Documenting seismogenic faults with public hydrocarbon exploration data in Italy

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Executive Summary

The geological characterization of potential seismogenic faults needs data capable of illuminating the Earth's subsurface at the depth where larger earthquakes nucleate. Among the most powerful data with this capability are those collected for hydrocarbon exploration, i.e., seismic reflection profiles and well logs, and their derived data products.

The scope of this report is to provide a preliminary estimate of the potential to document seismogenic faults with publicly available hydrocarbon exploration data in Italy. To this end, the ViDEPI project has provided access to such data since 2009, and the DISS provides location and geophysical characterization of seismogenic faults in the Italian territory and surrounding regions.

Here, we perform a spatial intersection of the records stored in these two databases to establish the common data coverage and the potential of documenting seismogenic faults by exploiting the wealth of data publicly provided by ViDEPI to promote the revision, update, or upgrade of existing record of the DISS and foster the positive identification of new ones.

Results show that the ViDEPI database can help document most of the existing DISS records.

Data and methods

In this analysis, we consider two datasets. One, concerning the seismogenic faults, is taken from the Database of Individual Seismogenic Sources (DISS, https://diss.ingv.it/) and the other, concerning hydrocarbon exploration data, is taken from Visibility of petroleum exploration data in Italy (Visibilità dei dati afferenti all'attività di esplorazione petrolifera in Italia, ViDEPI, https://www.videpi.com).

The DISS is a geospatial repository of tectonic, fault, and paleo-seismological information expressly devoted, but not limited, to potential applications in assessing earthquake hazards at the regional and national scales (Basili et al., 2008). This database considers various categories of seismogenic sources, but in this analysis, we consider only the Composite Seismogenic Source (CSS; **Figure 1**). A CSS is a simplified three-dimensional model of a crustal fault encompassing multiple seismogenic sources that cannot be individually identified. Unlike other seismogenic sources, CSSs are not linked to any specific set of earthquakes or earthquake distribution but can be used to develop earthquake forecast models.

The main priority of the DISS is to provide reliable and quality-checked information about seismogenic faulting in a wide region that includes Italy and its surrounding areas. This area is called the "Area of Relevance" (AoR; **Figure 1**) and is primarily defined to locate potential sources of seismic shaking that may impact the Italian onshore territory. Three buffers around the Italian border, each with increasing widths and decreasing priority, represent the AoR. The first buffer is 100 km wide and marks the highest priority region. Seismogenic faults outside the AoR are also investigated because they may represent sources of tsunamis in the Mediterranean Sea or be relevant to defining a geodynamic unit.

The ViDEPI project's main objective is to provide easy access to technical documents related to hydrocarbon exploration activities in Italy. These documents pertain to mining titles that have been terminated and expired. They have been deposited at the National Mining Office for Hydrocarbons and Georesources (UNMIG) under the Ministry of Economic Development since 1957. All the public technical documents related to the Italian exploration activities since 1957 can be accessed and consulted on the project website.

