

Site Characterization and Geohazard Considerations for Floating Offshore Wind Developments in Volcanic Environments

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ABSTRACT: Floating offshore wind (FOW) developments are nowadays considered in volcanic environments, bringing new challenges to site characterization. Bedrock can vary drastically in lithology, strength, abrasiveness and weathering, while the seafloor sediment cover contains unconventional sediments such as fragments of volcanic rocks, pumice materials and ashes. Reliable data from regional surveys and historic records enable assessment of specific geohazards for these regions. For upcoming developments, planning accurate geotechnical sampling and testing is essential for determining rock and soil properties, which directly influence the design of anchors and associated infrastructures. This article discusses initial feasibility assessments conducted in the Aegean Sea, Greece and offshore Gran Canaria, Spain. The regional geological setting is presented, together with anticipated seabed sediment properties and bedrock conditions. Geohazards are identified using publicly available data combined with geophysical and geotechnical surveys, to support the creation of a detailed hazard risk assessment for FOW development. Design considerations for various anchor types are presented along with site characterization survey strategies to address the challenges presented by volcanic environments. Last, potential areas of development from a geoscientific standpoint are listed to serve this market development: synthetic cone penetration tests (CPTs), autonomous underwater vehicles (AUVs), CPT crushability effect, and predictive ground modeling.

KEYWORDS: Floating offshore wind (FOW), volcanic environments, geohazards, anchors, ground model.

1 BACKGROUND

FOW projects are increasingly considered in volcanic regions, presenting new challenges for site characterization. Similarly, routing of associated subsea cables near volcanic features in complex geological settings are arduous. This study depicts development feasibility assessments conducted in the Aegean Sea, Greece and offshore Gran Canaria, Spain. Both regions present specific geological conditions displaying a large span of geohazards.

Gran Canaria - part of the volcanic archipelago of the Canary Islands - has strong offshore wind potential and is advancing pilot FOW projects supported by European initiatives like WIP10+ and Oceanic Platform of the Canary Islands (PLOCAN). Greece has identified 25 offshore zones with a potential of 12.4 GW, mainly relying on FOW due to deep waters, with key projects in the Cyclades, Dodecanese islands, and near Alexandroupolis.

2 SITE CONDITIONS

This study relies on publicly available sources combined with peer-reviewed scientific literature to understand the geological framework, regional stratigraphy, and seabed sediment characteristics in both regions.

2.1 Tectonic and Dynamic Setting

The Canary Islands consist of an active volcanic 8-island archipelago stretching over 500 km. This geological hotspot is located on oceanic crust ensuing the opening of the Central Atlantic Ocean. The regional volcanic province was formed through a series of different eruptive events with the western islands lying on younger basement than the eastern islands, in range 150 to 180 million years ago (Hoernle and Carracedo, 2009). Over the thick igneous part of the oceanic crust, sedimentation occurred from the African continental margin, exposing the islands to erosion through time. As a result, volcanic structures such as domes and pitons were uncovered.

The Aegean Sea region is one of the most geologically dynamic in the Mediterranean Sea, resulting from the collision of microplates which initiated during the Upper Cretaceous.

Volcanism is considered in modern hazard assessments as the region historically underwent severe eruptive volcanic events. Tectonic features at stake include a continental convergence with the subduction of the North African plate under the European plate at the Hellenic Trench, the melting of the overridden plate at the subduction zone resulting in the concave South Aegean Volcanic Arc (SAVA), the high-rate extension in the Back-Arc region of the Aegean Sea caused by the rollback of the African Slab attested by the frequent presence of normal faulting, and the right-lateral strike slip faulting towards the northern Aegean Sea due to the offset between the aforementioned continental convergence to the west and the Anatolian plate westward progress to the east (Kassaras et al., 2020).

2.2 Bathymetry and Geomorphology

Available bathymetry datasets were acquired in both regions with varying resolutions. Offshore Gran Canaria, the potential areas of development could spread from a shelf area of approximately 100 m depth towards a sharp escarpment. The latter reveals a dipping seafloor with slopes up to 15 degrees to reach up to 600 m depth. Multiple seabed features are anticipated such as rock outcrops heavily related to steep slopes and underwater volcanoes, boulder fields likely resulting from erosion and deposition related to underwater currents, ripples with wavelength smaller than 50 m in a sporadic pattern, and dune fields with wavelength up to 100 m perpendicular to the island escarpment.

The Aegean Sea is geomorphologically described as an epicontinental microtidal marine basin with an irregular bathymetry and multiple subregions (Poulos, 2009). Using publicly available bathymetric data with an average resolution (EMODnet, 2025), major visible morphological features consist of large basins, mass wasting processes (e.g., landslide scarps and submarine canyons), steep slope gradients, fault scarps, seamounts, rippled scour depressions, megaripples, dunes, and seafloor irregularity in places (see Figure 1).

