Editorial Manager(tm) for Marine Geophysical Research
Manuscript Draft

Manuscript Number:

Title: Seafloor mapping for geohazard assessment: state of the art

Article Type: SI Seafloor Mapping

Keywords: geological risks, multibeam bathymetry, natural hazards, seafloor morphology, submarine landslides

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Abstract: During the last two decades, increasing use of full-coverage sonic mapping of the seafloor, has made us more aware of the large and different number of seafloor processes and events bearing significant geohazard potential. This awareness combines with the increasing use of seafloor for infrastructures and with the high density of population and settlement on the coast.
Seafloor mapping is the first step to make a census of the geohazard-bearing features present in a given offshore area. It often provides the only tool for a comprehensive seafloor geohazard assessment over large areas, scarcely groundtruthed by acoustic prospection and seafloor sampling. Indeed, the characterization of geohazard features on a morphological basis alone is however limited, as and more detailed investigations are needed to define the character and state of activity of potentially hazardous features. Such investigations include the use of deep-tow or autonomous platforms designed to acquire HR data at depth as well as in situ measurements, both being very expensive activities not applicable over large areas. This is the reason why seafloor mapping is often not only the first and the main but also the only tool for a comprehensive seafloor geohazard assessment over large areas, often scarcely groundtruthed by acoustic prospection and seafloor sampling.
This special issue represents an example of the diversity of approaches to seafloor geohazard assessment and summarizes the present state of this discipline. Both the diverse technologies applied and the specific aims of offshore geohazard assessment brought different communities to deal with the study of seafloor processes/events from remarkably distinct viewpoints. We identified three end members in offshore geohazard assessment: 1) geohazard assessment "sensu stricto", 2) "engineering" geohazard assessment, 3) "non-specific" geohazard assessment. These are being conducted by industry, academia and public agencies in charge of civil protection and land planning and management. Understanding the needs and geohazard perception of the different groups is a necessary step for a profitable collaboration in such an interesting and rapidly developing field of marine geology.

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# Seafloor mapping for geohazard assessment: state of the art

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## Keywords

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### Abstract

During the last two decades, increasing use of full-coverage sonic mapping of the seafloor, has made us more aware of the large and different number of seafloor processes and events bearing significant geohazard potential. This awareness combines with the increasing use of seafloor for infrastructures and with the high density of population and settlement on the coast.

Seafloor mapping is the first step to make a census of the geohazard-bearing features present in a given offshore area. It often provides the only tool for a comprehensive seafloor geohazard assessment over large areas, scarcely groundtruthed by acoustic prospection and seafloor sampling. Indeed, the characterization of geohazard features on a morphological basis alone is however limited, as and more detailed investigations are needed to define the character and state of activity of potentially hazardous features. Such investigations include the use of deep-tow or autonomous platforms designed to acquire HR data at depth as well as in situ measurements, both being very expensive activities not applicable over large areas. This is the reason why seafloor mapping is often not only the first and the main but also the only tool for a comprehensive seafloor geohazard assessment over large areas, often scarcely groundtruthed by acoustic prospection and seafloor sampling.

This special issue represents an example of the diversity of approaches to seafloor geohazard assessment and summarizes the present state of this discipline. Both the diverse technologies applied and the specific aims of offshore geohazard assessment brought different communities to deal with the study of seafloor processes/events from remarkably distinct viewpoints. We identified three end members in offshore geohazard assessment: 1) geohazard assessment “sensu stricto”, 2) "engineering" geohazard assessment, 3) "non-specific" geohazard assessment. These are being conducted by industry, academia and public agencies in charge of civil protection and land planning and management. Understanding the needs and geohazard perception of the different groups is a necessary step for a profitable collaboration in such an interesting and rapidly developing field of marine geology.

## 1. Introduction

In May 2009, an international conference on “Seafloor Mapping for Geohazard Assessment” was held in the charming location of the Giardini “La Mortella” in the volcanic island of Ischia (Naples Gulf, Italy) within the umbrella of the IGCP project 511 and the MaGIC Italian National Project. Ischia island was affected in the recent geological past by a massive sector collapse and debris avalanche (Chiocci and De Alteriis 2006, De Alteriis et al. 2010), whose deposits and scar morphology were the object of a pre-conference fieldtrip.

The conference  brought together some hundred participants from 12 countries, representing the academic, industry and public administration communities. The participants presented several case studies and discussed on the state of the knowledge of geohazard assessment in the submarine domain, focusing especially on the use of seafloor mapping by multibeam echosounder data complemented by other geophysical and in situ data and measurements for the purpose of geohazard assessment(Chiocci et al. eds., 2009).

Noticeably, about one third of the presentations were directly or indirectly linked to, and given by, representatives of industry and private companies working for geohazard offshore surveys, witnessing the applied nature of the topic. It was made evident early during the conference that industry and academia do not share the same point of view as to what represents a geohazard and what is simply a constraint for offshore activities (see section 3). The Special Issue resulting from the conference contribution aims, among others, to bridge the gap between academic research (not much funding, relative long-term development research themes) and the industry practice (spectacular, often very costly dataset focused on specific, applied issues, with little time to carry out bibliographic comparisons and a comprehensive view of the study area). Both the Ischia conference and this volume cover different areas worldwide, with higher density in the Mediterranean Sea (Fig.1).

## 2 Seafloor morphology exploration in the recent decades: seafloor mapping programs and offshore geohazard investigations

Because of the widespread and always increasing use of multibeam and other mapping techniques, marine geology is undergoing a very stimulating and active historical moment as the scientific community is flooded by a massive amount of extremely high-resolution morpho-bathymetric datasets that allow an unprecedented look at the seafloor. The impact of these data is tremendous, sometimes comparable with the effect that the production of the first bathymetric map of ocean floor (Heezen and Tharp 1954, Heezen et al. 1959) exerted on the understanding of global tectonic processes that lead to the definition of plate tectonics. Thanks to multibeam mapping techniques, our ability to produce a near-continuous bathymetric surface of the seafloor has revolutionized our understanding of marine morphodynamics. This has significantly changed the detail with which we can interpret seafloor tectonic and sedimentary process at the origin of geohazards (Hughes Clarke et al. 1996).