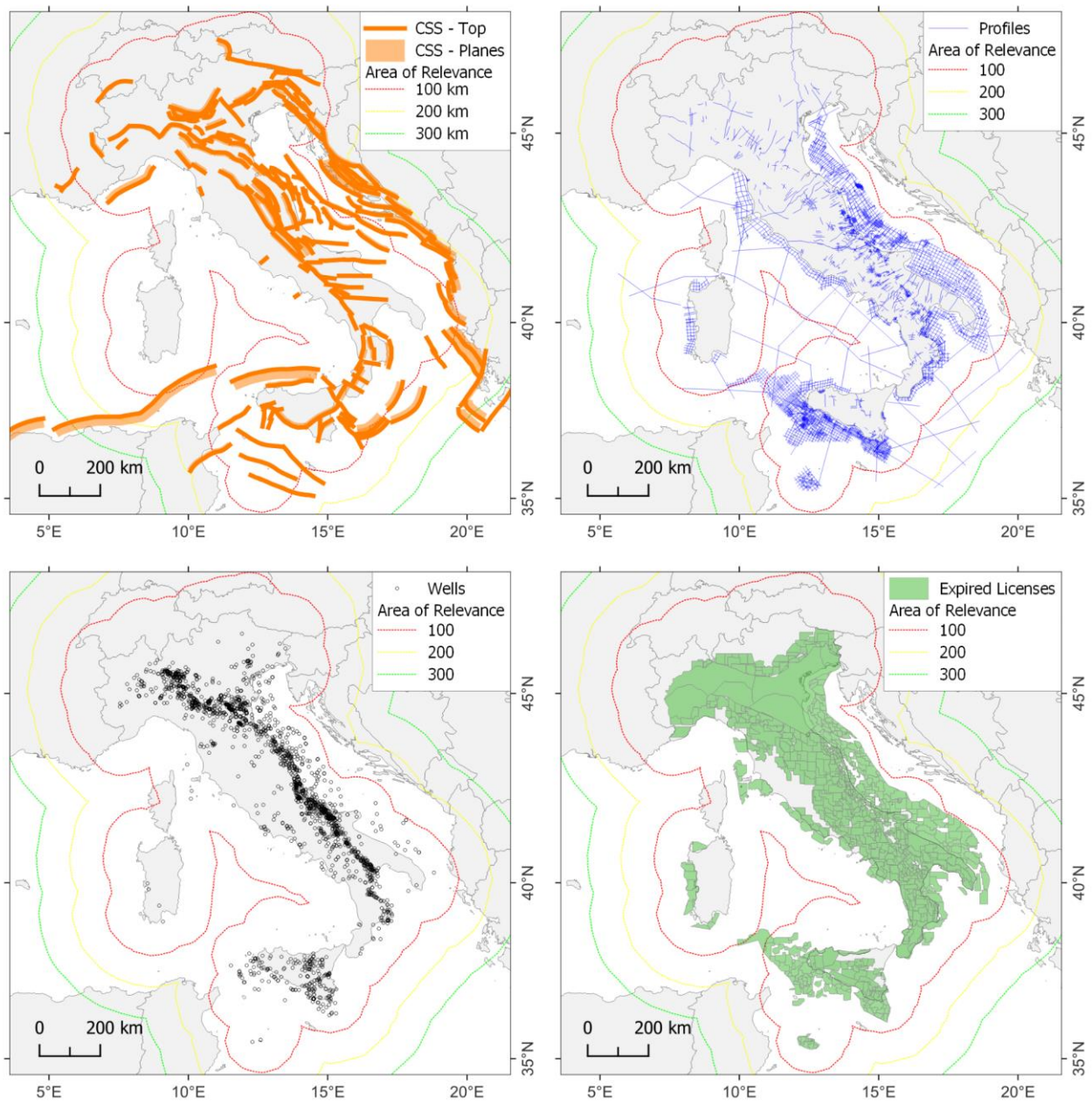

Figure 1 – Maps showing the data analyzed in this work. Composite Seismogenic Sources from DISS v. 3.3.0 (DISS Working Group, 2021) (upper left). Hydrocarbon exploration datasets from ViDEPI (https://www.videpi.com): seismic reflection profiles (upper right), well logs (lower left), and expired licenses (lower right). All panels show the DISS Area of Relevance for reference.

The hydrocarbon exploration activities in Italy are governed by Law No. 6 of January 11, 1957, which established the UNMIG. The law mandates that companies operating individual mining titles must furnish the UNMIG with progressive technical reports on the activity carried out in those titles. This includes copies of geological maps, structural maps, final well profiles, seismic lines, and other sample documents. The documents handed over by the companies become publicly available one year after the termination of the title for which they were produced.

The publicly available data includes seismic reflection profiles, drilled wells, structural and isochrone maps, geological maps, and other technical reports useful for the Company's studies investigating the area of interest for hydrocarbon exploration and production. Researchers can access technical documents on Italian

oil exploration filed by operators since 1957 with relevant mining authorities. The technical documentation is made available in PDF format. The project comprises about 15,000 files, totaling about 34 GB of data, and constitutes an important database for researchers, regional agencies, associations, and citizens.

