Geological Field Trips and Maps

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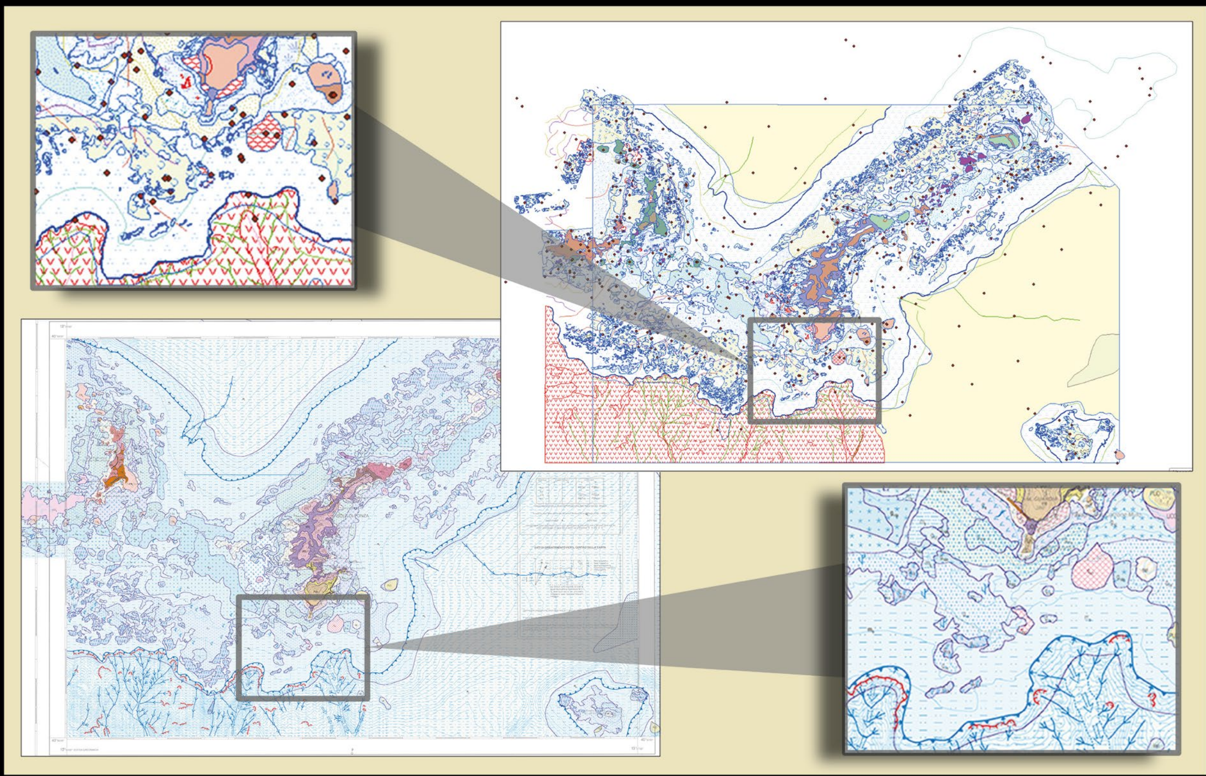

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Digital mapping of geological events in European Seas

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Cover page Figure
Pontine Islands: geological map at 1:50,000 scale (Servizio Geologico d'Italia, 2019) compared to a GIS elaboration.

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Abstract

Geological mapping has been fundamental in understanding Earth history and in gathering information necessary to tackle land-use related problems. In recent decades, digital mapping and database criteria have provided additional contributions to traditional cartography management.
The Geological Survey of Italy is involved in the EMODnet Geology Project, which promotes the collection and harmonization of marine geological data in European Seas, to be represented on digital maps at multiple scales, accessible online through a dedicated Portal. Data are subdivided into Work Packages (WP) dealing with different features. The Geological Survey of Italy has contributed constructively to the realization of geological datasets and leads the WP "Geological Events and Probabilities" with the aim to identify and map significant earthquakes, submarine landslides, volcanic centers, tectonics, tsunamis and fluid emissions occurring in European Seas.
In order to provide harmonized European digital maps, the process of WP6 deliverable production was subdivided into several phases: Guidelines elaboration, data collection, harmonization, data processing and implementation.
The activity resulted in the collection of a large amount of data which are displayed on the Portal. A few examples are provided to illustrate digital maps and how to browse through them and use data contained in the attached database.

Keywords: Digital mapping, European Project, GIS, Database, Data interoperability

Introduction

At the joint Congress of the Italian Geological Society (SGI) and the Italian Society of Mineralogy and Petrology (SIMP), held in Catania from the 12th to the 14th of September 2018, the Geological Survey of Italy presented a contribution on the characteristics of digital mapping and its differences from traditional mapping, in the session "From analogue to digital geological mapping: opportunities and risks in the use of new tools". The contribution focused on the experience gained within the European Marine Observation and Data Network (EMODnet) Geology Project in the creation of digital maps of geological events in European Seas which is illustrated herein.
In the first part of the paper, the reader will be guided through the procedure set up for the construction and appropriate use of digital mapping. In the second part examples of maps of the main geological events reported from Italian Seas will be shown, as a result of an updated database, relying on data from the main national projects and literature, revised, validated and harmonized according to a European standard and compliant with the INSPIRE Directive (2007/2/EC).
Examples reported in the following paragraphs evidence how much the visual impact of digital maps differs from that generated by traditional mapping (printed maps). Digital maps and related datasets can be viewed online, browsing through different layers and retrieving the relevant amount of information stored in the database by selecting specific attributes for each feature.
All of the images of digital maps in this paper are GIS elaborations, which in their printed version do not allow to acknowledge the actual resolution of digital products. We suggest to visit the EMODnet Geology Portal (www.emodnet-geology.eu/map-viewer/) in order to browse through them and correctly visualize maps to completely understand the wealth of data they provide. They cannot be compared to traditional maps as well.

The EMODnet Project

EMODnet is a network of organizations supported by the EU's integrated maritime policy. These organizations work together to collate existing data from European Seas, process them according to common international standards and make information freely available as interoperable data layers and data products. The EMODnet Project provides access to European marine datasets through digital mapping across seven discipline-based themes (http://www.emodnet.eu/): bathymetry, geology, sea-bed habitats, chemistry, biology, physics and human activities.
EMODnet Geology (2009 to present) promotes the collection and harmonization of marine geological data in European Seas, subdivided into Work Packages (WP) concerning seafloor sediments grainsize, sedimentation rates, Quaternary and pre-Quaternary geology, coastal behaviour, geological events and probabilities, mineral resources, web services and technology. The Project, at the end of its second phase (2013-2016), has provided access to harmonized digital maps at 1:250,000 scale, complemented by 1:1,000,000 scale maps, where more detailed data were not available. The third ongoing phase is aimed at obtaining products at least at 1:100,000 scale or more detailed.
Information displayed on the Portal is principally held by Project Partners (mainly Geological Surveys from 30 European countries), although other organizations contributed to the geological mapping objectives in many of the participating countries. Data sources include national and European projects as well as pre-existing literature, maps and databases.

The Geological Survey of Italy in EMODnet Geology

The main institutional duty of the Geological Survey of Italy, since its institution in 1873, has been to "produce and publish the Geological map of Italy", playing a

