Earthquakes-Induced Environmental Effects in Coastal Area: Some Example in Calabria and Sicily (Southern Italy)

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Abstract

The Messina Strait, between Calabria and Sicily's Coast, is one of the most seismically active areas of the Southern Italy. Since 1783, there have been 7 earthquakes with M ranging between 6.0 and 7.2 .They have produced wide damages and induced numerous and spectacular coseismic environmental effects (primary and secondary effects) overall along the coast where the impact was particularly catastrophic. These earthquakes caused several changes in elevation, landslides and settlements, relevant landslides (the 1783 event triggered in Scilla, along the cliff of the M. Pacì a huge rock avalanche of 5 Mm^3 in the areal and 3 Mm^3 in the submarine zone, generating a disastrous tsunamis), ground fractures (Capo V. area, during the 1905 seismic event; in Messina, Reggio C., Villa S. Giovanni, during the 1908 event); liquefaction phenomena (Messina, Ganzirri and Reggio C., 1908 event), and catastrophic tsunamis (5 induced by the 1783 events, other 2 by 1905 and 1908 events).
The run-up observed ranging from few centimeters to tens of metres: the highest tsunami wave was about 16 m in Scilla (Feb. 6, 1783 tsunami), 13 m in Pellaro (1908 event) and 1,30 m along the Calabrian coast (1905 tsunami). Finally, it is important to consider the seismically induced effects with the aim to reduce the future risk for the population living along the coast and the potential damage to structures and natural environment, through a more precise estimate of their type, size and distribution, according to the new macroseismic scale ESI2007.

1 Introduction

The seismicity of the Calabria and Sicily regions and in particular of the Messina Strait is strictly connected with the Siculo-Calabrian rift zone, one of the most seismically active areas of the Italian peninsula, characterized by several seismogenic sources (ITHACA) capable of producing earthquakes with $M \geq 7$ and intensity values $I \geq X$ both on the MCS scale (CPTI04) and on the new macroseismic scale ESI 2007 [12]. The historical seismicity occurred in this area, is well documented and shows a very high-recurrence of large events with at least 34 earthquakes with $VII \leq I \leq XI$ on the MCS scale; nine events with I = X-XI in the last 2000 years, five of which in the last 225 years and two in XX century (Table 1 and Figure 1). The Siculo-Calabrian seismic belt includes the largest earthquakes which have occurred in southern Italy in the last six centuries as the 1693 earthquakes, the 1783 seismic sequence, the 1905 Calabria earthquake and the 1908 Messina - Reggio Calabria earthquake. These earthquakes produced wide damage on the urban design and triggered spectacular coseismic environmental effects along the coastal area.

2 Methodology

According to the original definition of macroseismic Intensity (MCS, MM, MSK, EMS Scales) the assessment degrees can be defined as a classification of earthquake induced effects on human, manmade structures and natural environment. Although geological effects were included in the traditional macroseismic scales, later on they have been disregarded by the seismologists dealing with intensity estimates. It was probably due to their inner complexity and variability requiring specific skills and knowledge. Specific studies on earthquake induced ground effects have offered new evidence that coseismic environmental effects provide precious information on the earthquake size and its intensity field, complementing the traditional damage-based macroseismic scale ([12] and references therein).
The Environmental Seismic Intensity Scale (ESI2007 Scale) is a new earthquake intensity scale only based on the effects triggered by the earthquake in the natural environment. The ESI2007 Scale follows the same basic structure as any other 12 degree scale, such as the MCS, MM, MSK etc. It is based on the observation of the enviromnental features, such as surface faulting, subsidence, uplift (primary effects) and liquefaction, ground crack, slope movement, hydrological changes, tsunami (secondary effects). As the traditional macroseismic scales, the ESI2007 Scale is a tool to assess both epicentral (I_0) and local (Il) intensities. The epicentral (I_0) intensity is defined as the intensity of shaking at epicenter; several techniques can be applied to assess I_0: according to Postpischl (1985) I_0 is "the value of the closed isoseismal line having the highest degree and including at least 3 different data points". Starting from intensity VII, the ESI2007 scale considers surface faulting parameters and total area of distribution of secondary effects as diagnostic element for I_0 assessment. According to this approach, ranges of surface faulting parameters (primary effects) and typical extents of total area of secondary effects for each intensity degree, have been defined [12].
These studies attempt at reconstructing the coseismic effects on the basis of a careful review of contemporary documents (i.e. documentary sources, historical and technical reports, expert investigations, diaries, historical books, iconographic material and newspapers) and on the most recent scientific literature. In this perspective, the environmental effects of three of the most ruinous earthquakes, of the last three centuries, in the area of the Messina Strait are analyzed according to the new macroseismic scale ESI 2007 (Environmental Seismic Intensity, [12]): the 1783 Calabrian seismic sequence, (I = XI MCS, M 6.91-7.2), the September 8, 1905, Calabria event (I = XI MCS, M 7.06-7.9), and the December 28, 1908 Messina - Reggio Calabria event (I = XI MCS, M 7.24-7.32).