This prominent database consists of (i) 3044 seismic reflection profiles, inclusive of 2396 seismic lines acquired in expired mining permits and concessions, 578 reconnaissance seismic campaigns of the offshore areas, 70 seismic profiles of the CROP Atlas Project; (ii) 2299 final well logs; (iii) more than 10,000 files of documentation for 1406 expired mining permits and concessions (**Figure 1**).

Methods

We performed a spatial intersection between the geographic features of the DISS and ViDEPI databases. To account for location uncertainty and relevance of the HC exploration data, we first drew a 5-km wide buffer around the vertical projection onto the ground surface of the fault planes represented by the CSS (**Figure 2**).

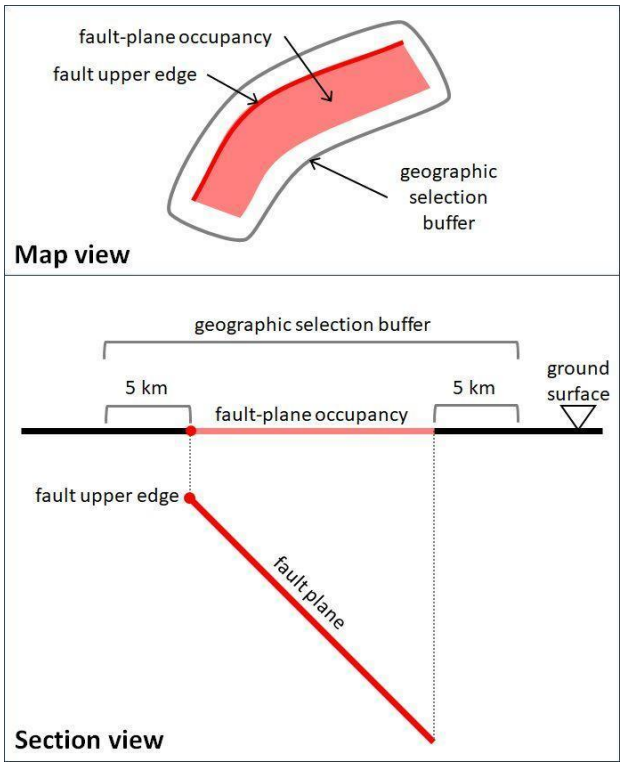

Figure 2 – Schematic illustration of the procedure used to select data.

We then performed a geographic intersection using the SQL tools embedded in QGIS. The count of ViDEPI intersected data was then stored in three new columns, added to the original CSS file, and exported as a .csv file (Supplementary file DISSvsViDEPI.csv) with the structure described in **Table 1**.

Table 1 - Structure of the DISSvsViDEPI.csv file providing the number of ViDEPI datasets intersecting the CSS.

Field name	Description	Variable
IDSource	Unique identifier of the CSS used as a primary key to link records of different tables in the DISS.	Coded string
SourceName	Name of the CSS.	String
Seismic Profiles	Number of seismic profiles intersecting the CSS.	Integer
Wells	Number of wells intersecting the CSS.	Integer
Expired Licenses	Number of expired licenses intersecting the CSS.	Integer

This procedure ensures the inclusion of HC exploration data that can be useful for the structural analysis of the principal fault plane and associated primary and secondary structures, such as stratigraphy, folded or bent horizons, fault splays, or fractures. Regarding wells, the count must be considered as a minimum because, depending on the structural setting, even very distant wells can be useful, for example, in the stratigraphic reconstruction or geochronology attributions.

Results

The outcomes of the spatial intersections between the CSS and the HC exploration datasets are displayed in **Figure 3**. Three of these maps show the distribution of CSS color-coded according to the number of seismic profiles, well logs, and expired licenses, respectively. The fourth map (lower right panel) shows the CSS intersected by at least one element of any of the three HC exploration datasets. Only a few (25) CSS lack HC exploration data inside the 100-km (highest priority) AoR.