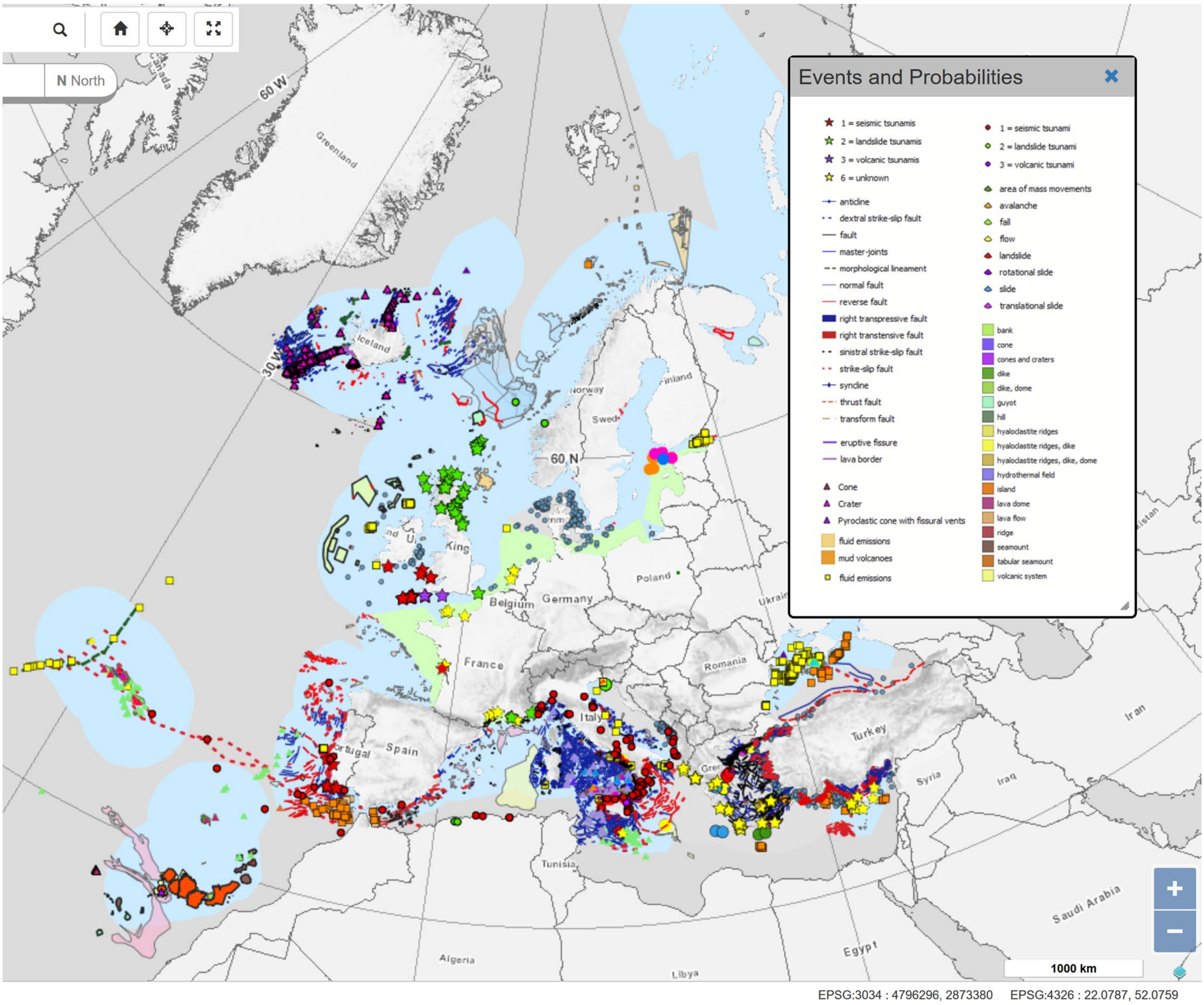

Fig. 1 - Visualization of all WP6 layers on the EMODnet Geology Portal. Events are represented according to selected characteristics. Tsunamis are represented by type of event origin (stars for origins and points for affected coasts); volcanic features (lines, points and polygons) are represented by morphological type; faults (lines), fluid emissions (squares) and landslides (polygons) are represented by type. (www.emodnet-geology.eu/map-viewer/)

key role in both the development and dissemination of Geological Sciences as the basic knowledge of the national territory. The Geological Survey of Italy, with its long experience of geological mapping and the large database created by the CARG (National Geological Mapping at 1:50,000 scale) Project, has contributed constructively to the realization of datasets, harmonized at European level, in which all of the geological knowledge of European marine areas has been conveyed. The Geological Survey of Italy leads Workpackage 6 (WP6) "Geological events and probabilities", whose objective is to identify and map all significant geological events occurring in European sea areas, such as: earthquakes, submarine landslides, volcanic centers, tectonics, tsunamis and fluid emissions of non-volcanic origin. All of the geological events stored in the database are visualized in Fig.1, which shows the abundance and wide distribution of data collated. Each layer is complemented by an Attribute table reporting descriptions and details of each occurrence and can be browsed through and queried individually.

Methods and techniques

The Geological Survey of Italy started its experience in database construction since the CARG Project required the informatization of geological maps. This database represented the primary archive to provide Italian geological data to EMODnet Geology, further

complemented by additional data deriving from other national databases or from validated references.
As coordinator of WP6, the Geological Survey of Italy defined the guidelines to produce deliverables and the procedure to realize digital maps to be shared on the EMODnet Geology Portal.

From the planning to the final products

The realization of WP6 digital cartography has been subdivided into several phases:

– elaboration of Guidelines and preparation of the "Table of Content", i.e. instructions to compile Attribute tables, with technical specifications on how to deliver GIS layers;
– systematic collection of data;
– generalization. Maps are generalized at the scale of harmonization;
– harmonization of data according to the technical specifications;
– data processing, compilation and structuring of shapefiles in European-wide layers;
– update, correction and implementation of files after review and validation by Partners;
– design and implementation of an index map related to all layers produced for WP6 by each country;
– delivery of the correct final products as digital cartography.

Elaboration of Guidelines

The main task in drafting Guidelines for "Geological events and probabilities" has been to take into account the geological and physiographic differences of European seabed settings. The first step has been to identify which parameters should be used to characterize events and which additional relevant information should be listed in the Attribute table of each GIS layer.
Since Guidelines have to be of general scope, tested and shared, a draft format with a list of potential characteristics to be considered was circulated among national Partners. Attribute tables have been implemented and updated through constant comparison with European Partners and thanks to their contributions.
Since pre-existing data had been in many cases collected for different purposes, the following specifications have been established in the Guidelines also according to Tender requests:

- **File format**: data must be provided in shapefile format (in the three features: polygons, lines and points) or in ESRI geodatabase format.
- **Scale**: the scale of data representation was 1:1,000,000 in phase I, 1:250,000 in phase II and 1:100,000 in phase III.
- **Coordinate system**: data must be geo-referenced in the WGS-84 system in geographic coordinates (Lat / Lon), which is the reference system for all EMODnet Lots.
- **Coastline**: the coastline has been provided by the European Environment Agency (scale 1: 100,000; last version modified in February 2015 for the coasts of Russia).

The elements that characterize each geological event were analysed in order to define classes of attributes, which were then organized into database tables that provide all the necessary information to create and compile files with distinct geometry (points, lines and polygons) chosen to represent the different type of events, in order to include any occurrence.
Particular attention has been devoted to the definition of the Attribute tables in order to achieve the best degree of harmonization and standardization according to the European INSPIRE Directive. Each geological event can be characterized by specific attributes, which may be different depending on the geometrical features representing the same event.
The "Tables of Content" consist of 7 columns containing the basic information needed to organize and compile the Attribute tables of the shapefiles (Fig. 2).

The first column describes the items of a specific shapefile, while the following ones explain how the fields should be built and implemented.

- Feature: lists the fields that must be created by type of event and geometry.
- Status: defines which are the mandatory fields to fill out.
- Format: identifies the format (numeric, text, etc.) in which the information must be stored.
- Definition: depending on the data type, defines a domain or a single code, a range of values, a kind of unit of measure.
- Description: when necessary, provides a description of the item and instructions to compile the field.
- Reference: when necessary, provides clarifications on the references used to determine the attributes of the table and an explanation on how to compile the field "References".
- Remarks: contains further clarifications and comments useful for the elaboration of the tables.

During this phase it was established which fields would have been mandatory, e.g. for all layers Unique

Feature	Status	Format	Definition	Description	Reference	Remarks
Sls_pt, Sls_pol	mandatory	Text (8)	points or polygons	unique identifier code (two letters country code, which corresponds to ISO3166- code e.g. "IT" plus progressive numbers that identify each spatial occurrence in the map e.g. "IT00001", "IT00002", "IT00003", etc.)		Polygons can be extended across the coastline in order to represent full extension of landslides including portions on land.
Age		Text (50)	geochronology/ ancient, recent	Indicate geochronologic unit where possible or specify only if it is ancient or recent		
Volume		Numeric Double (12)	cubic meters			
Thickness		Numeric Long (5)	meters	Maximum thickness of the displaced mass or, alternatively, evaluated average thickness		
Type		Text (50)	landslide, fall, topple, slide, rotational slide, translational slide, flow, lateral spread, complex landslide, slide/flow, translational slide/flow, turbidity current/debris flow, avalanche, creep, deep-seated gravitational slope deformations (DSGSD), turbidity currents, area of mass movements, zones of net erosion, compound landslide, scar	**Scar:** area of missing material on failure surface		outcropping or buried
Source area		Text (12)	above, below (sea level)			
Lithology	mandatory in case Type = flow	Text (50)	rock, debris, mud			
Name		Text (50)	literature name			
Slope gradient		Numeric Short (2)	percentage (%)	express slope gradient as a percentage, "difference in altitude divided by planimetric distance multiplied 100"		
References	mandatory	Text (200)	in case of long text, fill with the name of a file.doc named "References + the identifier code" as in the following example: References_sls_pol_IT00001.doc			
Comment		Text (200)	free comments			

Fig. 2 - The "Table of Content" for submarine landslides (geometry: points, polygons).

Identifier Code and References (where each Institution or author appears as the owner of the data), and which would have been optional.

Collection of data

EMODnet Geology Partners provided shapefiles containing data from marine areas surrounding their countries. Data come from Partners datasets or from pre-existing literature, including maps, databases, national and European projects.
Datasets delivered consist of several specific layers representing each type of geological event; the use of different geometric features is related to the peculiar characteristics of each occurrence as well as to the scale of representation.
In this phase, data were systematically collected and inconsistencies, were identified.

Generalization

Maps, coming from different sources at different scales, were generalized at the scale of representation. It was agreed that at 1:250,000 scale, foreseen by the second phase of EMODnet Geology, the smallest area that can be represented has an extension of 60 hectares (10mm^2 on the map); for example landslides smaller than 60 hectares have been plotted as points. During the following phase, at 1:100,000 scale, or finer wherever possible, the smallest area which can be represented is of approximately 4 hectares (4 mm^2 on the map); landslides represented by points in the previous phase can be better represented by polygons (if information is available).