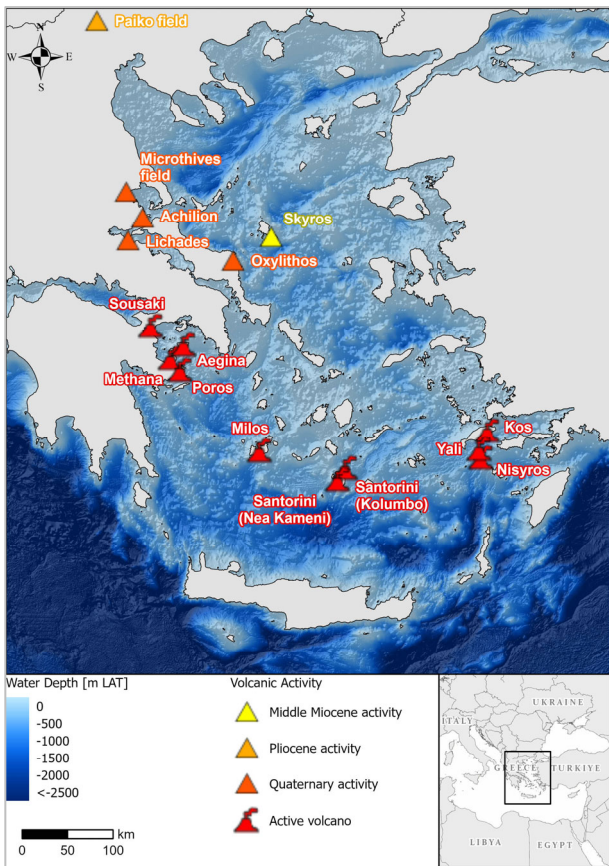


Figure 1. Aegean Sea: Regional Bathymetry and Volcanic Activity.

2.3 Seabed Sediments

Offshore Gran Canaria, bioclastic sediments and alluvial-fan deposits with varying granulometry have accumulated from the mainland further offshore: fine to medium-grained sands containing fragments of volcanic rocks and fragments of bioclasts, and coarse to very coarse-grained sands with a presence of marl. The shelf area surrounding Gran Canaria exhibits a sediment thickness up to 10 m, whereas the deeper seabed indicates a maximum thickness of 3 m with most of the escarpment slope gradient not indicating any sediment accumulation.

In the Aegean Sea, multiple open sources provide historic geotechnical data together with published literature including boreholes, grab samples, piston cores, and gravity cores (HEDNO, 2023; EAGME, 2025; EMODnet, 2025). It is worth noting that the Cretan Sea to the South of the Aegean Sea possesses volcanic ashes of coarse silt and fine sands (Brambati et al., 1983) and pyroclastic layers called tephra composed of either platy or rounded particles from pumice fragments and volcanic glass shreds (Chassefiere and Monaco, 1989).

2.4 Rock properties

For this study, bedrock outcrops consist of exposed volcanic rocks on or just below the seafloor. These rocks can be basaltic rocks, pyroclastic rocks such as breccias and tuffs, or altered plutonic intrusive rocks. Hard ground could lead to constraints for installation of multiple FOW assets (e.g., drag anchors, driven piles, suction caissons, submarine cables).

Given the inherent challenges in characterizing bedrock during the feasibility phase, it is possible to extrapolate geotechnical data between onshore sources and the underlying offshore bedrock. For Gran Canaria, bedrock is expected to comprise extrusive basaltic igneous rock, which can vary drastically in lithology, strength, abrasiveness, and weathering.

Indicative average and standard deviation values for selected geotechnical properties are presented in Table 1 (modified after Gobierno de Canarias, 2013).

Table 1. Indicative Geotechnical Property Values for Basaltic Rock in Gran Canaria.

Geotechnical Property	Average	Standard Deviation
Point load strength index	5.0	2.4
Unconfined Compressive Strength (MPa)	63.0	38.0
Young's Modulus (GPa)	30.0	7.3

Similarly, onshore geological maps of Greece suggest a wide range of anticipated rock basement in the Aegean Sea: claystones, limestones, sandstones, dolomites, metamorphic rocks (e.g., gneiss, amphibolite, phyllite, schists), metasedimentary rocks (e.g., marble, metaflysch). Representative properties are presented in Table 2 (modified after EAGME, 2025).

Table 2. Indicative Geotechnical Property Values for Anticipated Rock Basement Types across the Aegean Sea.

Lithology	Unconfined Compressive Strength (MPa)	Cohesion (MPa)	Friction Angle (degrees)	Young's Modulus (GPa)
Claystone	1 to 4	<1	20 to 32	--
Limestone	34 to 176	10 to 30	27 to 45	3 to 100
Dolomite	1 to 12	<1	25 to 45	--
Sandstone	20 to 177	10 to 40	30 to 48	4 to 25
Gneiss	60 to 200	10 to 30	35 to 45	70 to 100
Amphibolite	20 to 177	10 to 40	30 to 48	4 to 25
Marble	7 to 120	1 to 4	28 to 32	--
Metaflysch				
Schist				
Phyllite				
Micaschist				

3 GEOHAZARDS

Marine geohazards in volcanic environments encompass a wide range of dynamic natural phenomena such as volcanic eruptions, earthquakes, landslides, and tsunamis. They all pose serious threats to offshore infrastructure, coastal communities, and marine ecosystems.