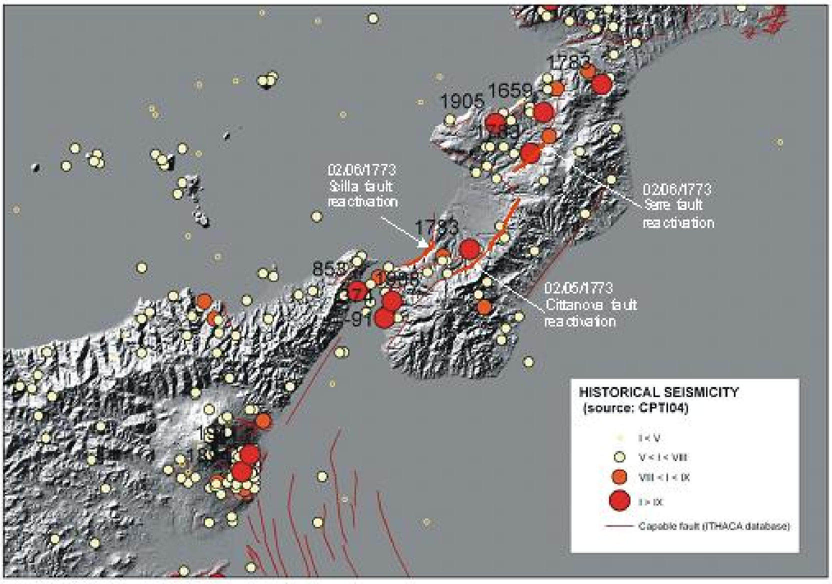


Figure 1: Historical earthquakes occurred in the last 2000 years in the Siculo-Calabrian Rift. Red bold line indicate active fauls (according to CPTI04 and ITHACA database).

3 The 1783 seismic sequence

The 1783 Calabrian seismic sequence was characterized by a three years long sequence and five main shocks generated by individual fault segments of regional WNW-ESE trends.

The 1783 multiple event started at the beginning of February and went on until the end of March, reaching a maximum release of energy on March 28 with assessed macroseismic magnitude M=6.9 (CPTI04). More than 30,000 lives were lost and 200 localities were completely destroyed by the February 5 main shock; the epicentral area (I_0 = XI MCS) was located on the Gioia Tauro plain, at the western foot of the northern Aspromonte mountain. The shock produced spectacular ground effects, both primary and secondary, such as tectonic deformations, ground fractures, liquefactions phenomena, tsunami, hydrological changes and diffuse landslides of large size, which in most cases dammed the rivers creating more than 200 new temporary lakes. The second shock, occurred on February 6, struck the coast between Scilla and Palmi and induced the large Monte Pacì-Campallà rock avalanche from the sea-cliff west of Scilla, generated a disastrous tsunami (Figure 2, run-up of 16 m), that affected the coast for a total length of 40 km, from Bagnara to Villa San Giovanni and from Torre Faro to Messina, causing more than 1500 casualties in Scilla [13, 16, 19].

