International Union of Geological Sciences
A proposal for a Task Group on Submarine Geohazards (TGSG)

Identification of the group as an IUGS Task Group

A group that summarizes global seafloor geoscientific data and seafloor geohazard risk assessment, assessment methods and capacity development.

Contents

1 Overview

1-1 Summary

Submarine geohazards are widespread across the globe. Submarine geohazards range from volcano eruption to earthquakes, tsunamis, seabed liquefaction, seabed creep, submarine slides, turbidity currents, shallow gas eruptions, mud volcanoes, and sediment instability such as migrating bedforms and scour and erosion around marine and offshore structures. Submarine landslide tsunamis are now seen from all geological environments; passive, convergent and transform margins, as well as volcanoes. The Task Group on Submarine Geohazards (TGSG) targets the full spectrum of such geohazards that impact people's lives and critical infrastructures. Offshore renewable energy systems are rapidly advancing to meet global requirements for sustainable development. Underwater fiber optic cables, underwater power cables, and underwater pipelines have been laid over many parts of the seafloor, and their importance, either strategic and economic, increased dramatically in recent years. However, these marine and offshore infrastructures are at risk from multiple cascading multi-geohazards that include landslides, tsunamis, earthquakes, and volcanic eruptions. Due to their widespread occurrence across the globe, submarine geohazards are a globally relevant and critical issue to be better addressed in the face of global climate change.

Therefore, the global development of offshore renewable energy systems is facing new challenges. For the development of offshore renewable energy in a wide variety of geological settings including narrow continental shelves, plate subduction zones and steep seafloor topography, risk management and geohazard mitigation strategies need to be defined. These require advancement and integration of research across marine geology, oceanography, and physical processes. To this end, TGSG will work with the offshore renewable energy and submarine cable industry to identify and address key knowledge gaps. Further, the TGSG aims to provide global mapping of submarine geohazard risks and create guidelines for assessing various submarine geohazard risks pertaining to emerging energy transitions. The targeted submarine geohazards are indeed broad, as described above. Suggested objectives and actions include providing the sector with (1) Case studies of submarine geohazards; (2) Data archive of offshore geological and geophysical data; (3) Guidelines of seafloor geological and geophysical surveys; (4) Submarine geohazards risk assessment; and (5) International capacity building and knowledge exchange. We aim to resolve these issues together with our cooperative works in this proposed international framework across Asia-Oceania, Europe-Africa, and North America-South America regions.

1-2 Scientific Rationale

The recurrence cycle for large-scale geohazards, including volcanic eruptions, earthquakes, and tsunamis, is frequent: 50 to 100 years. Continental shelves and submarine slopes in steep-sided and tectonically active areas are at high risk from numerous submarine geohazards, including seabed liquefaction, seabed creeps, submarine slides, turbidity currents, shallow gas eruptions, mud volcanoes, seabed sand wave migrations, and scour and erosion around marine and offshore infrastructures (Table A1, Appendix 1). Global warming in recent years has intensified typhoons, hurricanes, and cyclones, increasing the demand for submarine geohazard risk assessment for coastal zone development.

There are numerous facilities along the coast, both on and offshore, which are constantly under threat from natural hazards. They include: major centers of population and industry; renewable energy systems, such as offshore wind farms, nuclear power plants, associated grid connections; international commerce and telecommunications, etc. In geologically active regions, the presence of mountain range close to the coast often force settlement, road and rail roads to be located near or at the coastline, so exposing them to marine geohazard. The life cycle of offshore renewable energy developments involves design and development, site selection, obtaining various permissions, facility manufacturing, installation, operation and maintenance, to final decommissioning. A significant proportion of costs on power generation come from the design and installation of foundations and then ongoing maintenance of sites. Government funded geological and geophysical data archives of submarine environments and geohazards, which help to characterize risks, are publicly accessible but are rarely complete or integrated internationally. Additional industry funded investigations may be essential on governmental requirements for pre-installation Environmental Impact Assessment surveys. Moreover, survey data needs expert interpretation to identify potential hazards. Yet for the offshore renewable energy sector, there are no guidelines on requirements needed to identify submarine geohazard risks to a given confidence level so that the development of global guidance and marine geological expertise could help to de-risk investment on offshore developments.

Offshore renewable energy systems are rapidly advancing to meet global requirements for clean energy growth. Market leadership, in terms of installed capacity, is currently centered in Northwest Europe. In Europe offshore wind has the potential to be the main source of renewable energy. The marine geology of Northwest Europe is characterized by predominately wide, shallow, tectonically stable seafloor. Coupled with a high wind power density, Northwest Europe has been the testbed to accelerate offshore renewable technology solutions, development, and sector growth. The seabed is, however, subjected to diverse forms of submarine geohazard risks owing to intensified environmental forcing under global climate change, amid an increase in needs for further offshore development.

Many other regions are now considering offshore renewable energy solutions, including Southern Europe, South and Southeast Asia, South and North America and Oceania. In contrast to Northwest Europe, the marine geology of many of these regions are plate subduction zones or transform plate boundaries that are characterized by narrow, topographically steep and tectonically active seafloor. Here the continental shelf is narrow and the space for conventional offshore development is limited. Exclusive economic zones for offshore development are predominately composed of deep marine environments, with water depths >100m. New technologies and solutions are therefore required for offshore development to grow to meet global demand.