3.1 Earthquakes

Earthquakes can trigger multiple events such as ground shaking, fault rupture, soil liquefaction, or slope instability. Active submarine faults amplify these risks by increasing slope gradients and weakening soil structures, while also serving as pathways for gas migration, facilitating the formation of slip surfaces and further instability.

The Canary Archipelago experiences volcanic-induced earthquakes of low magnitude, typically shallow and associated with magma intrusion. High seismicity was punctually recorded in La Palma and El Hierro, especially during strong eruptive phases. Tectonic and hydrothermal related seismicity was occasionally registered in Tenerife. The Aegean Sea is one of the most seismically active regions in Europe, experiencing moderate to strong earthquakes, with notable recent events including the 2020 Samos–İzmir Mw 7.0 earthquake and the 2021 Crete Mw 6.3 earthquake. In February 2025, thousands of tremors hit the region between Amorgos and Santorini, with 14 earthquakes larger than Mw 5.0 and up to Mw 5.3.

3.2 *Volcanism*

Active submarine volcanoes have the potential for explosive eruptions, caldera collapses, and fluid emissions, which can also trigger secondary hazards such as earthquakes, tsunamis and submarine landslides (Ercilla et al., 2021). Volcanism has demonstrably affected subsea infrastructures, such as the 2022 Hunga Tonga-Hunga Ha'apai eruption which caused a disruption to two subsea cables (Clare et al., 2025).

Volcanic activity in the Canary Island region is prevalent (e.g., the 2021 Cumbre Vieja eruption on La Palma Island, the 2011 to 2012 submarine eruption near El Hierro), often followed by several months of seismic unrest. Volcanic activity in Greece is infrequent, however, numerous Quaternary to Holocene volcanic centers exist throughout the Greek territory and historical destructive eruptive episodes have been recorded such as the 1950 Santorini event within the Aegean Sea, which was preceded by seismic activity (see Figure 1).

3.3 *Landslides*

Submarine landslides typically occur at the continental shelf-slope transition and result from complex interactions between internal seabed processes (e.g., earthquakes, active faults, gas hydrate dissociation, submarine volcanism) and external factors (e.g., storm waves, tides, human activities, tsunamis, sea level changes). They have the potential to mobilize large sediment volumes and travel long distances. Seabed landslides and sediment flows can undermine anchor stability by eroding the seabed and exposing or overburdening cables, increasing the risk of damage and infrastructure failure (Clare et al., 2025).

In the Canary Islands, at least ten large landslides have occurred within the last million years, with major events involving tens to hundreds of cubic kilometers (Ferrer et al., 2021). El Golfo in Lanzarote Island and El Hierro experienced multiple large flank failures over the past 200,000 years, illustrating geological instability in the region. The Aegean Sea exhibits a high susceptibility to offshore landslides with key contributing factors including rapid sedimentation, seismic loading, caldera collapses, and hydrothermally altered volcanic materials (Nomikou et al., 2012). These conditions are particularly prevalent in the SAVA region, where volcanic islands such as Santorini, Kolumbo, and Nisyros have experienced flank collapses and sector failures linked to both eruptive and tectonic processes.

3.4 *Subsidence*

Subsea subsidence can result from various natural processes associated with volcanic activity, particularly in tectonically active marine regions. One key mechanism is caldera collapse, where the expulsion of magma from chambers during volcanic eruptions leads to the structural failure and downward collapse of overlying rock strata (Lipman, 1997). These can cause abrupt and large-scale subsidence of the seafloor, significantly altering seabed morphology. Lava loading and the accumulation of volcanic material can also cause flexural subsidence of the underlying crust, especially in oceanic island chains such as Hawaii (Watts and ten Brink, 1989). Hydrothermal alteration of volcanic rocks may further weaken structural integrity, with the risk of localized seabed failure.

Subsidence is a critical hazard to FOW development due to its impact on anchors, mooring systems and subsea cables by altering their performance. Subsidence can also increase the risk of fatigue damage in dynamic power cables, particularly near touchdown zones.

3.5 *Tsunamis*

Tsunamis - as secondary hazards generated by earthquakes, slope failures, or volcanic eruptions - pose significant threats through abrasion, drag, debris entanglement, and sediment burial of offshore infrastructure (Ercilla et al., 2021). Tsunami occurrence may affect FOW structural integrity due to important wave forces and dynamic pressure, increasing stresses and potentially causing floaters to drift. Tsunami side effects may also be linked to seabed scouring and erosion.