Recently a dynamic numerical modelling by FDM code FLAC 6.0 was performed by [3], to back-analyse the landslide occurred

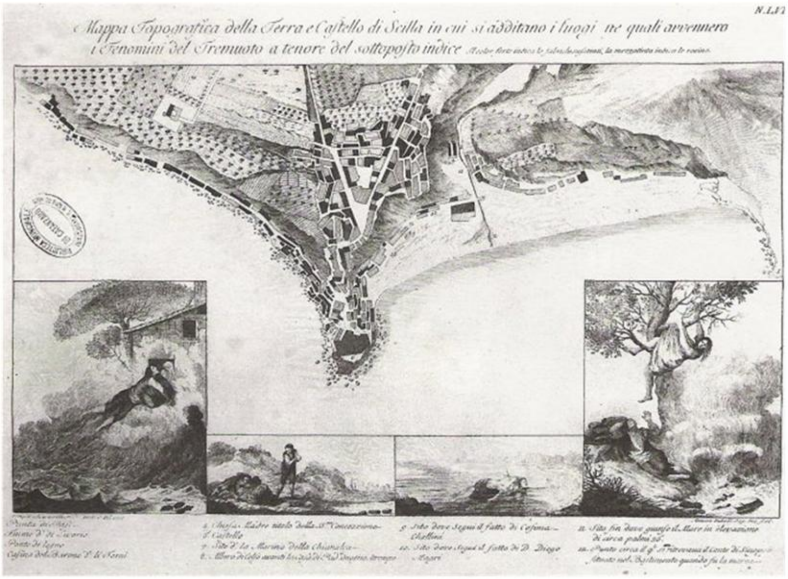
374	Southern Calabria	9.5	6.30
853 08 31	Messina	9.5	6.30
1169 02 04 07	Eastern Sicily	10.0	6.60
1184 05 24	Crati Valley	9.0	6.00
1509 02 25 22 20	Southern Calabria	8.0	5.57
1626 04 04 12 45	Girifalco	9.0	6.08
1638 03 27 15 05	Calabria	11.0	7.00
1638 06 08 09 45	Crotonese	9.5	6.60
1659 11 05 22 15	Central Calabria	10.0	6.50
1693 01 11 13 30	Eastern Sicily	11.0	7.41
1743 02 20 16 30	Southern Ionio	9.5	6.90
1767 07 14 01 05	Cosentino	8.5	5.83
1783 02 05 12	Calabria	11.0	6.91
1783 02 06 00 20	Southern Calabria	8.5	5.94
1783 02 07 13 10	Calabria	10.5	6.59
1783 03 01 01 40	Central Calabria	9.0	5.92
1783 03 28 18 55	Calabria	10.0	6.94
1786 03 10 14 10	North-East. Sicily	9.0	6.02
1791 10 13 01 20	Central Calabria	9.0	5.92
1818 02 20 18 15	Catanese	9.0	6.00
1823 03 05 16 37	Northern Sicily	8.5	5.87
1832 03 08 18 30	Crotonese	9.5	6.48
1835 10 12 22 35	Cosentino	9.0	5.91
1836 04 25 00 20	Northern Calabria	9.0	6.16
1854 02 12 17 50	Cosentino	9.5	6.15
1870 10 04 16 5	Cosentino	9.5	6.16
1894 11 16 17 52	Southern Calabria	8.5	6.05
1905 09 08 01 43	Calabria	11.0	7.06
1907 10 23 20 28	Southern Calabria	8.5	5.93
1908 12 28 04 20	Southern Calabria	11.0	7.24
1909 07 01 06 24	Calabro- Messinese	8.0	5.55
1947 05 11 06 32	Central Calabria	8.0	5.71
1978 03 11 19 20	Southern Calabria	8.0	5.36
1978 04 15 23 33	Patti Gulf	9.0	6.06

The largest earthquakes occurred in the Calabria an Sicily in the last 2000ys

Table 1: List of the largest earthquakes occurred in Southern Italy in the last 2000 years (I $\geq$ VIII MCS, CPTI04).

in Scilla during the 1783 seismic sequence, the results of modeling show a post-seismic trigger of the rock-avalance, related to the second main shock of the 1783 events.