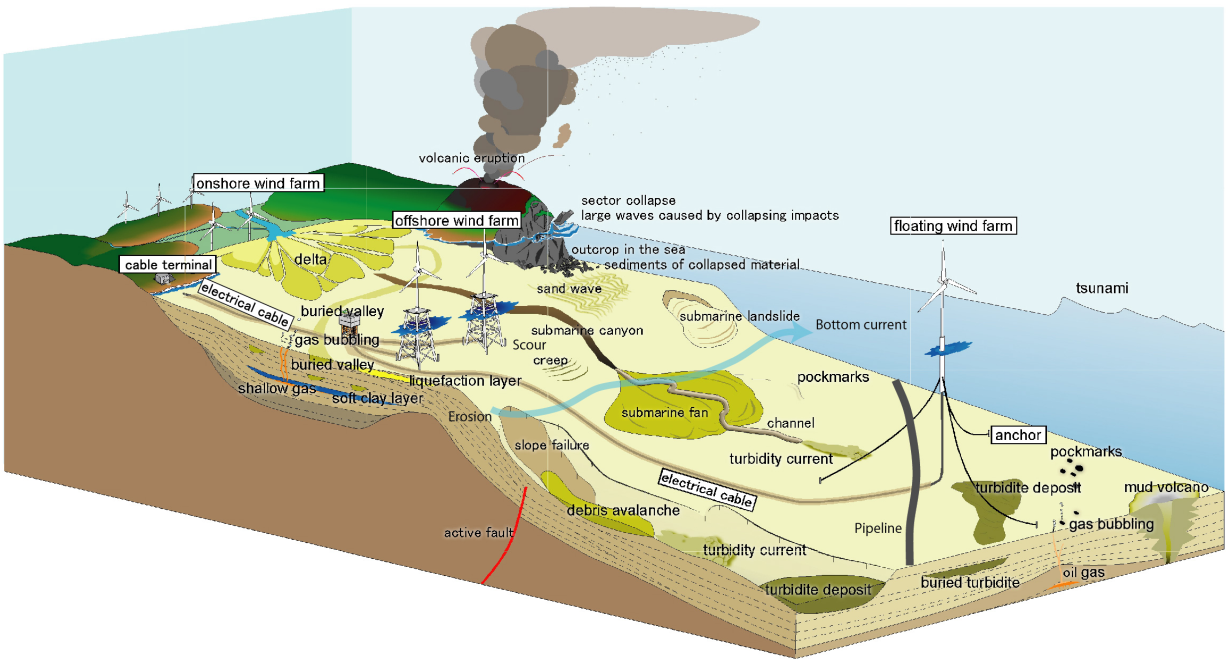

Figure 1. Submarine geohazards and risks to offshore renewable energy developments on continental shelves and submarine slopes.

Continental shelves and submarine slopes including convergent and transform plate boundaries are at risk from numerous geohazards (Table A1, Appendix 1, Figure 1). Large-scale geohazards include volcanic eruptions, earthquakes, and tsunamis (either earthquake- and landslide-induced). The recurrence cycle for large-scale events is frequent, 50 to 100 years, within the expected lifespan of existing windfarms or other offshore infrastructures. In addition to the large-scale geohazards, offshore renewable energy systems that are generally installed at water depths of up to 200m are at increasing risk from numerous submarine geohazards, including seabed liquefaction, seabed creeps, submarine slides, turbidity currents, shallow gas eruptions, mud volcanoes, large scale sand wave movements and scour and erosion around marine and offshore structures. These natural activities could cause damages and failures in offshore renewable energy systems, from foundations to arrays and export cables. With the transition to clean energy solutions, these submarine geohazards pose risks to power supply at regional and global levels.

A study of submarine geohazard risks to offshore renewable energy systems is therefore essential for global sustainable development. To secure clean energy futures globally, integrated international advancement on geological data and research are necessary to understand and assess both low-magnitude, high frequency and high-magnitude, low(er)-

frequency submarine geohazards to offshore renewable system installations (Figure 1). In this context, academic, governmental, and industrial strategies to manage and mitigate risks are required.

1-3 Aims and Objectives

The aim of the IUGS Task Group on Submarine Geohazards (TGSG) is to enable a safe and secure society through sustainable offshore energy development in a wide range of geological settings susceptible to submarine geohazards. Crucial to this is to advance our knowledge and understanding of geohazards to manage and mitigate industry identified risks. TGSG will meet its aim by providing a coordinating body to motivate future funded, and unfunded, programmes of work and research. To integrate these programmes, the TGSG has proposed five objectives, listed as O1-O5 below:

- **O1**. To review case studies of submarine geohazards events, detailing damage to infrastructure as well as management and the mitigation strategies emplaced before and after the events.
- **O2**. To collate an archive of international geological and geophysical survey data, highlighting how potential submarine geohazards are recorded in the data.
- **O3**. To detail the requirements of offshore geological and geophysical surveys to properly characterize submarine geohazard risks including interpretation of seafloor and subseafloor features.
- **O4**. To develop a global review of expected submarine geohazard risks, identifying expected frequency and magnitude of events as well as the risks posed on sustainable offshore development.
- **O5**. To build international capacity in sustainable offshore development, enabling the integration of academia, industry and policymakers for technology and solutions for the sector to grow into new marine environments.

Programmes of work and research across the Objectives will ensure successful delivery of key outputs and deliverables listed in D1-D6 below. Each group of O1 to O5 manages its own data collected.

- D1) A portfolio of submarine geohazards with their impact on marine infrastructure.
- D2) A global mapping/archive of submarine geological and geophysical data.
- D3) Guidelines for geological and geophysical surveys for submarine geohazard risk assessment.
- D4) A submarine geohazard map for sustainable offshore development with bilingual explanation.
- D5) An active and sustained programme of knowledge exchange activities between academia, industry, and policymakers.
- D6) A project report, summarizing recommendations to industry and government for global development of offshore renewable energy systems in shallow to deep marine environments.

2 Management and Governance

2-1 Management Structure

The Task Group on Submarine Geohazards (TGSG) will be composed of the Executive Bureau, Secretariat, Consortium, and Advisory Organization (Figure 2, also see remit and terms of reference in Appendix 2). Via committee meetings, the Executive Bureau will ensure the effective and efficient functioning of all TGSG activities as well as the effective completion of TGSG Objectives. The Executive Bureau will be responsible for reporting of activities to the IUGS.

