Satellite Activity for the UN Ocean Decade Safe Ocean Laboratory

Further Challenges for Warnings of Tsunamis
SESSION A: Learnings from recent tsunamis generated by non-seismic and complex sources

6. What are the risks of volcano-generated tsunamis in other ocean basins?

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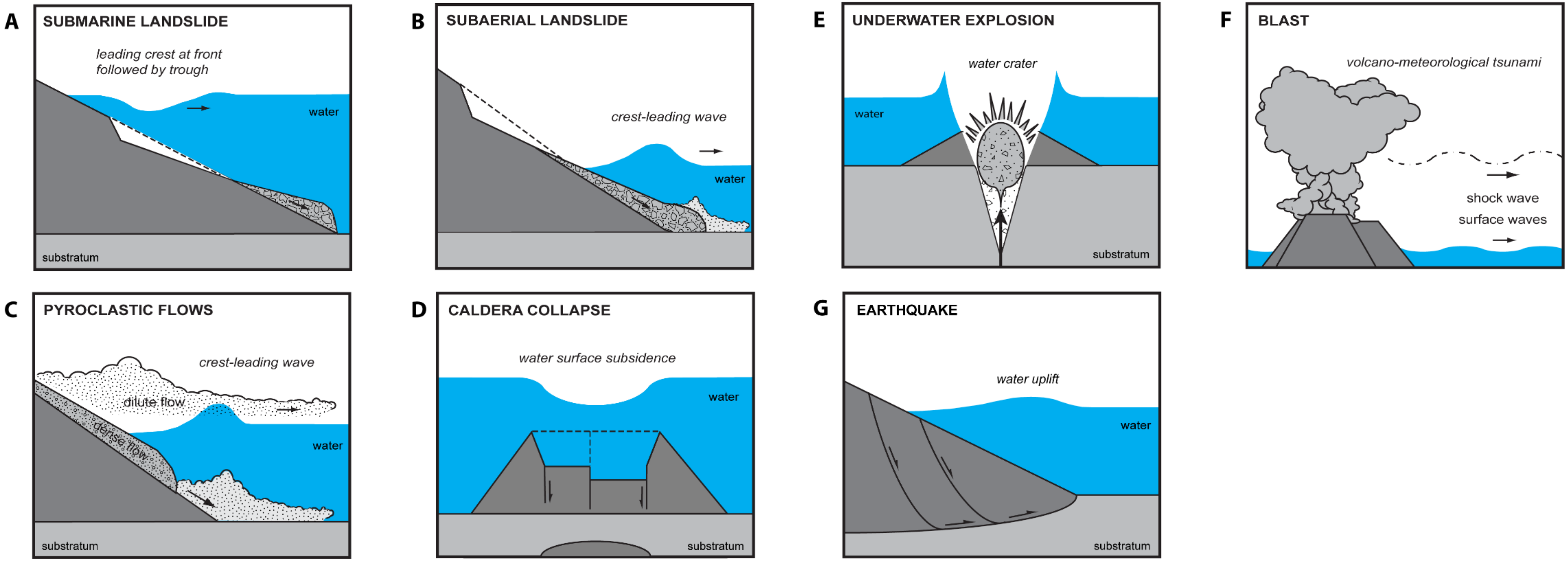
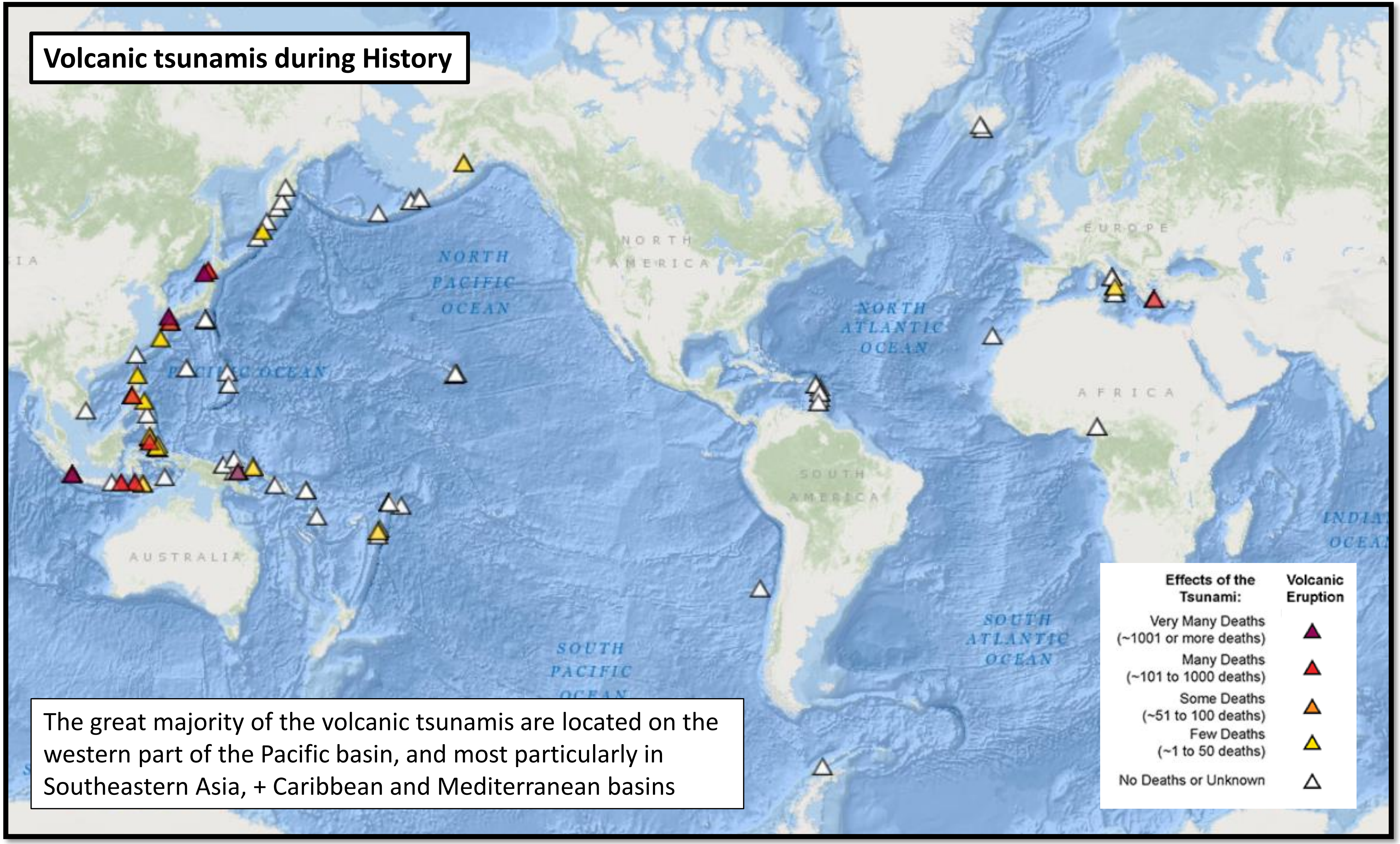
The activity and instability of volcanic edifices can produce tsunamis, so-called volcanic tsunamis.

