

Chapter 1 – Tsunamis generated by volcano activity and instability

- > background information on the physical phenomena associated with each identified possible tsunami source in a volcanic setting
- > references on historical and recent case-studies.

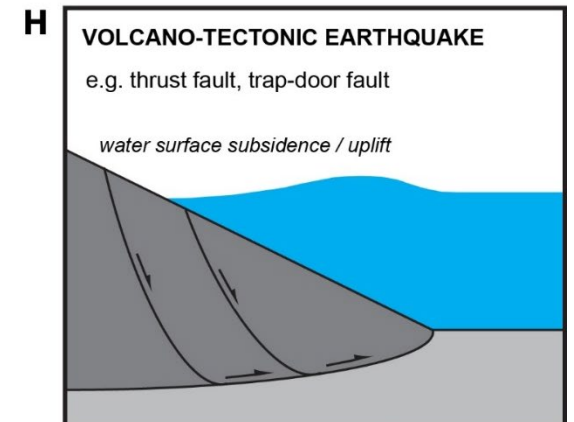
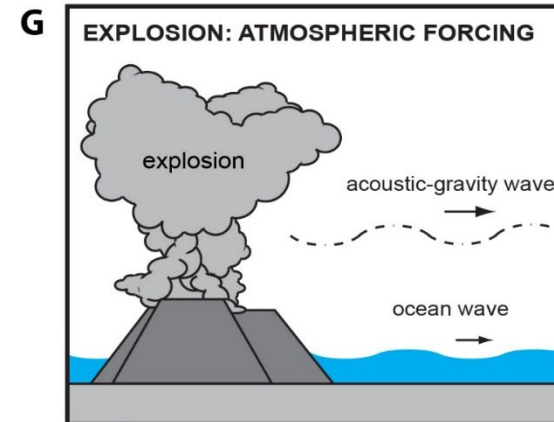
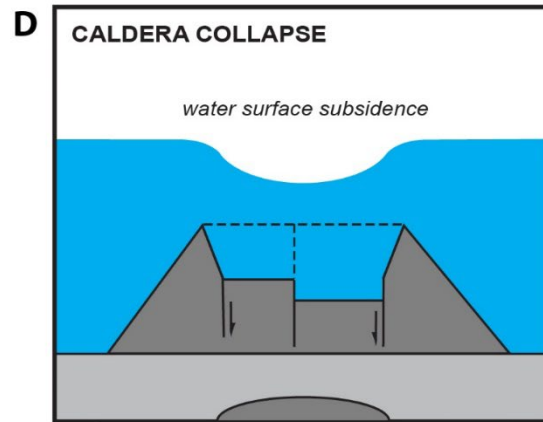
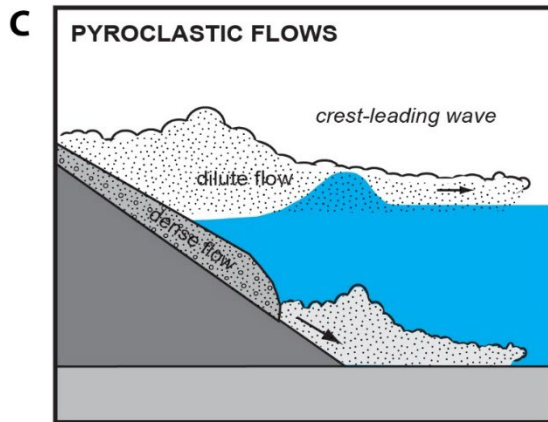
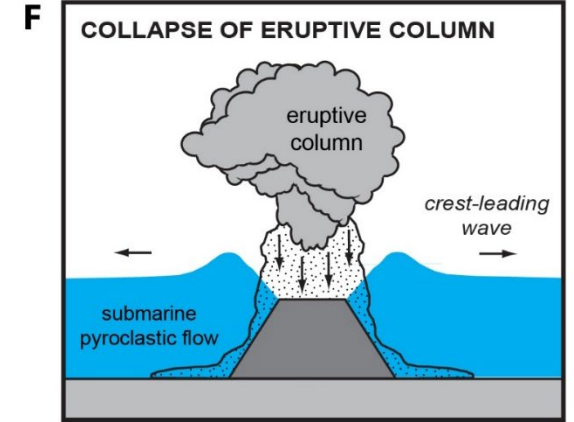
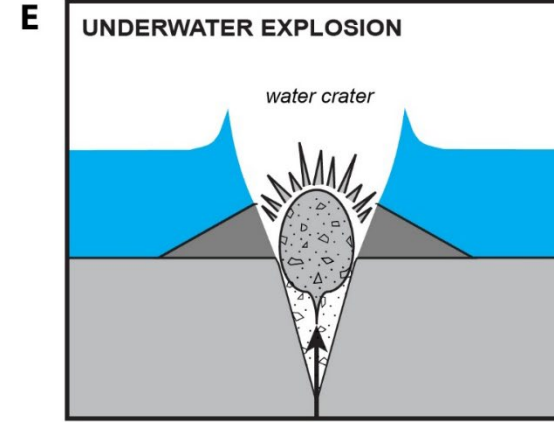
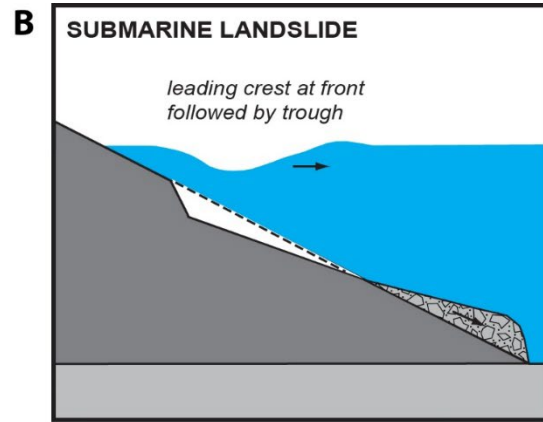
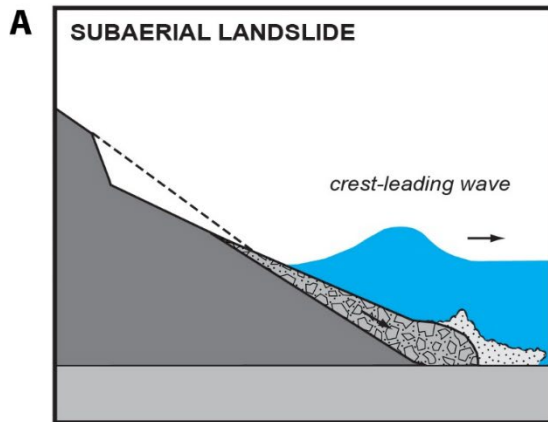