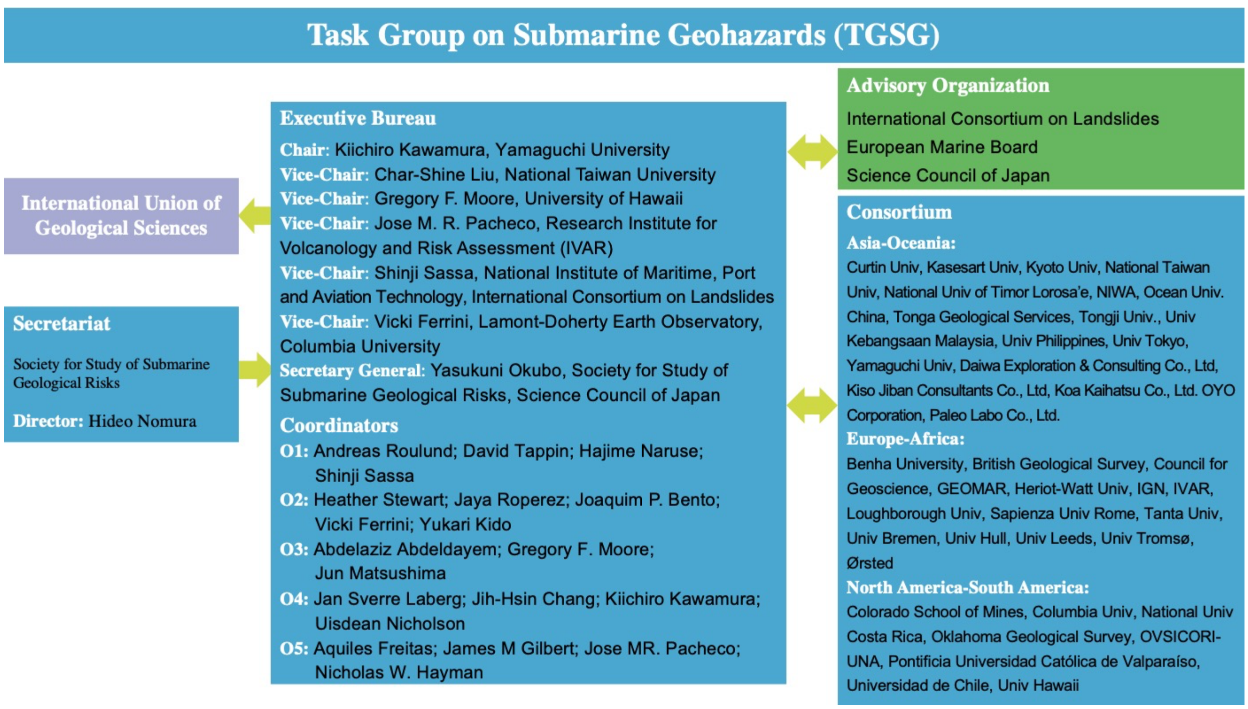

Figure 2. Management Structure of the Task Group on Submarine Geohazards.

TGSG progress, ensuring delivery of aims and objectives, will be reviewed by the Executive Bureau through biannual Management Board meetings. Management Board meetings will be led by the TGSG Chair, supported by the Executive Bureau. Vice-Chairs represent a global perspective on submarine geohazards pertaining to offshore renewable energy systems. Coordinators will be responsible for integrating the input of members of the TGSG consortium on the various objectives, and reporting progress to the IUGS Management Board. The TGSG consortium consists of academic and governmental organizations as well as private sectors dedicated to offshore renewable energy systems. To enable delivery of Objectives, Coordinators will arrange and hold sub-committee meetings as needed. Further supporting IUGS Management Board meetings and the roles of the Coordinators, the TGSG Secretariat will provide platforms for sharing of information within and beyond, the TGSG by enabling online and physical meetings. The Secretariat will also maintain a public webpage to disseminate information of TGSG activities and key deliverable outputs and will perform financial management. The Secretariat will be set up through the Society for Study of Submarine Geological Risks (SSSGR), Tokyo, Japan (https://www.kisojiban.com/sssgr/). An Advisory Organization will be integrated within the TGSG to provide intellectual support of the Executive Bureau, and hence will act as a source of information and guidance to steer direction and development of programmes of work.

3 Workplan

3-1 Programme Schedule

An initial 4-year schedule for the TGSG to achieve Deliverables D1–D6 via Objectives O1–O5 is detailed in Table 2. However, through development of programmes of work and research to address the objectives, the TGSG intends to have long-term longevity beyond the initial programme. We will have a mid-term summary with a brief report at 27th month.

Table 2. Gantt Chart for the Task Group on Submarine Geohazards

	Month	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	48+
Objectives																		
O1 Hazard case studies																		
O2 Geological surveys																		
O3 Survey requirements																		
O4 Global Risk Review																		
O5 Capacity Building																		
Deliverables																		
Hazard portfolio																		
Geological data archive																		
Survey Guidelines																		
Geohazard map																		
Knowledge Exchange																		
Sector recommendations																		
Management & Governance																		
Executive Board Meeting																		
International Workshops																		

3-2 Objectives

Over the lifespan of TGSG, objectives will be delivered by developing programmes of work or research, including securing additional funding where necessary. Identified TGSG funds will be used as seed funds to initiate and enhance programmes of research. As highlighted, specific programmes of work and research may address multiple objectives of the TGSG.

3-2-1 (O1) Case Studies of Submarine Geohazard Events

Numerous offshore and coastal geohazards have been recorded on plate subduction zones and the transform plate boundaries, including earthquakes, volcanic eruptions, tsunamis and landslides (Appendix 1, Table A1). For example, the 2002 Stromboli volcanic eruptions induced submarine landslides, causing a tsunami that damaged local infrastructure (Tinti et al., 2005). The submarine landslide off Papua-New Guinea in 1998 caused a tsunami that resulted in 2,200 deaths (Tappin et al., 2001). The Great Alaskan earthquake that took place in Seward and Valdez, Alaska in 1964 induced submarine landslides and tsunamis. The Grand Banks earthquake in 1929 induced submarine landslides, which broke submarine cables over a distance of 1,000 km from its source (Heezen & Ewing, 1952; Whelan, 1994). Recent major events include multiple tsunamis caused by coastal and submarine landslides (Sassa & Takagawa, 2019). Furthermore, seabed soils undergo flows and depositions repeatedly following various events such as storms, earthquakes, sediment transport and gravity flows, making seabed soils susceptible to liquefaction. Case histories and damages of earthquake- or wave-induced seabed liquefaction have been documented by numerous authors (Field et al., 1982; Sumer & Fredsoe, 2002; Sassa et al., 2006; Sumer, 2014; Miyamoto et al., 2020). Resultant damages include flotation, settlement, and significant displacement/breakage of pipelines (Christian et al., 1974; Herbich et al., 1984; Damgaard et al., 2006) and subsidence and inclination/failure of offshore and coastal gravity structures (Miyamoto et al., 1989; Sumer, 2014).

The global risk these geohazards pose to offshore renewable energy systems, from turbine to national grid, has not been elucidated. **O1** will develop programmes of work where submarine geohazard event case studies will be organized and critically reviewed. Crucially the potential for damage to offshore and coastal infrastructures will be demonstrated, highlighting risk to offshore renewable energy systems. This includes the impact of liquefaction for destabilizing a wide range of offshore structures with linkage to scour and landslides. Ongoing and future global climate change is expected to change the severity of wave conditions at the world's coasts, which would pose a further risk on offshore renewable energy systems as a consequence of wave-seabed-structure interaction. In light of recent advances in understanding of the mechanics and physics involved, mitigation and management strategies will be identified. Data will be compiled from:

- Existing papers, documents and reports.
- Proceedings from science meetings hosted by TGSG.

