multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

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1. Technical references

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* PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

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0.5	31/07/23	RF+WP Coordinators and TK Leader	Final review and editing

2. ABSTRACT

This report summarized the scientific research activities carried out in the period January – July 2023 by the Task 2.2.1 "Identification of areas at different scales affected or predisposed to ground instabilities, either in the subaerial (a) and submerged (b) environment by existing inventories and archives –implemented and updated by EO services – and permanent and temporary geophysical observatories (dynamic mapping)" (hereinafter referred to as TK1) of the Work Package 2.2 "State of the art and knowledge base to define impact-oriented hazard indicators" (hereinafter referred to as WP2) inside the vertical spoke VS2 "Ground Instabilities" of the Extended Partnership RETURN.

It should be noted that VS2 structured WP2, WP3 and WP4 by identifying the following areas of interest for each of them:

- WP2 focuses on the detection and analysis of PREDISPOSING factors to ground instabilities.
- WP3 targets PREPARATORY factors to ground instabilities.
- WP4 is centred on TRIGGERING and multiple geohazards cascading scenarios (MULTIHAZARD).

In accordance with the definitions given within the VS2, the distinction between predisposing, preparatory and triggering factors/processes is made on a temporal basis: in fact, it means that the predisposing factors are considered invariable on the observation scale, while the preparatory factors show changes or cyclical trends during the same period. As consequence, a trigger is considered as a process that acts in a very short and well-defined time.

The activities of WP2 were directed in the reference period to the examination of the factors predisposing the ground instabilities, starting from a series of case studies (defined Learning Examples, LEs) which represent experiences that each partner has carried out in recent times, and which include cutting-edge analyzes in the theme of characterization of predisposing factors and in the spatial and temporal quantification of susceptibility.

The partner involved in the WP2 are ENEA, OGS, POLITO, UNIBA, UNIBO, UNIFI, UNIGE, UNINA, UNIPA, UNIPD and UNIROMA1. WP2 leaders are Riccardo Fanti (UNIFI) e Mario Parise (UNIBA), TK1 leader is Francesco Maria Chiocci (UNIROMA1), TK2 leader is Mario Parise (UNIBA), TK3 leader is Matteo Berti (UNIBO). 72 researchers participate in the activities of WP2/TK1 (i.e., TK 2.2.1): 5 from ENEA, 3 from OGS, 6 from POLITO, 5 from UNIBA, 6 from UNIBO, 7 from UNIFI, 7 from UNIGE, 8 from UNINA, 13 from UNIPA, 8 from UNIPD and 4 from UNIROMA1.

The goal of TK1 (Identification of areas at different scales affected or predisposed to ground instabilities, either in the subaerial (a) and submerged (b) environment by existing inventories and archives –implemented and updated by EO services – and permanent and temporary geophysical observatories (dynamic mapping)) and the issue of DV 2.2.1 (Collection of inventoried events in a comprehensive integrated dataset) have been interpreted in the framework of the LEs collection. They therefore represent the "comprehensive integrated dataset" of the Deliverable and this document focuses on this.

According with the main idea of the Project and of VS2, the learning phase had the objective of building a Rationale for preparatory processes to be used as input to the Proof of Concept (PoC). This phase has been articulated in three stages:

i) Inventory of Learning Examples (LE).
ii) Individuation of the preparatory processes analyzed in each LE.
iii) Definition of a Rationale for each process based on the available LEs.

During the implementation of the activities of TK1 (but also of TK2) the peculiarity of the theme of the submerged environments highlighted: the team working on this theme in fact proved to be of great quality, but small in number. This is also evident in the number of LEs dedicated to submarine landslides present in the dataset. For this reason, in the continuation of the Project, a specific analysis will be dedicated to the submarine

phenomena, which can be considered as a sort of "parallel" TK, which will be coordinated by Francesco Chiocci (UNIROMA1), as TK1 leader, but above all as expert of the theme.

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4.1 Inventory of Learning Examples (LEs)

During the first months of the project (January – March 2023) each partner of the Spoke carried out an internal review of its past and recent research works, with the aim of selecting the most complete case studies that allow to extract learning and principles that could be extended to other contexts. These case studies, defined "Learning Examples" (LEs), have subjects that could be focused on i) the detection and analysis of PREDISPOSING factors to ground instabilities (WP2), ii) PREPARATORY factors to ground instabilities (WP3), iii) TRIGGERING and multiple geohazards cascading scenarios. For each LE, some scientific papers were stored in a repository (Windows Teams) accessible to all the institutions, in order to provide the reference for the contents of the works. The list of papers collected for WP2 is reported in Section 5.

Once the papers database has been populated, each LE has been inserted in an online inventory (one for each WPs), represented by a shared online table file. This table constituted a synoptic view of the research works, for which several information was provided by the authors of the LEs, including:

- The name/denomination of the LE (site name and/or geographical location or area of interest);
- The environment (subaerial/submerged);
- The context (mountain/hill/plain/coast/near-shore);
- The effect (landslide/subsidence/sinkhole/liquefaction);
- The scale (local/intermediate/regional);
- The analysis tools and techniques (on site monitoring/remote monitoring/deterministic analysis/statistical analysis/machine learning).

4.2 Dataset of LEs

The table for WP2 LEs is summarized in Table 1. The information included has been useful to highlight which research field and topic was well covered by the case studies and which was under-represented, and to realize the quantity and type of case studies available which represent the basis of the subsequent phases of the project. The LEs selected for the WP2 are located in the map of Figure 1.

Appendix A shows some examples relating to the identified processes, taken from the publications concerning the LEs.