Table 1 – Examples of tsunami generated by volcano flank instability.

Volcano	Location	Year	Landslide volume	Max tsunami runup (dist. from source)	Reference
Anak Krakatau	Sunda Strait, Indonesia	2018	$210 \times 10^6 \text{ m}^3$	85 m (4 km)	Muhari et al. (2019), Walter et al. (2019), Borrero et al. (2020), Perttu et al. (2020), Putra et al. (2020), Hunt et al. (2021)
Stromboli	Aeolian Islands, Italy	2002	$17 \times 10^6 \text{ m}^3$ and $5 \times 10^6 \text{ m}^3$	11 m (1.5 km)	Bonaccorso et al. (2003), Maramai et al. (2005)
Kilauea	Hawaiï, USA	1994	$\sim 10^5 \text{ m}^3$	15 m (50 m)	Mattox and Mangan (1997)
Iliwerung	Lembata, Indonesia	1979	$50 \times 10^6 \text{ m}^3$	9 m (18 km)	Lassa (2009), Yudhicara et al. (2015)
Ritter Island	Papua New Guinea	1888	5 km^3	15 m (9 km)	Johnson (1987), Ward and Day (2003), Kartens et al. (2019)
Unzen-Mayuyama	Kyushu, Japan	1792	$340 \times 10^6 \text{ m}^3$	57 m (7 km)	Tsuji and Hino (1993), Inoue (2000)
Oshima-Oshima	Japan Sea, Japan	1741	2.4 km^3	13 m (50 km)	Satake & Kato (2001), Satake (2007)

Nb – similar tables are provided for pyroclastic flows, underwater explosions, and atmospheric forcing (HTHH-type).

Table 6 – Types of potentially tsunamigenic volcanoes and associated source mechanisms of tsunamis (updated from Paris et al., 2014a).