Different types of source mechanisms were identified from past events.



For more information on the different types of volcanic tsunami – see session B talk #4 April 7, 07:40 am.

Volcanic tsunamis during History



The great majority of the volcanic tsunamis are located on the western part of the Pacific basin, and most particularly in Southeastern Asia, + Caribbean and Mediterranean basins

Task team IOC/UNESCO TOWSD-WG on **Atypical Tsunami Sources**, *lead. François Schindelé (CEA France)*

Report on:

- Recent tsunami events such as Greenland 2017, Palu 2018, Anak Krakatau 2018
- Review of the atypical tsunami sources, both seismic and non-seismic, i.e. not related to subduction earthquakes
- Current state of the art related to monitoring and warning for such events
- Provide guidance and recommendations to the Member States

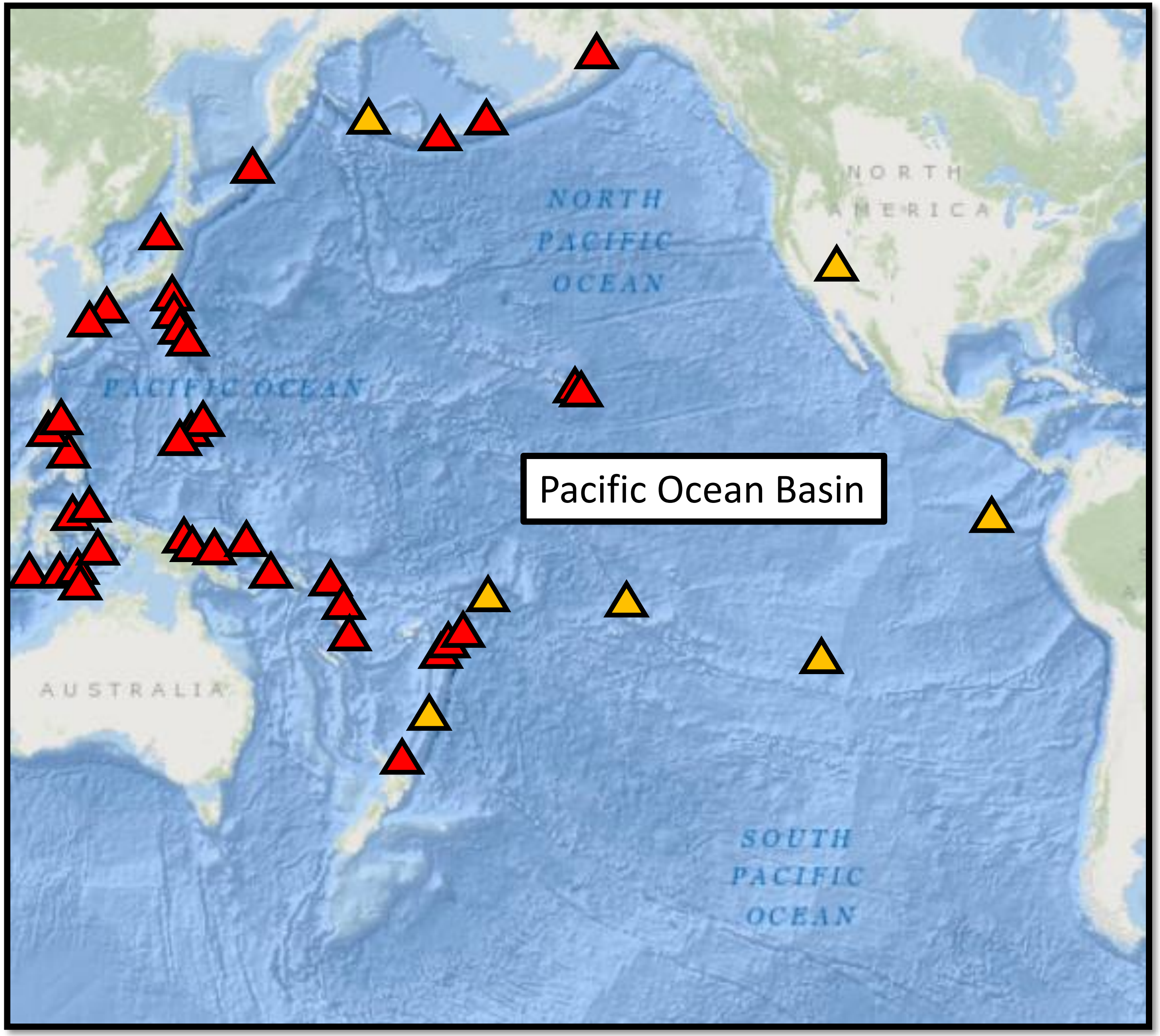
The report also provides in annex a preliminary list of ~50 potentially tsunamigenic volcanoes around the world, with the following criteria:

Volcano is currently active or was active during the XXth or XXIst century

It belongs to one of these four types of volcanic edificies:

1. Steep-flanked stratovolcano whose main eruptive centre is located less than 6 km from the sea or lake: Stromboli (Italy), Soufrières Hills (Montserrat)
2. Complex of eruptive centres in a partly submerged caldera: caldera lake (Taal, Philippines) or caldera opened to the sea (Krakatau, Indonesia; Rabaul, Papua New Guinea).
3. Submarine volcano, whose activity and instability are potential sources of tsunamis: Kick'em Jenny (Grenada, Caribbean), Hunga Tonga - Hunga Ha'apai (Tonga).
4. Ocean shield volcano showing evidence of flank deformation: Kilauea (Hawaii), Piton de la Fournaise (Reunion Island)

Particular attention was paid to volcanoes who already generated tsunamis, even small-scale tsunamis.



The Pacific « Ring of Fire » hosts many volcanoes that are potentially tsunamigenic.

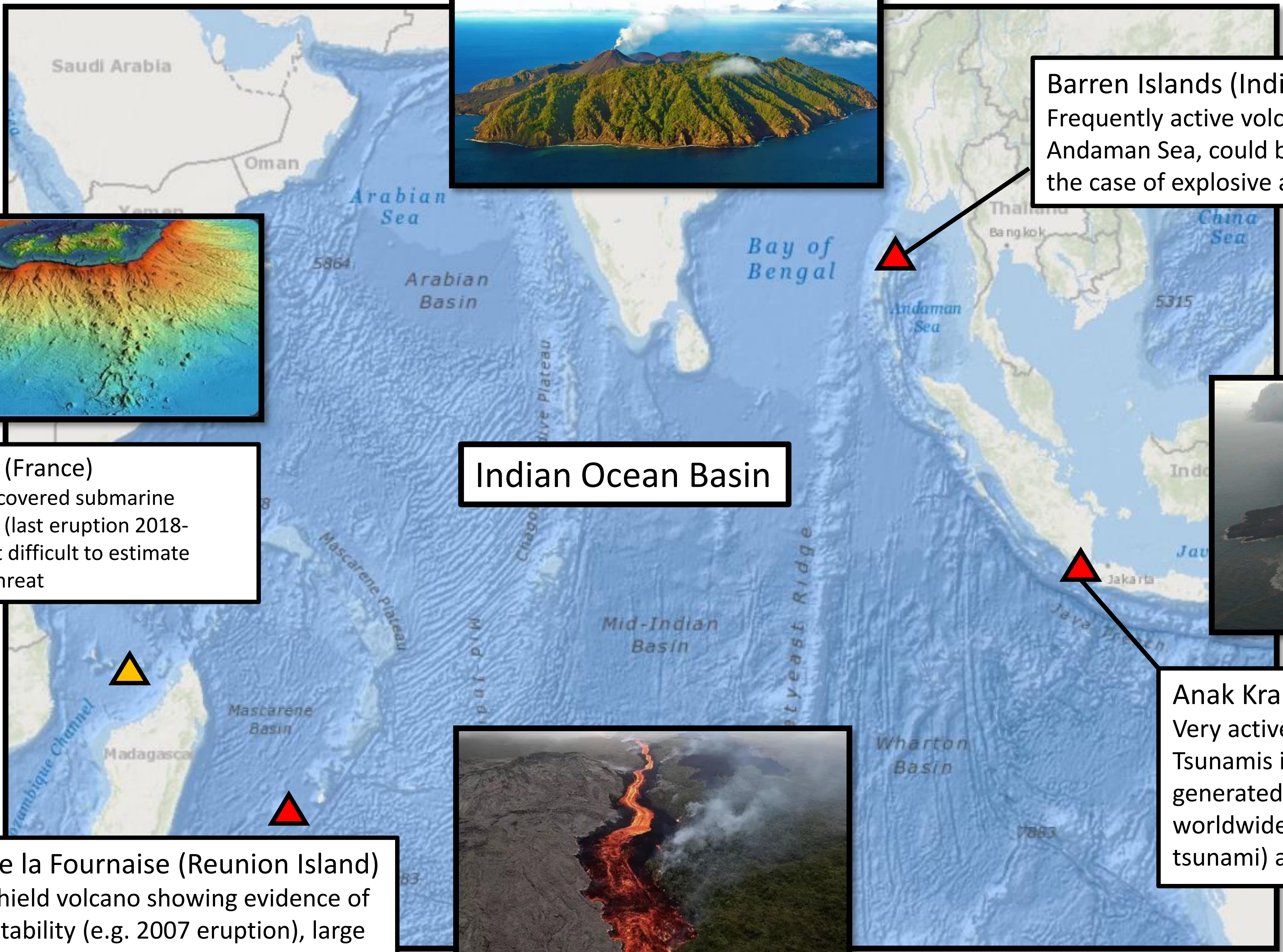
All types of volcanic edifices and volcanic tsunamis are represented

-> target basin #1

Priority volcano (in the list): volcanic tsunami hazard to be considered and scenarios implemented in SOP

Secondary volcanic areas (not in the list): very low probability for a tsunami hazard (but not 0).

