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White Paper

Good reasons for IODP to address submarine geohazards (with focus on the Mediterranean)

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Abstract
Following a number of international workshop held in the last few years, this documents synthesise the reasons why future scientific ocean drilling should prioritize geohazards among the scientific objectives. In essence the reasons are the societal relevance, the opportunity to deepen the knowledge of basic geological processes in basin evolution, and the opportunity for technological development. A focus in placed on the Mediterranean Basin because of its high vulnerability to submarine geohazards, and to the known widespread occurrence (in the present and in the recent geological record) of geohazards. Among geohazards of the Mediterranean, a focus is placed on the submarine landslides because of their potential to affect seabed structure and the coastline via the tsunamis they can generate. A list of technological needs and a list of the international workshops is added for reference at the end of the document.

Foreword.

Submarine geohazards mainly addressed in the scientific literature are earthquakes, landslides, volcanic flank collapses, volcanic eruptions, the tsunamis that these generate, gas emissions, bolide impacts. Geohazards are therefore geological events and processes that in highly vulnerable areas produce a situation of risk to population, to infrastructures, and to the environment. In one word: to Society.
The following are ideas and concepts originated mainly in a series of international workshops listed towards the end of this documents and published in the reports that these workshops have generated (to which reference is made for details on scientific objectives, drilling strategies and technological needs are contained technological development). The authors of this documents have condensed and adapted some of these concepts to the format of a White Paper on Geohazards for the INVEST Conference in order to provide good reasons why scientific ocean drilling beyond 2013 should place geohazards among the scientific priorities. This document is viewed as complementary to other White Papers with scientific and technological affinity to geohazards.

3 good reasons why IODP should address submarine geohazards

1. Submarine geohazards may have **important consequences for society** in terms of lives loss, environmental damage, and economic impact. They strike society through infrequent catastrophic events (with recurrence of 10^2-10^3 years), more frequent smaller-scale events, and through continuous geological processes (such as creep of continental slopes, or fluid and gas emissions). Governing processes and episodicity of geohazards are still poorly constrained and incompletely understood.
2. Submarine geohazards are **geological processes that accompany the evolution of sedimentary basins** (Fig. 1). Their study will improve the knowledge of the Earth cycles and dynamics, will lead to the understanding of the links, where appropriate, between geological events and climate evolution, and will contribute to societal risk mitigation.
3. Addressing submarine geohazards presents a unique opportunity for **technology development** and improvement of current sampling and measurement/monitoring techniques.

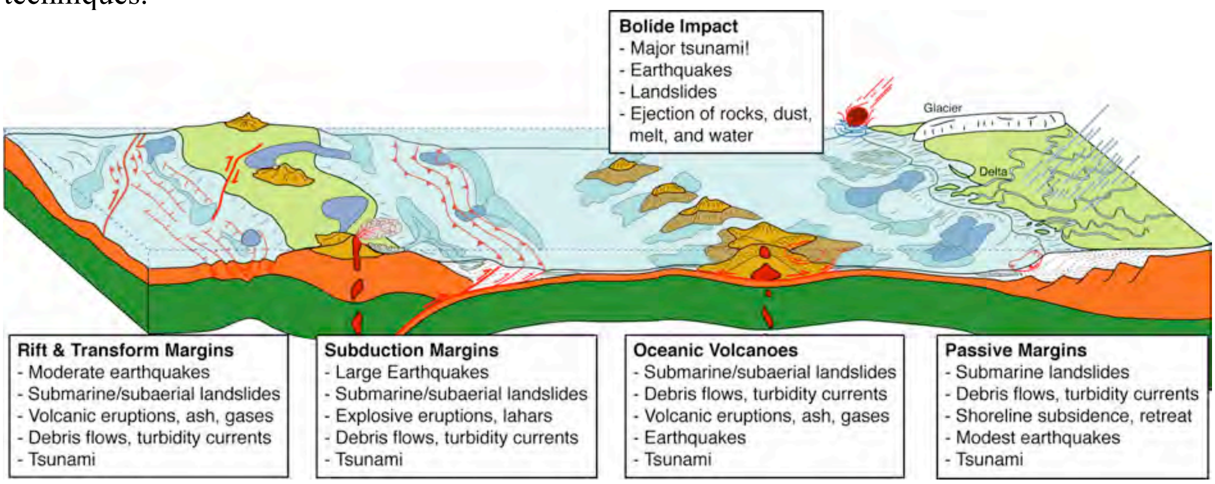

Figure 1. Geohazards in oceanic basins (Morgan et al., 2008)