O1 will be supplemented by development of further funding for collaborative research (integrating TGSG consortium, supporters and correspondents) on submarine geohazards and risks they pose. Research projects to be developed within the TGSG include, but are not limited to, work on:

- Sedimentary archives of tsunami magnitude and frequency in Europe and SE Asia. Potential funding from Japan Society for the Promotion of Science and/or UK Research and Innovation.
- Scour and sediment transport by turbidity currents. Potential funding from US National Science Foundation and/or UK Research and Innovation.
- Flow and wave loading on fixed and dynamic cables. Potential funding from Joint Industry Projects and/or UK Research and Innovation.

Through integrating the existing research and developing new research, the TGSG will develop a novel portfolio of submarine geohazards with their impact on marine infrastructure (**D1**).

3-2-2 (O2) Submarine Geological and Geophysical Data Archives

O2 proposes to develop a programme of work that will integrate open-source offshore geological and geophysical subsurface data for continental shelves including the subduction and transform plate boundaries across the globe. The funding support will be sought from National Institutes. This subsurface data archive will provide a single source of detailed geophysical information. The data will be reviewed to highlight potential geohazard risks. The archive is developed to serve as an initial resource for site risk assessment. Some of data sources to be integrated include:

1. Australian Government, Geoscience Australia, National Offshore Petroleum Information Management System (NOPIMS): https://nopims.dmp.wa.gov.au/nopims
2. British Oceanographic Data Center: https://www.bodc.ac.uk/
3. Geological Survey of Japan: https://gbank.gsj.jp/geonavi/?lang=en and https://gbank.gsj.jp/sbp_db/pages/cover-E.html
4. Japanese Coast Guard: https://www.msil.go.jp/msil/htm/main.html?Lang=1
5. Japan Agency for Marine-Earth Science and Technology: http://www.jamstec.go.jp/e/http://www.jamstec.go.jp/e/database/ and http://www.jamstec.go.jp/obsmcs_db/e/
6. Published data (see, e.g., https://doi.org/10.1038/s41597-021-00969-w)
7. Data collected by programmes of work in O1, O3 and O4.
8. Data provided by TGSG Consortium and Supporters members, for public open access.
9. Marine geohazard maps of the Italian seas provided by the Italian Civil Defence Dept. (https://github.com/pcm-dpc/MaGIC).
10. Marine geohazard are the Norwegian MAREANO project (https://mareano.no/en), the Irish INFOMAR (https://www.infomar.ie)

TGSG will make all collated data available, either directly or cross-linked, from a single portal site hosted by the SSSGR secretariat. By doing so it will provide a global mapping/archive of submarine geological and geophysical data (**D2**).

3-2-3 (O3) Submarine geological surveying requirements

To complement the archive of geological and geophysical data, **O3** will provide a report that integrates guidelines on survey methods for submarine geohazards risk assessment. Expected topics of the report are:

1. Executive summary of submarine geohazards, provided by **O1** Case Studies
2. Exemplary data sets quantifying geohazard risk, provided by **O2** Data Archives
3. Methods and requirements of data acquisition and processing
4. Geohazard risk assessment through data integration, interpretation, and site investigation

Detailed data acquisition and processing guidelines will provide the required types of measurements, data quality, and resolution. The data acquired and processed in a marine geophysical investigation shall be interpreted and integrated with geological information to identify submarine geohazard risks. Although there are great variations in the complexity of the seafloor and sub seafloor, the guidelines described here will be common to many marine site investigations, the differences being in the scope and level of detail involved. Such guidelines can be created with reference to ISO 19901-10 (Petroleum and natural gas industries –Specific requirements for offshore structures –Part 10: Marine geophysical investigations). An example is the preparedness for a manual for tsunami deposit research (Goto, 2021). On-shore hazard maps, showing the probability of floods, landslides, earthquakes, debris avalanches, are common. Hazard maps are common as they are essential in infrastructure design and planning. In the future, hazard maps and risk assessment maps will be needed for offshore as well as onshore developments. The report will provide example calculations, and references, to estimate the impact of key processes, including seafloor movement, liquefaction, sediment transport (Watanabe et al., 2018), and infrastructure loading.

Through TGSG, **O3** will develop and release the report, it will be published through the SSSGR. This report will serve to provide the sector with guidelines for geological and geophysical surveys, necessary for sustainable offshore development in areas susceptible to submarine geohazards (**D3**). It is also important to have a thesaurus and a multilingual document in order to let the subject to be easily accessible both to technicians and policy-makers throughout the world.

3-2-4 (O4) Global review of submarine geohazard risks to offshore renewable energy

Based on the data collected in **O1-O3,** the TGSG will propose a roadmap for a safe and secured sustainable offshore development. A global interactive review of submarine geohazard risks will be developed for regions where sustainable offshore developments have been identified. Risks, including volcanic eruptions, earthquakes, tsunamis, liquefaction, mud volcanoes and seabed morphologic variations will link directly back to outputs from **O1-O3**. A submarine geohazard map for offshore renewable energy development (**D4**) as a benchmark will initially be hosted by SSSGR. National development funding will be sought to develop the risk map into a stand-alone, publicly accessible resource platform.

The research in O4 aims to conduct basic research prior to formulating guidelines for assessing submarine geohazard risks for constructing and maintaining offshore wind farms. The submarine geohazards are assumed to be submarine landslides, turbidity currents, shallow gas, mud volcanoes, liquefaction, tsunamis, sand deposition, erosion and movement, etc., but their distribution, frequency, and scale are unclear. Therefore, we will compile the existing available data on the continental shelf where the offshore wind farms are planned to be constructed, and create a seafloor geohazard distribution map. Through these efforts, we aim to create a draft guideline for research and construction.

Considering that continental margins around Japan present various types of geohazard risks, as a benchmark, O4 aims to create a seafloor geohazard distribution map on the continental shelf up to a water depth of about 100 m around Japan. Sonic exploration data on the Japanese continental shelf have already been acquired by the Japan Coast Guard, National Institute of Advanced Industrial Science and Technology (AIST), and Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and these data will be compiled and analyzed. The compilation will be done with the cooperation of Dr. Tomoyuki Sato, who is engaged in the management of sound wave exploration data at AIST and has a track record. Publications such as submarine geology maps have already been published using existing data, and with reference to them, the flow paths of the assumed submarine landslides and turbidity currents, the shallow gas distribution area and other potential geohazard features, such as active faults, volcanic intrusions, etc., will be identified. Five evaluation items of the sand sediment distribution area and the assumed liquefaction distribution area will be extracted, and a submarine geohazard distribution map will be created.