The Canary Islands face tsunami hazards, primarily linked to volcanic flank collapses, submarine landslides, and distant seismic events in the North Atlantic. Although the historical record of tsunami impact on the archipelago is limited, geoscientific evidence suggests a high risk, especially in relation to the unstable island flanks in La Palma, El Hierro, and Tenerife (Masson et al., 2006). The Aegean Sea is considered a moderate to high tsunami risk area due to the region seismicity, with historic records indicating volcanic- and landslide-induced events. The Aegean Sea contains well documented geological and sedimentary evidence of past tsunami events across the Hellenic Arc, the Corinth Gulf, and the SAVA region specifically near the island of Santorini. Stratigraphic and sedimentological studies have identified tsunami-related deposits in both coastal and shallow marine settings (Dominey-Howes, Papadopoulos and Dawson, 2000; Minoura et al., 2000).

3.6 *Shallow Gas*

Seepage can occur in various geodynamic contexts across both active and passive continental margins. This process generally involves the leakage of hydrocarbons, primarily methane, either dissolved or as free gas. Fluid escape can result in diverse seafloor morphologies: positive relief features (e.g., mounds, gas hydrates, and mud volcanoes), and negative topographies (e.g., pockmarks and collapses) (Ercilla et al., 2021). These processes can cause seafloor instability, seabed scars, and even blowouts when escaping and igniting at sea level. Pockmarks can indicate weak or unconsolidated sediments, worth considering in anchor design. Cables stretching across depressions can be damaged by currents and sediment movements.

Evidence of fluid and gas seepage in the Canary Islands region has been observed in association with volcanic activity and tectonic structures along the submarine slopes of the archipelago. Seepage features such as pockmarks, gas plumes, and hydrothermal vents have been identified by geophysical surveys and remotely operated vehicle (ROV) operations, particularly near submarine volcanic edifices and rift zones (López et al., 2012). Active seabed pockmarks were documented off the coasts of Patras and Aigion in Greece, where features up to 15 m deep vented gas in association with seafloor instability prior to the 1993 Mw 5.4 earthquake (Hasiotis et al., 1996).

4 ANCHOR DESIGN CONSIDERATIONS

In both the Canary Islands and the Aegean Sea, volcanic activity has produced highly variable seabed compositions: basaltic lava flows, pyroclastic sediments, and hydrothermally altered materials. They pose challenges to FOW systems such as anchors, mooring lines and submarine cables.

4.1 *Anchor Types*

Recent advancements in FOW have led to the development of various anchor systems with the aim of enhancing performance, reducing costs, and minimizing environmental impacts. Four main classifications presented hereafter are in general

agreement with industry types: gravity anchors, pile anchors, plate anchors, and composite anchors.

In volcanic environments, hard seabed conditions are anticipated due to limited sediment cover. FOW anchoring systems capable of securing rock engagement are required. The most appropriate solutions are (i) **gravity anchors** sustained by their own weight, and (ii) individual or grouped **pile anchors**. Both types have proven to be viable through experimental theoretical testing in weak rock (Bañuelos-García et al., 2021), such as the tephra layers anticipated in certain part of the Aegean Sea. Traditional dimensions and operational constraints of gravity anchors saw the emergence of alternatives such as ballasted boxes or grillages where a rock fill or an iron ore berm is placed after the installation of a pre-cast box or assembled grillage net on the seafloor (Randolph and Gourvenec, 2017; Cerfontaine et al., 2023). Pile-type solutions are more favored as they offer a larger holding capacity, a possible installation on uneven seafloor, a reduced footprint, and an accurate placement. Pile anchors include driven, drilled, drilled and grouted open ended cylindrical tubular piles, and suction caissons. Like gravity type anchors, they rely on their submerged weight complemented with the pile shaft resistance provided by the soil shear strength. Generally, pile anchors provide robust multi-directional resistance, ideal for taut or vertically tensioned mooring configurations.

Plate anchors are embedded into the seabed and rely on a consistent volume of soil to oppose the mooring line loads. They are not suitable when a shallow bedrock is encountered, or on a seafloor with outcropping rock. However, certain types such as drag embedment anchor (DEA) and vertically load anchor (VLA) for inclined loads, are suitable for catenary mooring used in FOW developments (Cerfontaine et al., 2023).

Hybridization warrants resistance to complex loads anticipated with FOW. **Composite anchors** generally feature a combination of more than one conventional anchor type discussed above, mainly integrating components from plate- and pile-type anchors: they display a central steel shaft like pile anchors, together with one or more helical plates or flukes like plate anchors. Another combination of the previously discussed conventional types is the caisson-plate gravity anchor (CGA) which merges the benefits of traditional gravity anchors and suction caissons, facilitating enhanced bearing capacity and stability (Rui et al., 2025).