Table 1 – Inventory of LEs for WP2. Env: environment (A - subaerial; W - underwater). Context: M – mountain; H – hill; P – plain; C – coast; NS – near-shore. Effect: LS – landslide; SU – subsidence; SI – sinkhole; LI – liquefaction. Scale: L – local; I – intermediate; R – regional. Learning Tools: RS - remote sensing monitoring; OS – onsite monitoring; D - deterministic analysis; S – statistical analysis; ML – Machine Learning.

Institution	LE name	Env		Context					Effect				Scale			Tools				
		A	***W***	***M***	***H***	***P***	***C***	***NS***	***LS***	***SU***	***SI***	***LI***	***L***	***I***	***R***	***RS***	***OS***	***D***	***S***	***ML***
UNIBA	***Daunia***	X		X	X				X				X	x			X	X	X	
	Coste Puglia e Basilicata	X					X		X				X		X	X	X	X	X	X
	Regione Puglia	X				X	X				X		X		X		X	X	X	
	Fossa Bradanica	X		X	X	X			X							X	X			X
UNIBO	***Alta Val Camonica (BS)***	X		X					X					X			X	X	X	
	Appennino Emiliano Romagnolo	X		X	X				X						X	X			X	
	Bologna area urbana	X				X				X			X			X				
ENEA	***Provincia di Messina***	X		X	X				X				X	X			X	X	X	
OGS	***Prealpi Carniche***	X		X	X				X				X			X	X			
UNIPA	***Frana di Scopello***	X		X	X	X	X		X				X	X		X	X		X	
	Messinese Ionico	X		X	X		X		X				X				X		X	
	Frana di Cerda	X			X				X				X	X			X			
POLITO	***Alpi Occidentali, Road Vallone d'Elva (CN)***	X		X					X				X				X	X	X	
UNIFI	***Appennino Settentrionale***	X		X	X				X				X		X	X	X		X	
	Regione Toscana	X		X	X	X			X	X						X	X		X	

	Italia settentrionale	X		X	X				X						X	X			X	
	Guidonia-Bagni di Tivoli	X				X				X	X		X			X			X	X
UNIGE	***Liguria e Piemonte***	X		X	X				X						X				X	
	Piccoli bacini idrografici del versante ligure-tirrenico	X		X	X				X				X	X				X	X	
UNINA	***Monti Lattari (campo prove M.te Faito)***	X		X					X				X			X				X
	Provincia Napoli N	X				X					X		X		X			X	X	
	Napoli	X			X				X					X			X		X	X
	Umbria Marche	X		X					X				X		X			X		
	Emilia Romagna	X				X						X			X				X	
	Regione Campania	X		X	X				X						X	X				
	Bisaccia	X			X				X				X			X			X	
	Pisciotta	X			X				X					X				X		
	Ischia	X		X					X					X						
UNIPD	***Po Delta***	X	X			X	X	X		X				X		X	X		X	X
	Pianura Veneto Friulana	X				X				X				X		X	X		X	
	Frana di S.Andrea e Perarolo di Cadore	X		X					X					X	X	X	X			
	Dolomiti	X		X					X					X		X	X	X	X	X
UNIROMA1	***Subappennino Dauno***	X			X				X					X			X	X		
	Alta Val D'Orcia	X			X				X					X		X		X		
	Area Urbana di Roma	X			X	X			X	X	X			X	X	X			X	
	Regione Lazio Liquefazione	X			X	X						X			X					
	Fiumicino	X				X				X			X	X		X		X		
	Provincia Frosinone e MUSAR	X		X	X				X						X	X		X		X
	Poggio Baldi, Santa Sofia	X		X	X				X				X				X	X	X	

	Frana Seymareh (Iran)	X						X	X					X			X	X		
	Frana Loumar (Iran)	X		X					X					X		X	X	X		

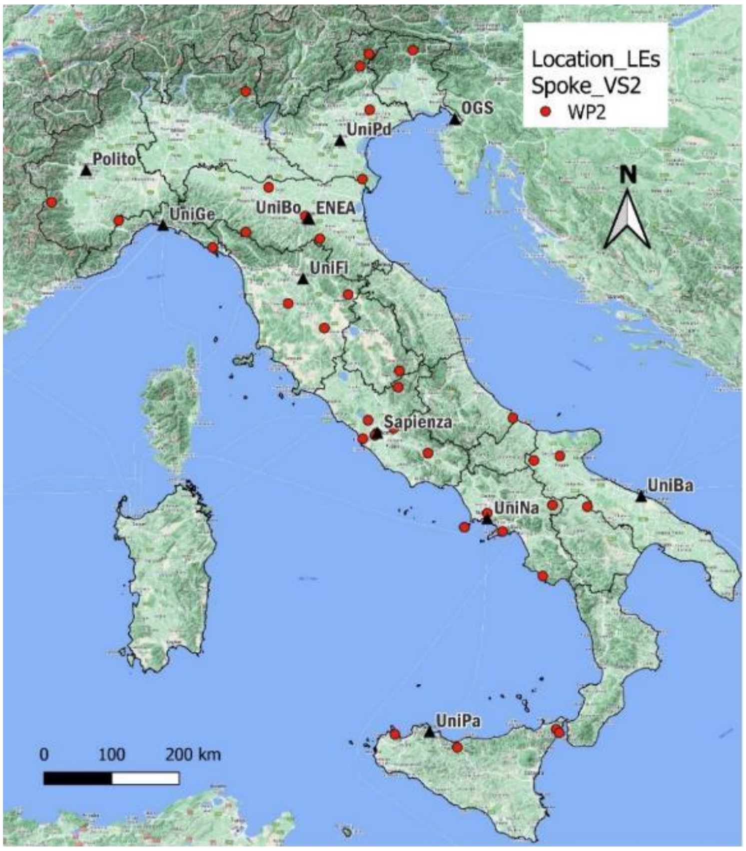

Figure 1: Location of LEs inventoried for WP2.