Harmonization

All terms used for the description of attributes needed to be checked, to verify that they matched WP6 Guidelines and complied with the INSPIRE Directive. The latter task has been particularly difficult, since INSPIRE Glossaries do not always suit specific needs. An accurate review of information entered in coded fields was necessary to verify that encodings fell within the assigned domains. Only after harmonization and standardization of non-homogeneous data, harmonized European-wide layers could be compiled for each type of event and each geometric feature.
Terms adopted for the landslides "Type" field derived from Varnes classification (1978) and were then integrated, according to Partners requests. "Lithology" was separated from "Type"; however, since relevant landslide information is provided by their combination (e.g. *debris flow*), it was established that when Type = *flow*, it is mandatory to fill in the Lithology field.

As regards polygonal features located across the coastline, it was decided after discussion with Partners to consider also their emerged portions in order to provide complete representations of their occurrences, even though Project specifications only referred to marine areas.
"Activity_age" of volcanic centers indicates the time range of activity until last eruption; it is a text field that must be filled in with the date or the geochronological unit; "Chemical composition" reports the TAS (Total Alkali Silica) content of volcanic products; in case such information is not available, the field can be compiled indicating magmatic series.
For Tsunamis origin, attributes contained in the table refer to the location of source events. These latter are also linked to other WP6 layers by key fields to be filled in with the Unique Identifier Codes of the geological events that generated tsunamis. The parameters of source events concerning an estimate of their consequences are also included.
The Tsunamis affected coast Attribute table contains the same fields of the Tsunamis origin except for those related to *source parameters*. The choice to adopt points instead of lines to represent affected coasts is due to two main reasons: 1) in many cases it is not possible to identify the exact extension of the stretch of coast affected by a tsunami; 2) in case of multiple events, there would be an overlap of many lines on top of each other and of the coastline. Points must be plotted in the most representative location of the invested coast.
Mud volcanoes and fluid emissions of non volcanic origin have been represented in a separate dedicated layer, in order to prevent possible confusion generated by terms adopted to describe "Morphological types", which are the same used for volcanoes. The "Composition" item has to be compiled indicating lithology for *mud volcanoes* or chemical composition and temperature for *fluid emissions*.
Concerning earthquakes, it was decided to link to the Seismic Portal of the European-Mediterranean Seismological Centre (EMSC) web-service (www.seismicportal.eu). However, since the EMSC applies a strict protocol to select data to be displayed, an earthquake layer has been included in WP6 products to allow Partners to provide additional harmonized data, which are not reported by the EMSC website.

Data processing

A semantic homogenization and standardization of data was performed, based on INSPIRE compliant dictionaries, as well as a geometric homogenization in order to respond to specific spatial and topological constraints. Data not responding to the technical specifications needed to be aligned to the Guidelines, by corrections, updates or, in some cases, reorganization of data in a different shapefile. The initial lack of topological rules required a spatial revision and correction of the geometric primitives.
When information available to Partners did not match any field, more fields have been added to the Attribute tables, in order not to lose any detail; however, in order to respect the hierarchical organization of data, in a few cases additional information was entered in the "Comments" field.
INSPIRE compliant terms newly adopted by Partners have been implemented in the corresponding domains, as was the case of several types of faults (Fig. 3). On the other hand, terms not aligned to coded domains have been changed into the allowed encodings.

Topological inconsistencies

Topology is an explicit redundant superstructure which encodes spatial relationships between different entities, ensures geometric consistency, facilitates the acquisition process, allows more efficient processing. Topology expresses the spatial relationships between vector geometries (points, polylines and polygons) connected or adjacent in a GIS. Topological data are useful to identify and correct digitization errors.
Topological errors disrupt the correct relationships between vector geometries, therefore they must be fixed in order to be able to analyse vector data by procedures such as measurements (e.g. determining the length of a fault). Creating or obtaining topologically correct vector data is necessary and useful for several reasons, for example when, in digitizing seafloor geology, polygons overlap or gaps are present. In case topology is not correct, measuring instruments cannot be used and the results obtained are also not correct. Consequently it would not be possible to obtain the correct surface area of every polygon or to define exactly where the boundaries between polygons are located.
Polygons overlaps have been eliminated by representing only the outcropping portions of underlying polygons. For example, Figure 4 shows the Gondola landslide, located off the coast of Puglia in the Adriatic Sea, which is constituted by several events that have occurred over time. From a geometric point of view the landslide is formed by several overlapping polygons. The most ancient of them are totally or partially hidden by younger events. When different events had been dated or their succession had been reconstructed, it was possible to restore a correct topology. This way layers can be queried in a GIS system or in a web portal by any user. Any relevant additional information has been stored in the fields of the Attribute table associated with each occurrence.
However, it was not always possible to overcome topological inconsistencies.

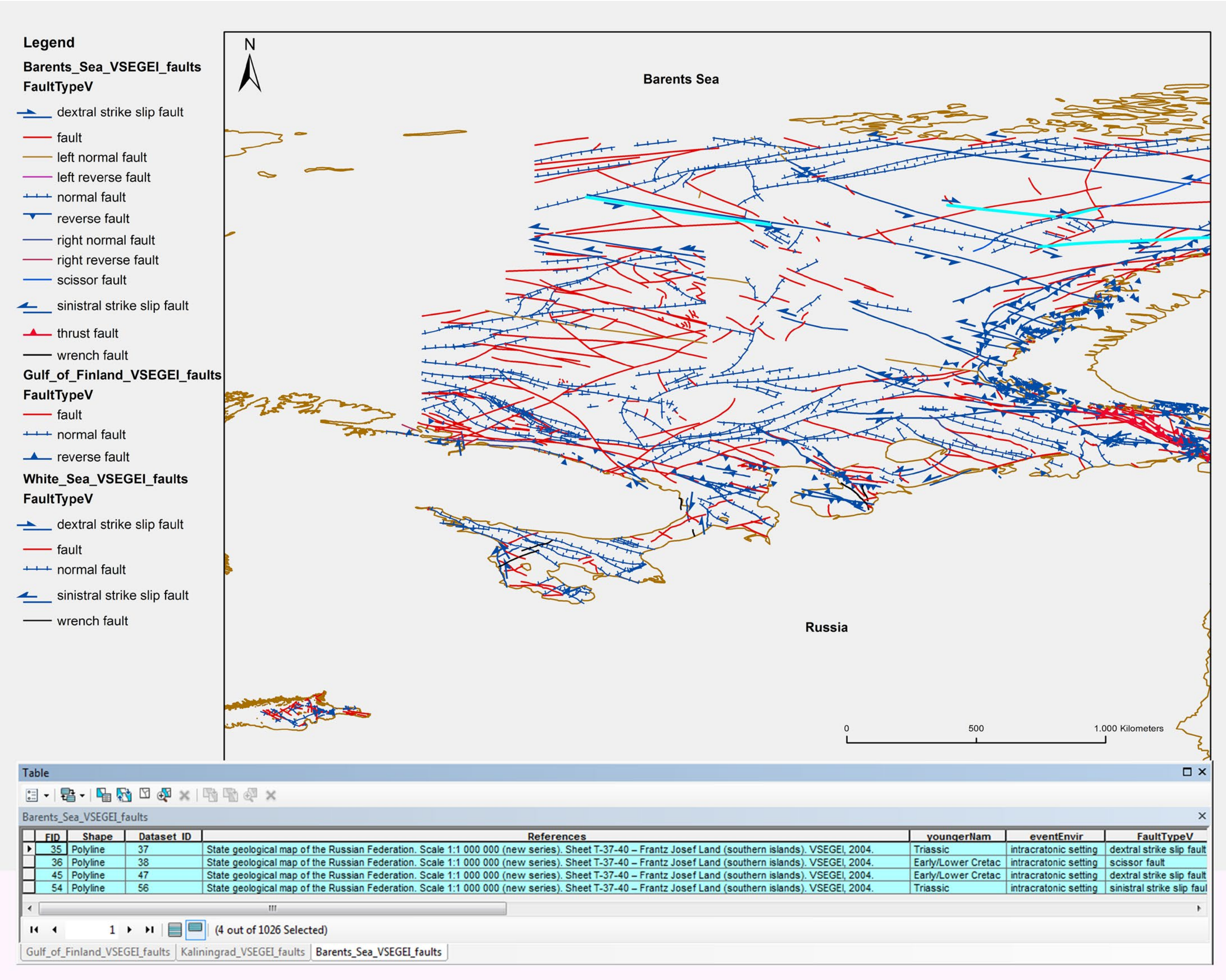

Fig. 3 – Visualization of a detail (Barents Sea) of faults reported in the tectonics map of EMODnet Geology. New INSPIRE compliant terms (highlighted in the Attribute table in the lower part of the figure) have been integrated into the domain, such as sinistral and dextral strike-slip fault, wrench fault, scissor fault. Data are reported as different deliveries provided by Partners before harmonization.

Update

Standardized data layers were submitted to Partners for validation and then updated, integrated and implemented by WP6 Leader, on the base of their observations.
The outcome was the production of homogeneous datasets and digital maps freely distributed as WMS, WFS and CSW services on the EMODnet Geology Portal.