Multibeam sonars underwent rapid development during the '80s (Farr 1980, Brown and Blondel 2008), although the number of surveys at sea using this technique was limited. Since the '90s, more performing systems have been used and technology improved to integrate acquisition of echosoundings including backscatter (de Moustier 1988, Lurton 2002). Today, the modern swath mapping sonar systems collect concurrent swath bathymetry and acoustic backscatter data. When processed together, these data can be used for remote sensing of seafloor characteristics, with several applications in geotechnical and geohazard surveys (e.g., offshore drilling and mining, dredging and disposal, subsea cable and pipeline routes; de Moustier et al. 2010).

It is only during the last 10-15 years that multibeam echosounders become a common tool in any kind of subaqueous survey, from very shallow coastal and lacustrine environments to full ocean depths, providing increasing amounts of high resolution data. These data constitute nowadays the unavoidable base for any geohazard assessment study. The use of AUVs and other near seafloor platforms has extended high-resolution surveys to the deep water. In addition, bathymetric data extracted from 3D seismic volumes rival in horizontal resolution with multibeam echosounders and allow the comparison of seafloor and buried seismic surfaces with a seismic geomorphology approach (Posamentier 2007).

As far as seafloor geohazard is concerned, multibeam bathymetry is not only able to identify features representing the trace of hazardous geological processes, but may also precisely measure morphometric parameters and their variation trough time, to enhance the monitoring of seafloor changes representing active processes. Multibeam bathymetry also provides boundary conditions and inputs to numerical modeling aiming to reproduce geological processes to make predictions for future scenarios (e. g. run out of failed sediment, tsunami modeling).

Obtaining a comprehensive seafloor map of homogeneous resolution at the regional, EEZ and oceanic level has been the focus of numerous initiatives. In the pre-multibeam era, large scale seafloor mapping has been first carried-out using low-frequency, long-range side scan sonar systems such as GLORIA (Geological Long-Range Inclined Asdic, Rusby and Revie 1975). A long-standing initiative to merge, collect, homogenize and edit existing datasets of mainly single-beam soundings such as GEBCO (General Bathymetric Chart of the Oceans, Carpine-Lancre et al. 2003, Hall

2006) is being carried out with the support of international organizations (UNESCO, IHO) and hydrographic national offices.

In the multibeam era, several projects aimed to acquire full -overage multibeam data for different purposes such as the Norwegian Mareano (Thorsens 2009, Dolan et al. 2009), the Californian CSMC (California Seafloor Mapping Program, OPC, 2007 ), the Irish INSS-INFOMAR (Irish National Seabed Survey), the mapping of the Spanish EEZ (Muñoz et al. 1998), the European MESH (Mapping European Seabed Habitats) and the Italian MAGIC (Marine Geohazard Along the Italian Coasts). At a Mediterranean scale, an effort to compile existing data in deep water is being made by CIESM and Ifremer (MediMap Group 2005).

## 3. Geohazards in the marine realm

Kvalstad (2007) defined geohazard in the offshore domain, as “local and/or regional site and soil conditions having a potential of developing into failure events causing loss of life or damage to health, environment or field installations”. Such definition is broad enough to include most of the geological processes shaping the seafloor, as no time frame is defined and potentially any modification of the seafloor may be damaging for structures resting on it.

Geohazards are one of the elements in the equation of geological risk. The geological risk is in fact the product of the occurrence of a given geological event or process (geohazard), the vulnerability of a given area or region to this geohazard and the possible damaging consequences on humans, structures and/or the environment.

In marine and coastal environments, the major geological hazards are linked to the occurrence of events such as earthquakes, volcanic eruptions, submarine landslides or rapid processes that are able to modify the morphology and character of the seafloor such as gravity-driven sediment flows, fluid emissions, bedform migration, retrogressive erosion at canyon heads, etc (Fig. 2). Secondary effects such as tsunamis (either triggered by earthquakes or landslides) also need to be considered, as both their genesis and propagation is strongly controlled by seafloor morphology.

Despite the definition of geohazards, though debatable, is relatively straightforward, their assessment is relatively complex. In fact, for the marine realm, it is often difficult if not impossible to define:

1) **the time scale of the hazard.** Seafloor sector collapses and related debris avalanches are common processes in the millennial-scale geologic evolution of volcanic islands, and thus an event bearing an extremely high damage potential

might reoccur in the future. However, do they have to be considered in a geohazard assessment if no signs of activity are present? In a similar way, retrograding canyon heads, that seldom affect the coastline, often show a clear match between subaerial and submarine erosional morphologies, showing that landslides shaped the coast inshore of the canyon head. The question is therefore: should this be considered a geohazard if no signs of instability are detected but there is only the knowledge that a geological process could cause mass wasting in an undefined future?

2) **the capability of a given process to produce dangerous effects**. Our knowledge on submarine processes is in many cases very limited. Do we have to assume a conservative approach (worst-case scenario) in any instance? For example, for landslide-generated tsunamis there are physical models linking the volume of the mobilized sediment and water depth to the tsunami wave height. Is it reasonable to consider all slide scars, caused by different failures (rotational, translational, complex etc.), as a result of catastrophic events, when we do not know precisely the failure dynamics? What would be the result of the assessment if many or most of the failures were slow enough not to produce significant effects on the overlying water column?

3) **the recurrence time of most of the hazardous events**. Sometimes only erosional scars witness the occurrence of mass wasting in a given setting, so hindering any possible definition of age and recurrence time of landslide events. For instance mass wasting at canyon heads is the main process for their genesis and retrogression, as witnessed by the multiple, complex and overlapping landslide scars that form it. However mass wasting there is usually occurring with the complete disintegration of the failed mass and its transformation into gravity flows dispersing down canyon. In this case we know that the process is frequent, but what does “frequent” mean?

