEM's system has successfully imaged through gas-charged sediments, helping to distinguish between biogenic and geologic gas origins and define their lateral extent. The technique revealed detailed characteristics of a palaeovalley obscured by gas, including the nature of its clastic infill, the harder substratum along its flanks, cap rock formations, and deeper lithologies. This ability to penetrate acoustic masks and resolve subsurface heterogeneities makes resistivity imaging a critical tool for mitigating risks in maritime developments.

Conclusions

P1DA presents a geologically complex and heterogeneous subsurface, with karstic voids, shallow gas zones, and lenticular stratigraphy that complicates borehole correlation and increases engineering risk. These conditions challenge foundation design, trenching feasibility, burial depth, and cable routing. Resistivity imaging offers a robust, non-invasive solution for characterizing such environments. It provides valuable insights into porosity, density, and geological structure, even in acoustically masked or difficult-to-access zones. MAPPEM's deep-towed systems have successfully addressed similar subsurface risks to those in P1DA across a range of marine environments and geographies, helping to build reliable ground models and improve confidence in offshore infrastructure design.

Lithology	Leederville Formation	Tamala Limestone	Becher Sand	Safety Bay Sand	Fremantle Blanket	Swamp Deposits
Age	Early Cretaceous	Pleistocene	Holocene (underlays Safety Bay Sand)	Holocene (overlays Becher Sand)	Holocene	Holocene (various, superficial)
Composition	Sand, shale, claystone, siltstone with conglomerate, coal, glauconite, feldspar, pyrite, heavy minerals	Calcarenite with quartz, clays, feldspar, glauconite, phosphate nodules	Quartz and skeletal sand with calcareous mudstone and organic layers	Calcareous or carbonate-quartz sands with shell fragments; minor feldspar, heavy minerals	Calcareous and quartzose sands	Organic rich with clay, silt, sand, peat
Consolidation	Weakly to moderately consolidated	Friable to well-lithified	Unconsolidated, bioturbated	Unconsolidated	Unconsolidated	Unconsolidated
Grain Characteristics	Poorly sorted; very fine to coarse, angular to subangular	Coarse to medium; well-rounded quartz grains	Well-sorted; fine to medium, subrounded to rounded, minor fractions of coarse to gravel	Moderately to well sorted; fine to medium, angular to rounded	Well-sorted; medium to coarse, minor fractions of very coarse to gravel	Fine grained
Porosity	Notable	High	High	High	High	High
Strength & Stiffness	Modest	Variable; affected by karstic features	Low	Moderate	Low shear strength	Very low shear strength
Compressibility	High	Moderate	High	Moderate to high	High	High
Engineering Risks	Poor borehole correlation, low shear strength	Void-related instability, poor seismic imaging, difficult sampling	Sensitive to groundwater, organic content affects stability	Loose to moderately cemented, superficial instability	Mobile sediments, instability under wave action	Poor bearing capacity, lateral spreading

Qualitative summary of key lithologies likely encountered in the near-surface of P1DA and their potential engineering implications. Note the general uncertainty and heterogeneity, which must be addressed through targeted subsurface investigations.

About MAPPEM Geophysics

MAPPEM Geophysics is a French company at the forefront of marine electromagnetic technology. Since 2015, we have specialized in the development of advanced electromagnetic instruments and methodologies, supporting a wide range of maritime site investigations. Our expertise enables high-resolution resistivity imaging of the marine subsurface, providing valuable insights into subsurface heterogeneities, porosity, and lithology, even beneath acoustically masked zones.

In addition to subsurface characterization, MAPPEM Geophysics identifies potential buried hazards and anthropogenic objects, and measures ambient electromagnetic fields in marine environments. These capabilities contribute to safer and more informed offshore engineering and environmental assessments. MAPPEM Geophysics is part of the Sea Vorian group of companies.

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MAPPEM’s vessel-towed 2D resistivity imaging system deployed near the coast. Image © Florent Colin.

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