Indian Ocean Basin



Barren Islands (India)
Frequently active volcano emerging from the Andaman Sea, could become tsunamigenic in the case of explosive activity or flank collapse

Mayotte (France)
Newly discovered submarine volcanoes (last eruption 2018-2021), but difficult to estimate tsunami threat

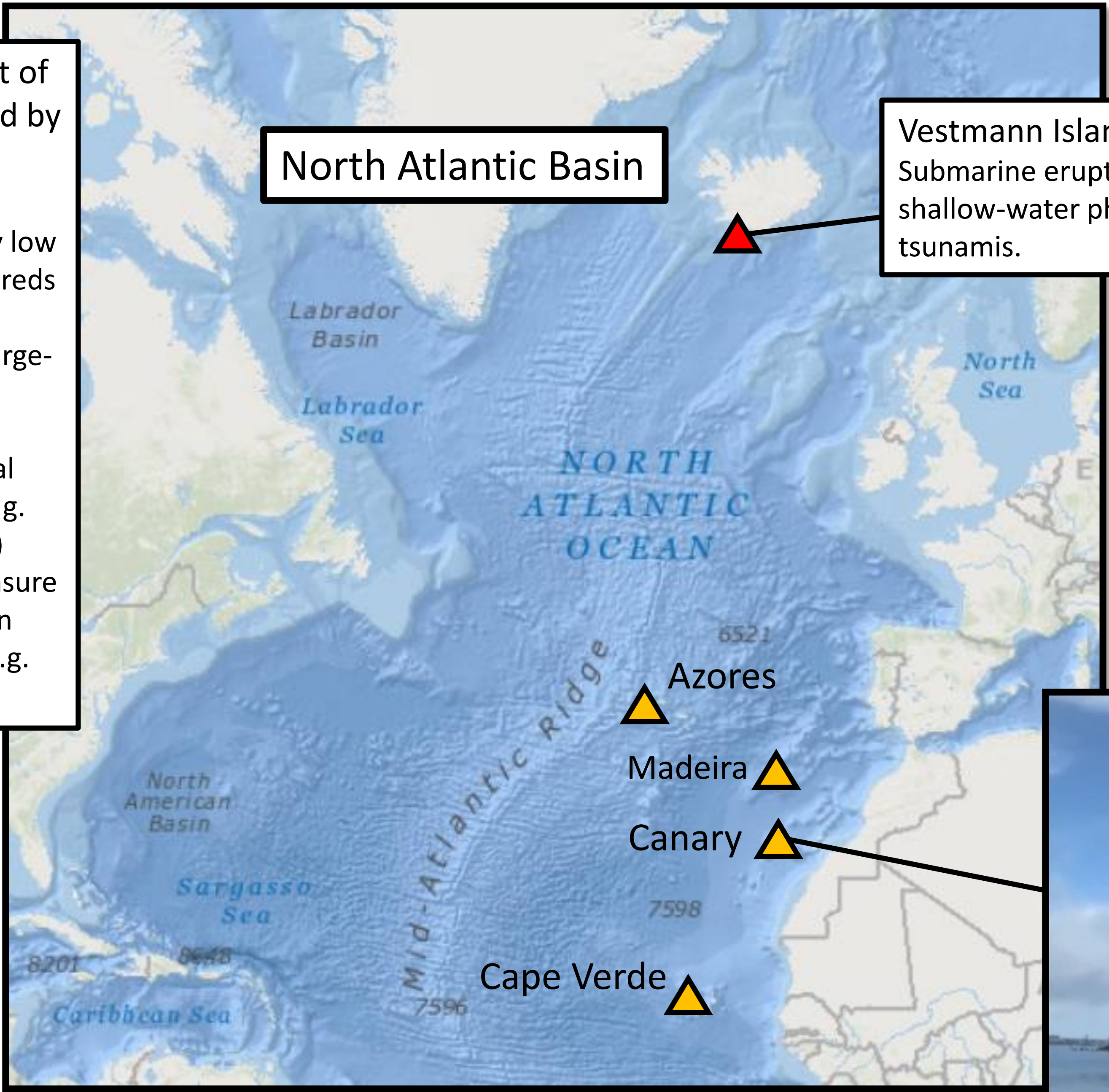
Anak Krakatau (Indonesia)
Very active volcano in Sunda Strait
Tsunamis in 1883 (local tsunamis generated by pyroclastic flows + worldwide volcano-meteorological tsunami) and 2018 (flank collapse)

Piton de la Fournaise (Reunion Island)
Ocean shield volcano showing evidence of flank instability (e.g. 2007 eruption), large flank collapse and tsunami 4500 years ago.