		Volcano type			
		Coastal / island stratovolcano	Submarine stratovolcano	Shallow-water caldera	Oceanic shield volcano
Tsunami source	Subaerial landslide				
	Submarine landslide				
	Underwater explosion				
	Caldera collapse				
	Column collapse				
	Pyroclastic flow				
	Volcano-tectonic earthquake				
	Atmospheric forcing				
Examples		Stromboli, Italy	HTHH, Tonga	Taal, Philippines	Kilauea, Hawaii
		Soufriere Hills, Montserrat	Kick'em Jenny, Grenada	Rabaul, Papua New Guinea	Fournaise, Reunion Island
		Unzen, Japan	Kolumbo, Greece	Krakatau, Indonesia	Fogo, Cape Verde

Conclusion

The great majority of volcanic eruptions do not generate tsunami, but a single eruption might combine different sources of tsunamis (Table 6). Thus, the source of a tsunami observed during an eruption is often difficult to characterize. All source mechanisms listed here have different characteristics in terms of location, duration, volume, mass flux, and energy, which have consequences on the waves generated. Landslides are the most frequent sources of volcanic tsunamis. From all points of view, volcanic islands (arcs) are the most exposed to volcanic tsunamis.

List of 89 potentially tsunamigenic volcanoes established upon precise criteria.

1. Volcano was active during the XXth or XXIst centuries.

2. It belongs to one of the following types of volcanoes:

A- It is a steep-flanked stratovolcano whose main eruptive centre is located less than 7 km from the coast (sea or lake). Typical examples: Stromboli, Soufrière Hills.

B- The volcano belongs to a complex of eruptive centres in a partly submerged caldera. A distinction can be made between caldera lakes (e.g. Taal, Philippines), calderas opened to the sea (e.g. Rabaul, PNG) and submerged calderas with emerged eruptive centres (e.g. Krakatau, Indonesia).

C- It is a submarine volcano with shallow-water vents, whose activity and flank instability are clearly potential sources of tsunamis, as demonstrated by the HTHH eruption in 2022.

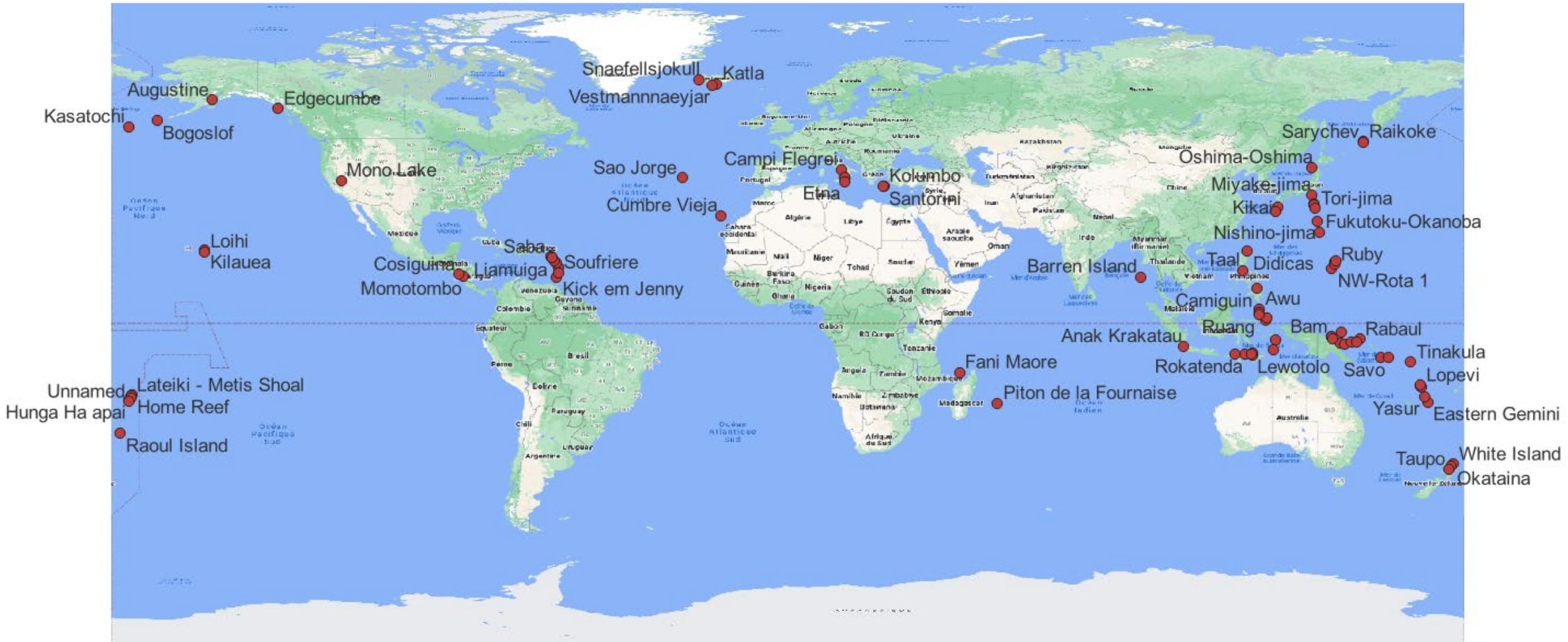
D- It is a shield volcano (ocean island) showing evidence of flank deformation, such as Kilauea volcano in Hawaii, and Piton de la Fournaise in Reunion Island.