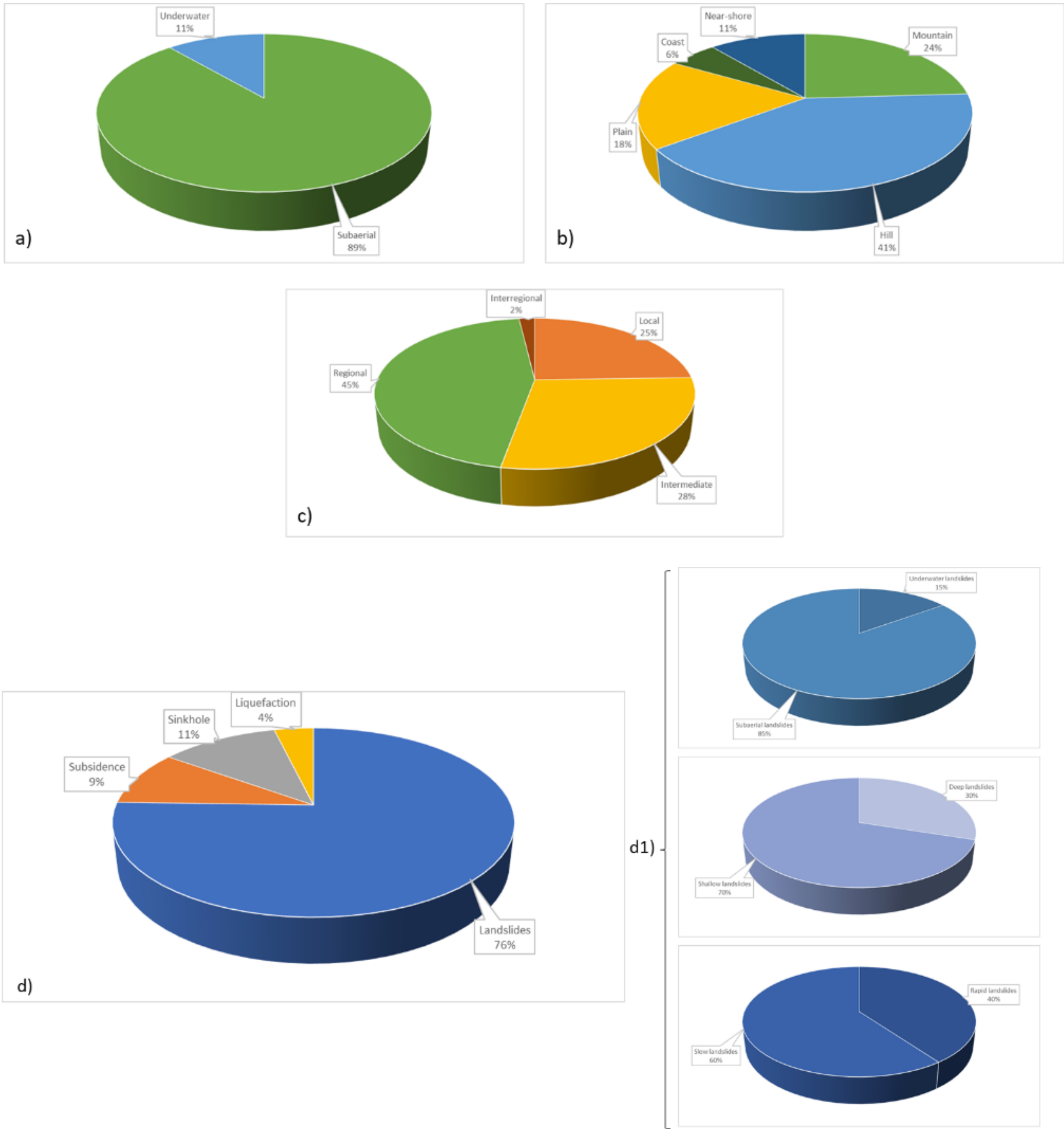

Figure 2. Distribution of WP3 LE2 as a function of (a) Environment: A - subaerial; W – underwater. (b) Context: M – mountain; H – hill; P – plain; C – coast; NS – near-shore. (c) Scale : L – local ; I – intermediate ; R – regional, X - Interregional. (d) Effect: LS – landslide; SU – subsidence; SI – sinkhole; LI – liquefaction. (d1) amongst Landslides: Underwater vs Subaerial; Rapid vs Slow; Deep vs Shallow

The LEs inventory file has been checked by WP2 leaders and TK leaders, during the subsequent phase of the research work (March - May 2023), with the aim of verify the suitable assignment of each LE to the analyzed factors/processes of each WP (predisposing processes – WP2; preparatory processes: WP3; trigger: WP4). WP2 leaders and TK leaders, in synergy with each institution, for each LE, tried to identify the most important factors/processes PREDISPOSING to instability. The association between each LE and the predisposing factors has been discussed and approved with the authors of the works. In a few cases, this kind revision has led to discarding some LEs initially proposed, or to found them more suitable for other WPs.

The following step of the work is to associate each predisposing factor to one or more LE (the "matrix inversion" step): the focus of this analysis was turned to the processes (instead of the single LEs).