4.2 Shared Anchor Configurations

When multiple mooring lines from adjacent turbines are terminated at a common anchor, shared anchor configurations provide substantial cost and environmental advantages by reducing the number of seabed penetration points and material logistics. An effective deployment in Norway demonstrated an approximate 40% reduction in anchor count and associated mooring costs (Frossard, Bendzovski and Tuveng, 2025). While load-sharing capabilities yield farm-level cost savings of 25 to 60% in larger arrays, the shared-anchor concept introduces critical challenges: anchors must resist forces from multiple directions, system reliability decreases under extreme loading unless anchor safety factors are heightened, and overall farm layout complexity increases. Integrated design methodologies, combining quasi-static line optimization and dynamic platform anchor simulations, are essential to harness shared anchor benefits while maintaining safety, operability, and cost effectiveness.

5 SURVEY STRATEGIES

The management of geohazards in volcanic environments requires a rigorous and integrated survey strategy, tailored to

the complexity of a given region. Deep-water sites often feature variable and poorly understood geology, including soft sediments, steep slopes, or hard seabed layers previously discussed. Main challenges complicating anchor design are related to identifying irregular and rugged seabed topography (due to lava flows, volcanic cones, and calderas), presence of fractured basalt, tuffs, and hydrothermally altered zones, unconsolidated ash layers overlying hard rock, high seismicity, and presence of fault zones.

While little published documentation exists to shape specific site investigations for FOW development, the primary framework can be found in guidelines and recommended practices by different national bodies (e.g., SUT OSIG, 2022; ISO, 2023; BOEM, 2024; CFMS, 2024).

5.1 Ground Model

The acquisition and integration of geodata should inform and support the development of an evolving ground model. In volcanic areas, it is crucial to characterize geologic formations, lithological variability and sediment instability. To that end, a **conceptual ground model** is generally derived from a desktop study and historical data review. Existing information is analyzed and helps plan specific surveys to cover data gaps. It should tackle both the regional and local geological setting, along with the development of a comprehensive geohazard understanding. A **preliminary Front-End Engineering Design (FEED) ground model** is then developed by considering geophysical and geotechnical survey results, which support responsible preliminary design, regulatory compliance, and resilient infrastructure planning. To mitigate localized hazards and inform the design before construction, a **detailed ground model and geohazard assessment** are built upon the previous ground model iteration using complementary geotechnical data collected at each anchor - or anchor group - location to support the detailed design of moorings, anchors, and cable burial systems.

5.2 Geophysical Surveys

A site-wide (layout agnostic) reconnaissance geophysical survey would typically aim to map the seafloor bathymetry and capture the extents of seismic facies of Tertiary and Quaternary formations as well as underlying bedrock. It is expected that hard constraints to engineering applications will be detected at this stage. Typically, a detailed geophysical survey would then be carried out to detect soft constraints and provide unexploded ordnance (UXO) clearance for engineering activities, to As Low As Reasonably Practicable (ALARP) standards. The line spacing of the detailed survey would be expected to be at a reduced interval compared to the reconnaissance survey but may be focused upon areas of proposed development.

The main geophysical methods include multibeam echosounders (MBES) with backscatter for high-resolution bathymetry acquisition, side scan sonar (SSS) with dual frequency for detecting sediment boundaries and detection of seabed features, sub-bottom profiling (SBP) for imaging shallow sub-seabed stratigraphy, and single or multichannel ultra-high resolution seismic (S- or MUHRS) reflection data for deeper sub-seabed stratigraphy. Magnetometers or gradiometers are employed to detect ferrous objects (e.g., UXOs)

In volcanic terrains, enhanced resolution and extended survey coverage are often necessary to capture highly variable deposits, complex structures (e.g., lava flows, hydrothermal deposits) and fault zones. Survey line orientation should consider the dip or strike of such features to image them with the greatest clarity. The possible presence of volcanic bombs

and ejected rocks within fine-grained tephra layers should be considered as a possible detection objective.

5.3 Geotechnical Surveys

Preferably executed after interpretation of the geophysical survey, a reconnaissance geotechnical survey permits to arrest stratigraphic profiles and to derive preliminary soil properties. When integrated with geophysical reflectors, these datasets define a three-dimensional seismo-stratigraphic framework capturing spatial ground variability for each soil unit and rock formation. The geophysical seismic velocity model is often calibrated during this phase with ground truthing boreholes or cone penetration testing (CPT) output. Site heterogeneity in a volcanic setting demands interpolation and modelling techniques, which may carry risk if poorly constrained.

Geotechnical investigations in deep-water environments require specialized vessels, deep-penetrating tools and extended mobilization times. In situ testing and sampling via CPT and boreholes (including rotary coring in high-strength volcanic formations), provide essential information on soil and rock properties. High-quality sample retrieval and laboratory testing (i.e., classification, strength, and dynamic tests) are key inputs for geotechnical design and ground model development. Diamond coring tools optimized for hard volcanic lithologies help collect intact core samples. Traditional offshore site investigations struggle with volcanic substrates like basalt, scoria, and tuff, but tools allow successful rotary coring in water depths larger than 1,000 m. Additionally, new deep-water tools are being adapted for in situ testing in volcanic settings such as CPT with enhanced tip resistance capabilities to penetrate consolidated volcanic ash and altered rock, downhole seismic CPTs providing shear wave velocity profiles crucial for seismic site classification and seabed dilatometers and pressuremeters allowing direct testing of deformation properties in fractured volcanic rock.