Implementation

Since features considered within WP6 have a scattered distribution, a Geological Events Distribution layer (Index Map) was designed to provide basic information on the distribution of geological events collated from marine areas surrounding European countries. Through the Index Map, it is possible to easily identify areas where: occurrences have been reported; no occurrences have been reported; no data are available. Index Maps can be visualized for each type of geological event and represent a proxy for confidence relative to data stored in the database (Fig. 5, example for landslides).

Final products

The harmonized digital maps of events occurrences, detected in European Seas, represent the final products of EMODnet Geology WP6 (Fig. 1). They have been

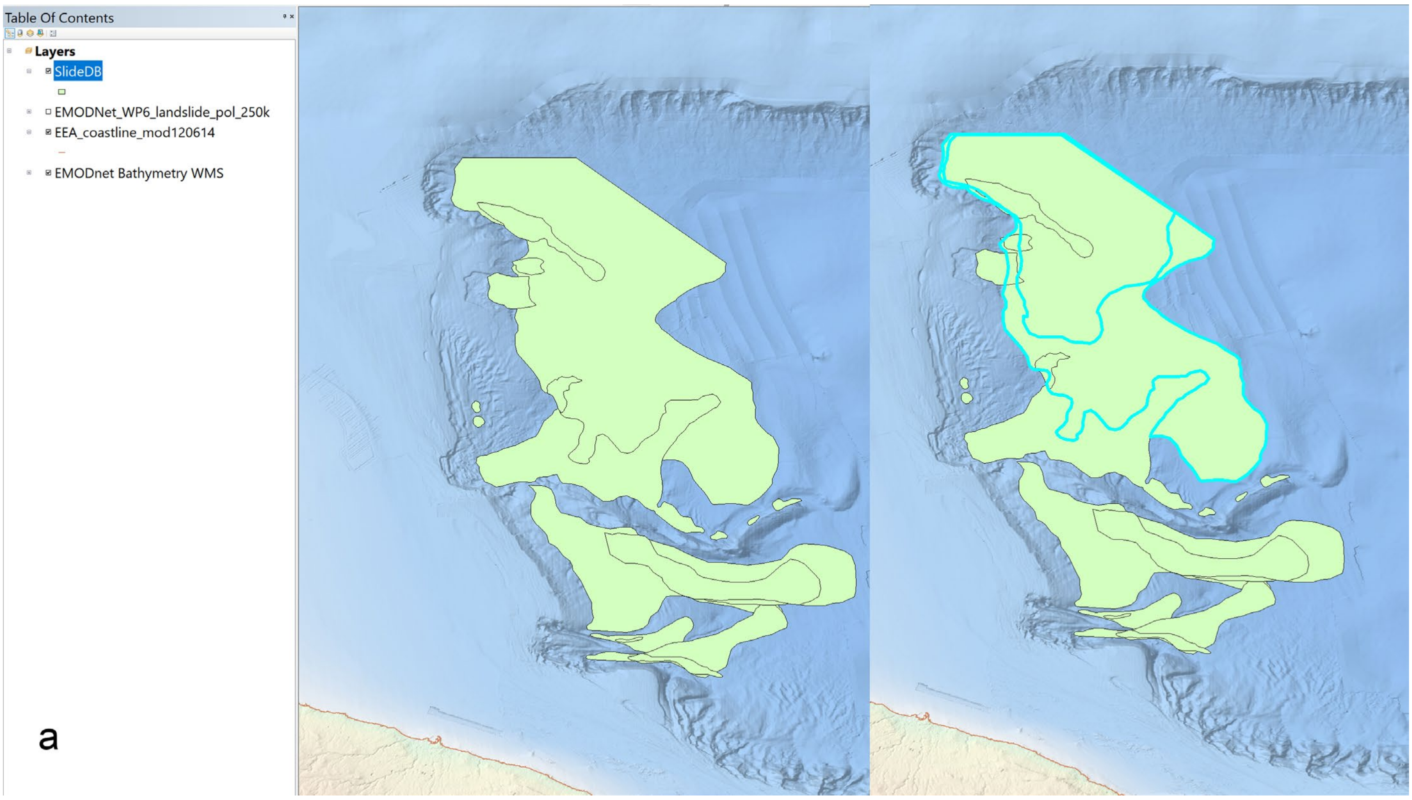

Fig. 4 a) – Gondola slide: the landslide is constituted by several overlapping deposits, derived from subsequent events; the outlines of the underlying polygons is consequently not completely visible (left view); only when highlighted (right view) polygons appear evidencing the topological inconsistency of the layer (1:750,000 scale).

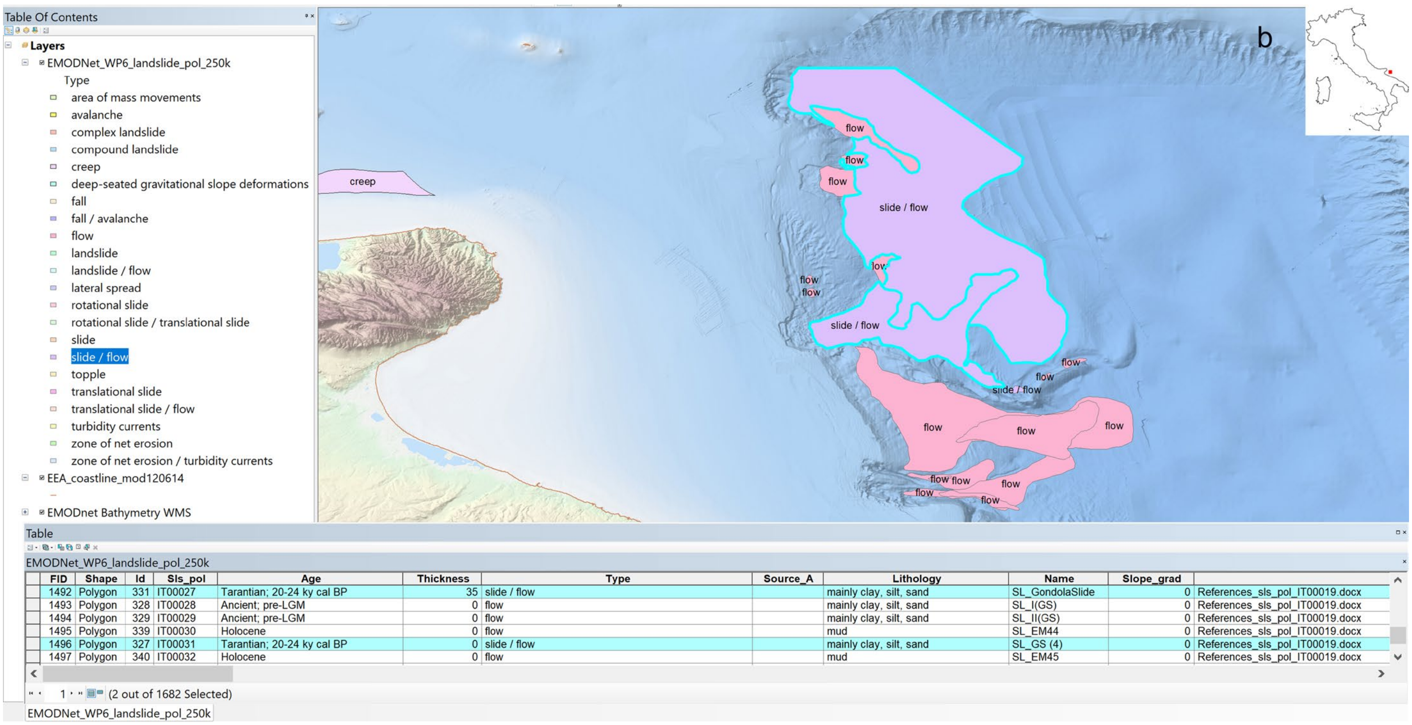

Fig. 4 b) – Gondola slide: after correction, polygons outlines are adjacent, perfectly aligned and searchable. Only the outcropping portions of the oldest polygons (small flow areas) are represented, after eliminating areas underlying the most recent events (polygons highlighted). Related data are stored in the Attribute table.