From February 7 to March 28, three main shocks took place with epicenters migrating northwards from Mesima Valley to Catanzaro. The last one caused severe damage along both the Tyrrhenian and Ionian coasts. The cumulative effects of all these earthquakes was devastating, more than 380 villages were damaged, 180 were totally destroyed. From a seismogenic point of view the 1783 sequence can be related to the active fault segments present in southern Calabria [7, 10, 8, 4, 14], combining geological, morphological and seismological data have been identified three of the most significant fault segments generating the 1783 sequences for a total length of ca.100 km. The amount of surface faulting (rupture length and maximum displacement and the minimum total area distribution of secondary effects 11.000 km^2 (Figure 3) indicate I_0 =XI on ESI 2007 scale, in good agreement with I_0 resulting from MCS scale.



Mappa topografica della terra e castello di Scilla in cui si additano i luogi ne quali avvennero i fenomeni del tremuoto... (Schiantarelli, 1784)

Figure 2: Historical drawing illustrating the tsunami triggered by the February 6, 1783 event along the Scilla coast (Schiantarelli, 1784).

4 The 1905 Southern Calabria earthquake

On September 8, 1905 a large earthquake with estimate Magnitudes ranging from M≃7.0 to M≃7.9 and MCS intensity XI occurred in the the Capo Vaticano peninsula (Calabria). Several Authors identified different epicenters both inland, near to Vibo Valentia, and offshore not far from the coastline, suggesting as capable faults the Vibo and Capo Vaticano normal fault segments [4]. This earthquake extensively ruined several villages located in the northern part of the Capo Vaticano peninsula within an area that suffered a MCS intensity greater than IX, causing the death of 557 people.

The event induced a great number of effects on the environment in a wide area [1, 5, 14, 17]: large landslides, accompanied by several cracks and fractures (Aiello Calabro, Martirano, Gerocarne, Cirò, Conidoni, Acri etc) and liquefaction features occurred in several places within the epicentral area (Tropea, Amantea, Seminara, Rosarno etc), hydrological variation (changes in flow and in the temperature of springs and rivers) were also observed over the entire Calabria region both in the near field (Piscopio, Curinga, Martirano, Rosarno etc.) and far field (Orsomarso, Cetraro etc). This event also generated a tsunami (Sieberg-Ammbraseys Int. 4) that inundated the whole northern coast of the peninsula from Vibo to Tropea with an estimated height of waves of about 1-2 m, the anomalous waves were observed also in Scalea, Ischia, Civitavecchia, Naples and Messina with a run-up of few cm, [18] and moreover submarine telephone cable 12 km East from Vulcano Island was cut (Figure 4). On the basis of all the collected data it was possible to estimate the total area distribution of secondary effects, about 15,000 km^2 and assess the ESI 2007 intensities values I_0 = X (Figure 5) in agreement with the equivalent MCS assessment (CPTI04).