6 DISCUSSION

As commercial FOW projects depend on multiple infrastructures, its final layout can vary regularly, influencing the scope of site surveys. Uncertainty in exploration depth range is triggered by the variety of anchor solutions considered: drag embedment anchors and gravity anchors typically require relatively shallow soil characterization (less than 10 to 20 m), whereas tension-leg platforms on driven piles would require deeper investigation (larger than 50 m).

Costs and feasibility challenges exist for FOW site characterization if a foundation-specific investigation approach is applied. Instead, anchors should be designed based on a grouped approach providing sufficient range in selected design parameters which could cover multiple design envelopes (de Wit and Siermann, 2025). This approach might alter current guidelines on marine site characterization for FOW development.

With seismic inversion and quantitative interpretation, synthetic CPTs could accelerate the site characterization process by reducing physical investigations while predicting geotechnical properties. It should be noted that synthetic CPTs do not replace but supplement physical testing (Michel et al., 2025). In deep-water environments, the use of autonomous underwater vehicles (AUVs) during geophysical surveys should be considered as they typically operate close to the seafloor resulting in enhanced data quality and resolution (Wynn et al., 2014).

Unconventional sediments such as those of volcanic depositional origin could infer a partial cementation involving a crushability effect when tested by CPT. Similar crushing is

anticipated in high carbonated sediments such as the marl present offshore Gran Canaria. Penetration-based testing methods such as CPT induce particle crushing and excess pore pressure development around the cone misleading material characterization. The latter is crucial in volcanic regions which are often subject to earthquake loading triggering liquefaction. Widely accepted liquefaction evaluation procedures were nonetheless derived on silica sands requiring proper implementation of cone correction factor(s).

To cope with the anticipated consequent soil information required for detailed design at each anchor – or anchor group – location, the use of predictive ground modeling could be valuable to forecast geological and geotechnical properties. Statistical methods, machine learning and probabilistic frameworks are used to estimate the distribution of soil types, stratigraphy and mechanical properties (Zinas et al., 2024; Caselitz et al., 2025). This modeling approach also helps quantifying confidence intervals or uncertainty of predictions supporting a risk-based decision-making for infrastructure design (Dimmock et al., 2025). A predictive approach aims at reducing site investigation surveys, optimizing and adjusting dynamically wind farm layouts, minimizing engineering design risks, and accelerating project timelines.

Subsea cable infrastructure, including export and inter-array cables, is particularly vulnerable to geological hazards in volcanic regions. Cable Burial Risk Assessments (CBRA) and Burial Assessment Studies (BAS) are essential for designing resilient cable systems.

7 CONCLUSIONS

FOW developments are expected to take place in deeper waters than conventional bottom-fixed projects, towards margins of continental shelves. This study takes stock on geoscientific considerations when advancing FOW in volcanic environments:

- A holistic understanding of regional seismotectonic setting, geomorphology features, sediment cover, and bedrock characterization apprehend initial development steps.
- Geohazards are intrinsically complex and can spark a chain-like reaction. Comprehension of hazards should be made from an early stage to embed risk reduction strategies in site-specific survey scopes.
- Volcanic environments require specific anchor types or composite anchors, which are worth being shared by multiple mooring lines. Their design should be based on a grouped approach.
- Deep-water environments in a volcanic setting imply a tailored site-wide geophysical and geotechnical survey strategy.
- Enhancements in geoscientific fields should bring value to FOW development: synthetic CPTs, use of AUVs, testing methods for unconventional sediments, cables studies (CBRA, BAS) and predictive ground modelling.

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9 REFERENCES

- Bañuelos-García, F., Ring, M., Mendoza, E. and Silva, R., 2021. A Design Procedure for Anchors of Floating Ocean Current Turbines on Weak Rock. *Energies*, 14(21), p.7347. <https://doi.org/10.3390/en14217347>.