5. Second Section

5.1 Strengths and Weaknesses of the approach

The strength of the Learning Examples lies in their provenance and the expertise behind their formulation. These examples were not randomly collected from various sources but were carefully curated by the researchers, ensuring that they align precisely with the specific objectives of the project. As a result, the dataset becomes a reservoir of high-quality information, providing a solid foundation for the analysis and investigation of ground instabilities.

Moreover, the in-depth analysis and scrutiny carried out by the researchers on each Learning Example enhance the richness of the dataset. Detailed examinations of various parameters, boundary conditions, and contributing factors provide a comprehensive understanding of the underlying mechanisms and complexities of ground instabilities. Such detailed analyses allow for a deeper exploration of cause-and-effect relationships, contributing to a more informed decision-making process for mitigating future ground instability risks.

However, while the dataset of Learning Examples boasts considerable strengths, it is also essential to acknowledge its inherent limitations. One of the primary weaknesses of the dataset is that it may not encompass the entirety of possible scenarios and contributing factors related to ground instabilities. The process of data collection, though meticulous, may exclude some phenomena, leading to potential gaps in the overall understanding of the problem.

So, this incompleteness of the dataset poses a challenge in making all-encompassing conclusions or generalizations about ground instabilities. Certain rare or unique cases may have been left unrepresented, and their exclusion might lead to incomplete or biased analyses.

Acknowledging the inherent limitations of the dataset of Learning Examples, WP2 undertook a meticulous and in-depth analysis of the available data. This analytical endeavor aimed to uncover and characterize the predisposing factors that were identified and proposed by the diverse project partners. The culmination of this effort was captured in the Deliverable 2.2.2, which served as a comprehensive documentation of the findings, insights, and methodologies employed in the analysis.

Main critical points derived from WP2 research work, and in particular in the collection of inventoried events for the definition of a comprehensive integrated dataset, are summarized together with some proposed solutions, in Table 2.

Table 2. Main critical points derived from WP2 research work of January - July 2023 and proposed solutions.

Critical point	***Solution to be implemented***
Lack of marine and underwater LEs for the definition of a comprehensive Rationale for the related predisposing	Dedicated ***cascade funding call*** to recruit new researchers with specific expertise in the marine environment.

Minor representation of liquefaction, subsidence and sinkhole effects with respect to landslide studies and LEs.	***Internal recall*** for LEs devoted to these analyses and eventual ***target search*** for international bibliographic data and processing methods.
Lack of coverage with sufficient LEs for some predisposing factors.	***Internal recall*** for LEs devoted to these analyses and eventual ***target search*** for international bibliographic data and processing methods.

6. Conclusions

In general, in the realm of data analysis and problem-solving, selecting the right analytical method is crucial for obtaining accurate and reliable results. Every analytical approach comes with its own set of strengths and weaknesses, and it is essential for researchers, scientists, and analysts to thoroughly evaluate and compare these aspects before making a decision. So, comparing the strengths and weaknesses of different analytical methods can lead to more robust and insightful conclusions.

In the first period of WP2 activities, the creation of a dataset of Learning Examples marked a pivotal milestone in the process of analyzing the predisposing factors of ground instabilities. This dataset served as a valuable repository of deeply mature scientific experiences conducted firsthand by the project partners. As a result, the Learning Examples were essentially case studies that held substantial significance, as they were intimately known and extensively analyzed by the participating researchers. This particular strength of the dataset is worth emphasizing, as it bestows a level of credibility and reliability to the subsequent analytical endeavors.

WP2 LEs Sheets (TK1)

The original working documents (WP2 LEs Sheets) have been classified and are available on the VS2 sharing platform (Microsoft Teams). They may be provided as a further appendix at a later stage of the Project.

7. WP2 LEs References

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8. Appendix A – Examples of the processes considered