Ocean islands and the threat of a regional tsunami generated by flank collapse

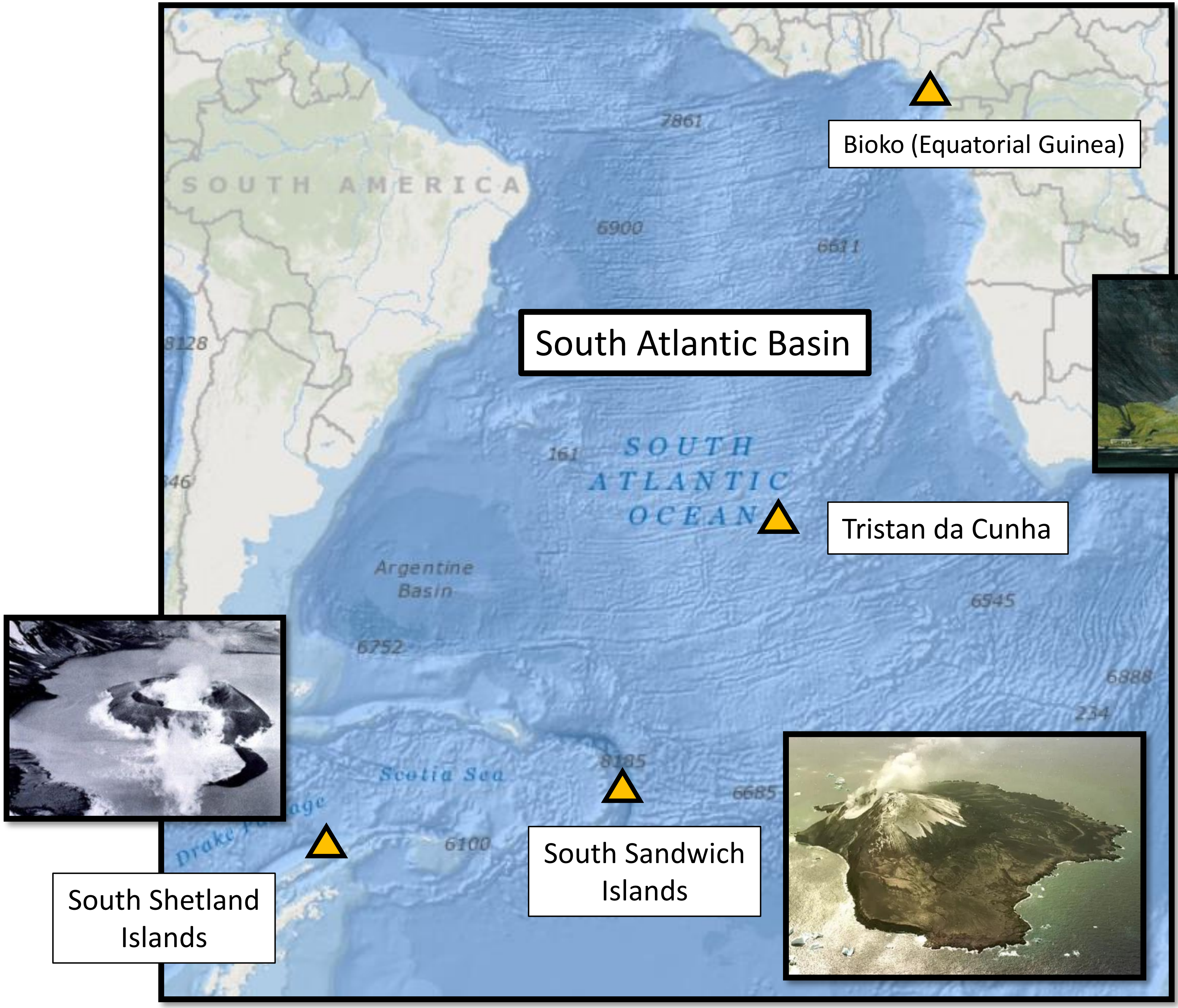
-> very high-magnitude but very low recurrence events (tens to hundreds of thousands of years)
-> no present-day evidence of large-scale instability of the flanks of these islands
-> most probable scenario = local tsunamis due to cliff collapse (e.g. Madeira 1930, La Gomera 2020)
-> not on the priority list, but ensure communication with institutes in charge of volcano monitoring (e.g. La Palma eruption 2021)

North Atlantic Basin



Vestmann Islands and Reykjanes ridge (Iceland)
Submarine eruptions along the Mid-Atlantic Ridge -> shallow-water phreatomagmatic explosions and local tsunamis.

Probability for a volcanic tsunami in the North Atlantic Basin is low, but local tsunami sources should not be neglected