3 good reasons why IODP should address submarine geohazards in one highly vulnerable oceanic basin: the Mediterranean Sea

1. The Mediterranean basin is a miniature ocean that serves as a "natural laboratory", because of the diversity of tectonic and sedimentary environments it contains. It offers a rather unique opportunity to study geohazards as they relate to different geo-tectonic environments in a relatively small, easily accessible, and geologically well known area of the world (Fig. 2). For example:

   - **Seismic hazard** can be studied in extensional setting (such in one of the fastest spreading rifts in the world, the Gulf of Corinth), strike slip setting (with extraordinary evidence of neotectonic activity and fluid expulsion at the seafloor in the Marmara Sea) and compressional environment of the incipient continental collision in the Mediterranean Ridge (e.g. Behrmann et al., 2007; Kopf & Bohnhoff, 2007).
   - **Volcanic Hazard** can be studied in and around the Aegean and Tyrrhenian seas active volcanic island (e.g. Stromboli, Volcano, Santorini, Nisyros) and in the coastal volcanic complexes of Mt. Etna, Campi Flegrei Caldera (e.g. McCOy and Heiken, 2000; Pareschi et al., 2006; Tibaldi et al., 2008).
   - **Submarine landslide hazard** can be studied in relation to external tectonic triggers and climatically modulated triggers in a variety of sedimentary environments (e.g. Urgeles et al., 2007; Camerlenghi et al., 2007). Submarine landslides can generate tsunamis (Tappin et al., 2001; Lee et al., 2003) and represent a major geohazard for offshore infrastructure and onshore structures (e.g. Longva et al., 2003; Sultan et al., 2004).