3. Additional volcanoes were added to the list, based on suggestions found in the questionnaires sent to volcano observatories.

NAME	COUNTRY	REGION	SUBREGION/ISLAND	BASIN	LONG, LAT (WGS84)	VOLCANO TYPE	DISTANCE / COAST (km)	LAST ERUPTION Ap	HISTORICAL TSUNAMI			
Mount Pelee	FRANCE	WEST INDIES	MARTINIQUE	CARIBBEAN	-61.16488,14.80937	A	5.6	1932	1902			
Soufriere	FRANCE	WEST INDIES	GUADELOUPE	CARIBBEAN	-61.66339,16.04370	A	8.7	1976				
Fani Maore	FRANCE	COMORES	MAYOTTE	INDIAN	45.62150,-13.17750	C	0	2022				
Piton de la Fournaise	FRANCE	REUNION ISLAND		INDIAN	55.70796,-21.24286	D	9	2021				
Kolumbo	GREECE	AEGEAN SEA	NE SANTORINI	MEDITERRANEAN	25.48477,36.52648	C	0	1650	1650			
Santorini	GREECE	AEGEAN SEA	SANTORINI	MEDITERRANEAN	25.39596,36.40419	B	0.8	1950				
Kick em Jenny	GRENADA	WEST INDIES	NW GRENADA	CARIBBEAN	-61.64121,12.29980	C	0	2017	1939, 1965?			
Katla	ICELAND	ICELAND		NE ATLANTIC	-19.05228,63.62868	A	23.4	1918	1918			
Vestmannnaeyjar	ICELAND	ICELAND	VESTMANN ISLANDS	NE ATLANTIC	-20.2646,63.4165	C	0	1973				
Snaefellsjokull	ICELAND	ICELAND		NE ATLANTIC	-23.77128,64.80388	A	7.8					
Barren Island	INDIA	ANDAMA ISLANDS	BARREN ISLAND	INDIAN	93.86073,12.27905	A	1.5	2020				
Anak Krakatau	INDONESIA	JAVA-SUMATRA	SUNDA STRAIT	INDIAN	105.42572,-6.10129	B	0.5	2022	1883, 1928, 1930, 1981, 2018			
Banda Api	INDONESIA	BANDA SEA	BANDA	PACIFIC	129.88246,-4.52215	A	1.5	1988				
Teon	INDONESIA	BANDA SEA	EAST BEBAR	PACIFIC	129.14375,-6.97622	A	1.5	1904				
Batu Tara	INDONESIA	FLORES SEA	KOMBA	PACIFIC	123.58594,-7.78829	A	1	2022				
Rokatenda	INDONESIA	FLORES SEA	PALUWEH	PACIFIC	121.70869,-8.32135	A	2.3	2013	1928			
Sangeang Api	INDONESIA	FLORES SEA	SANGEANG	PACIFIC	119.07065,-8.19806	A	5.2	2022				
Gamalama	INDONESIA	MALUKU	GAMALAMA	PACIFIC	127.33344,0.80993	A	4.3	2018				
Gamkonora	INDONESIA	MALUKU	HALMAHERA	PACIFIC	127.52982,1.37824	A	4.8	2007	1673?			
Iliwerung	INDONESIA	NUSA TENGGARA EAST	LEMBATA	PACIFIC	123.57291,-8.53105	A	1.5	2021	1973, 1979, 1983			