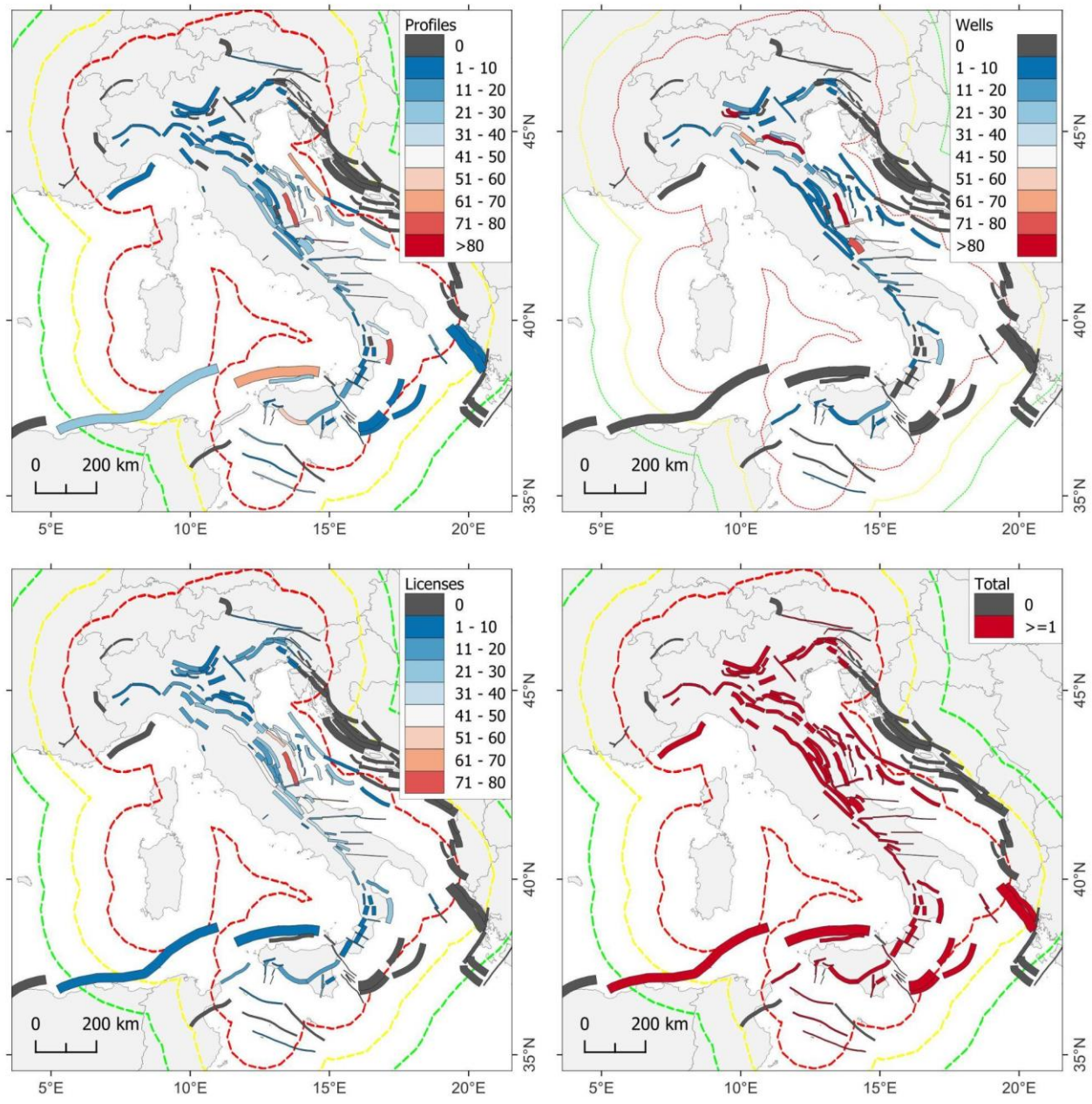

Figure 3 - Maps displaying the distribution of data count for each Composite Seismogenic Source (CSS)

analyzed in this study, categorized by data type, along with the final cumulative data distribution. The symbols of the Area of Relevance are as in **Figure 1**.