4) **the frequency – magnitude relationship of observed geohazards**. In addition to frequency-dependant attenuation, hull mounted multibeam systems have an inherent loss of resolution with increasing water depth. Therefore, the capability to depict and characterize geohazard-bearing features is water depth-dependant. This problem is shown in Figure 3 with an example of size distribution of submarine landslides in the Mediterranean basin with data compiled from the public literature (Camerlenghi et al. 2010). The fact that landslides appear to have a characteristic size-magnitude, probably reflects our inability to image small-sized landslides (hundreds of $m^2$ or lower), or/and to a subjective underestimate by the operator (small=not hazardous?).

The impact of offshore geohazards for coastal communities is also depth-dependent, i.e. the deeper the geohazard generating feature, the smaller the potential impact, so this somehow counterbalances our inability to depict small geohazard features in deep water. However, the impact of geohazard processes for offshore infrastructure, can be very high, also in deep water, no matter the size of the geohazard generating feature. To confront this, industry is massively using AUVs and ROV-mounted multibeam systems for seafloor mapping to achieve the high resolution of hull-mounted coastal surveys also in very deep waters.

5) **the spatial distribution of hazardous events.** In open slope settings, it is common practice to highlight features such as submarine landslides as evidence for geohazard, and pipeline and cable routes are often set to avoid these features. However, how likely is that the next failure occurs over the same area where failure already occurred? Isn't it more likely that the next failure occurs in a nearby area that shows no current signs of seafloor disturbance? In other words, is it a wiser decision to lay a pipeline through a submarine landslide scar or through an area that apparently shows no signs of recent failure but is near to another area that failed?

Despite the above mentioned limitations, geohazards have to be defined, depicted and evaluated because the use of the seafloor for settling structures continues to increase as is the coastal population. Therefore, assessment of marine geohazards must be a key element in coastal and seafloor management. For instance the always increasing use of the seafloor for cable route and drilling facilities (more and more extending in deep water), let marine geohazard to be a major concern for industries and public agencies dealing with marine infrastructures. Also onshore, for coastal communities and structures, marine geohazards may produce either direct effect as for submarine landslides retrogressively propagating onshore such as Finneidfjord in 1996 (Longva et al. 2003) or Stromboli in 2002 (Chiocci et al. 2008) or indirect effects as for submarine landslide generating or contributing to tsunamis such as Great Banks in 1929 (Piper et al. 1999) or Nice in 1979 (Malinverno et al. 1988).

For geologically active regions (such as the Mediterranean, the Caribbean and many regions around the Pacific belt of fire), which are often highly touristic regions, the risk is extremely high as the scenic coasts are often volcanic or fault-controlled and tourists and coastal settlements are packed in narrow coastal belts and constricted pocket beaches. In such a setting, even limited coastal landslides or tsunamis may have enormous effects, as witnessed by the Nice 1979 landslide and subsequent tsunami (Sultan et al. 2010).

## 4. Diverse approaches and characterizations of geohazard

One of the main outcomes of the Ischia conference and of this volume is the evidence that there are ***three end-member approaches in geohazard characterization*** that we hereafter refer as 1) "geohazard assessment sensu-stricto"; 2) "engineering geohazard assessment" and 3) "non specific geohazard assessment" (Fig. 4).

The **“geohazard assessment sensu-stricto”** is the one conforming to the classical definition (see beginning of section 2) and is typical of applicative surveys as it is aimed to precisely identify one or more hazards in a specific site and the possibility this hazard might occur in a given time span (see for instance L’Heureux et al. this volume, Strasser et al. this volume). This approach needs a precise knowledge of the character of the process/event considered hazardous, its recurrence time, the present state of the seafloor and subseafloor and the factors controlling it. For instance, for a submarine landslide, the knowledge of the state of stability of the slope (based on geomechanical characters of the potentially failing mass) and the definition of possible triggers of the instability is needed.

The study should therefore rely on a suite of geophysical data and in situ measurements that made it very costly and only possible for small areas and limited number of features/hazardous processes. The outcome of the study however is not only a truthful assessment of the hazard but may also define the character of the infrastructure in order to reduce the vulnerability to the hazard. In this case, a real risk assessment is possible.

The **“engineering geohazard assessment”** considers the presence of any uneven feature at the seafloor that constitutes a geohazard in itself as it is a development constraint that may impact the seafloor structure, if not taken into the due account. As an example the presence of a rock outcrop or a slope-break at the seafloor is considered by the industry a geohazard to be avoided or carefully considered for operational planning of a cable or pipeline route to avoid free spans. In strict terms these uneven features (ridges, boulders, …) should not be considered as real “geohazards” because by themselves they have no “potential of developing into failure events” (Kvalstad 2007). In other words, the hazard results from human action at the location of this feature without the feature itself necessarily develops into a failure event. Furthermore, in this approach, the time span considered for the assessment is usually comparable with the life span of the infrastructure at the seafloor (e.g., pipeline, submarine cable), generally not longer than a few decades and thus shorter in time of the return period of most geological processes (see for example Dyer this volume, Cecchini et al. this volume).

Finally the **“non-specific geohazard assessment”** involves the census of potentially hazardous features present in a whole region without targeting at any specific process/event and at any specific effect on exposed good. Such assessment is aimed to define in a general perspective the presence and character of all the hazardous marine geological processes/events and possibly the seafloor and subseafloor predisposition to these processes/events. This approach does not attempt to define the precise age and recurrence period of the hazard; it rather evaluates the spatial occurrence of hazardous events and highlight the possibility that similar events occur in the future, given the similarity of the morpho-structural and lithostratigraphic setting of the surroundings.

In strict terms the “non-specific geohazard assessment” should not be considered as a real geohazard assessment but, in our perception and given the present technology, is the only possible way to define at a regional scale the location, type and characteristics of the geohazards present in a given region, with possible indication on their state of activity. Cost-efficient multibeam mapping is in this respect the fundamental tool for such assessment, that therefore relies essentially on geomorphic interpretation of high-resolution bathymetric data. Examples of this type of geohazard assessment are provided in Chiocci and Ridente (this volume), Larroque et al. (this volume) and Lo Iacono et al. (this volume).