A goal of O4 is to create a benchmark geohazard map as follows:

1) The detailed seafloor topography data at SW Japan will be obtained from the Japan Coast Guard. Although the topographical data depends on the year of acquisition, there are paper-based data with different positioning systems.
2) We will convert those old data into currently available digital data.
3) We will interpret the data in collaboration with Dr. Jih-Hsin Chang and several other researchers of the National Taiwan University and Dr. Sato of AIST. The data includes the seafloor topography data converted above and the chirp sonar data owned by AIST. Then, the seafloor topography data will be drawn and the topography will be discriminated.
4) Chirp sonar profile data present very high resolution 2D cross section images of the substrata down to several tens of meters below seafloor. We will interpret them and integrate a grid of 2D profiles to 3D data with various technical advices from Dr. Uisdean Nicholson and Prof. Jan Sverre Laberg. As a result, the 3D interpreted substrata data are drawn on the seafloor topographic map.
5) Based on these works, we consider the sedimentation processes of each layer in the 3D chirp sonar data. In particular, the five evaluation items to be examined are the assumed submarine landslide flow path, the assumed turbidity current flow path, the shallow gas distribution area, the completely moving sand body distribution, and the assumed liquefaction distribution.

Finally, we make a submarine geohazard distribution map based on the study results described above. We first study around Japan, but it is only a kickoff case study to produce a submarine geohazard map. We would like to create submarine geohazard maps in all the necessity regions in the world on the basis of the skills and procedures.

3-2-5 (O5) International Capacity Building

To establish and develop a network of industry, academia and policy makers who share their knowledge of geohazard risks, in the meantime, knowledge gaps and industry challenges will be identified. This network will share relevant information through electronic means and facilitate network meetings and conferences, both face to face and online. In order to promote online and physical lectures, TGSG will establish a network of capacity building.

Expected members of the network are Universities, National Institutes and Academic Associations. Examples of activities to help on capacity building and network developing include:

- Remote collaborative workshops to identify key research and innovation challenges in submarine geohazards, and to establish working groups to develop project proposals.
- Remote lecture corroboration among the Hull Univ., the Yamaguchi Univ., IVAR, OGS and NUTL on topics of offshore wind energy and related marine geology. Expected lecture contents include Marine Geology, Shallow Marine Sedimentology, Soil Mechanics, Exploration Geophysics, as well as broader topics in offshore renewable energy.
- Remote access for TGSG members to the research seminar programme organized by the participating organizations.
- TGSG will organize special sessions and lectures at international meetings and conferences.
- Reciprocal membership of relevant research project advisory boards
- Sharing of relevant research data and analysis methods
- Seeking funding to support research visits and joint research projects

In 2023, Yamaguchi University will begin a class on submarine geological risk assessment. The program includes practical lectures at SSSGR. This sort of practical education will be continued at Yamaguchi University.

Through these activities, **O5** will deliver an active and sustained programme of knowledge exchange activities between academia, industry and policymakers (**D5**).

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Appendix 1 – Submarine Geohazard Risks

There are numerous geohazard risks that need to be considered for offshore renewable energy systems (Table A1). Addressing this range of risks comprises the remit of the TGSG proposal.

Table A1. Submarine geohazard risks

Event	Description & Risks	Frequency (Typical)	References
Volcano	There are about 1,350 potentially active volcanoes worldwide, aside from the continuous belts of volcanoes on the ocean floor at spreading centers like the Mid-Atlantic Ridge. About 500 of those 1,350 volcanoes have erupted in historical time. Many of those are located along the Pacific Rim in what is known as the "Ring of Fire." Various volcanic activities including eruption, pyroclastic flow and so on are also potential low-frequency but large-magnitude geohazards.	The frequency of volcanic eruption is highly variable. For example, Kilauea and Sakurajima for several months, Etna for several years, Pinatubo and Krakatau for about one hundred years.	https://www.usgs.gov/faqs/how-many-active-volcanoes-are-there-earth https://www.jma.go.jp/jma/kishou/know/faq/faq7.html
Earth-quake	Earthquake causes elastic deformation of rocks. The earthquakes sometimes cause rapid seabed displacement along underwater active faults and strong seabed shaking, which induces liquefaction of sediments. Earthquake shaking would be closely related to the occurrence of submarine slides and turbidity currents.	Recent devastating earthquakes in Haiti, Chile and China, as well as magnitude 7 plus earthquakes in Indonesia and California, might give the impression that earthquake activity is increasing. In fact, a quick look at earthquake statistics over the last twenty years shows that this is not the case. On average there are about fifteen earthquakes every year with a magnitude of 7 or greater. As with any quasi-random phenomena, the number of earthquakes each year varies slightly from this average, but in general, there are no dramatic variations. So far this year, there have been six magnitude 7+ earthquakes, in keeping with the annual rate.	https://www.jma.go.jp/jma/kishou/know/faq/faq7.html http://www.earthquakes.bgs.ac.uk/news/EQ_increase.html

Tsunami	Tsunami is a wave with a long wave length being generally excited due to various activities in terms of earthquakes, volcanoes, submarine slides and so on. They destroy various facilities, farms, infrastructures etc. along coastal regions.	Tsunami frequency is basically similar to earthquake frequency. This is because a tsunami is generated by a large earthquake. However, tsunamis are not necessarily caused by displacement of the seafloor due to submarine active faults caused by earthquakes. Tsunamis caused by submarine landslides are known in places such as Papua New Guinea, and tsunamis caused by submarine volcanic eruptions have also occurred in Tonga. Considering these facts, it can be strictly said that the tsunami frequency is still basically unknown.	https://www.jma.go.jp/jma/kishou/know/faq/faq7.html
Seabed Lique-faction	Seabed liquefaction takes place when water-saturated or unsaturated sediments at or near the seabed lose their strength in response to cyclic shearing due to earthquakes or ocean waves.	Although traces of liquefaction are extremely common in strata deposited on the seafloor, the frequency of its occurrence is still not well understood.	Field et al. (1982) Sumer & Fredsoe (2002) Sassa et al. (2006) Sumer (2014) Miyamoto et al. (2020)
Seabed Creep	Seabed creep is the slow downslope movement of a surface sediment layer that occurs on every slope covered with loose soft materials. Folding or other sedimentary structures may be formed by creeping.	It is possible that this occurs all the time on the slopes of the deep sea, but the frequency of creep is still not well understood.	Hill et al. (1982) Nitta et al. (2021)
Submarine Landslide	A submarine landslide is a broad term for indicating the phenomena of failure of near-seabed sediments under the effect of gravity. A coastal landslide is also involved.	The frequency of submarine landslides varies considerably between different regions, and magnitude events. Average reported frequencies: Mediterranean Sea, ~1,400 years (Clare et al., 2014); and the Norwegian coast and North Sea, ~4,000 years. Human construction activities may make sensitive slope conditions susceptible to submarine slides.	Tinti et al. (2005) Tappin et al. (2001) Clare et al. (2014) Mountjoy & Micallef (2018) Sassa & Takagawa (2019)