- BOEM, 2024. Guidelines for Providing Geophysical, Geotechnical, and Geohazard Information Pursuant to 30 CFR Part 585.
- Brambati, A., Catani, G., Lenardon, G., Pirini Radrizzani, C., Pugliese, N. and Zucchi Stolfi, M.L., 1983. Sedimentological Aspects of the Cretan Sea. *Istituto di Geologia e Paleontologia dell' Università di Trieste, Italy*.
- Caselit, B., McKay, A., Widmaier, M., Oukili, J., Davies, D. and Pernin, N., 2025. Harnessing 3D ultra-high-resolution seismic technology for offshore wind farm development: Advancements, challenges, and future prospects. *The Leading Edge*, 44(3), pp.170–177. <https://doi.org/10.1190/tle44030170.1>.
- Cerfontaine et al., 2023. Anchor geotechnics for floating offshore wind: Current technologies and future innovations. *Ocean Engineering*, 279, p.114327. <https://doi.org/10.1016/j.oceaneng.2023.114327>.
- CFMS, 2024. *Recommendations for planning and designing anchor foundations of floating wind turbines*.
- Chassefiere, B. and Monaco, A., 1989. Role of organic matter and particle fabric in mass-physical and geotechnical properties: Implications for undrained slumping in Aegean Sea and Ionian Sea modern sediments. *Marine Geology*, 87(2), pp.165–182. [https://doi.org/10.1016/0025-3227\(89\)90059-5](https://doi.org/10.1016/0025-3227(89)90059-5).
- Clare, M.A., Yeo, I.A., Nash, J., Hunt, J.E., Panuve, S., Wilkie, A., Williams, R., Dowey, N., Rowley, P., Barclay, J., Phillips, J., Scarlett, J., Engwell, S., Henstock, T.J., Seabrook, S., Watson, S., Wysoczanski, R., Ribo, M., Cronin, S., Talling, P.J., Cassidy, M., Watt, S. and Robertson, R., 2025. Volcanic eruptions and the global subsea telecommunications network. *Bulletin of Volcanology*, 87(6), p.51. <https://doi.org/10.1007/s00445-025-01832-1>.
- Dimmock, P.S., Sharma, S., Tam, T., Tapper, L., Vanneste, M., Klinkvort, R.T., Forsberg, C.F., Kort, D.A., Griffiths, L., Bozorgzadeh, N., King, T.A. and Hill, A.W., 2025. A ground modelling framework for offshore wind farm developments.
- Dominey-Howes, D.T.M., Papadopoulos, G.A. and Dawson, A.G., 2000. Geological and Historical Investigation of the 1650 Mt. Columbo (Thera Island) Eruption and Tsunami, Aegean Sea, Greece. *Natural Hazards*, 21(1), pp.83–96. <https://doi.org/10.1023/A:1008178100633>.
- EAGME, 2025. *Ελληνική Αρχή Γεωλογικών & Μεταλλευτικών Ερευνών - Ελληνική Αρχή Γεωλογικών & Μεταλλευτικών Ερευνών*. [online] Available at: <<https://www.eagme.gr/>>
- EMODnet, 2025. *EMODnet Map Viewer*. [online] Available at: <<https://emodnet.ec.europa.eu/geoviewer/>>
- Ercilla, G., Casas, D., Alonso, B., Casalbore, D., Galindo-Zaldívar, J., García-Gil, S., Martorelli, E., Vázquez, J.-T., Azpiroz-Zabala, M., Do Couto, D., Estrada, F., Fernández-Puga, M.C., González-Castillo, L., González-Vida, J.M., Idárraga-García, J., Juan, C., Macías, J., Madarieta-Txurruka, A., Nespereira, J., Palomino, D., Sánchez-Guillamón, O., Tendo-Salmerón, V., Teixeira, M., Valencia, J. and Yenes, M., 2021. Offshore Geological Hazards: Charting the Course of Progress and Future Directions. *Oceans*, 2(2), pp.393–428. <https://doi.org/10.3390/oceans2020023>.
- Ferrer, M., González de Vallejo, L., Maderia, J., Andrade, C. and García-Davalillo, J.C., 2021. Megatsunamis Induced by Volcanic Landslides in the Canary Islands: Age of the Tsunami Deposits and Source Landslides. *GeoHazards*, 2(3), pp.228–256.
- Frossard, R., Bendzovski, R. and Tuveng, E., 2025. Hywind Tampen – A geotechnical- and structural design of shared suction anchors, from concept to installation.
- Gobierno de Canarias, 2013. *Laboratorio - Guías Técnicas - Geotecnia GETCAN-011*.
- Hasiotis, T., Papatheodorou, G., Kastanos, N. and Ferentinos, G., 1996. A pockmark field in the Patras Gulf (Greece) and its activation during the 14/7/93 seismic event. *Marine Geology*, 130(3), pp.333–344. [https://doi.org/10.1016/0025-3227\(95\)00131-X](https://doi.org/10.1016/0025-3227(95)00131-X).
- HEDNO, 2023. Financial Statements 01/01/2023 – 31/12/2023 based on International Financial Reporting Standards, as adopted by the European Union. *HCMR Hellenic Centre for Marine Research*. Available at: <<http://www.hcmr.gr/en/>>