Assessment of geohazards according to these 3 end-members is very clearly divided by the approach that different communities have when studying geohazards (Fig. 4). In fact, Academia (universities and research institutes) moves between the “geohazard assessment sensu-stricto” and the “non-specific geohazard assessment” approaches, as it is mainly interested in understanding the processes and events both at small and large scale. Academic studies are often focused in small areas that are investigated in detail to characterize the seafloor and subseafloor. Academia is also interested in the overall geological evolution of continental margins and therefore the “non-specific geohazard assessment”, is seen as a way to understand the processes shaping the seafloor and the relationship between processes and long-term morphological evolution.

On the contrary, industry moves between the “engineering geohazard assessment” and the “geohazard assessment sensu-stricto”, and often these two are performed in sequential order. The need to find the safest route or site for laying and installing infrastructures at the lowest possible economic cost often means that even small seafloor features have to be considered in geohazard assessment, as they constrain the deployment of the structure.

Finally, stakeholders and public administrations (including geological surveys) are interested in the “non-specific geohazard assessment”, needed to wholly assess the risk for public goods in a given region and the “engineering geohazard assessment” approach needed for public works and land management.

## 5. Special Issue outline

Here follows a succinct outline of the contributions of the Special Issue, grouped by thematic affinity. Due to the location of the venue, the majority of the contributions show case studies from European, and in particular Mediterranean, continental margins (Fig. 1). This fact also reflects the increased attention towards offshore geohazard assessment in this densely populated region and towards the management of marine areas and marine spatial planning, which is for the moment limited to the coastal areas (e.g., Schaefer 2009), but will impact in the near future entire regional seas or marine basins for activities where seafloor geohazards are relevant, including installations of offshore eolian plants, offshore oil and gas activities (COM 2010).

### 5.1 Methodological aspects of offshore geohazard mapping

The first group of papers is devoted to generic aspects of seafloor mapping for geohazard purposes. Chiocci and Ridente (this volume) describe the efforts made by the Italian community in trying to produce regional maps of geohazard features, and the need to standardize cartographic representation amongst the diverse settings and parties involved in such effort. Mosher (this volume) highlights the limitations of multibeam data and the risks of data over-interpretation resulting from system resolution problems. Along a similar line, Dyer (this volume) discusses a few cases of inappropriate data processing and how this had an impact on offshore installations.

### 5.2 Seafloor morphology and implications for geohazards

The second group of papers provides a few examples of how seafloor mapping techniques are useful in delineating zones of active geohazards, or excluding certain seafloor features as the source of potential geohazard. Urgeles et al. (this volume) perform a detailed analysis of prodeltaic bedforms that had been previously interpreted as indicative of early seafloor deformation. Cecchini et al. (this volume) discuss the seaforms on the eastern Sardinia-Corsica continental shelf that could represent a hazard for pipeline routing. Boudillon et al. (this volume), Ercilla et al. (this volume), Lo Iacono et al. (this volume) and Morelli et al. (this volume) depict the complex geomorphology and stratigraphic architecture of various continental margins and the implications of the structural and sedimentary-erosive features for geohazard assessment. Finally, Hough et al (this volume) present an integrated and systematic map-based approach for the assessment and mitigation of seabed geohazards and risk to proposed deepwater development.

### 5.3 Faults and fluids

This section illustrates the ability of multibeam mapping, together with other geophysical techniques, in delineating active faults and fluid seepage structures. Larroque et al. (this volume) and Nomikou et al. (this volume) provide two examples of recent fault activity in the Ligurian margin and Aegean Sea and show how multibeam mapping can help in redefining regional seismic hazard. Dalla Valle et al. (this volume) provide evidence of interaction between fluid seepage, faulting and mass-wasting. Léon and Somoza (this volume) present a GIS application to help identify marine geohazards derived from gas hydrate dissociation using seafloor mapping data.

### 5.4 Landslide identification, modeling and possible tsunami implications

The last section in this special issue presents a series of papers characterizing submarine slope failures and slope failure potential and how the morphometric parameters extracted from seafloor mapping and subsurface geophysical data help define the post-failure dynamics of these events and their consequent tsunamigenic potential. Migeon et al (this volume) and Casas et al. (this volume) define various types of mass failure events and deduce the controlling factors in the development of the observed failures. Casalbore et al (this volume) show the advantage of differential bathymetric surveys for depicting seafloor dynamic processes at the origin of geohazards. Mazzanti et al. (this volume) use constraints from an historical event and observed seafloor morphology to test landslide propagation and tsunami generation models. Tinti et al. (this volume) and Argnani et al (this volume) use morphometric parameters from a large sector collapse on the island of Ischia and the Eastern Adriatic Basin, respectively, to test tsunami worst-case scenarios for the adjacent Italian coasts. L'Heureux et al. (this volume) use multibeam bathymetric data together with additional geophysical and geotechnical data to clarify the sequence of events around the 1888 landslide and tsunami in the bay of Trondheim. Finally, Strasser et al. (this volume) present a new concept for evaluating basin-wide slope stability through time as a potential tool for regional seismic and tsunami hazard assessment.

## 6. Challenges in offshore geohazard mapping

Multibeam bathymetry probably offers the most cost-effective way to chart the ocean floor, yet this only portrays a static view of the seafloor. Marine sedimentary processes often occur over large time spans and/or at very low recurrence rates, and therefore this static view of the ocean floor depicts a series of potentially hazardous phenomena that are not active anymore or not representative of present day processes, particularly in formerly glaciated margins (see also cautionary note in Mosher this volume). In active geodynamic settings or in areas close to sources of high sediment supply, the seafloor offers a much more dynamic environment, and differs greatly from one season to another. This also offers the opportunity to witness the processes at the origin of geohazards at work with **repetitive surveys**.