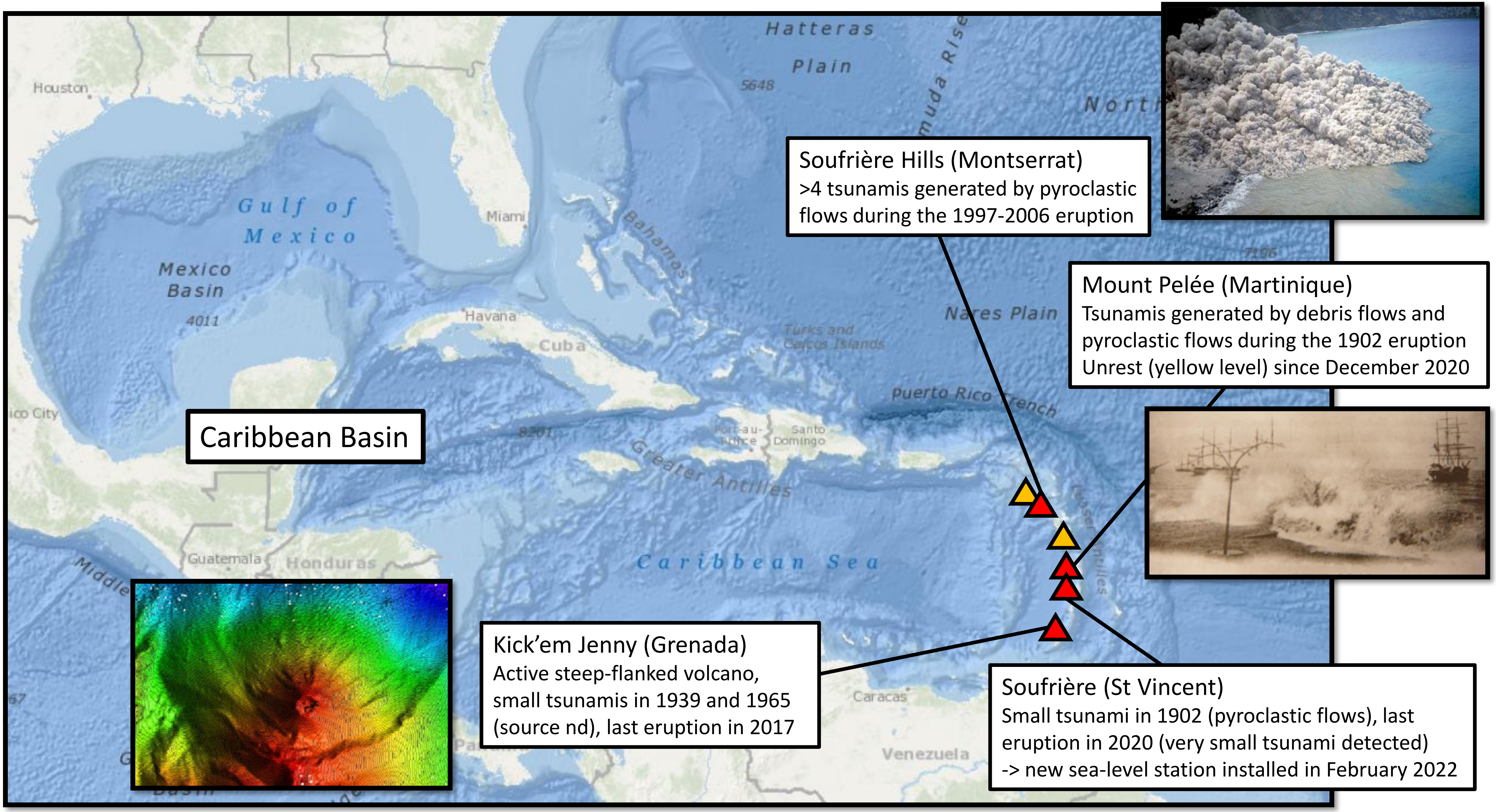
Volcanic provinces active in the South Atlantic basin

At least 12 volcanoes active during the XXth and XXIst centuries

No documented volcanic tsunami during the three last centuries

Difficult to estimate the probability for a volcanic tsunami, but it is probably very low

NB- submarine volcanism along the Mid-Atlantic Ridge does not produce tsunamigenic eruptions (water depth 2000-4000 m)


Soufrière Hills (Montserrat)
>4 tsunamis generated by pyroclastic flows during the 1997-2006 eruption
Mount Pelée (Martinique)
Tsunamis generated by debris flows and pyroclastic flows during the 1902 eruption
Unrest (yellow level) since December 2020
Caribbean Basin
Kick'em Jenny (Grenada)
Active steep-flanked volcano, small tsunamis in 1939 and 1965 (source nd), last eruption in 2017
Soufrière (St Vincent)
Small tsunami in 1902 (pyroclastic flows), last eruption in 2020 (very small tsunami detected)
-> new sea-level station installed in February 2022
Houston
Gulf of Mexico
Mexico Basin
4011
Miami
Hatteras Plain
5648
Bahamas
Havana
Cuba
Turks and Caicos Islands
Nares Plain
Puerto Rico Trench
Santo Domingo
Greater Antilles
Caribbean Sea
Guatemala
Honduras
Caracas
Venezuela

VOLCANO	COUNTRY	ISLAND	LAT	LONG	LAST ACTIVITY
Saba	Netherlands	Saba	17.63	-63.23	1640
The Quill	Netherlands	St Eustatius	17.478	-62,96	250
Liamuiga	St Kitts & Nevis	St Kitts	17.37	-62.8	160
Nevis	St Kitts & Nevis	Nevis	17.15	-62.58	unknown
Soufrière Hills	United Kingdom	Montserrat	16.72	-62.18	2013
Soufrière	France	Guadeloupe	16.04	-61.66	1977
Morne Watt	Dominica	Dominica	15.31	-61.31	1997
Morne Plat Pays	Dominica	Dominica	15.26	-61.34	1270
Mount Pelée	France	Martinique	14.81	-61.17	1932
Qualibou	St Lucia	St Lucia	13.83	-61.05	1766
Soufrière	St Vincent & Grenadines	St Vincent	13.33	-61.18	1979
Kick 'em Jenny	Grenada	submarine	12.30	-61.64	2017
St Catherine	Grenada	Grenada	12.15	-61.67	unknown

Table 6. List of active volcanoes of the Lesser Antilles (Smithsonian Institution Holocene volcano list available at http://volcano.si.edu/list_volcano_holocene.cfm).