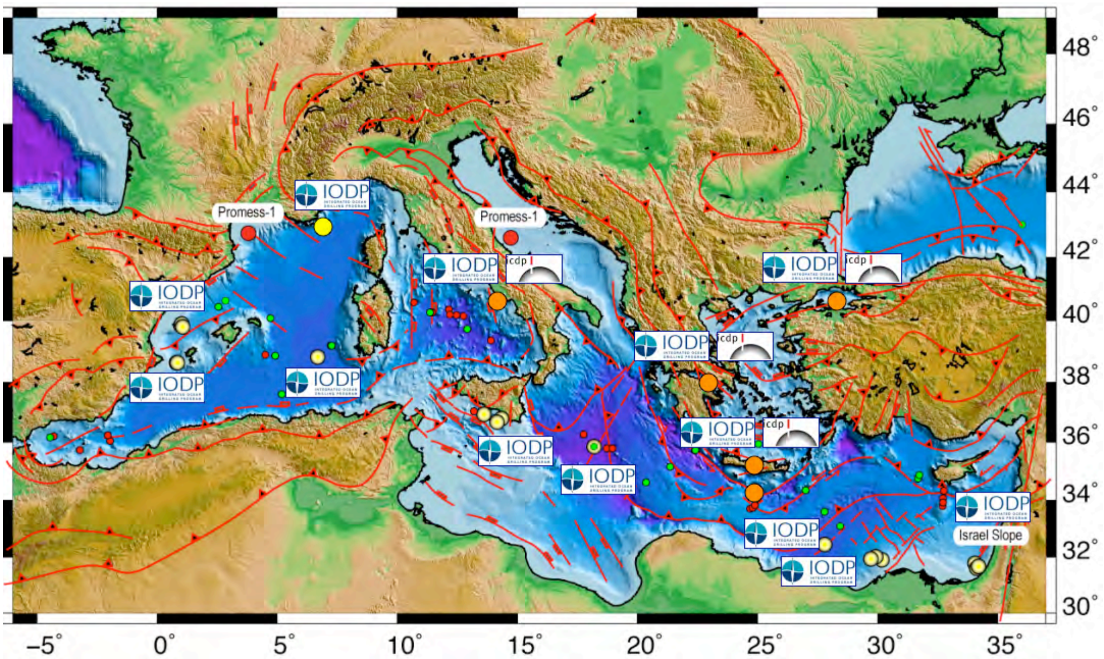

Figure 2. Bathymetry, main structural elements and drillsites in the Mediterranean Sea: Yellow: Proposed IODP sites; Orange: Proposed IODP/ICDP sites; Red Big: drilled PROMESS-1 sites; red and green small: Drilled DSDP/IODP sites.

2. When compared to other basins, the Mediterranean has **larger vulnerability** due to:

- **Very densely-populated coastline**, totalling 160 million inhabitants sharing 46,000 km of (3.5 inhabitants per m of coastline). The Mediterranean area is the world's leading holiday destination, receiving up 30% of global tourism and an average of 135 million visitors annually; this is predicted to increase to 235-350 million tourists by year 2025 (European Environmental Agency - EEA).
- **Relatively small dimensions**, resulting in close proximity to tsunami source. Recent examples include the 1979 Nice airport submarine landslide and tsunami (Sultan et al., 2004), the 2002 Stromboli volcano landslide and tsunami (Tinti et al., 2005), the 2003 earthquake offshore Algeria and subsequent tsunami along the coasts of the Balearic Islands (Alasset et al., 2006).
- **Extremely intense seafloor infrastructure**, on which the impact of sediment mass movement can lead to destruction destruction, economic loss, and environmental damage.

3. The most devastating event in the Mediterranean would be that of an **earthquake- or submarine landslide-induced tsunami**. There is increased evidence that tsunamis have been common in the Mediterranean Sea during the Holocene (<10,000 years), and that their consequences have included destruction and loss of life in ancient coastal settlements (e.g. Salamon et al. 2007; Papadopoulos and Fokaefs, 2005).

4 good reasons why IODP should address submarine landslides in the Mediterranean Sea (un addition to the above mentioned)

1. The Mediterranean Sea continental slopes provide **increasing evidence** of occurrence of submarine landslides in recent times (Fig. 3; Camerlenghi et al., 2009).