Turbidity Current	A turbidity current is a rapid, downhill subaqueous gravity flow driven by excess density due to high amounts of suspended sediment. Turbidity currents occur by various processes such as submarine landslides, storms, river flooding and tsunamis. It is known that facilities on sea beds such as cables and moorings may be subject to turbidity currents.	According to the geological record, the frequency of this event is estimated to be once every few hundred years, but observations in the modern environments have shown that in some areas it occurs more than ten times a year.	Heezen & Ewing (1952) Hsu et al. (2008) Su et al. (2012) Clarke (2016) Azpiroz et al. (2017) Paull et al. (2018)
Shallow Gas Eruption	Methane may be released under over pressure near the surface of the ocean floor. The release of methane blows away the surface sediments and forms a pockmark-like topography.	The frequency of shallow gas release has not been quantitatively determined, but pockmarks are very common in accretionary complexes, thrust belts, and large submarine fans, so it is likely that shallow gas emissions occur with high frequency in such tectonically active areas.	Dimitrov & Woodside (2003)
Mud Volcano	A mud volcano is a mound of mud heaved up through overlying sediments. Mud volcanoes are thought to be created by the release of enormous amounts of fluids, including gases, from deep subsurface regions. Gas hydrates are often associated with deep-water mud volcanoes.	Similar to pockmarks, mud volcanoes are quite common topographic features in tectonically active regions. It has been reported that terrestrial mud volcanoes often erupt in sync with large earthquakes, although there impact on seafloor infrastructure is unclear.	Milkov (2000) Mellors et al. (2007)
Bottom Current	Strong currents induced by extreme events change the seabed morphology. Permanent currents drive sediment transport impacting turbine foundation and cables over their lifetime.	Seafloor bottom currents, contour currents, are always flowing. Even if the flow is generally slow (a few cm/s) under normal conditions, it increases intermittently, and the flow velocity changes on the order of 10 to 100 times during a year.	Games & Gordon (2014), Roetert et al. (2017) Thran et al. (2018)
Sediment stability	Sediment distribution changes drastically due to short period agitation as storms, typhoons, tidal currents and so on. Drastic erosion with the storm and rapid sedimentation with reworking and flooding should be significant geohazard risks for all buried structures on the seabed. Another type of seafloor sediment movement is the sand wave migration. Giant and large sand	Asian coasts are frequently controlled by typhoons. The typhoons are strengthened with global warming. The seabed agitation at the shelves would increase. Coastal bars are constantly moving 50 m/yr (max. 85 m/yr) in a coastal region along the Sea of Japan. There are not many publications on seafloor morphodynamic changes caused by sand wave movements due to lack of repeated high-	Saito (1989) Sumer & Fredsoe (2002) Liao & Yu (2005) Yuhi (2013) Zhou et al. (2018) Collins et al. (2019) as IPCC report Liao (2020) Reddy & Sassa (2021)

	waves with wave height up to 15 m and wavelengths from several hundred meters up to over 1 kilometer have been reported on continental shelf and slope regions. Constant movement of sand waves due to strong bottom current and tidal current may cause seafloor depth variation up to 10 m in a short period of time, thus pose a threat to the cables laying on the seafloor and to the wind turban foundation. Sediment instability involves scour and erosion around marine and offshore structures.	resolution seafloor mapping. Previous reports suggest that sand waves move from few meters to few tens of meters per year with seafloor elevation changes up to 10 meters. However, a recent study has shown that with repeated seafloor mapping at short duration, large sand waves show a migration rate of 10.3 m/month in two months period. In this case, the fast-moving sand waves could cause large seafloor depth variations in a year, and presents significant impacts on the design of cable routes and foundation constructions.	

Appendix 2 – Executive Bureau: Remit and Terms of Reference

Table A2. Remit of Executive Bureau of the Task Group on Submarine Geohazards.

Member	Remit
Chair	To provide internal and external leadership for the TGSG as required. To ensure orderly and inclusive meetings. To enable the Executive Bureau to act strategically. To monitor implementation of Executive Bureau decisions.
Vice Chair	To support, and as necessary deputize, for the chair internally and externally. To chair subcommittee/international meetings and an oversight of the work of coordinators.
Secretary General	To ensure the smooth functioning of the Executive Bureau and all task group meetings and TGSG activities.
Secretariat	To provide general financial oversight across all TGSG activities.
Coordinator 1	To lead organization of work into submarine geohazard event case studies.
Coordinator 2	To lead organization of work into global mapping/archiving of submarine geological and geophysical data.
Coordinator 3	To lead organization of work into guidelines for submarine geological and geophysical surveying.
Coordinator 4	To lead development of work into a submarine geohazard map for offshore development.
Coordinator 5	To lead international academic, industry and policymaker capacity building.

Table A3. Terms of Reference	
Chair	Senior Responsible Owner (Chair or Vice-Chair)
Membership	Senior Responsible Owners (SRO): TGSG Chair & Vice Chairs Voting: TGSG Secretary General, Coordinators Non-Voting (as necessary): Consortium members, Supporters and IUGS representative.
Voting	Quorum: minimum 1xSRO, TGSG Secretary General Expected turnout: TGSG Executive Bureau and IUGS representative Casting Vote: SRO
Meetings	Biannual
Location	Virtual and/or face-to-face when possible (international conferences)
Majority	Over 50% (casting vote to SRO in the event of a tie)
Terms of Reference	· To provide ultimate responsibility for the TGSG, ensuring the delivery of the TGSG Aim, via programme Objectives, to the IUGS. · To set, and review progress towards, TGSG Targets, Milestones and Plans. · To provide a platform to ratify cross-programme decisions, decision making processes and management structures. · To report progress to the IUGS as appropriate. · To engage and exchange appropriate information with, and receive advice from, external industry and academic partners. · To ensure that the TGSG is meeting evolving research challenges and needs of the offshore renwable industry. · To review and approve programme finances and expenditure, as needed.
Secretary	Secretary General

Appendix 3 – Track Record

Kiichiro Kawamura (https://orcid.org/0000-0003-0501-4033) is a Research Professor in Earth Science at Graduate School of Science and Technology for Innovation, Yamaguchi University, Japan (https://researchmap.jp/read0192788?lang=en). He is a marine geologist specialising in processes and mechanisms of submarine mass movements, deep-sea microplastic sedimentation and early diagenesis of fine-grained sediments, and he has 48 peer-reviewed journal articles with an H-index of 18. He was the secretary general of 5th international symposium of submarine mass movements and their consequences (Kyoto University, November, 2011) in terms of IGCP585. He is currently the president of Society for Study of Submarine Geological Risks (SSSGR).