Intergovernmental Oceanographic Commission

Workshop Report No. 291

Experts Meeting on Sources of Tsunamis in the Lesser Antilles

Fort-de-France, Martinique (France)
18–20 March 2019

YEAR	MONTH	DAY	COUNTRY	VOLCANO	LAT	LONG	CAUSE	WAVE HEIGHT
1902	5	5	MARTINIQUE (FRANCE)	MOUNT PELEE	14.82	-61.17	DEBRIS FLOW	≤ 4 m
1902	5	7	SAINT VINCENT - GRENADINES	SOUFRIÈRE	13.33	-61.18	PYROCLASTIC FLOW	≤ 1 m
1902	5	8	MARTINIQUE (FRANCE)	MOUNT PELEE	14.82	-61.17	PYROCLASTIC FLOW	
1902	5	20	MARTINIQUE (FRANCE)	MOUNT PELEE	14.82	-61.17	DEBRIS FLOW	
1902	8	30	MARTINIQUE (FRANCE)	MOUNT PELEE	14.82	-61.17	DEBRIS FLOW	≤ 1 m
1939	7	24	GRENADA	KICK 'EM JENNY	12.3	-61.63	EXPLOSION ?	≤ 2 m
1965	10	24	GRENADA	KICK 'EM JENNY	12.3	-61.63	EXPLOSION ?	
1997	12	26	MONTSERRAT	WHITE RIVER VALLEY	16.72	-62.18	PYROCLASTIC FLOW	≤ 3 m
1999	1	20	MONTSERRAT	SOUFRIÈRE HILLS	16.722	-62.18	PYROCLASTIC FLOW	≤ 2 m
2003	7	12	MONTSERRAT	SOUFRIÈRE HILLS	16.722	-62.18	PYROCLASTIC FLOW	≤ 4 m
2006	5	20	MONTSERRAT	SOUFRIÈRE HILLS	16.722	-62.18	PYROCLASTIC FLOW	≤ 1 m

Table 5. List of historical volcanic tsunamis that were observed in the Lesser Antilles since 1902 (modified from NCEI database: https:/www.ngdc.noaa.gov/hazard/tsu.shtml).

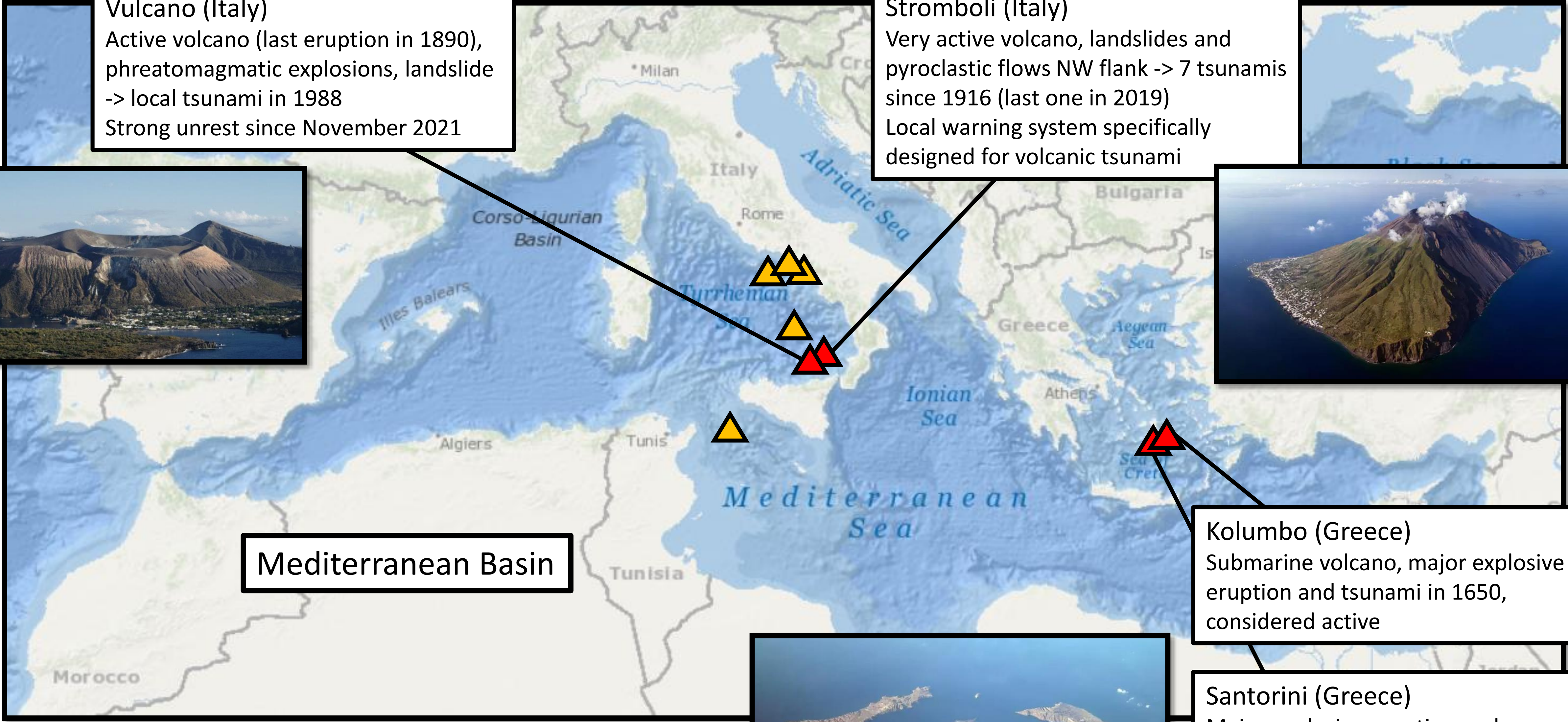
SCENARIO	VOLCANO	LOCATION	LAT	LONG	CAUSE	REMARKS
1a	Kick'em Jenny	central crater	12.30	-61.64	underwater explosion	Explosion energy E = 10^{13}J
1b	Kick'em Jenny	central crater	12.30	-61.64	underwater explosion	Explosion energy E = 10^{14}J
1c	Kick'em Jenny	central crater	12.30	-61.64	underwater explosion	Explosion energy E = 10^{15}J
1d	Kick'em Jenny	central crater	12.30	-61.64	underwater explosion	Explosion energy E = 10^{16}J
2a	Montserrat Hills	eastern flank	16.71	-62.18	pyroclastic flow	Volume V = 16 x 10^6 m^3
2b	Montserrat Hills	southwestern flank	16.71	-62.18	pyroclastic flow	Volume V = 20 x 10^6 m^3
3a	Soufrière St Vincent	western flank	13.33	-61.18	debris flow	Volume V = 5 x 10^6 m^3
3b	Soufrière St Vincent	western flank	13.33	-61.18	debris flow	Volume V = 10 x 10^6 m^3
4	Dominica	Morne Patate SW	15.22	-61.36	subaerial landslide	Volume V = 0.3 km^3
5a	Kick'em Jenny	northwestern flank	12.30	-61.64	submarine landslide	Volume V = 0.1 km^3
5b	Kick'em Jenny	northwestern flank	12.30	-61.64	submarine landslide	Volume V = 0.6 km^3
5c	Kick'em Jenny	northwestern flank	12.30	-61.64	submarine landslide	Volume V = 1 km^3
6a	St Vincent	western flank	13.33	-61.18	massive flank collapse	Volume V = 10 km^3
6b	St Vincent	western flank	13.33	-61.18	massive flank collapse	Volume V = 30 km^3
7a	Cariaco Basin	northward	10.46	-64.78	submarine landslide	Volume V = 1 km^3
7b	Cariaco Basin	northward	10.46	-64.78	submarine landslide	Volume V = 5 km^3
7c	Cariaco Basin	northward	10.46	-64.78	submarine landslide	Volume V = 10 km^3
8a	Muertos Trough	southward	17.55	-69.30	submarine landslide	Volume V = 1 km^3
8b	Muertos Trough	southward	17.55	-69.30	submarine landslide	Volume V = 5 km^3
8c	Muertos Trough	southward	17.55	-69.30	submarine landslide	Volume V = 10 km^3
9a	Desirade Graben	southward	17.25	-60.75	submarine landslide	Volume V = 1 km^3
9b	Desirade Graben	southward	17.25	-60.75	submarine landslide	Volume V = 5 km^3
9c	Desirade Graben	southward	17.25	-60.75	submarine landslide	Volume V = 10 km^3