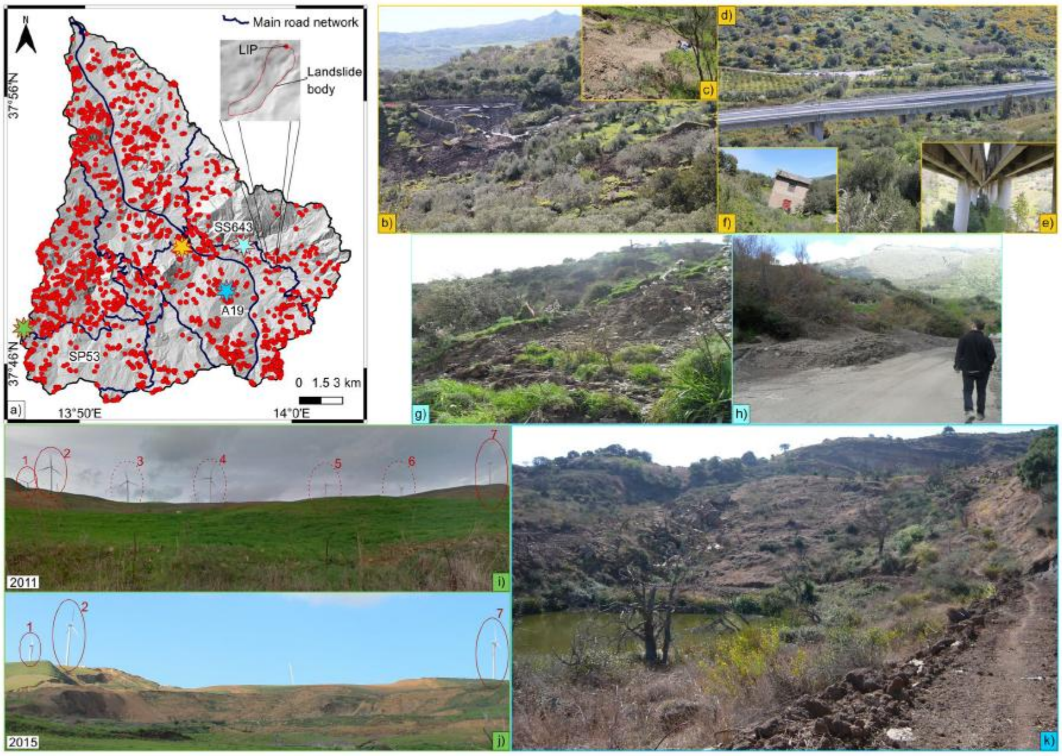

Fig. 2 (a) Map of the landslide identification points (LIPs) and field view of the following: lateral (b) and main (c) scarps and damaged sectors (d, e, f) at the foot area of the 2015 rotational/flow complex landslide affecting the A19 motorway; translational slides; main scarp (g) and landslide accumulation (h) of the 2015 rotational slide affecting the SS643 national road; damage caused to a wind farm (i, before; j, after) in the head zone of the rotational slide affecting the SP53 country road; (k) landslide scarp/head sector of the rotational slide/flow complex landslide in the Suvari area. The stars in (a) indicate the sites for the (b)–(k) field examples, with the same colours as the corresponding picture frameworks

Figure A.1. Example of landslide, subaerial environment, rotational slide/flow/complex phenomena (from Martinello et al., 2022).

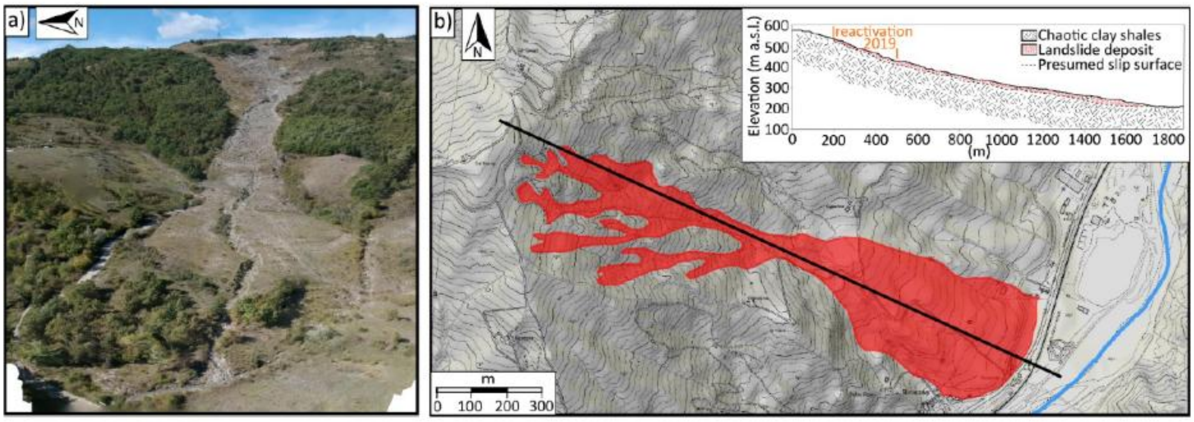

Figure 3. UAV photograph of the Carbona earthflow taken after reactivation (a). Schematic map and profile of the landslide deposit (b).

Figure A.2. Example of landslide, subaerial environment, earthflow (from Ciuffi et al., 2021).

Fig. 84.2 Channelised (*on the left*) and unconfined (*on the right*) debris flows

Figure A.3. Example of landslide, subaerial environment, debris flows (from Puglisi et al., 2015).

Fig. 6 Examples of shallow landslides induced by the 25 October 2011 rainfall event in the Vernazza basin (**a**–**c**) and comparison between post-event conditions just upstream the inhabited area showing debris flood deposits (**d**) and the same area after the removal of debris and mud (**e**). All photographs by A. Cevasco

Figure A.4. Example of landslide, subaerial environment, shallow phenomena (from Cevasco et al., 2014).