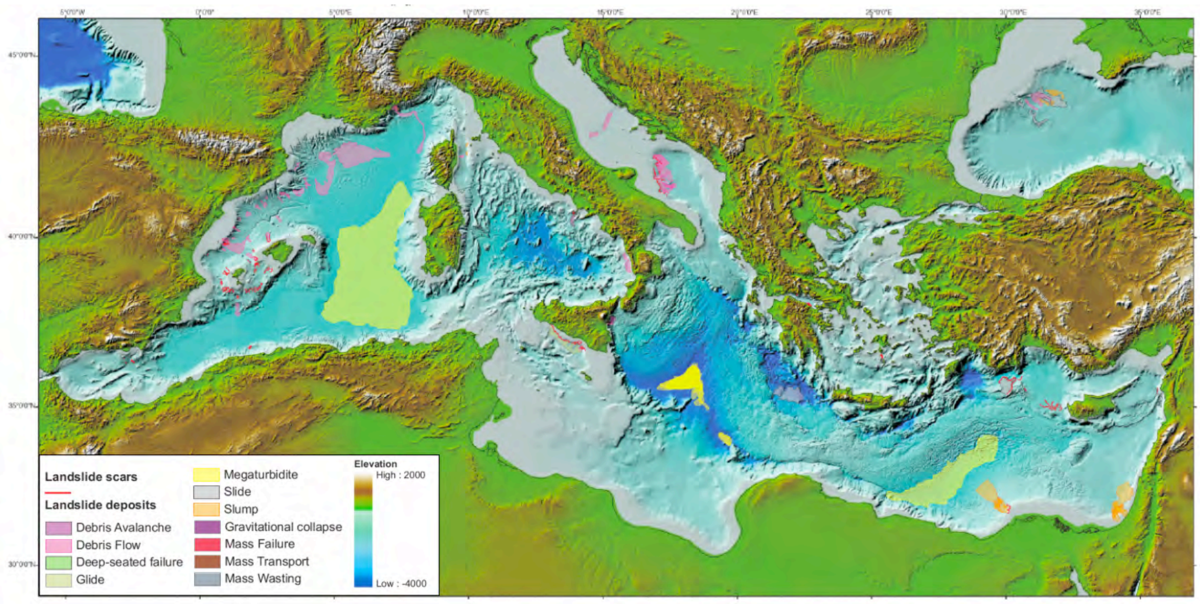

Figure 3. Distribution of known submarine landslides and megaturbidites in the Mediterranean Sea (Camerlenghi et al., 2009).

2. **Increasing use** of the deep Mediterranean sea for human industrial and economic activities augments the vulnerability to sediment mass movements, (Fig. 4; see for example the Mediterranean cable crisis of early 2008).

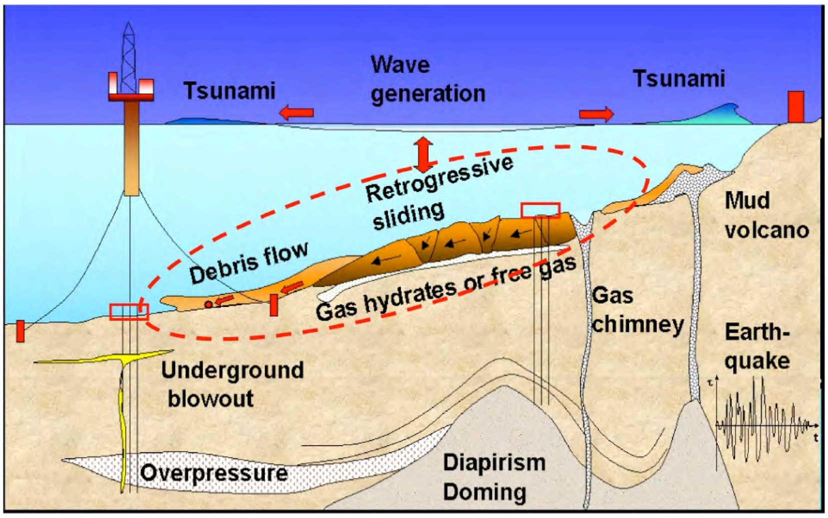

Figure 4. Submarine landslides are recognized as potential geohazards to seafloor and coastal infrastructures (image provided by NGI in Camerlenghi et al., 2007 and Morgan et al., 2008).

3. The distal products of submarine landslides can provide information on earthquake and volcanic hazards, for example, because slope failure recurrence and magnitude is used as a proxy of **paleo-seismicity** (Goldfinger et al., 2003). The Medierranean is known to contain a record of datable and correlatable turbidites and megaturbidites with a potential to unravel the history of major sediment mass movement events (e.g. Rothwell et al., 1998; 2000; Hieke, 2000; Rebesco et al., 2000; Cita et al., 1984; Cita and Aloisi, 2000).

4. Submarine landslides occur on tectonically-dominated margins as well as on passive margins and volcanic island flanks of Mediterranean margins. However, tectonically quiet zones seem to have the highest density of known large events. This observation stresses that the balance between **pre-conditioning and triggering factors** needs to be correctly assessed. Factors inherent to the slope, some of which climatically modulated, that may concur to significantly decrease sediment strength are high interstitial fluid pressures resulting from sediment input type and amount, fluid migration resulting from margin architecture and distribution of stresses, gas hydrate dissociation (Lee, 2008). When some of these factors coincide, cyclic loading from the smallest earthquakes may induce slope failure. The passive margins of the Mediterranean Sea appear therefore as an area where these preconditioning factors prevail over tectonic triggers.