Table 7. Selected scenarios of non-seismic sources of tsunamis in the Lesser Antilles

9 scenarios of volcanic and landslide tsunamis proposed
(with different sub-scenarios based on parameters such as explosion energy and flow volume)

1 scenario (Kick'em Jenny landslide) added to CATSAM
(Caribbean and Adjacent Regions Tsunami Sources and Models)

Task Team on tsunami procedures for volcanic crises created in 2016 (*lead. Paul Martens and Valérie Clouard*)



Vulcano (Italy)
Active volcano (last eruption in 1890), phreatomagmatic explosions, landslide -> local tsunami in 1988
Strong unrest since November 2021

Stromboli (Italy)
Very active volcano, landslides and pyroclastic flows NW flank -> 7 tsunamis since 1916 (last one in 2019)
Local warning system specifically designed for volcanic tsunami

Kolumbo (Greece)
Submarine volcano, major explosive eruption and tsunami in 1650, considered active

Santorini (Greece)
Major explosive eruption and regional tsunami Late Bronze Age, historical eruptions (effusive) inside the caldera (last eruption in 1950)

FP7 European project ASTARTE (Assessment, strategy and risk reduction for tsunamis in Europe) 2013-2017: updated catalogue of past volcanic tsunamis, source mechanisms, guidelines for hazard assessment, and strategies of numerical modelling.

Conclusions

- All ocean basins are potentially exposed to volcanic tsunami, but the Pacific basin and its adjacent seas (Sulawesi Sea, Banda Sea, Bismarck Sea, Solomon Sea, etc.) is far more exposed than the other basins.

- The probability for a volcanic tsunami triggered in the Atlantic basins is low, especially in the South Pacific basin. However, local tsunamis generated by volcanic activity and cliff collapses should be considered (Canary Islands, Azores, Cape Verde, Iceland).

- The volcanic tsunami threat is non negligible in the Caribbean and Mediterranean basins, lower than in the Pacific basin, but higher than in the Atlantic.

  - In the Caribbean >10 volcanic tsunamis occurred during the two last centuries and caused no fatalities, but this is a sign not to be taken lightly -> initiatives such as the Expert meeting in Martinique (2019) and the Task Team on tsunami procedures for volcanic crises (since 2016).

  - In the Mediterranean, volcanic tsunami hazard is concentrated on Italy and Greece volcanoes. Italy has the most sophisticated local tsunami warning system designed to deal with volcanic tsunami hazard at Stromboli. There are currently discussions on how to address this hazard at Vulcano, Vesuvius and Campi Flegrei (Civil Protection, INGHV and universities). In Greece, the Hellenic Geological Survey launches a new project to improve quantitative hazard and risk assesment, including volcanic tsunami hazard.