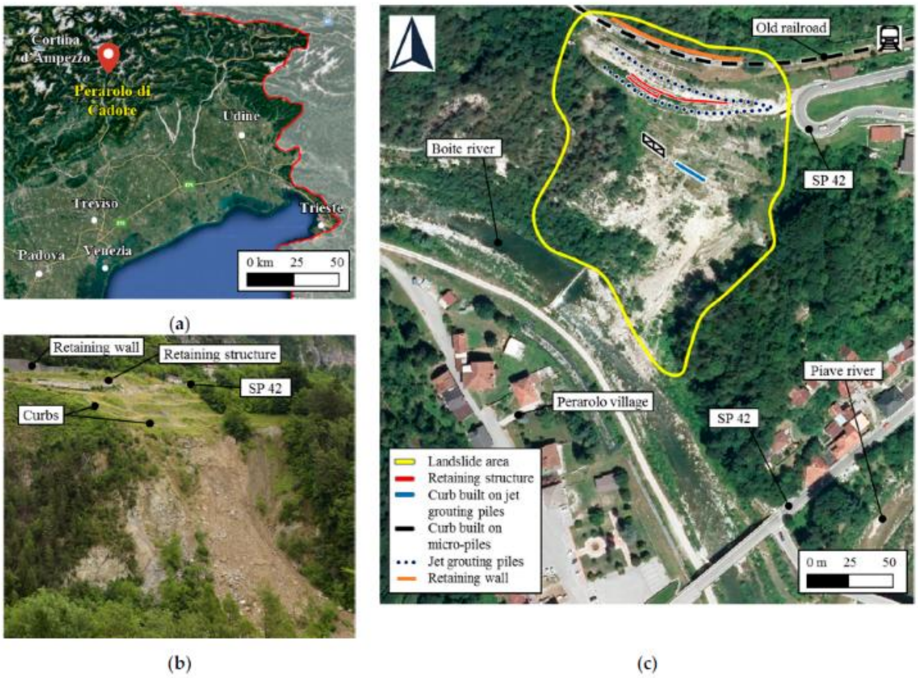

Figure 1. (a) Location of Perarolo di Cadore (NE Italy); (b) frontal view of the landslide area; (c) orthophoto of Sant'Andrea landslide site and its neighborhood. In the orthophoto the boundary of landslide as well as the rivers Boite and Piave, Perarolo village, the main human infrastructures existing near the landslides and the main reinforcement structures built in the past to stabilize the slope are indicated.

Figure A.5. Example of landslide, subaerial environment, rapid phenomenon (from Brezzi et al., 2021).

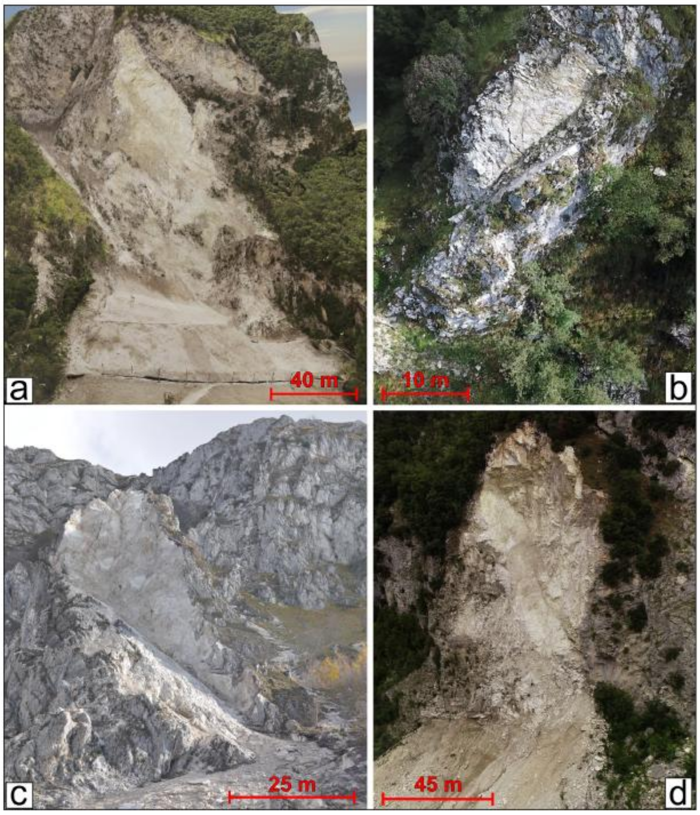

Fig. 3. Scar areas for the studied rock slides: a) Nera (NR); b) Costa Cattiva (CC); c) Piè La Rocca (PR); d) Rubbiano (RB).

Figure A.6. Example of landslide, subaerial environment, rockslides (from Forte et al., 2021).

Figure 4. Instabilities of 2 June 2018 (about 250 m^3) and 25 February 2015 (more than 2000 m^3).

Figure A.7. Example of landslide, subaerial environment, rockfalls (from Migliazza et al., 2021).