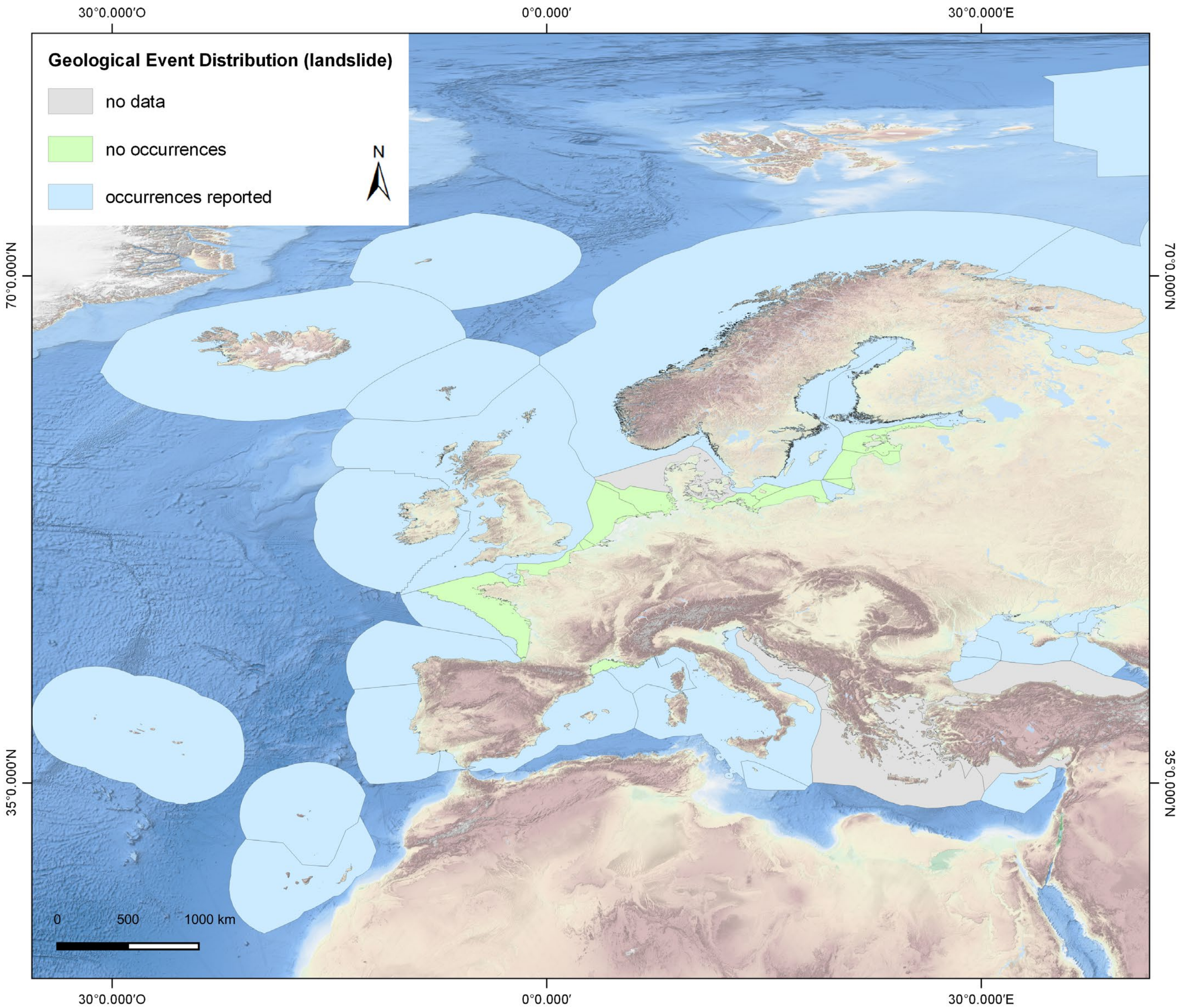

Fig. 5 – Visualization of the submarine landslide distribution in European Seas. The Index Map is designed to display the distribution of each type of geological event.

realized at different resolutions and we are currently working to obtain the highest possible resolution in the areas considered.

Digital maps of Geological events in Italian Seas

The inventory of Geological events data collected within EMODnet Geology can be downloaded from the Portal at the link: http://www.emodnet-geology.eu/data-products/ by selecting "download" under "Events and Probabilities" or can be visualized by selecting "show on map". A few examples of digital maps will be shown below, by visualizing shapefiles included in the Portal.
Different layers of geological data have been visualized in each map, aiming to illustrate peculiar geological characteristics in different physiographic settings and at different scales. The underlying DEM is an EMODnet Bathymetry product (http://www.emodnet.eu/bathymetry).
Validated and harmonized geological events occurring in Italian Seas are represented in the map. They provide information on the geological history of the Italian submerged territory. The recent opening of the Tyrrhenian basin is highlighted by the intense Plio-Quaternary tectonics and by the decreasing age of volcanism southward. Underwater eruptions and tsunamigenic seismic activity are responsible for most of the submerged landslides so much as the rapid uplift, still active in some areas, is responsible for large mass movements along the continental slope.

Sediment classes, from coarser to finer moving away from the coast, follow the general physiographic setting of the Italian seafloor marking respectively coastal areas (beaches and submerged paleo-beaches), continental shelf and slope and deeper basinal areas.
This map is one of the first representations of Italian seafloor geology since a long time and includes an updated review of a large number of studies, which up to now were fragmented and had never been harmonized at national level. Further elaborations are going to be published as traditional cartographic products, such as the "Atlas of Italian submarine volcanic structures" (D'Angelo et alii, 2019) and a "Structural map of Italian Seas" (in prep.).

Sicily Channel

The Sicily Channel (Fig. 6) lies between southern Sicily and north eastern Tunisia. It is characterized by WNW-

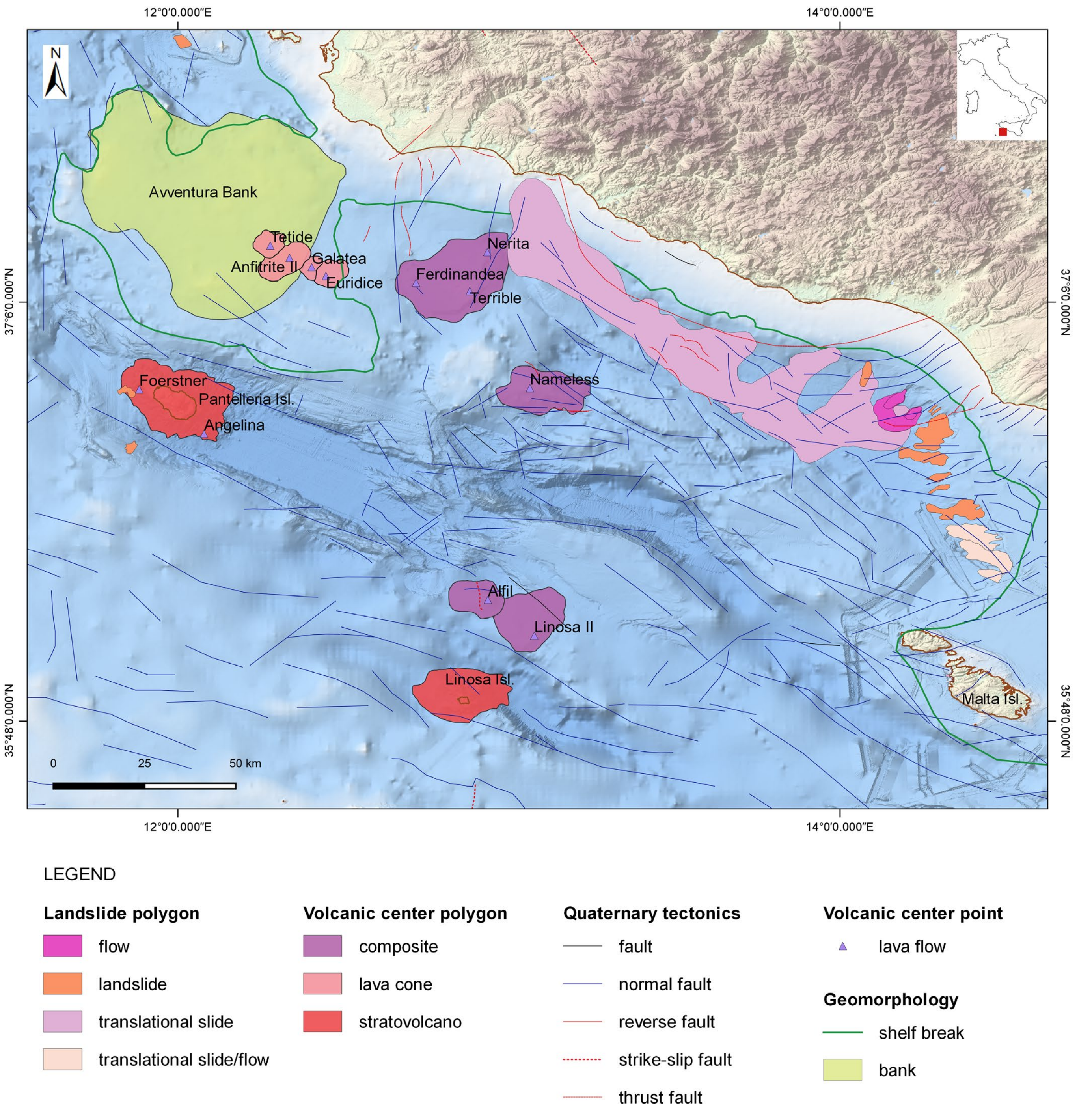

Fig. 6 - Geological events in the south western Sicily offshore.

ESE normal faults tectonics, parallel to the Channel itself and by reverse faults with weak compressive deformation in a Maghrebide (NE-SW) direction.
The continental shelf is extended, including the Avventura Bank and Malta Island. It is modeled on a tectonized substrate of Mesozoic to Neogene rocks (Catalano & D'Argenio, 1978). The shelf-break is located at depths varying between -90 m and -201 m. Its continuity is interrupted by numerous indentations connected to mass movements and landslides.
The remaining part of the area is constituted by a slope affected by continuous landslides in the inner portion and spread by intraslope basins and submerged volcanic edifices in the distal portion.
The Sicily Channel Volcanic Seamount Sector (Pensa et alii, 2019) is composed by different volcanic morphologies as simple cones, composite edifices and stratovolcanoes (Pantelleria Island and Linosa Island). Volcanism is here of Quaternary age and is associated with the development of a NW-SE trending rift system. Tetide (T), Anfitrite (A), Galatea (G) and Euridice (E) volcanic seamounts are located on the Avventura Bank. The overall NW-trend of this cluster of seamounts is parallel to the main direction of the Sicily Channel extensional structures, evidencing that the cones are structurally controlled. The Graham Bank, which partly corresponds to the Empedocle volcanic seamount, is constituted by the coalescence of several edifices (Pensa et alii, 2019). One of them (F) last erupted on the 1st of August 1831, initially under water and later emerged during hydrovolcanic Surtseyan explosions (Argnani & Vigliotti, 2003), witnessed by local fishermen. Ownership and naming of the new island was disputed between "Due Sicilie" Kingdom, United Kingdom and France: consequently the island was named Ferdinandea, Graham Bank and Iulia in the respective countries. The dispute was still unresolved when the island was progressively destroyed by marine erosion in 1832.