Lewotolo	INDONESIA	NUSA TENGGARA EAST	LEMBATA	PACIFIC	123.50796,-8.27324	A	4	2012				
Awu	INDONESIA	SULAWESI	SANGIHE	PACIFIC	125.4496,3.6901	A	5.5	2004	1856, 1892			
Karangangetang	INDONESIA	SULAWESI	SIAU	PACIFIC	125.40605,2.78095	A	4	2020				
Ruang	INDONESIA	SULAWESI	RUANG	PACIFIC	125.36997,2.30081	A	1.6	2002	1871			
Stromboli	ITALY	AEOLIAN ISLANDS	STROMBOLI	MEDITERRANEAN	15.2120,38.7939	A	1.6	2022	1343, 1879, 1916, 1919, 1930, 1944, 1954, 2002, 2019, 2021, 2022			
Vulcano	ITALY	AEOLIAN ISLANDS	VULCANO	MEDITERRANEAN	14.96104,38.40333	B	0.9	1890	1988			
Campi Flegrei	ITALY	CAMPANIA		MEDITERRANEAN	14.13877,40.82674	B	0	1538				
Vesuvius	ITALY	CAMPANIA		MEDITERRANEAN	14.42678,40.82131	A	6.4	1944	1631			
Etna	ITALY	SICILIA		MEDITERRANEAN	15.00195,37.73129	A	17	2023	1329			
Fukutoku-Okanoba	JAPAN	IZU ISLANDS	N MINAMIIWO	PACIFIC	141.48436,24.27931	C	0	2021	2021			
Miyake-jima	JAPAN	IZU ISLANDS	MIYAKE	PACIFIC	139.52650,34.08570	A	3	2010				
Myojinsho	JAPAN	IZU ISLANDS		PACIFIC	139.918002,31.888013	C	0	1970	1953			
Nishino-jima	JAPAN	IZU ISLANDS		PACIFIC	140.87387,27.24725	B	0.2	2021				
Sumisu	JAPAN	IZU ISLANDS		PACIFIC	140.05,31.486	C	0	1916	1984, 1996, 2006, 2015, 2018			
Tori-jima	JAPAN	IZU ISLANDS	TORI	PACIFIC	140.30291,30.48421	A	1.1	2002				
Oshima-Oshima	JAPAN	JAPAN SEA	OSHIMA	PACIFIC	139.36710,41.51003	A	1	1790	1741			
Kikai	JAPAN	RYUKYU ISLANDS	IWO-JIMA	PACIFIC	130.30526,30.79310	B	1	2020				
Suwanose-jima	JAPAN	RYUKYU ISLANDS	SUWANOSE	PACIFIC	129.71366,29.63857	A	2.2	2020				
Soufriere Hills	MONTSERRAT	WEST INDIES	MONTSERRAT	CARIBBEAN	-62.17969,16.72027	A	3.2	2013	1997, 1999, 2003, 2006			
Saba	NETHERLANDS	WEST INDIES	SABA	CARIBBEAN	-63.23923,17.63598	A	1.3	1640				
The Quill	NETHERLANDS	WEST INDIES	ST EUSTATIUS	CARIBBEAN	-62.96368,17.47764	A	1.2					
White Island	NEW ZEALAND	BAY OF PLENTY	WHITE ISLAND	PACIFIC	177.18057,-37.51937	A	0.8	2019				
Raoul Island	NEW ZEALAND	KERMADEC	RAOUL ISLAND	PACIFIC	-177.91931,-29.26417	A	1.6	2006				
Okataina	NEW ZEALAND	NORTH ISLAND		PACIFIC	176.50012,-38.12027	B	0	1981				