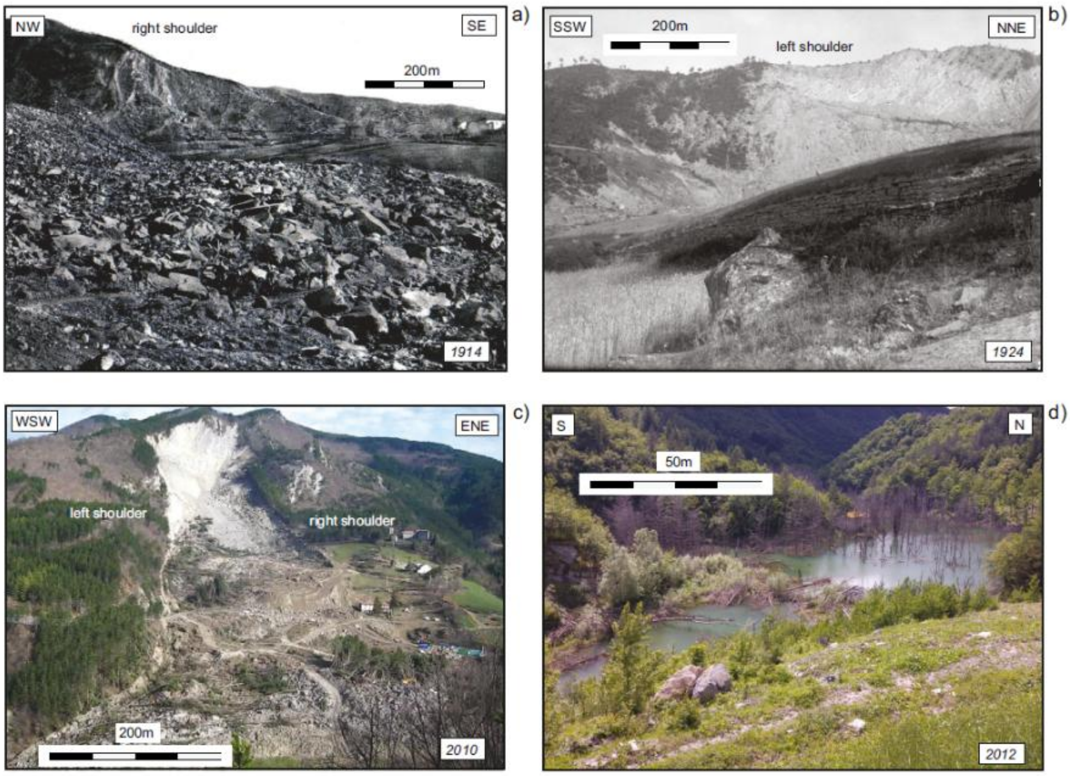

Fig. 2. a) Accumulation area of the Poggio Baldi landslide event on 25th March 1914; b) the Poggio Baldi detachment area in a picture taken in 1924; c) the Poggio Baldi landslide in the week following its reactivation the 18th March 2010; d) the Poggio Baldi barrier lake formed after the 2010 landslide event.

Figure A.8. Example of landslide, subaerial environment, DSGSDs (from Esposito et al., 2021).

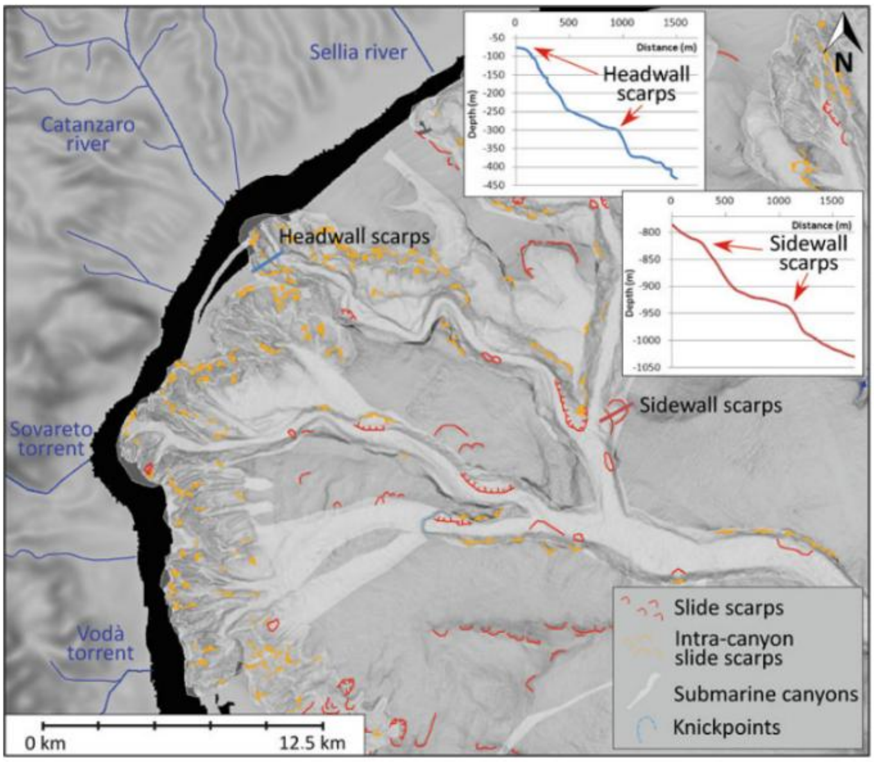

Fig. 26.5 Headwall and sidewall scarps in the Squillace canyon system (location in Fig. 26.1). The cauliform headwall lies 1–3 km from the coast, not all branches of the dendritic network connect with the hydrographic system onshore (in *blue*)

Figure A.9. Example of landslide, submarine environment, canyon system (from Ceramicola et al., 2014).