Northern Calabria offshore

The area in the map (Fig. 7) represents a segment of the eastern Tyrrhenian margin facing northern Calabria. The Paola basin is one of the peri-Tyrrhenian basins (Selli & Fabbri, 1971), located in a transitional area between the Tyrrhenian Bathyal plain and the rising Apennine chain (Kastens & Mascle, 1990).The continental shelf is here characterized by very limited extensions (5 km wide, north of Capo Suvero, and 10 km wide in the S. Eufemia Gulf).
Since late Miocene times the whole Calabrian area has been affected by strong uplift and intense tectonic activity, associated with the opening of the Tyrrhenian Basin, that started in the Tortonian Age (Finetti & Morelli, 1972). Uplift and Tyrrhenian subsidence continued throughout Pliocene times inducing relative movements that generated very high sedimentation rates and considerable instability along the entire Calabrian continental margin. Seamounts of volcanic origin located offshore constitute a morphological barrier for gravitational flows, preventing sediments from draining further downslope. Consequently, the Paola basin has become the greatest depocentre of Plio-Quaternary sediments of the eastern Tyrrhenian margin, locally exceeding 4 km of thickness (Chiocci & Orlando, 2004).

Adriatic Sea

The Quaternary fine-grained succession lying on the Adriatic shelf and slope (Fig. 8) includes deposits related to repeated eustatic sea level changes occurred during late Quaternary-Holocene times. Sediment deformation has been observed at selected stratigraphic levels, such as the rapid progradation episodes recorded by depositional rates of 30 m in less than 10 ka (Trincardi et alii, 2004). When sedimentation rates are so high, overpressures can develop within the deposits.
The considerable amount of organic matter supplied by rivers and its rapid decay cause the formation of biogenic gases that permeate deposits up to a few meters below the seabottom. Pockmarks and little mud reliefs indicate expulsion of overpressured fluids (Trincardi et alii, 2011).
The combination of overpressures induced by rapid deposition and gas impregnation in surface sediments can induce instability processes. Two debris flow areas affect the northern slope of the Mid-Adriatic Depression. A large creep area is present between 40 and 68 m depth where slope is maximum (ca 1°). It runs parallel to the coastline for 55 km and is 10 km wide in a perpendicular direction. Such ribbon-like deposits are typical of continental margins and are particularly restricted in time and space.

Eastern Tyrrhenian Sea

The map in Fig. 9 shows a portion of the eastern Tyrrhenian margin facing northern Campania, between the Gulf of Napoli and the Volturno River mouth. Sediment textures match physiographic units: continental shelf (muddy sand), upper continental slope (sandy mud), basins and intraslope basins (mud) and

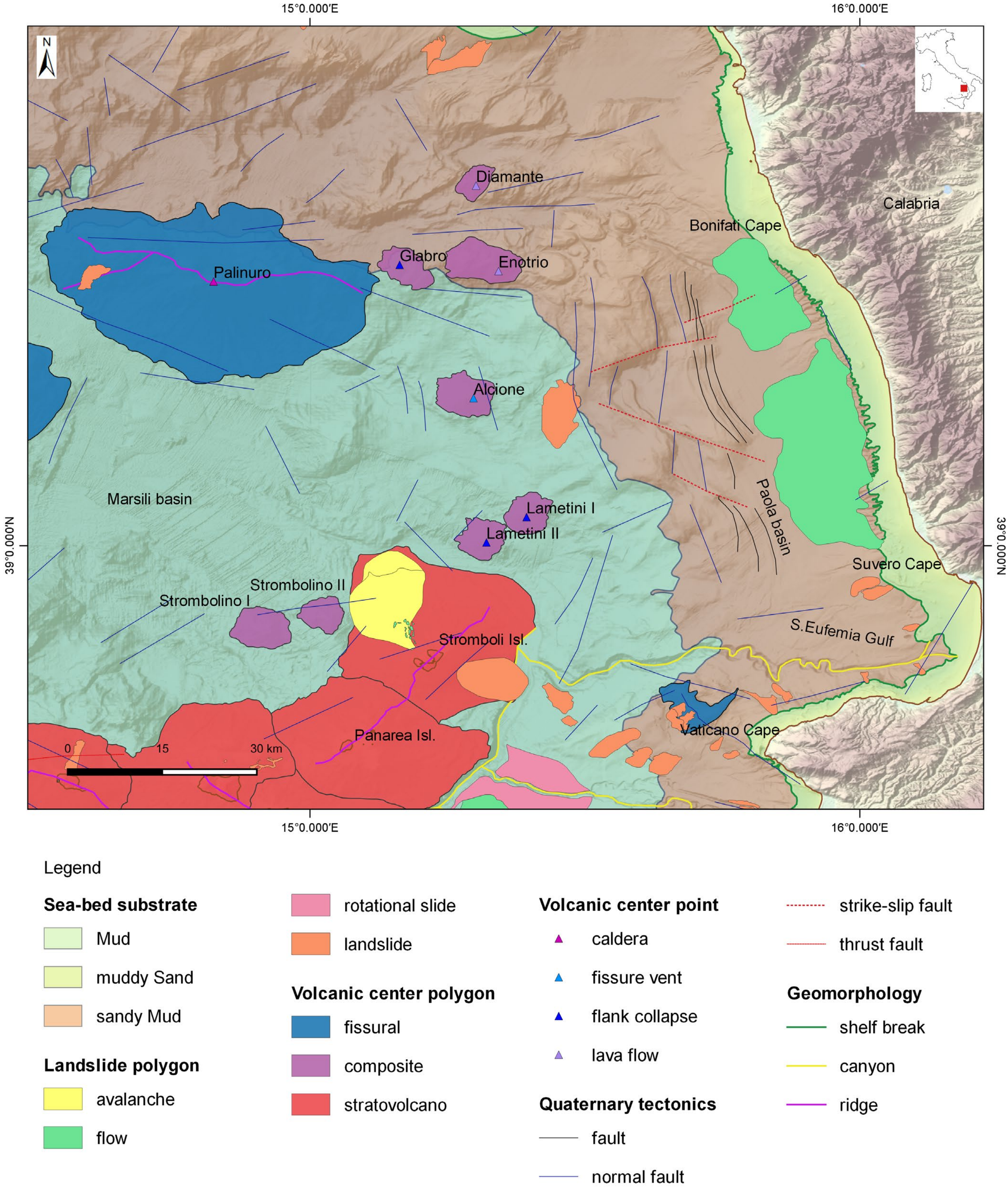

Fig. 7 - Geological events in the Northern Calabria offshore.

peri-Tyrrhenian seamounts (volcanic rocks). Tectonics and volcanoes, active since Pleistocene-Holocene times, evidence that extensional processes related to the opening of the Tyrrhenian back-arc basin are still ongoing. Lithospheric extension contributed to the uprise of differentiated magmas. The eastern portion of the sector is particularly active (Ischia Island) being characterized by areas of substantial hydrothermal gases discharge (Banco della Montagna, Nisida, Campi Flegrei).