Approximately two-thirds of the CSS have at least one set of HC exploration data of any of the three types, and one-third have several data between 1 and 10. The distribution of the number of CSS vs number of HC exploration data elements, separated into the three different types, is shown in **Figure 4**. Notice that the first set of three bars in this histogram shows the count of CSS with zero data of each type; thence, the actual number of CSS with zero data is necessarily lower. Of the 197 CSS in the DISS version 3.3.0, 130 have at least one public seismic line, 98 sources have at least one well log, and 135 are covered by at least one expired license.

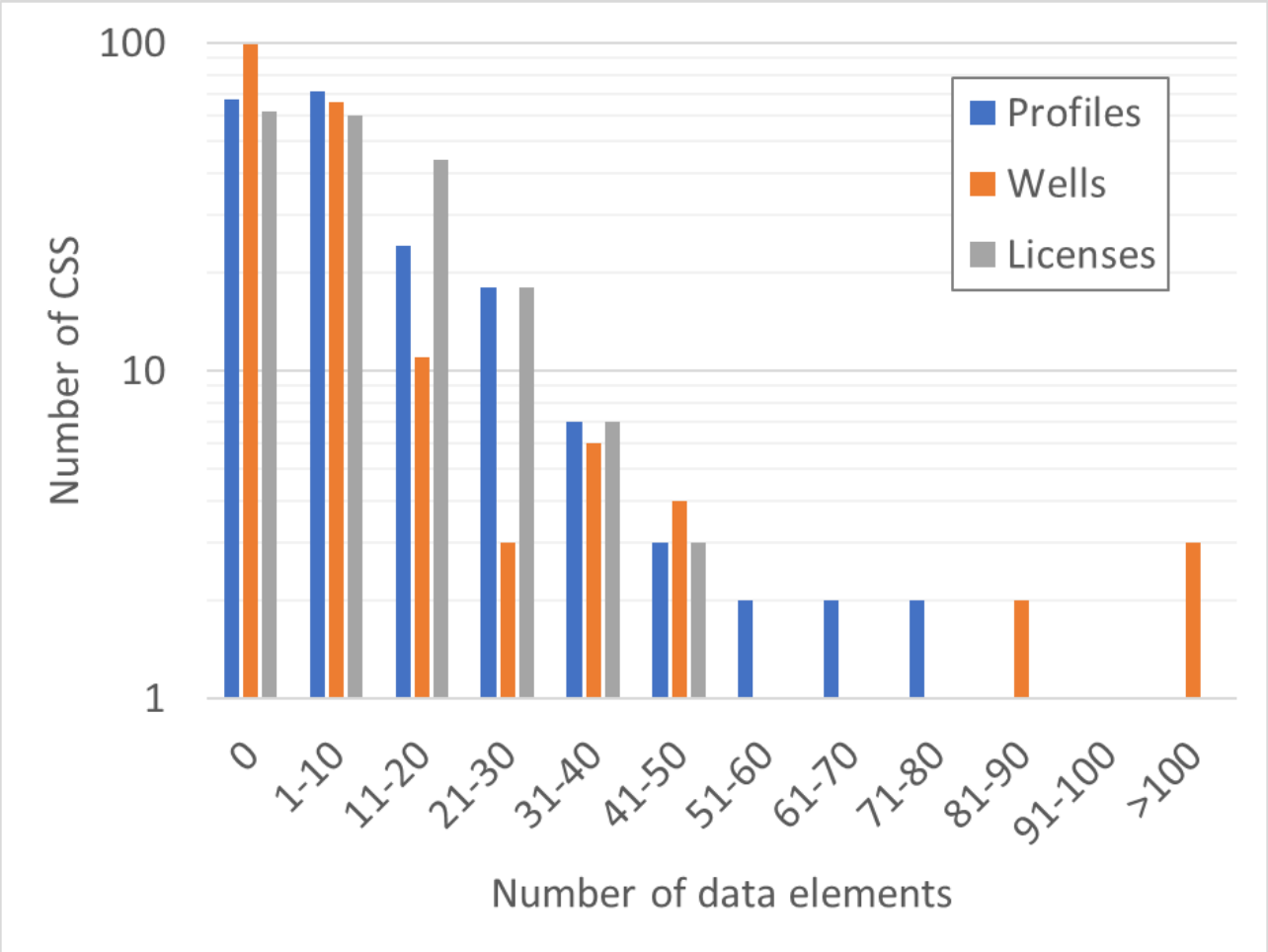

Figure 4 - Histogram showing the number of seismogenic faults from DISS with zero data and with a 10x number of data.

More details of these counts, by data types and considering the CSS inside and outside the 100-km (highest priority) AoR, are reported in **Table 2**, whereas **Table 3** shows the relative proportions of HC exploration datasets intersecting CSS and the total number of elements in the ViDEPI database. Notice that the non-intersecting data elements can still be used to complement the documentation of existing CSS's off-fault zones and explore seismogenic faults that have not yet been mapped.

Table 2 - Summary data for all the composite seismogenic sources, with no data and at least one data, inside and outside the 100-km Area of Relevance.

	Seismic profiles		Final well logs		Expired licenses	
	inside 100-km AoR	outside 100-km AoR	inside 100-km AoR	outside 100-km AoR	inside 100-km AoR	outside 100-km AoR
Number of CSS with NO VIDEPI datasets	43	24	75	24	38	24
Number of CSS with at least 1 VIDEPI dataset	129	1	98	0	135	0

Table 3 – Hydrocarbon exploration datasets intersecting CSS. In parenthesis are the number of seismic profiles acquired in expired mining licenses, offshore reconnaissance, and from the CROP Atlas, respectively.

	ViDEPI datasets intersecting CSS	Total ViDEPI Datasets*
Number of Seismic profiles	1369 (932+400+37)	3044
Number of Final well logs	1232	2299
Number of Expired licenses	916	1406

* Number of elements in the datasets as declared on the ViDEPI website. The actual number in the downloaded files can be different.