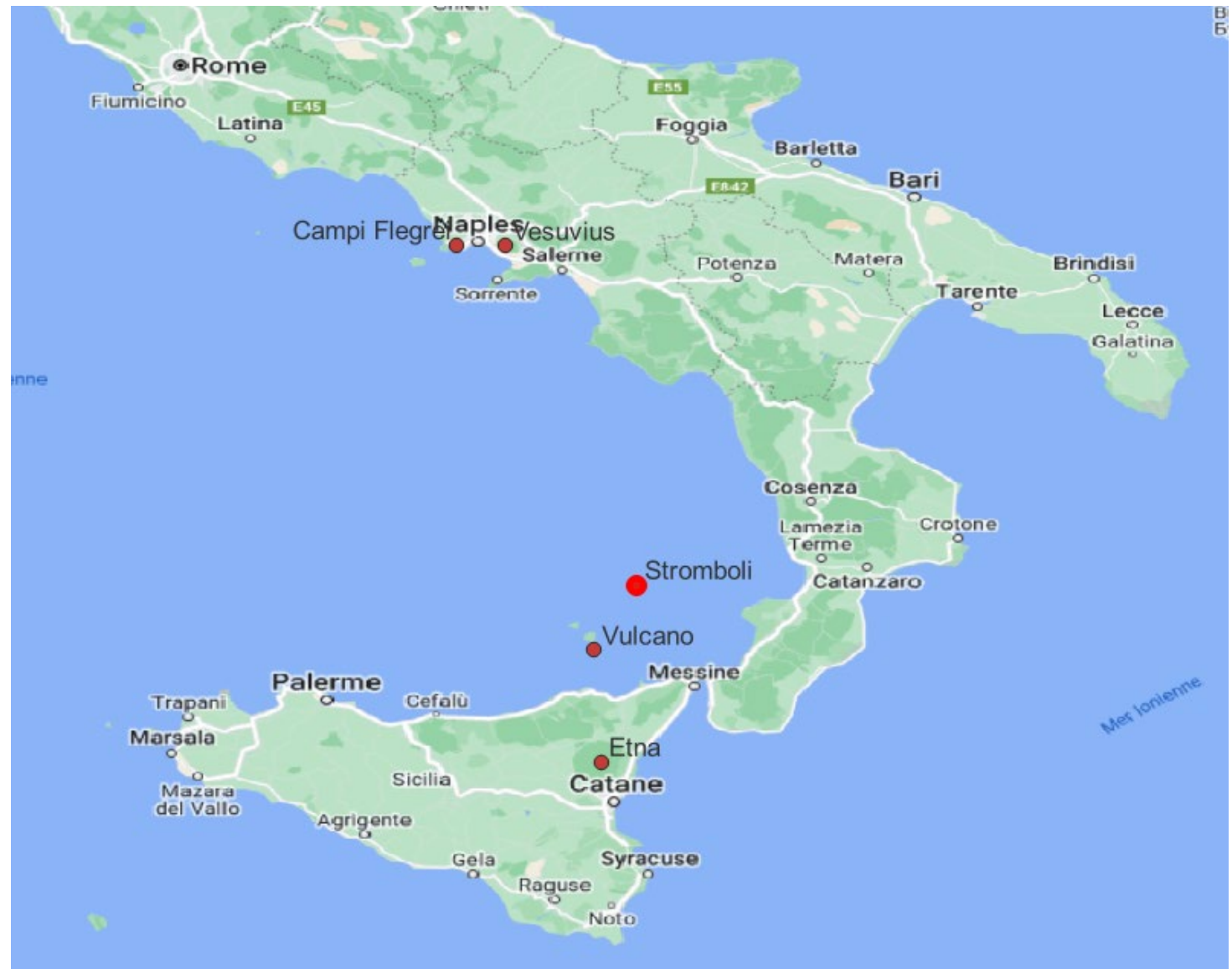
NAME	COUNTRY	REGION	SUBREGION/ISLAND	BASIN	LONG, LAT (WGS84)	VOLCANO TYPE	DISTANCE / COAST (km)	LAST ERUPTION A	HISTORICAL TSUNAMI				
Taupo	NEW ZEALAND	NORTH ISLAND		PACIFIC	175.91988,-38.80097	B	0	260					
Momotombo	NICARAGUA	LAKE MANAGUA		PACIFIC	-86.53808,12.42113	A	3.5	2016					
Cosiguina	NICARAGUA	PACIFIC COAST		PACIFIC	-87.57093,12.98246	A	6.1	1859	1835?				
Bam	PAPUA - NEW GUINEA	BISMARCK SEA	BAM	PACIFIC	144.81801,-3.61275	A	1.1	1960					
Kadovar	PAPUA - NEW GUINEA	BISMARCK SEA	KADOVAR	PACIFIC	144.58806,-3.60754	A	0.5	2020	2018				
Long Island	PAPUA - NEW GUINEA	BISMARCK SEA	LONG ISLAND	PACIFIC	147.11783,-5.35215	A	7	1993					
Manam	PAPUA - NEW GUINEA	BISMARCK SEA	MANAM	PACIFIC	145.03743,-4.07896	A	5	2020					
Ritter Island	PAPUA - NEW GUINEA	BISMARCK SEA	RITTER ISLAND	PACIFIC	148.11472,-5.51957	C	0	2007	1888, 1972, 1974, 2007				
Dakataua	PAPUA - NEW GUINEA	NEW BRITAIN		PACIFIC	150.10607,-5.05447	B	5.5	1895					
Rabaul	PAPUA - NEW GUINEA	NEW BRITAIN		PACIFIC	152.20300,-4.27081	B	0.6	2014	1878, 1937, 1994				
Tuluman	PAPUA - NEW GUINEA	NEW BRITAIN	SOUTH MANUS	PACIFIC	147.30293,-2.45519	C	0	1957					
Ulawun	PAPUA - NEW GUINEA	NEW BRITAIN		PACIFIC	151.32889,-5.05038	A	10.5	2022					
Didicas	PHILIPPINES	BABUYAN ISLANDS	NE CAMIGUIN	PACIFIC	122.20254,19.07709	B	0.2	1978	1969?				
Camiguin	PHILIPPINES	BOHOL SEA	CAMIGUIN	PACIFIC	124.7201,9.1754	B	4	1953	1871				
Taal	PHILIPPINES	LUZON		PACIFIC	120.9930,14.0070	B	2.2	2021	1716, 1749, 1754, 1911, 1965				
Sao Jorge	PORTUGAL	AZORES ISLANDS	SAO JORGE	ATLANTIC	-28.07764,38.65153	D	1.5	1902					
Raikoke	RUSSIA	KURIL ISLANDS	RAIKOKE	PACIFIC	153.24978,48.29220	A	0.7	2019					
Sarychev	RUSSIA	KURIL ISLANDS	SARYCHEV	PACIFIC	153.20003,48.09158	A	2.8	2021					
Tinakula	SOLOMON ISLANDS	EAST SOLOMON	TINAKULA	PACIFIC	165.80392,-10.38640	A	1.1	2020	1897, 1966				
Kavachi	SOLOMON ISLANDS	WEST SOLOMON	SOUTH VANGUNU	PACIFIC	157.97888,-8.99099	C	0	2021	1951				