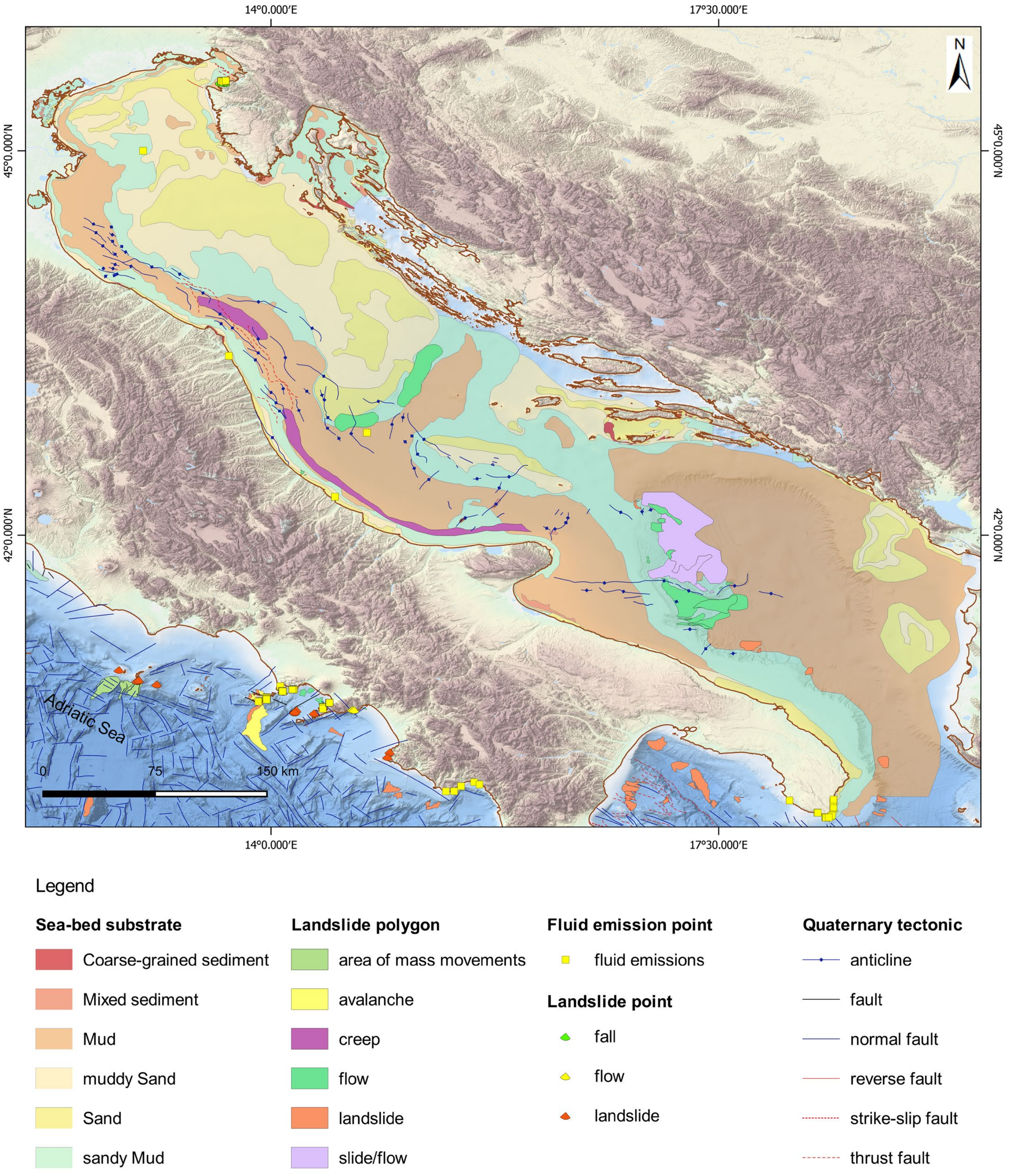

Fig. 8 - Geological events in the Adriatic Sea.

Ventotene Island represents only the emerged part of a much larger, rather conical volcanic edifice. The base of the seamount extends for 25 km in diameter and has a maximum depth of -880 m; therefore, the total average height of the edifice is 915 m. Ischia Island reaches 1,366 m of average height, including its subaqueous extension, while Procida is only 151 m high. The morphology of the submerged

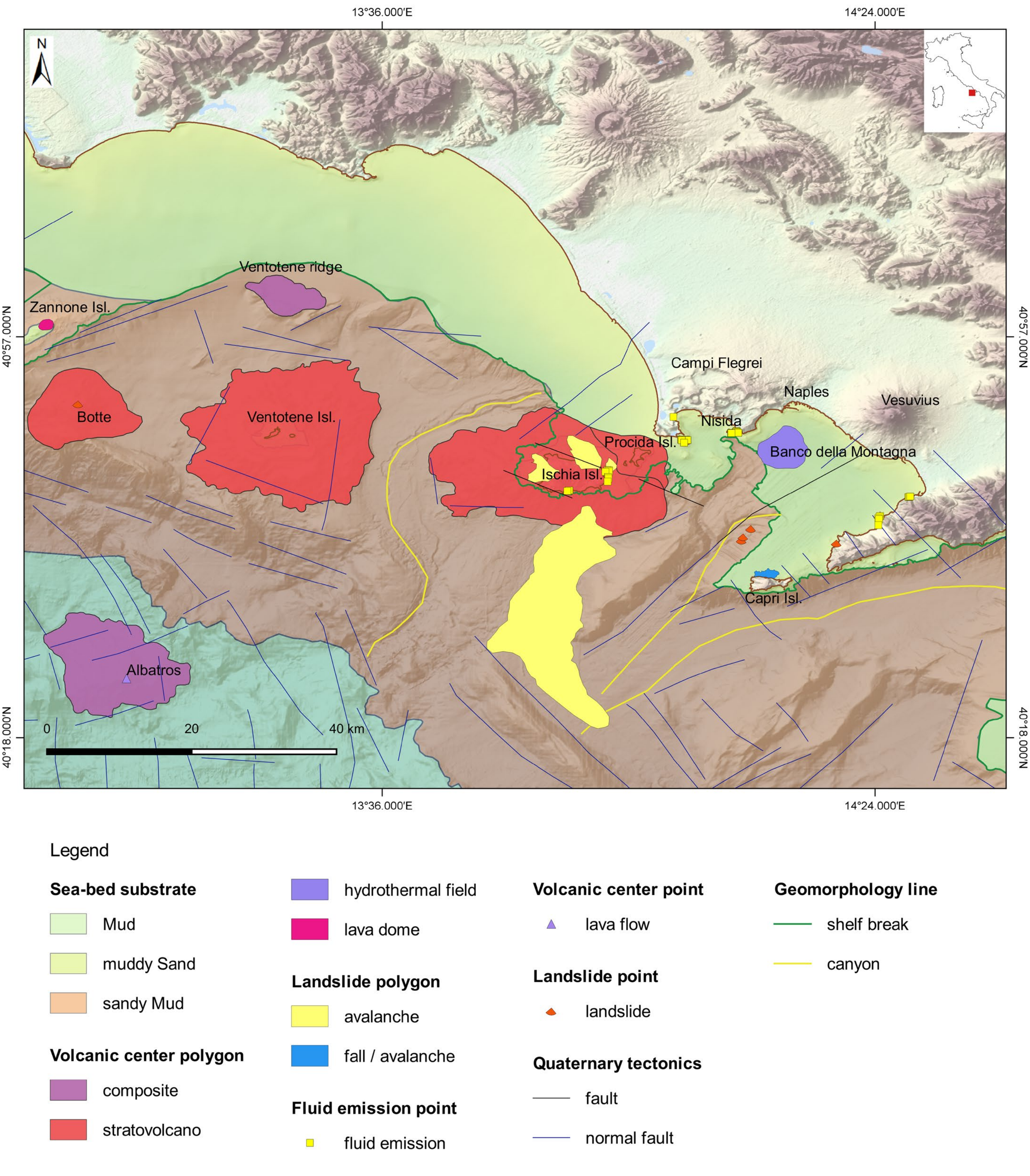

Fig. 9 - Geological events in the Eastern Tyrrhenian Sea.

parts of Ischia and Procida islands is influenced by their location across the edge of the continental shelf. Slopes are steeper (20° to 35°) around Ischia, especially southward, whereas they are less steep (6° to 20°) elsewhere (Pensa et alii, 2019 and references therein). The steep southern flank of the Ischia edifice is affected by large volume landslides and sector collapses of both its subaerial and subaqueous portions (De Alteriis et alii, 2010 and references therein).

Aeolian Arc

The Aeolian Islands (Fig. 10) are located in the south-eastern portion of the Tyrrhenian Sea, between the Calabrian western coasts and northern Sicily shores. This volcanic arc is composed not only by the seven Aeolian stratovolcanoes (Stromboli, Panarea, Vulcano, Lipari, Salina, Alicudi and Filicudi Islands), but also by several submerged volcanic edifices. This Volcanic Sector is related to the fast retreat of the Ionian slab and the associated spreading of the Marsili Basin (2-1 Ma) which overlaps both in time and space with arc-magmatism (Pensa et alii, 2019). As a result of this complex geodynamic framework, rock compositions range from calc-alkaline to shoshonitic and potassic alkaline (Peccerillo, 2017).
The Vulcano, Lipari and Salina islands are located along the Tindari-Letojanni strike-slip tectonic system (Billi et alii, 2006 and references therein) and constitute a NNW-SSE-oriented volcanic cluster within the Aeolian archipelago.
Volcanic eruptions, submerged lanslides and flank collapses are here strictly connected: on December 30th 2002 the coast of Stromboli was struck by two tsunamis generated by landslides that took place on the north-western flank of the volcano. The landslides and the tsunamis represented the most impressive and threatening episodes of a strong effusive eruption, started on December 28th from a new vent which opened close to the north-eastern crater of the volcano (Tinti et alii, 2005).