5 The 1908 Southern Calabria-Messina earthquake

The December 28, 1908 Southern Calabria-Messina earthquake (I = XI MCS, M 7.2) is one of the strongest seismic events that struck Italy during the XXth century and the most ruinous in terms of casualties (at least 80,000). The epicentre was located at sea in the Messina Straits. The impact of the earthquake was particularly catastrophic in Reggio Calabria and Messina, damages have been more intense and widespread along the Calabrian coast, between south of Reggio Calabria and south-west of Scilla. In Sicily the most damaged area was the coast from its easternmost tip to south of Messina. Some minutes after the earthquake, a destructive tsunami (Sieberg-Ambraseys Int.6) inundated both sides of the Strait, with a run-up that rose above 10-13 meters in some places (Sant'Alessio, Pellaro), killing at least 2,000 people, with maximum onland water penetration of 600 m in Pellaro and 700 m in Catania [11]. More than 100 environmental effects were catalogued among them, particularly relevant were the changes in elevation along both sides of the Strait, partly due to the settlement of loose sediments and artificial filling (e.g., Messina and Reggio Calabria harbor areas), and partly ascribed to landslides and tectonic slip. Liquefaction was reported in the areas of Messina, Pantano (lake Ganzirri) and Reggio Calabria. Portions of the coast were lost, especially on the Calabrian side, most of them eroded by the tsunami. The most relevant ground cracks were reported in Messina, Reggio Calabria and at San Procopio near Sant'Eufemia in Calabria (4-5 km long, according to [2]). Landslides and rockfalls occurred in many Sicilian and Calabrian localities (especially between Reggio C. and Bagnara C.). A submarine telephone cable between Gallico (in Calabria) and Gazzi (in Sicily) was cut likely by a slide. In both the regions ground collapses and also several hydrological anomalies occurred: springs flowrate and elevation changes, water temperature variations and gas emissions [6]. The obtained database allows a comprehensive view of ground coseismic environmental effects [6], giving also the possibility to apply the ESI 2007 environmental intensity scale in order to corroborate the intensity evaluation of the earthquake. It is readily evident that, apart from the huge tsunami wave, in agreement with a submarine location of the epicentral area, coseismic environmental effects appear to be modest with respect to the effects reported for earthquakes of similar magnitude occurred in the same region (i.e., 1783 Calabrian and 1905 earthquakes) in this case the epicentral intensity based on the ESI 2007 scale I_0 = X is slightly lower than the corresponding MCS I_0 = XI.

6 Discussion and conclusion

The contemporary documents analyzed, include descriptions of environmental coseismic phenomena effects associated with the earthquakes, becoming more and more scientifically accurate with time. In this study, this wealth of knowledge is reviewed for a set of chosen events, to scrutiny the practical applicability of the ESI2007 scale in order to: (a) reassess the epicentral intensities (I_0) for three historical events in the same region, and (b) contribute to reduce the future risk from environmental effects, through a more precise estimate of their type, size and distribution in the earthquake-prone areas.

The review of the effects on the natural environment triggered by these three catastrophic earthquakes, through the last three centuries, has allowed estimation of epicentral intensity values independently from the damage effects on the man made structures.

The ESI 2007 epicentral intensity (I_0) values, are based essentially on primary effects and in particular on the length of surface faulting, as the maximum offset is generally not available. The actual surface rupture length is not readily provided by historical information. At best, only its most prominent part is reported. However, the total rupture can be inferred, based on the distribution of ground ruptures interpretable as coseismic faulting and the characteristics of the macroseismic field.

The earthquakes analysed here share the same epicentral intensity (X and XI ESI 2007 scale) in good agreement with the corresponding MCS XI values. Similarly, the total area distributions of secondary effects have provided I_0 values consistent with these estimates, when the primary effects are not available.

The comparison between ESI scale and MCS scale intensities has shown a difference for the 1905 and 1908 events, where maximum ESI intensity is one degree lower than the corresponding MCS ones, according to the concentrated areal distribution of the ground effects occurred.

The use of Earthquake Environmental Effects for intensity assessment recently promoted by the ESI 2007 scale provide an added value to traditional intensity evaluations being applicable also in not inhabited areas and not afflicted by saturation of all diagnostic effects even for the greatest earthquakes, improving the intensity evaluations based on the classical macroseismic scales. In addition, some environmental morphogenetic effects (either primary and secondary) can be stored in the palaeoseismological record, allowing to expand the time window for seismic hazard assessment up to tens of thousands of years [9, 15]. Finally, it is important to consider the seismically induced effects with the aim to reduce the risk for the population living along the cost and the potential damage to structures and natural environment, through a more precise estimate of their type, size and distribution, especially in Calabria and Sicily regions characterized by a very high level of seismicity.