Savo	SOLOMON ISLANDS	WEST SOLOMON	NORTH GUADALCANA	PACIFIC	159.80749,-9.13400	A	2.3	1847?					
Cumbre Vieja	SPAIN	CANARY ISLANDS	LA PALMA	ATLANTIC	-17.83715,28.56832	D	1.2	2021					
Liamuiga	ST KITTS & NEVIS	WEST INDIES	ST KITTS	CARIBBEAN	-62.80896,17.37007	A	4.4	1843?					
Soufriere	ST VINCENT	WEST INDIES	ST VINCENT	CARIBBEAN	-61.18092,13.33104	A	3.5	2020	1902, 2020				
Home Reef	TONGA	TONGA	WEST NEIAFU	PACIFIC	-174.77517,-18.99183	C	0	2006					
Hunga Haapai	TONGA	TONGA	NORTH TONGATAPU	PACIFIC	-175.39068,-20.54491	B	0.1	2022	2015, 2021, 2022				
Lateiki - Metis Shoal	TONGA	TONGA	WEST NEIAFU	PACIFIC	-174.86999,-19.18002	C	0	2019					
Tofua	TONGA	TONGA	TOFUA	PACIFIC	-175.07002,-19.75023	A	3	2014	1892				
Unnamed	TONGA	TONGA	WEST TONGATAPU	PACIFIC	-175.55041,-20.85174	C	0	2017					
Augustine	USA	ALASKA	AUGUSTINE	PACIFIC	-153.43023,59.36302	A	4	2006	1883				
Bogoslof	USA	ALEUTIAN ISLANDS	BOGOSLOF	PACIFIC	-168.03530,53.93010	A	0.2	2017					
Kasatochi	USA	ALEUTIAN ISLANDS	KASATOCHI	PACIFIC	-175.50881,52.17454	A	0.4	2008	2008				
Mono Lake	USA	CALIFORNIA		PACIFIC	-119.02835,38.00242	B	0.6	1790					
Kilauea	USA	HAWAII	BIG ISLAND	PACIFIC	-155.2889,19.4202	D	14	2022	1975				
Loihi	USA	HAWAII	SOUTH BIG ISLAND	PACIFIC	-155.2681,18.9262	D	0	1996					
Anatahan	USA	MARIANA ISLANDS	ANATAHAN	PACIFIC	145.67389,16.35038	A	1.5	2008					
NW-Rota 1	USA	MARIANA ISLANDS	WEST SINAPALU	PACIFIC	144.77496,14.60064	C	0	2010					
Ruby	USA	MARIANA ISLANDS	NORTH SAIPAN	PACIFIC	145.56974,15.61975	C	0	1995					
South Sarigan	USA	MARIANA ISLANDS	SARIGAN	PACIFIC	145.77989,16.57998	C	0	2010	2010				
Edgecumbe	USA	ALASKA	EASTERN ALASKA	PACIFIC	-135.75289,57.05220	A	5.1	2080 BCE					
East Epi	VANUATU	VANUATU	EAST EPI	PACIFIC	168.37002,-16.68009	C	0	2023					
Eastern Gemini	VANUATU	VANUATU	SOUTH ANATOM	PACIFIC	170.28844,-20.98807	C	0	1996					
Kuwae	VANUATU	VANUATU	SOUTH EPI	PACIFIC	168.53500,-16.83028	C	0	1974					
Lopevi	VANUATU	VANUATU	SE AMBRYM	PACIFIC	168.34504,-16.50700	A	2.2	2007					