Char-Shine Liu (https://orcid.org/0000-0003-0357-714X) is a Research Fellow and CEO of the Ocean Center, National Taiwan University and Professor Emeritus, National Taiwan University. He is a marine geophysicist specializing in seismic investigation of the ocean floor from deep crustal structures to high-resolution seafloor features. He has extensive working experiences on various seafloor mapping, marine geohazard analysis and hazard potential assessment projects. He has also involved in many international programs, such as ODP/IODP, ILP, InterMARGINS, Source to Sink study. He served as Chair of Taiwan SCOR Committee from 2004-2009, and has coordinated many international cooperative research projects with scientists from US, Japan, France, Germany, etc. Since 2016, he has led a team actively engaging in Taiwan offshore wind farm (OWF) geohazard analysis and ground model building projects.

Gregory F Moore (https://orcid.org/0000-0001-8541-3194) is Professor Emeritus in University of Hawaii. He is a marine geophysicist. He spent 4 and 1/2 years on the research staff at the Scripps Institution of Oceanography, 1 and 1/2 years as research geologist at Cities Service Research Lab, and 5 years as an associate professor at the University of Tulsa before joining the U.H. faculty in 1989. He has participated in 26 oceanographic expeditions, including 18 as Chief or Co-chief scientist and six cruises for the Ocean Drilling Program (two as co-chief scientist). He is a fellow of the Geological Society of America, and a member of the American Geophysical Union, the Society of Exploration Geophysicists, and the American Association of Petroleum Geologists. During 2006-2008, He worked at JAMSTEC in Yokohama, Japan as Advisor to Asahiko Taira, Director General of the Center for Deep Earth Exploration (CDEX). He was one of four co-chief scientists on Expedition 338, and participated in Exp 358.

Jose M R Pacheco (https://orcid.org/0000-0002-9558-8868) is an Auxiliary Researcher at the Azores University. He was the director of the Geosciences Department of the Azores University from 2005 to 2009 and from 2014 to 2016. Since 2016 he is the director of the Institute of Volcanology and Risk Assessment (IVAR) of the Azores University and coordinates the IVAR’s Scientific Unit of Physical Volcanology and Magmatism. Since 2008 he is also a member of the Centre of Information and Seismo-volcanic Surveillance of the Azores (CIVISA), responsible for the seismo-volcanic monitoring of the Azores archipelago and the scientific advisory of the civil protection authorities. His research develops mostly on physical volcanology and main interests are the characterization of volcanic deposits and corresponding eruptive styles; volcanostratigraphy and geologic mapping; characterization of genetic processes associated with the development of subaerial and submarine volcanic eruptions; and volcanic hazard and risk assessment. These interests are especially aimed to determine the eruptive history and define eruptive scenarios for quiet volcanoes, such as the Azorean volcanoes.

Shinji Sassa (https://orcid.org/0000-0002-0269-200X) is Head of Soil Dynamics Group and Research Director of International Research Center for Coastal Disasters, Port and Airport Research Institute, National Institute of Maritime, Port and Aviation Technology, Japan. He is best known for his seminal works on wave-induced seabed liquefaction that have been extensively cited worldwide. His main research areas are Soil Dynamics, Geodynamics, Coastal and Offshore Geotechnics, and Submarine Landslides and Tsunami.
Sassa served as a panelist leader at the UNESCO IGCP conference on Submarine Mass Movements and Their Consequences, 2011, and is the recipient of numerous distinguished awards, including the Commendations by the Prime Minister for Disaster Prevention Merit, the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Outstanding Research Accomplishment Award, Best Paper Award thrice, Best Technical Development Award twice, National Land Technology Development Award, and several outstanding review awards for Coastal Engineering, Journal of Rock Mechanics and Geotechnical Engineering, Applied Ocean Research, and Journal of Waterway, Port, Coastal, and Ocean Engineering. His Liquefaction Prediction and Assessment Paper was Top-Read Paper in ASCE Most Read Articles 2017. He is currently Chair of the International Society for Soil Mechanics and Geotechnical Engineering Technical Committee on Scour and Erosion, Editor for Landslides: Submarine Landslides and Tsunamis, and has been Editor in Chief of the Special Issue on Offshore Wind Turbine Foundations and Vice Chairman of Soils and Foundations. He is Director of the International Consortium on Landslides.

Vicki Ferrini (https://orcid.org/0000-0002-6054-5040) is a Senior Research Scientist at Columbia University's Lamont-Doherty Earth Observatory (LDEO). Her research focuses on using mapping techniques to understand the processes that shape the seafloor in a variety of environments. She has participated in research expeditions around the world mapping shallow water and deep-sea environments using ships, boats, submersibles and towed platforms. Most of her work is in the field of geoinformatics and is focused on ensuring that high-quality marine geoscience research data are made available to the science community and to the public. She is the Head of the Seabed 2030 Regional Center for the Atlantic and Indian Oceans.

David Tappin (https://orcid.org/0000-0003-3186-8403) is Principal Researcher at the British Geological Survey, where he leads Tsunami Hazard research, and Honorary Professor in the Earth Sciences Department at University College, London. He is a marine geologist specialising in submarine landslide and volcanic tsunamis and their onland sedimentary signatures. His research on the Papua New Guinea event of 1998 was seminal in proving the hazard from submarine landslide tsunamis. Since this time, he has researched all recent major tsunami events including those in the Indian Ocean (2004) and Japan (2011). Most recently he has been researching the Krakatau and Anak Krakatau tsunamis of 1883 and 2018. His research is internationally recognised and is extensively cited.

Hajime Naruse (https://orcid.org/0000-0003-3863-3404) Assoc Prof Hajime Naruse, Kyoto University (KU) is a leading researcher in geohazard sediment transport. Naruse specialises in, and in ***CHaRTS*** will support, the use of AI in inversion of flow processes from geologic records, including ancient tsunami deposits. His expertise covers geological surveys of turbidites and tsunami deposits, numerical modelling and flume experiments of suspended sediment transport. Naruse has conducted field surveys of modern tsunami deposits, including the 2011 Tohoku-Oki and 2004 Indian Ocean events. He has 12 grants, from JSPS and MEXT, 46 peer-reviewed journal articles and an H-index of 18. He is Associate Editor for *Frontiers in Earth Science*, and is on the International Editorial Board for *Depositional Record.* Naruse is a director of JpGU.