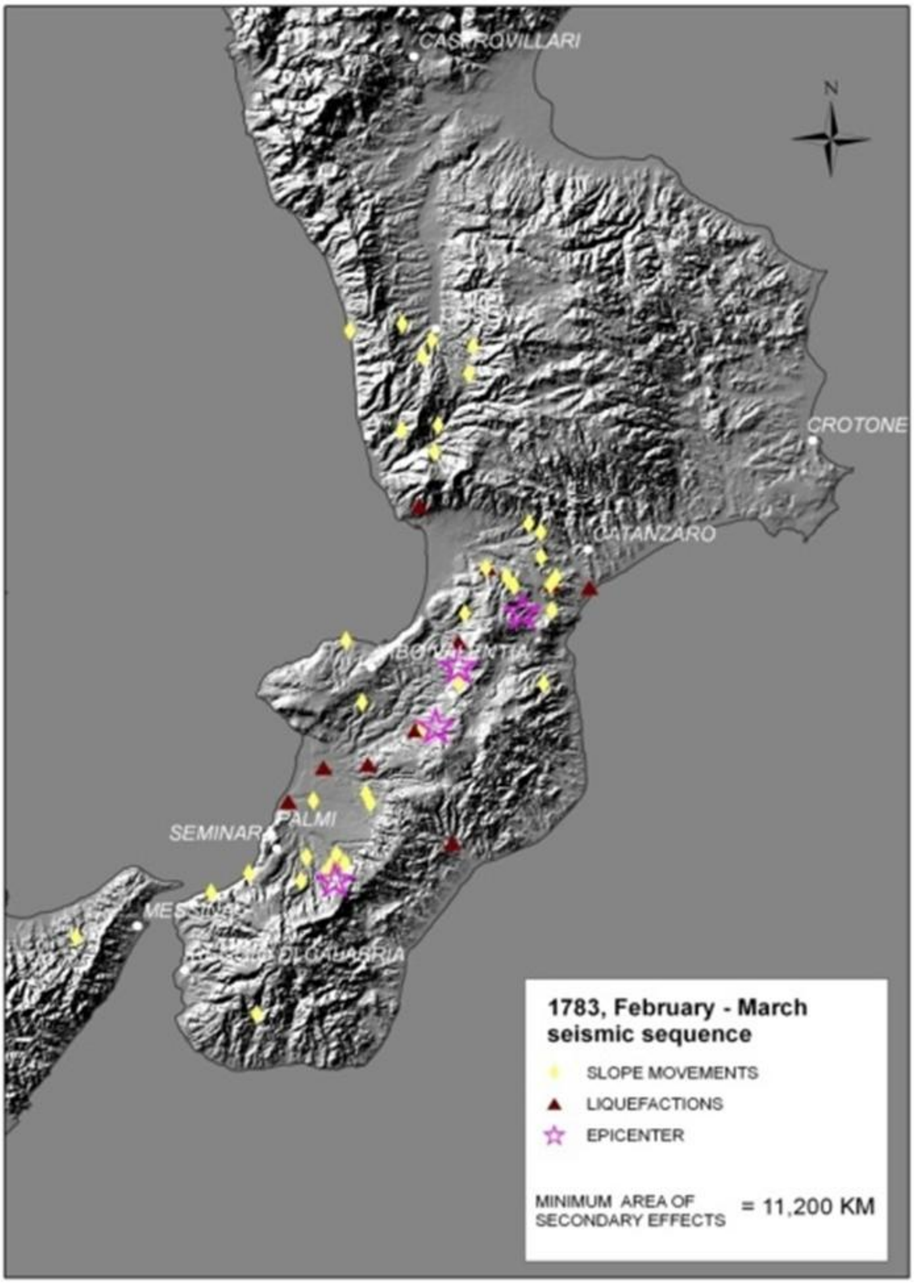


Figure 3: The February-March 1783 seismic sequences: epicenters and the most important secondary effects distribution: slope movements, liquefactions and hydrological changes (minimum area of secondary effects 11.200 km^2).