Programs are just being established to monitor seafloor dynamic systems using multibeam surveys. For example Duffy and Hughes-Clarke 2005, Smith et al., 2005 and Hughes Clarke et al. 2009 have shown that using repetitive multibeam surveys it is possible to measure seafloor bedform migration. Knowledge of migration rate together with bedform height theoretically enable the calculation of sediment transported within the migrating bedforms or "bedload transport" (Duffy and Hughes-Clarke 2005). The repetitive surveys have also wide application to monitoring mass-wasting phenomena, both in sedimentary and volcanoclastic environments as already shown in Chiocci et al. 2008, Hughes-Clarke et al.2009, Casalbore et al (this volume), or affecting man-made structures (Dan et al. 2007, Li et al. 2009). A series of backscatter multibeam surveys has also been used to assess the impact on benthic ecosystems of hyperpycnal flows and related turbiditic deposition associated with major flood events (Urgeles et al. 2002).

Yet, for monitoring morphological change, the typical scale of spatial change must be greater than the total survey accuracy, which significantly limits our ability to monitor geohazard processes in deep sea environments. Due to survey accuracy issues, the scale of the apparent vertical difference is usually proportional to the slope of the seafloor (Hughes-Clarke et al. 2009).

Repetitive surveys are often planned in an opportunistic manner, constrained by the availability of previous surveys and the occurrence of catastrophic events such as floods (e.g. Urgeles et al. 2002, Casalbore et al. this volume) or seafloor failures (Chiocci et al. 2008). However, monitoring seafloor dynamic processes requires careful planning and some idea of the rate of seafloor change. Duffy and Hughes-Clarke 2005 and Hughes Clarke et al 2009 already indicate that in order to track moving dunes, the surveying period needs to be close enough for the dunes not to migrate more than half their spacing.

The common practice for geohazard assessment in the domain of offshore exploration includes a reiterative approach where geohazard are identified with repeated and more and more focussed surveys. This include the use of **AUV-ROV seafloor surveys**, also because of the need to identify potentially hazardous features at the scale of the planned seafloor infrastructures (Kvalstad 2007). Also academic research may take advantage from these new technologic developments. Migeon et al. (2011b) propose a closer look at the seafloor down the area of the Nice 1979 event with the use of an AUV with spatial resolution of 2 m (compared to the 25 m of the Simrad EM300 echosounder). Apart from the increased number of submarine landslide scar detected, the main advantage is the possibility to identify clearly the signature of retrogressive erosion and the traces of gravity flow transformations at meter scale, with implication for the understanding of the causal sedimentary processes.

The importance of **groundtruthing** remains in any case a key point in most common practice of geohazard assessment, especially when quantitative data are needed to support modelling. The search for the crucial site to obtain in situ data is in any case based on the use of swath bathymetry and seismic profiles: indirect geophysical data may actually guide the selection of significant measures, for example of sediment pore pressure to evaluate the possible effects of a recent earthquake (Sultan et al. 2008).

The increasing amount of data and the diversity of dataset in the offshore domain has already propelled the integration of large and complex datasets in Geographic Information Systems as a current practice to evaluate the areal and size **distribution of geohazards**. Concerning the distribution of submarine landslides along entire continental margins, for example, a limited number of studies exist at large scale to evaluate if there is a scaling relationship between submarine landslide area/volume and frequency of occurrence, as it is the case for earthquakes and their magnitude (e.g., Chaytor et al 2009). In some cases mapping is supported by other analyses such as landslide susceptibility linked to seismic activity (Strasser et al. this volume), and susceptibility maps of submarine landslides and of fluid flow features related to possible controlling parameters (Leon and Somoza, this volume).

Finally, another need related to large seafloor datasets, especially when data have to be summarized in synthetic views, is the rapid analysis of the data with the application of automatic **seafloor classifications** (e.g., Atallah and Smith 2004). These approaches have the advantage of allowing to make some predictions on the state of the seafloor that can be tested with successive surveys integrating additional techniques. The literature on this subject is sizeable and rapidly expanding (e.g., Hamilton 2005). Some attempts to compare different methods show that the success of a method in recognizing known patterns depends on the character of the seafloor morphology and its dominant grain size (Müller et al. 2007). The use of these techniques may serve as a guide to interpretation and a basis to formulate hypotheses, but it needs to be applied with caution and to be accompanied by control from independent data.

The increasing number of seafloor mapping studies at local and regional scale will certainly contribute to capture any inherent pattern in the signature of potentially catastrophic processes and thus provide enhanced seafloor geohazard assessment.

## 7. Conclusion

Seafloor geohazards are one of the increasing concerns worldwide because of the increasing development of offshore and coastal facilities and growth of marine services' exploitation. Assessment of seafloor geohazards involves several communities facing different interests and needs.

Technological development is offering marine geology powerful seafloor mapping tools, multibeam bathymetry above all; they are essential for geohazard characterization and, trough repetitive surveys, monitoring and understanding of ongoing geological processes. Does not only high-resolution seafloor mapping enhance the assessment of marine geohazard, but it is also boosting the scientific knowledge on seafloor tectonic, erosional and depositional processes.

The study of geohazard-bearing features provides an opportunity for collaborative activities between academia and industry as well as with public authorities in charge of land planning or civil defense. However, for the different communities, geohazard assessment has different objectives, time span and required precision in forecast. Accordingly, we identify three types of geohazard assessment: sensu-strictu, engineering and non-specific. Regardless of the different approach, seafloor mapping remains the unavoidable if not the main step in the geohazard assessment process.

For industry, focused in short time span and small areas, seafloor mapping is the first step in zoning the area of interest, in order to define the physical environment where the infrastructure will lay and define geohazards that may recur during the life-span of the infrastructure. Sea floor mapping is also the base to plan further investigations and in-situ measurements aimed to identify type, location and possible timing of hazardous event.