Discussion and conclusion

Digital mapping is organized according to criteria not completely comparable to those applied in the production of paper maps. However it allows to reach further than the representation provided by the latter.
Traditional cartography allows to express the contents of a map by graphic elements, whereas a GIS map does not allow to use colors and symbols as unique expressions of information.
Representation of submerged areas deposits in the geological map of Italy at 1:50,000 scale is carried out according to the same criteria adopted on land. Therefore, ages of deposits are represented by colors, their depositional environments by different shades of color, sediment grainsize by overprinted patterns, mapping units by acronyms, geomorphological elements by symbols. This way it is possible to represent the spatial distribution of multiple geological aspects of an area. However, the main characteristic of traditional maps is to mark an achievement, to be an "historic document" which attests the knowledge acquired at a given time. Consequently, the map itself becomes an official document, even of legal value.
In GIS cartography the meaning of colors and symbols cannot be set once and forever. On the other hand, GIS cartography provides the opportunity to store and display a large amount of information and offers many additional possibilities. The most relevant characteristics are the extremely precise geographic location as well as the geometric accuracy of each element mapped, which allow for any kind of exact measurement. The representation of each feature is not dependent on the scale or on the thickness of the marking tool. A lot of data can be stored in correspondence of each point of the map and much more information can be displayed through the related attribute tables.
Data stored in a digital map can be implemented and updated. Each element can be considered and evaluated within its own class (i.e. landslides, geology, tectonics, etc.) or in relation with other classes (e.g. landslide --> tsunami). Digital maps allow to re-use data for different purposes, to elaborate derivative maps or to obtain particular information by selecting from time to time the parameters considered significant, allowing to push further interpretation concerning specific issues.
The EMODnet Geology Portal provides access to data and products, that allow to overcome the fragmented condition of the European marine data archives by means of a shared and interoperable structure. Interoperability was one of the objectives pursued, in order to provide more complete, correct and reliable information and facilitate exchange and re-use of data even among non-homogeneous systems.
Information provided by EMODnet constitutes a knowledge baseline and is useful in the planning of researches or in support of decision making for European policies management regarding submerged areas. Moreover, by combining these harmonized and standardized datasets, it might be possible to develop additional thematic maps that could support further research.

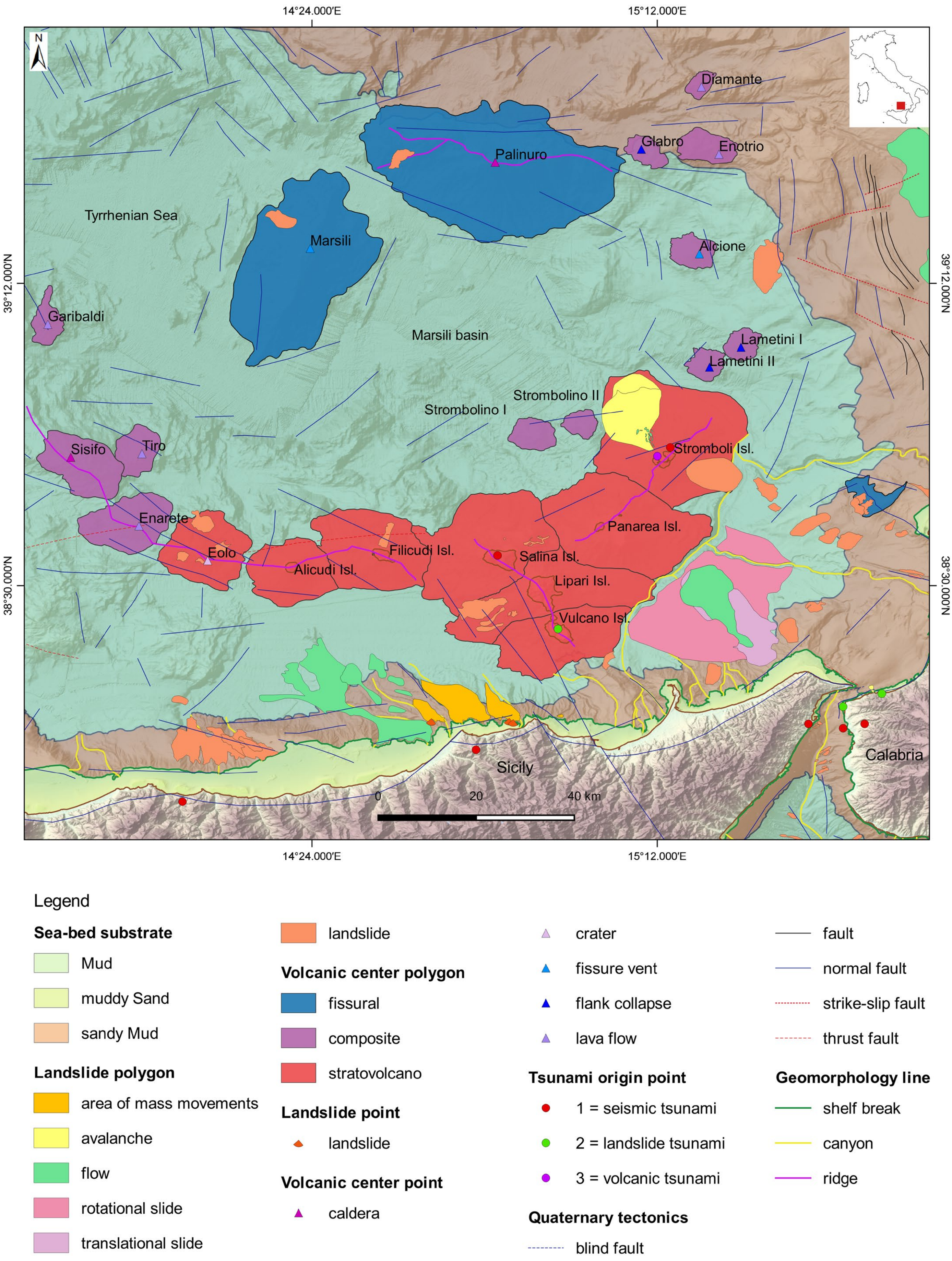

Fig. 10 - Geological events in the Aeolian Arc.

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References

Argnani A. & Vigliotti L. (2003) - *L'isola che non c'è più*. Tuttoscienze, La Stampa, n. 1059.

Billi A., Barberi G., Faccenna C., Neri G., Pepe F. & Sulli, A. (2006) - *Tectonics and seismicity of the Tindari fault system, southern Italy: crustal deformations at the transition between ongoing contractional and extensional domains located above the edge of a subducting slab*. Tectonics, 25(2).

Catalano R. & D'Argenio, B. (1978) - *An essay of palinspastic restoration across western Sicily*. Geologica Romana, 17, 145-159.

Chiocci, F. L. & Orlando, L. (2004) - *Terrazzi deposizionali sommersi nel settore meridionale del Golfo di S: Eufemia (Calabria)*. In: Chiocci, F. L., D'Angelo S. & Romagnoli C. (Eds), *Atlante dei terrazzi deposizionali sommersi lungo le coste italiane*, Mem. Descr. Carta Geol. d'It. vol. *58*, 75-80.

D'Angelo S., Fiorentino A., Giordano G., Pensa A., Pinton A. & Vita L. (Eds) (2019) - *Atlas of Italian submarine volcanic structures*. Mem. Descr. Carta Geol. d'It., vol.104.

De Alteriis G., Insinga D.D., Morabito S., Morra V., Chiocci F.L., Terrasi F., Lubritto C., Di Benedetto C. & Pazzanese M. (2010) – *Age of submarine debris avalanches and tephrostratigraphy offshore Ischia Island, Tyrrhenian Sea, Italy*. Marine Geology, 278: 1-18.

Finetti, I. & Morelli, C. (1972) - *Wide scale digital seismic exploration of the Mediterranean Sea*. Boll. Geofis. Teor. Appl, 14(56), 291-342.

Kastens, K. A. & Mascle, J. (1990). *The geological evolution of the Tyrrhenian Sea: an introduction to the scientific results of ODP Leg 107*. In *Proceedings of the Ocean Drilling Program, Scientific Results*, 107(3), 26. College Station, Texas.

Mancuso M. R. & Catalano R. (in press) - *Seismic-stratigraphic evidences of surficial and buried fluid flow phenomena in the Sciacca - Agrigento offshore (Southern Sicily)*. Mem. Descr. Carta Geol. d'It.

Peccerillo A. (2017) - *The Aeolian arc*. In: Cenozoic Volcanism in the Tyrrhenian Sea Region, 217-263. Springer, Cham.

Pensa A., Pinton A., Vita L., Bonamico A., De Benedetti A.A., Giordano G. (2019) - *ATLAS of Italian Submarine Volcanic Structures*. In: D'Angelo S., Fiorentino A., Giordano G., Pensa A., Pinton A. & Vita L. (Eds): *Atlas of Italian submarine volcanic structures*. Mem. Descr. Carta Geol. d'It., vol.104, 77-184.

Selli, R. & Fabbri, A. (1971) - *Tyrrhenian: a foundered deep sea*. Accad. Naz. Lincei. Rend. C, 1.

Tinti S., Manucci A., Pagnoni G., Armigliato A. & Zaniboni F. (2005) - *The 30 December 2002 landslide-induced tsunamis in Stromboli: sequence of the events reconstructed from the eyewitness accounts*. Natural Hazards and Earth System Science, Copernicus Publications on behalf of the European Geosciences Union, 2005, 5 (6), 63-775.

Trincardi F., Argnani A. & Correggiari, A. (2011) - *Note Illustrative della Carta Geologica dei Mari Italiani alla scala 1:250.000. Foglio NK 33-1-2 "Ancona"*. S.EL.CA, Firenze.

Trincardi F., Cattaneo A., Correggiari A. & Ridente, D. (2004) - *Evidence of soft sediment deformation, fluid escape, sediment failure and regional weak layers within the late Quaternary mud deposits of the Adriatic Sea*. Marine Geology, 213(1-4), 91-119.

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