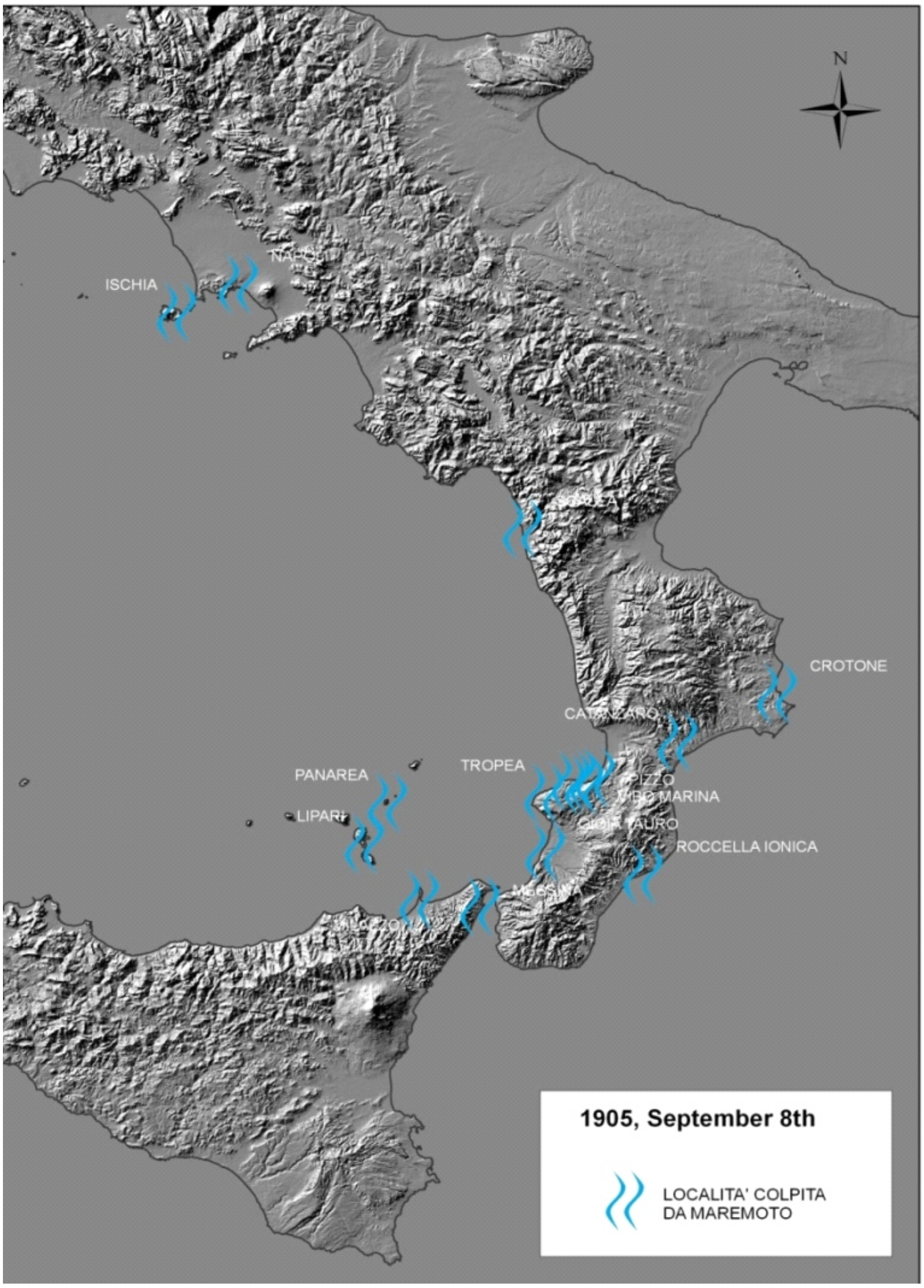


Figure 4: The 1905 Southern Calabria earthquake: general map of the localities hit by tsunami.