For public authorities, seafloor mapping is the main tool to obtain a homogeneous product over vast offshore areas. Given the impossibility to achieve a precise (definite) assessment of geohazard for any seafloor feature, the assessment mainly relies in the identification of geomorphic features linked to hazardous processes/events that might re-occur in the future over the same area, without any specific indication of time and precise location. This assessment does not involve a specific indication of time or precise location of geohazard occurrence.

Finally, scientific research, is interested in defining in detail the physical processes that shape the seafloor with the maximum possible resolution. However seafloor mappingis also the primary tool to define the amount and type processes occurring in a given area that are the key to interpret the long-term morphostructural and stratigraphic evolution of the continental margin and ocean basins.

## Acknowledgments

We acknowledge the Chief Editors of Marine and Geophysical Researches for their willing to publish a joint academic-industry contribution on seafloor mapping, and for their patience in following all the steps towards publication.

This volume was partially supported by the UNESCO and IUGS through project IGCP-511 “Submarine Mass Movements and Their Consequences”, currently superseded by IGCP project 585, “Earth’s continental MARgins: aSsessing geoHAzard from submarine Landslides (E-MARSHAL; http://www.igcp585.org) and of MAGIC project “Marine Geohazards along the Italian Coasts” (www.magicproject.it).

Finally, National Civil Protection Department of Italy and namely Prof. B. de Bernardinis, are acknowledged not only for the aid they gave to the Ischia conference and to the volume but for supporting the MaGIC Project (Marine Geohazards along the Italian Coasts, www.magicproject.it) that is boosting a new wave of marine geology researches among the Italian marine geology community.

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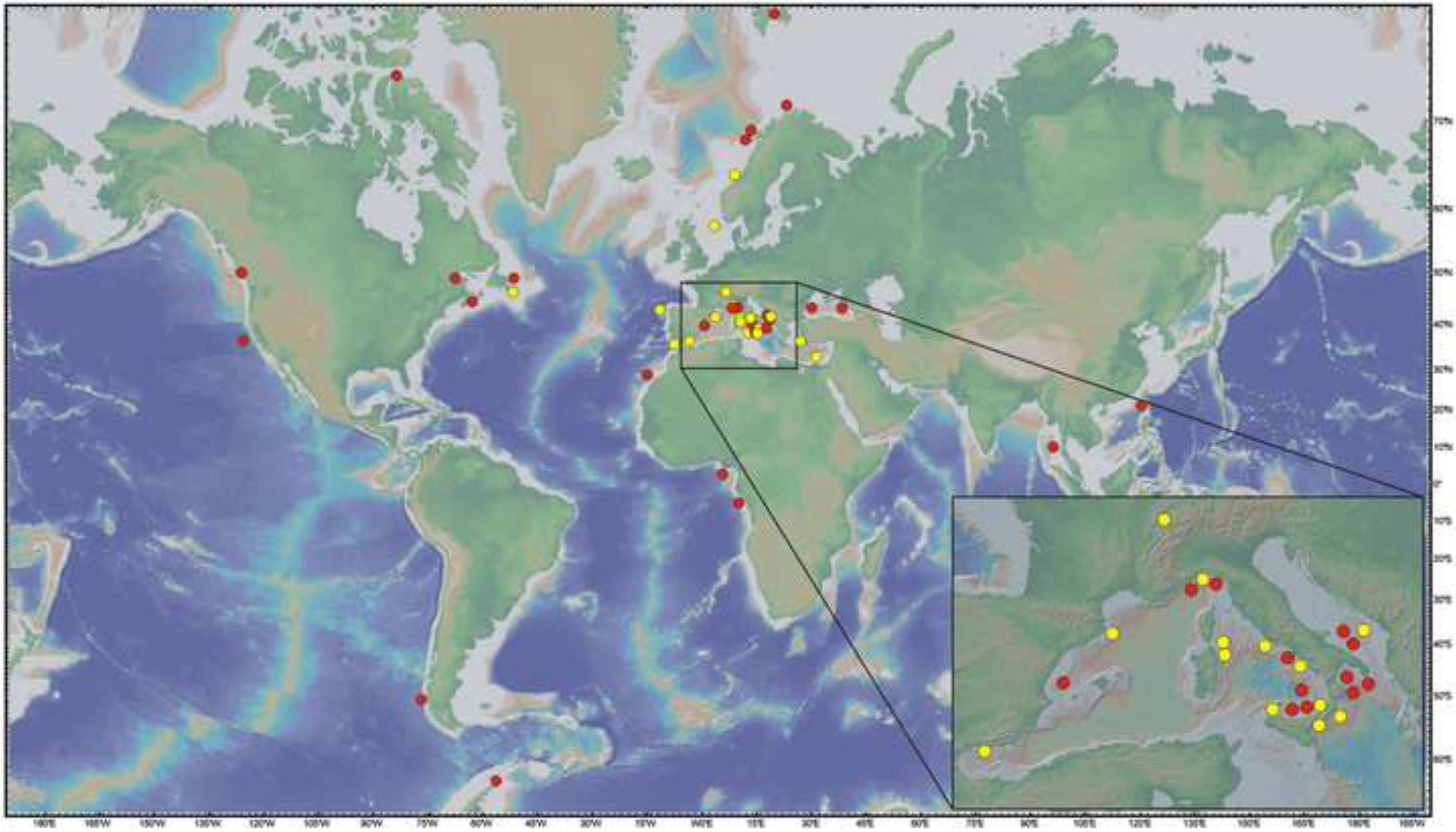
## Figure Captions

Figure 1. Location of the study areas described in the articles of this volume (yellow dots). Further case histories presented at the Ischia Conference in May 2009 but not included in this volume are reported as red dots. Their extended abstracts are collected in Chiocci et al. eds. (2009).

Figure 2. Cartoon summarizing the seafloor features linked to potentially hazardous geological processes. This figure depicts an idealized continental margin with both natural geohazard-bearing features and main anthropogenic structures lying on the seafloor.

Figure 3. Frequency of magnitude (log-area) for submarine landslides from the Medditerranean landslide database (see Camerlenghi et al. 2010) in the Mediterranean basin showing incomplete view of distribution (i.e. smaller landslides are not picked in the distribution).