Final remarks

We performed a preliminary 2-dimensional analysis of the spatial intersection between the seismogenic faults included in the DISS and the hydrocarbon exploration data publicly available from the ViDEPI database.

The ViDEPI datasets can help document the large majority of potential seismogenic faults identified in the DISS v. 3.3.0. Within the highest priority area, documentation by ViDEPI data cannot be explored only for a few CSS. However, this spatial intersection cannot guarantee successful documentation in all cases. The main limitations would be the quality of the data, the depth explored, and the relevance of the information included in each individual element of the ViDEPI database. Full exploitation of these data can be warranted by resources provided by the Reflection Seismology Laboratory "SismoLab-3D" (https://sismolab3d.ingv.it/index.php/en/) at INGV.

An update of the data available in ViDEPI is expected in the next few years. This update will enable more accurate estimations of the analysis performed here. Different outcomes of this analysis may also come from a newer version of the DISS thanks to potential seismogenic faults identified based on other data types (e.g., tectonic geomorphology or paleo-seismology).

The hydrocarbon exploration data coverage can also improve due to the availability of other datasets from neighboring countries (e.g., the Malta government dataset https://continentalshelf.gov.mt/en/Pages/Oil-and-Gas-Exploration.aspx) or confidential company data (e.g., TGS, https://www.tgs.com/seismic; PGS, https://www.pgs.com/data-library/map/). Confidential data from oil and gas companies have already been used to document seismogenic faults included in DISS, e.g., among the most recent ones, onshore source

ITCS128 (Buttinelli et al., 2021; Di Bucci et al., 2021) and offshore sources ITCS131 and ITCS132 - (Maesano et al., 2020).

Data Availability Statement

All the datasets used in this work are publicly accessible at the URLs listed below.

- Seismic profiles, well logs, and expired licenses on the Italian territory are accessible from ViDEPI (https://ww.videpi.com)
- DISS: https://diss.ingv.it/

Acknowledgments

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