DRILLING STRATEGY FOR SUBMARINE LANDSLIDES

- Drill **sequences** of submarine landslides including areas of **incipient and recent deformation**. 2 to 3 shallow penetration sites in failed and unfailed sediments.
- Drill **stratigraphic holes** at all locations with continuous coring in multiple holes for high-resolution stratigraphy. Logging While Drilling (LWD) from the seafloor to get petrophysical ties for core-log-seismic integration.
- Drill **dedicated geotechnical sites** for high-quality geotechnical sampling of key horizons will be drilled last. Including Cone Penetration Tests (CPTU), pore pressure monitoring, in situ un-drained shear strength.
- Drill **basinal turbidite and 'megaturbidite'** sequences in abyssal plains neighbouring submarine landslide sites.
- **Monitor** a few boreholes in proto-failure zones (inclinometers, piezometers, fluid flow, strain meters).

TECHNOLOGICAL NEEDS

Submarine geohazards tie very well with the need of **observing processes at the seafloor and subseafloor** (observatories). All sensors can be installed on a borehole (strainmeters, sensors in casing (temperature, strain), rapture, pressure, fluid flow, inclinometers, accelerometers, temperature, fluid geochemistry, gas detectors, fluid sampling,

Among these new/improved techniques are **high-quality logging** near the seafloor and development of seabed frame for better control of tools for logging, in situ sampling, and near-surface monitoring. There are also a number of exiting techniques that have never been used within the frame of IODP such as thin –**wall samplers/geotechnical samplers** that would allow retrieving high quality samples, and **CPT (Cone Penetration Testing)** for sediment classification, and geotechnical parameters including dissipation tests to obtain large-scale in-situ permeability. Technological challenges for investigating geohazards are further discussed in the **White paper of the Engineering Development Panel**.

Drilling for submarine geohazards is seen as an opportunity of **multiplatform drilling** in general, and for Mission Specific drilling in particular.

WORKSHOPS HELD

Specific Workshops

ESF - ECORD *MAGELLAN* WORKSHOP
Scientific Ocean Drilling Behind the assessment of Geo-Hazards from submarine landslides Barcelona, Spain, October 25-27, 2006

IODP International Workshop
Addressing Geologic Hazards Through Ocean Drilling Workshop
Portland, Oregon USA, August 26-30, 2007

ESF - ECORD *MAGELLAN* WORKSHOP
Ocean Drilling for Seismic Hazard in European Geosystems
Luleå, Sweden, August 18-20, 2008

Related Workshops

Deep Sea Frontier Workshop: an integrated approach to study the deep sea floor.
ECORD-NET WORKSHOP, Napoli, Italy, June 1-2, 2006.

IGCP-511 project on Submarine Mass Movements and Their Consequences
3rd International Symposium on Submarine Mass Movements and Their Consequences. Santorini, Greece, 2007.

4th International Symposium on Submarine Mass Movements and Their Consequences. Austin Texas, 2009.

International Conference on Seafloor Mapping for Geohazard Assessment
Ischia, Italy 11-13 May 2009.

VISO Workshop (Virtual Institute of Scientific Users of Deep Sea Observatories)
Tromsø, Norway 11-12 June 2009.

OUTCOME OF THE RECENT WORKSHOPS

- The establishment the **state of knowledge** regarding conditions and distribution of catastrophic geohazards
- The definition **key unresolved scientific questions** relating to geohazards
- The formulation of **realistic science plans** to answer them
- The evaluation of the **tools and technologies available** for geohazards study
- The identification of **potential drilling targets** for specific hazardous phenomena
- The **enhancement international collaborations** and stimulate proponent teams to develop competitive IODDP proposals.

WHAT ELSE DO WE NEED?

- Future international scientific drilling must **include submarine geohazards among priority scientific objectives with direct societal impact**
- The **science advisory structure** must be prepared to receive and evaluate proposal specifically addressing submarine geohazards.
- The **implementing organizations** need to be prepared for the technological needs of drilling proposals addressing geohazards.
- Geohazards must be studied through their **geological record**, as parts of the **sedimentary basins evolution**, in the framework of **plate tectonics**, in relation to **climate** (when this relation applies).
- Rather than a pure engineering exercise, the study of submarine geohazards should result in a **close cooperation between earth scientists and engineers**.
- The study of submarine geohazards will offer opportunities to **develop new technology** and apply it to scientific studies with a high societal impact.

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