Figure 4. Triangular diagram summarizing the different type of geohazard assessment and how the different communities relate to them. See text for details.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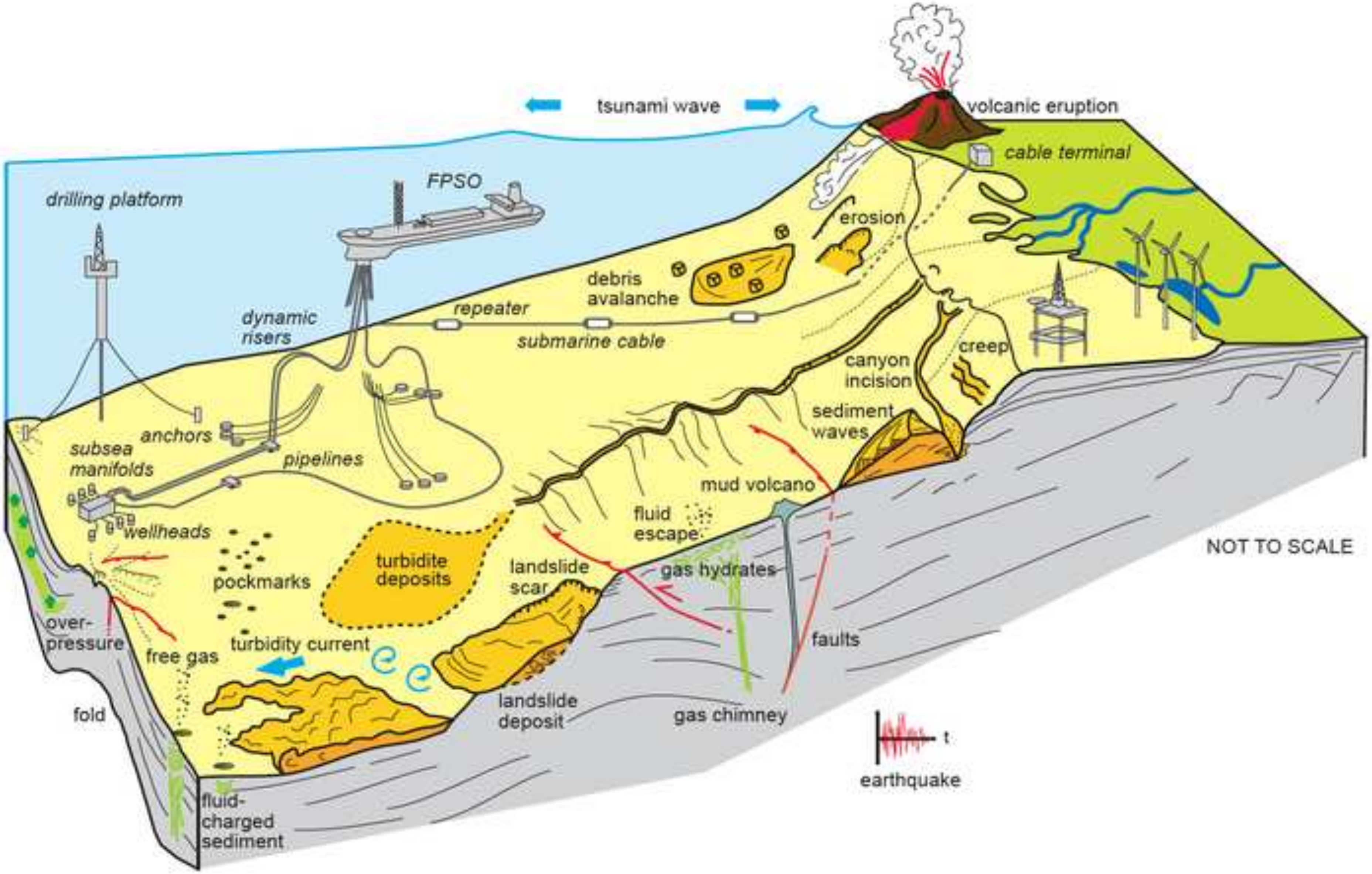