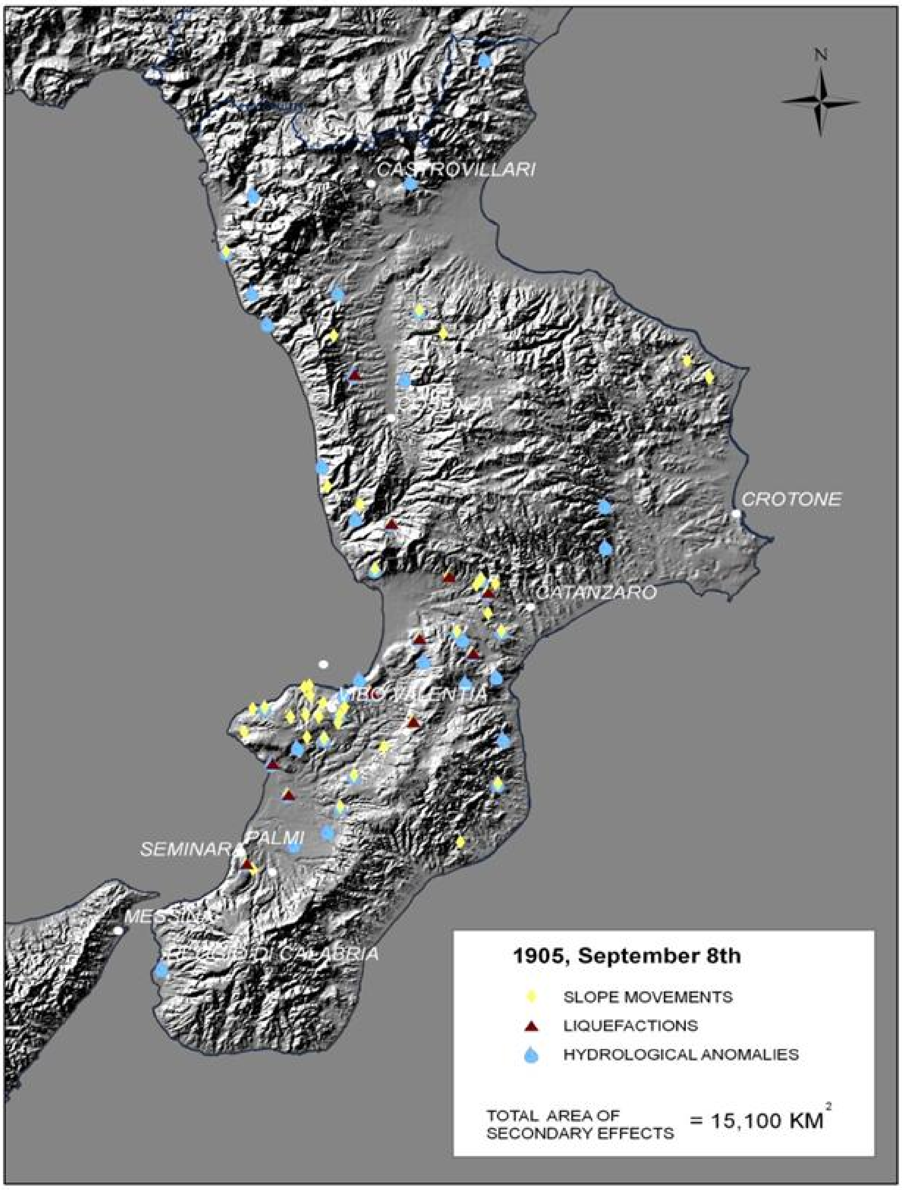


Figure 5: The 1905 Southern Calabria: sites of ground effects: slope movements, liquefactions and hydrological changes (total area of secondary effects 15.000 km^2).

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