- Hoernle, K.A. and Carracedo, J.C., 2009. Canary Islands, geology. *Encyclopedia of islands*, pp.133–143.
- ISO, 2023. *ISO19901-8, Oil and gas industries including lower carbon energy – Offshore structures – Part 8: Marine soil investigations*.
- Kassaras, I., Kapetanidis, V., Ganas, A., Tzanis, A., Kosma, C., Karakonstantis, A., Valkaniotis, S., Chailas, S., Kouskouna, V. and Papadimitriou, P., 2020. The New Seismotectonic Atlas of Greece (v1.0) and Its Implementation. *Geosciences*, 10(11), p.447. <https://doi.org/10.3390/geosciences10110447>.
- Lipman, P.W., 1997. Subsidence of ash-flow calderas: relation to caldera size and magma-chamber geometry. *Bulletin of Volcanology*, 59(3), pp.198–218. <https://doi.org/10.1007/s004450050186>.
- López, C., Blanco, M.J., Abella, R., Brenes, B., Cabrera Rodríguez, V.M., Casas, B., Domínguez Cerdeña, I., Felpeto, A., de Villalta, M.F., del Fresno, C., García, O., García-Arias, M.J., García-Cañada, L., Gomis Moreno, A., González-Alonso, E., Guzmán Pérez, J., Iribarren, I., López-Díaz, R., Luengo-Oroz, N., Meletlidis, S., Moreno, M., Moure, D., de Pablo, J.P., Rodero, C., Romero, E., Sainz-Maza, S., Sentre Domingo, M.A., Torres, P.A., Trigo, P. and Villasante-Marcos, V., 2012. Monitoring the volcanic unrest of El Hierro (Canary Islands) before the onset of the 2011–2012 submarine eruption. *Geophysical Research Letters*, [online] 39(13). <https://doi.org/10.1029/2012GL051846>.
- Masson, D. g. Harbitz, C. b, Wynn, R. b, Pedersen, G. and Løvholt, F., 2006. Submarine landslides: processes, triggers and hazard prediction. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 364(1845), pp.2009–2039. <https://doi.org/10.1098/rsta.2006.1810>.
- Michel, G., Coughlan, M., Stanca, R., Trindade, L. and Joseph, T., 2025. A review of benefits and pitfalls for prediction of geotechnical parameters in offshore wind ground models using synthetic CPTs.
- Minoura, K., Imamura, F., Kuran, U., Nakamura, T., Papadopoulos, G.A., Takahashi, T. and Yalciner, A.C., 2000. Discovery of Minoan tsunami deposits. *Geology*, 28(1), pp.59–62. [https://doi.org/10.1130/0091-7613\(2000\)028<0059:DOMTD>2.0.CO;2](https://doi.org/10.1130/0091-7613(2000)028<0059:DOMTD>2.0.CO;2).
- Nomikou, P., Carey, S., Papanikolaou, D., Croff Bell, K., Sakellariou, D., Alexandri, M. and Bejelou, K., 2012. Submarine volcanoes of the Kolumbo volcanic zone NE of Santorini Caldera, Greece. *Global and Planetary Change*, 90–91, pp.135–151. <https://doi.org/10.1016/j.gloplacha.2012.01.001>.
- Poulos, S.E., 2009. Origin and distribution of the terrigenous component of the unconsolidated surface sediment of the Aegean floor: A synthesis. *Continental Shelf Research*, 29(16), pp.2045–2060. <https://doi.org/10.1016/j.csr.2008.11.010>.
- Randolph, M. and Gourvenec, S., 2017. *Offshore Geotechnical Engineering*. London: CRC Press. <https://doi.org/10.1201/9781315272474>.
- Rui, S., Wang, L., Zhou, Z., Jostad, H.P. and Guo, Z., 2025. *Bearing performance of a novel caisson–plate gravity anchor | Géotechnique | Emerald Publishing*.
- SUT OSIG, 2022. *Guidance notes for the planning and Execution of geophysical and geotechnical ground investigations for offshore Renewable energy developments*.
- Watts, A.B. and ten Brink, U.S., 1989. Crustal structure, flexure, and subsidence history of the Hawaiian Islands. *Journal of Geophysical Research: Solid Earth*, 94(B8), pp.10473–10500. <https://doi.org/10.1029/JB094iB08p10473>.
- de Wit, S. and Siermann, J.F., 2025. Geotechnical site characterisation challenges for floating offshore wind – a developer’s perspective.
- Wynn, R.B., Huvenne, V.A.I., Le Bas, T.P., Murton, B.J., Connelly, D.P., Bett, B.J., Ruhl, H.A., Morris, K.J., Peakall, J., Parsons, D.R., Sumner, E.J., Darby, S.E., Dorrell, R.M. and Hunt, J.E., 2014. Autonomous Underwater Vehicles (AUVs): Their past, present and future contributions to the advancement of marine geoscience. *Marine Geology*, 352, pp.451–468. <https://doi.org/10.1016/j.margeo.2014.03.012>.
- Zinas, O., Papaioannou, I., Schneider, R. and Cuéllar, P., 2024. *Multivariate Gaussian Process Regression for 3d Site Characterization from CPT and Categorical Borehole Data*. <https://doi.org/10.2139/ssrn.4995360>.