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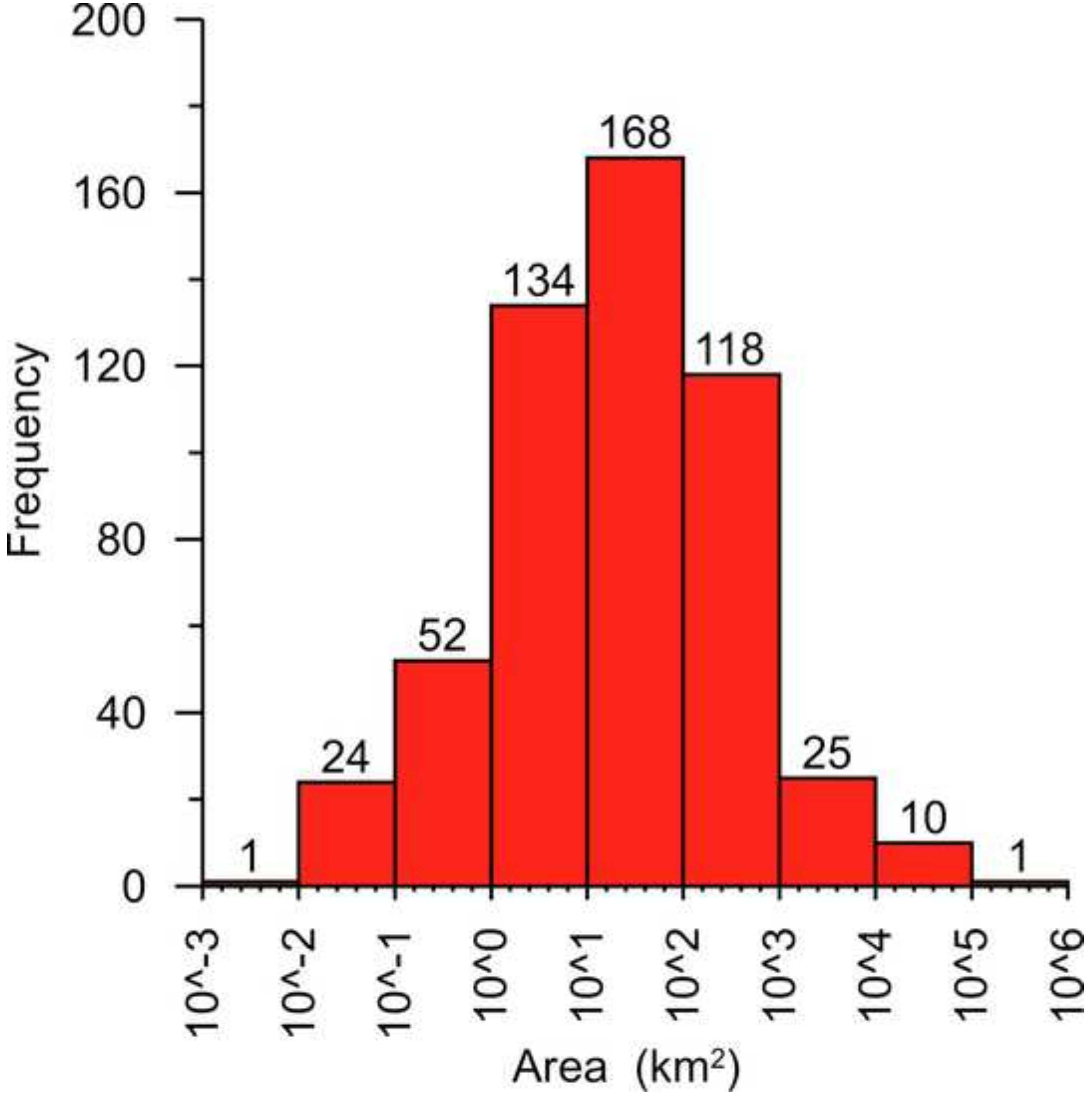
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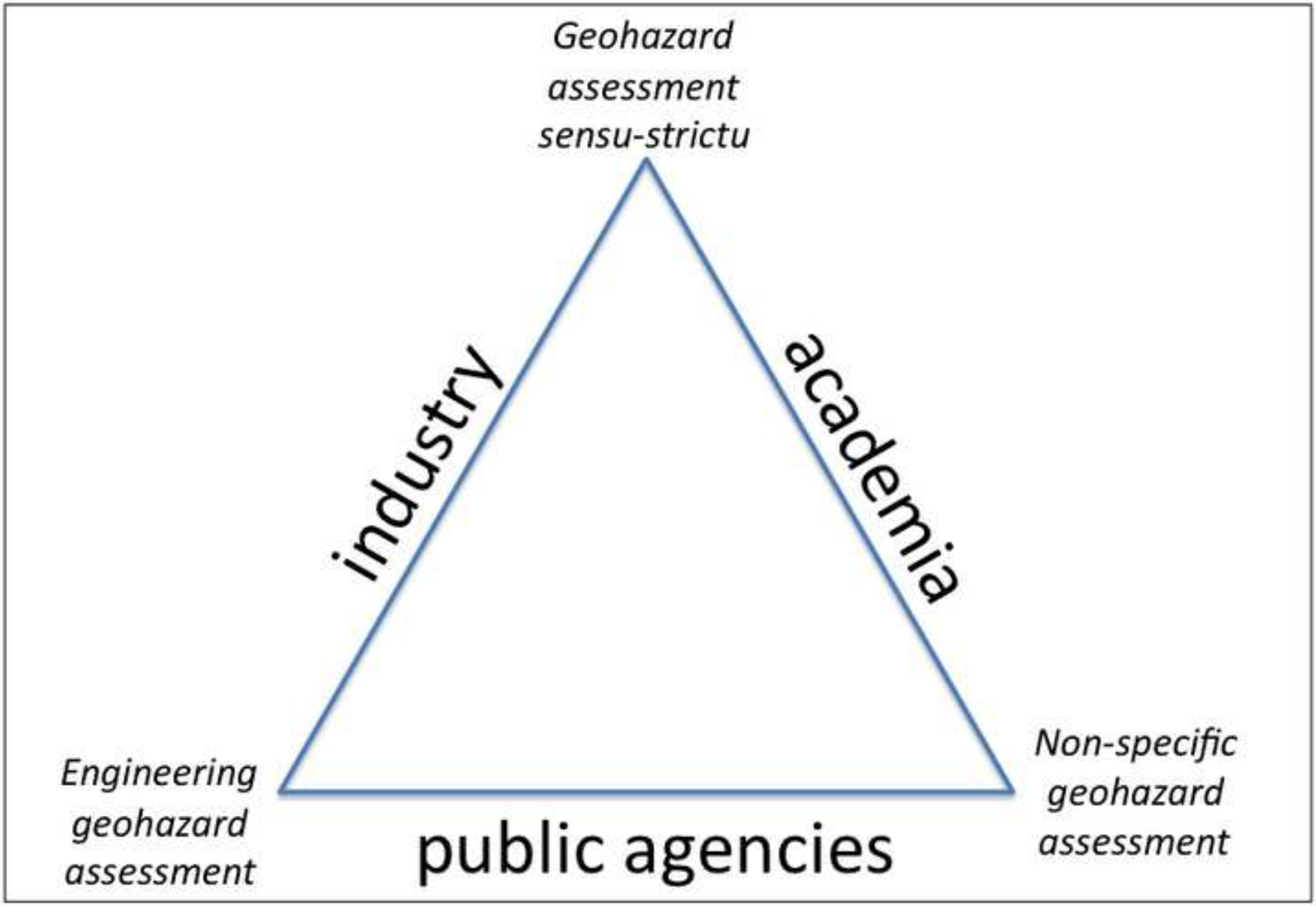
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