Jan Sverre Laberg (https://orcid.org/0000-0003-3917-4895#3054) is a Professor in marine geology at the University of Tromso, the Arctic University of Norway. His primary scientific interests are in Geomorphology, Continental margin processes and evolution, Continental shelf and fjords landforms. The concepts of his Geomorphological studies are interwoven with issues related to paleoclimate, paleoceanography and slope stability. His studies deal with the Paleogene, Neogene, and Quaternary.

Jih-Hsin Chang (https://orcid.org/0000-0002-7666-2911) is Assistant professor in Institute of Oceanography, National Taiwan University. He is a marine geologist specializing in sedimentology, stratigraphy and reflection seismic interpretation. He has wide research interests and currently works for the sedimentation of modern sediments (Taiwan Strait) and the evolution of tectonic basins (South China Sea).

Uisdean Nicholson (https://orcid.org/0000-0003-0746-8549) is a marine geologist at Heriot-Watt University, where he leads the Seismic Stratigraphy and Sedimentology research group. He specialises in the interpretation of seismic reflection and bathymetry data, integrated with sedimentological observations from core. He has recently (since 2019) been a Principal Investigator on three research grants focused on oceanography and submarine landslides (Falkland Plateau and Indonesia) and one research grant focused on deepwater sediment waves. He is also a member of the Science Evaluation Panel of the Integrated Ocean Discovery Program (IODP) and sailed on the NanTroSEIZE expedition offshore Japan in 2007/2008. He has an active research collaboration with AIST in Japan, focused on the impact of ocean currents (principally the Kuroshio) on sediment distribution and seabed mobility in the Okinawa-Ryukyu region.

Abdelaziz Abdeldayem (https://orcid.org/0000-0002-5786-4307; https://www.linkedin.com/in/prof-abdeldayem-7baa12a0) is a Research Professor in Geophysics at the Faculty of Science, Tanta University, Egypt (http://tdb2.tanta.edu.eg/staff/aabdeldayem). He is a specialist in the paleomagnetic and magnetic rock fabric applications on all types of rocks and deep-sea marine sediments. During a long-term visit to Geological Survey of Japan (1997-2000) he participated in a cruise to the Japan Sea where he shared conducting several deep-marine geophysical measurements and collection of several cores. He also had the chance to study the magnetic/ rock magnetic properties of a vast collection of samples from many deep-sea sediment cores raised off the Japanese islands (Japan Sea and off-Tokai) and China. In an interesting study he, together with a Japanese active team, managed to use these tools to trace the flow path of the 1993 Hokkaido Nansei-oki earthquake through the study of the AMS of seismoturbidite located at the southern margin of the Japan Sea north basin (https://doi: 10.1111/j.1365-246X.2004.02210.x). Abdeldayem further participated in projects to study the accretionary prism sediments from Boso peninsula (southern Japan) and granite (Yakushima, southwestern Japan). More recently he took part in a collaborative project with US research team to carry out a Magnetosusceptibility and Cyclostratigraphy (MSEC) comparative study to correlate Cretaceous and Paleogene sections, including GSSP sections, from Egypt and the US. Most recently, he participated in a studies concerning the development of the Nile Delta (https://doi.org/ 10.3390/rs13101934; https://doi.org/10.3390/su142214699).

James Gilbert (https://orcid.org/0000-0002-4932-938X) is Professor of Engineering at the University of Hull and has extensive experience of researching innovative sensing schemes, particularly for monitoring manufacturing processes. His current focus is on offshore wind energy including being UoH PI on the £7.6M EPSRC/industry funded Prosperity Partnership: A New Partnership in Offshore Wind with Siemens Gamesa Renewable Energy (SGRE) – the world's largest manufacturer of offshore wind turbines, Ørsted – the world largest developer of offshore wind farms and Durham and Sheffield Universities. He leads on novel blade technologies, including fibre optic sensors for manufacturing process monitoring. He is a co-director of the £9M EPSRC Supergen Offshore Renewable Energy Hubwhere he works on the application of distributed (fibre optic) sensors in large scale offshore structures as well as leading on Equality, Diversity and Inclusion (EDI). He also leads on industry interaction for the £5.8M EPSRC/NERC funded Aura Centre for Doctoral Training in Offshore Wind Energy and the Environment In addition to delivering research projects, he leads on the Research Development and Innovation programme for Aura, a collaboration led by UoH including Sheffield and Durham Universities, SGRE, Ørsted and Offshore Renewable Energy Catapult. This programme of research and associated commercialisation provides key underpinning for the Aura Innovation Centre, a £12M ERDF/Greenport Hull/UoH funded facility focussed on supporting innovation in offshore wind and the low carbon economy.

Robert Dorrell (https://orcid.org/0000-0003-4257-7273) is Reader in Environmental Fluid Dynamics at the University of Hull, with a background in experimental, numerical and theoretical fluid dynamics of natural and industrial systems. Dorrell holds a current NERC Independent

Research Fellowship (NERC NE/S014535/1) and a Royal Society Apex Award (RS APX\R1\180148) on fluid transport of particulates. Further, Dorrell holds a NERC Capital Call Award for the development advanced metrology of multiphase flows (NERC NE/V017160/1). He also has significant experience across the offshore renewables sector, including research on Wave Energy Convertor design (EPSRC EP/V040561/1), as well as in resource modelling, forecasting, evaluation of wave energy resources and science policy.
Dorrell's research has included: fluvial microplastic fluxes, National Geographic (National Geographic NGS-56269R-19); Coriolis and Rotational Effects on Stratified Turbulence (EU FP7 European High-Performance Infrastructures in Turbulence 312778); environmental risks to marine infrastructure (NERC NE/P009190/1); and six joint industry projects, cumulatively worth >£2M. Dorrell leads international research collaborations on marine hydrodynamics (RF-2018-16, JSPS 18KK0378, JSPS 18J22211). He is Deputy Director of the £5.8M EPSRC-NERC Centre for Doctoral Training in offshore wind energy and the environment (Aura CDT). He has >40 peer-reviewed papers and is the recipient of the Gerhard Jirka Award by the IAHR and the Humber Renewables Award for Renewable Education.

Yasukuni Okubo is Specialized manager of Geothermal Energy Research & Development Co., Ltd., Member of Science Council of Japan, Technical advisor of Society for Study of Submarine Geological Risks, Member of Engineering Academy of Japan and Chairman of Mottainai Society. He is a geophysicist, specializing in analysis of aerial magnetic data. The main research results are the mapping of a crustal temperature distribution by Curie point depth analysis and the modeling of the crustal structure. He was the chair of IUGS Task Group on Geohazards in 2017-2020.