List of potentially tsunamigenic volcanoes -> GIS database



▼ **Table_tsunamigenic_volcanoes-V2**

▼ NAME	Stromboli
▶ (Dérivé)	
▶ (Actions)	
NAME	Stromboli
COUNTRY	ITALY
REGION	AEOLIAN ISLANDS
SUBREGION/ISLAND	STROMBOLI
BASIN	MEDITERRANEAN
LONG	15,212
LAT (WGS84)	38,7939
VOLCANO TYPE	A
DISTANCE / COAST (km)	1,6
LAST ERUPTION April 2022 update	2022
	1343
	1879
	1916
	1919
	1930
	1944
	1954
	2002
	2019
	2021
	2022



Next step to be completed soon: adding possible source (e.g. landslide, explosion) of tsunami for each volcano (from table 6).

Chapter 2 – Numerical modeling of volcanic tsunamis

1. General consideration of model applications for volcanic tsunamis

- Complex sources (different fluids, fast processes, phase-shifts) = sophisticated models = high computational cost
- Shorter wave length compared to earthquake-induced tsunamis -> faster attenuation -> local tsunamis
- Short time to forecast -> real-time applications are thus challenging
- How far can we go in the approximation in order to save time?

2. Tsunami generation and initialization modeling: *the most challenging phase*

- ❑ Instantaneous initialization : tsunami happens rapidly compared to the shallow water wave speed
E.g. underwater explosions, ~~caldera collapse~~ (not realistic)
- ❑ Finite time initialization : forcing happens over a specified time at the start of the modelling
 - Ground deformation : sea floor motion as a forcing term. *E.g. submarine landslide, caldera collapse.*
 - Multi-layer models : all fluids are modelled as separated layers + interactions. *E.g. subaerial landslides, pyroclastic flows.*
 - Ongoing forcing by a pressure anomaly, such as Lamb waves produced by *large explosions in the atmosphere.*

3. Tsunami propagation modeling

Most propagation models are suitable, but dispersive effects are important -> Boussinesq approximation often required.

4. Tsunami inundation modeling

Similar to any long wave inundation, but distribution of wave runups is similar to landslide (local) tsunamis (except HTHH-type)