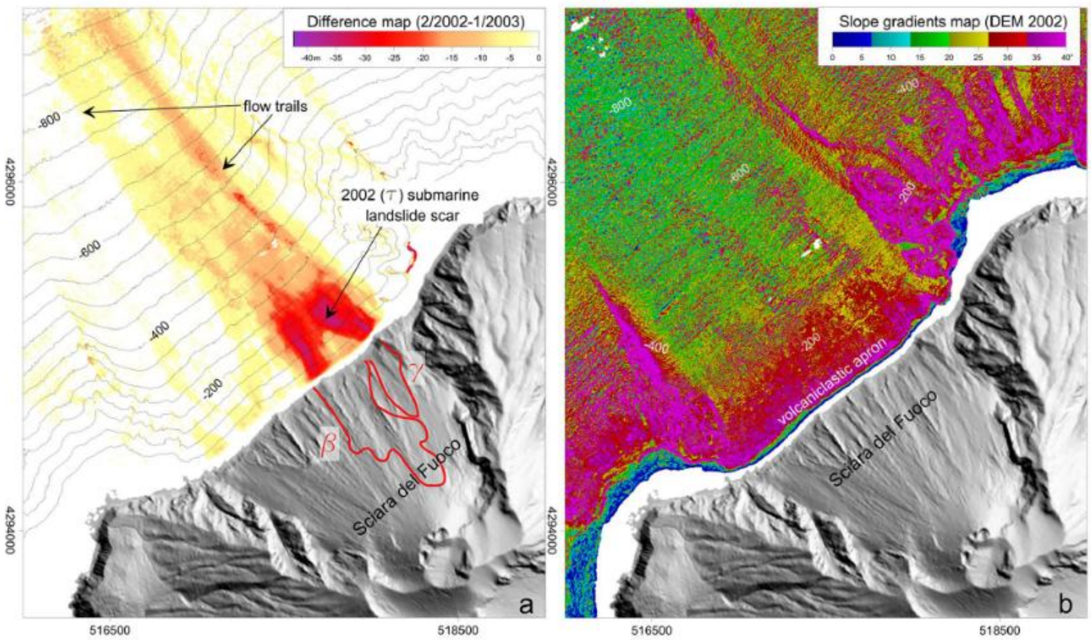

Fig. 2 **a** Difference map obtained by comparing multibeam bathymetries acquired pre- (February 2002) and post-slide (January 2003) showing the geometry of the 30th December 2002 submarine scar down to—350 m; at greater depths two flow trails, associated to the erosion exerted on the seafloor by the sliding mass, are also recognizable; **b** Slope map (in degrees) computed on the pre- (February 2002) slide DEM, indicating a steeper part of the submarine slope (volcaniclastic apron) in the first 300 m of depth

Figure A.10. Example of landslide, submarine environment, slope slide (from Casalbore et al., 2020).

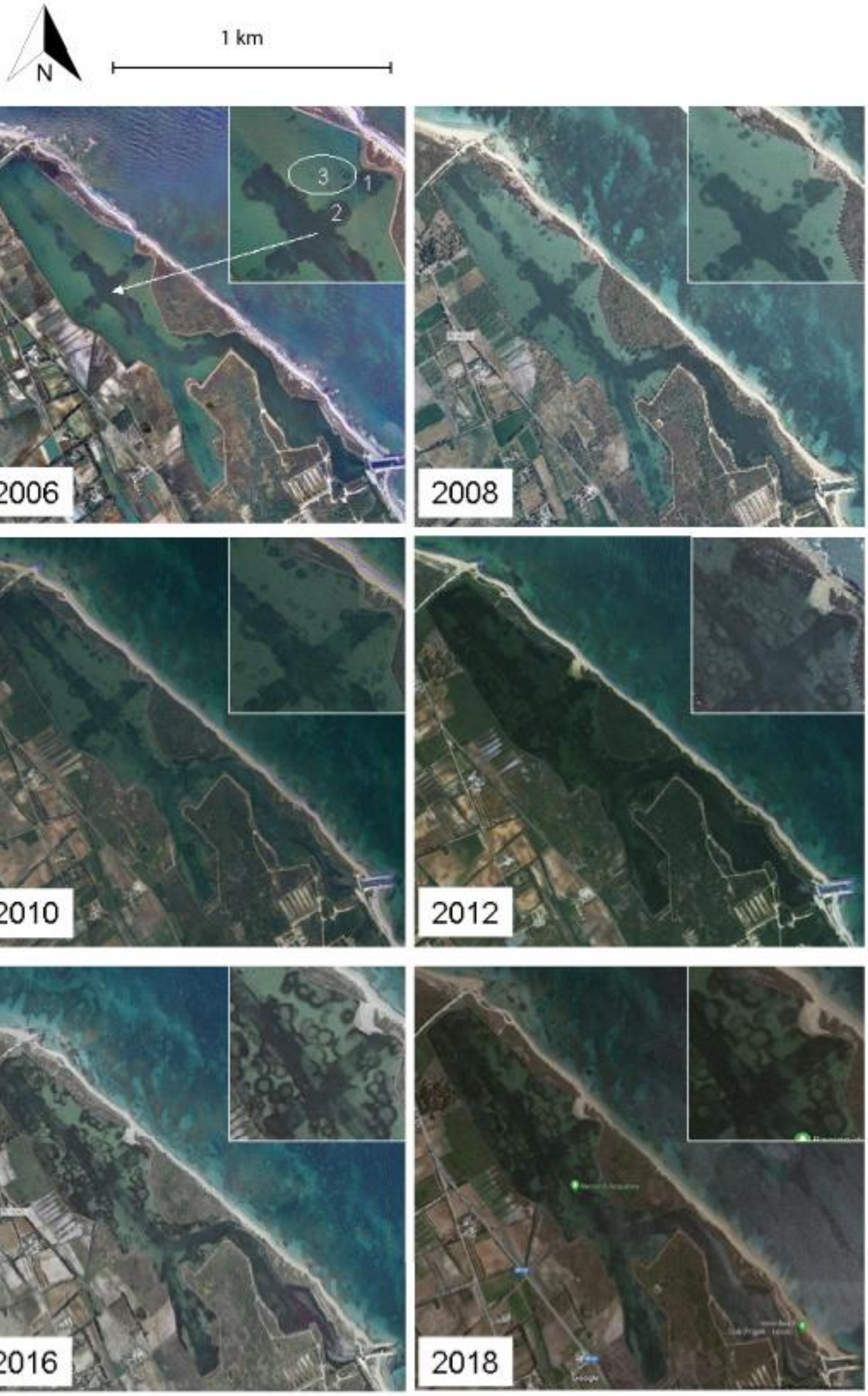

Figure 10. Sequence of aerial photographs (time span from 2006 to 2018), showing evolution of the sinkhole phenomena.

Figure A.11. Example of sinkholes (from Margiotta et al., 2021).

Fig. 3 Examples of sinkholes located in the city of Naples: **a** Via Girolamo Santacroce, Vomero municipality, 15/02/2019; **b** viale Calascione a Monte di Dio, 08/11/2019; **c** via Jacopo De Gennaro, Fuorigrotta municipality, 18/12/2019 (modified from www.ilmattino.it); **d** parking of Ospedale del Mare, 08/01/2021

Figure A.12. Example of anthropogenic sinkholes in urban area (from Tufano et al., 2022).

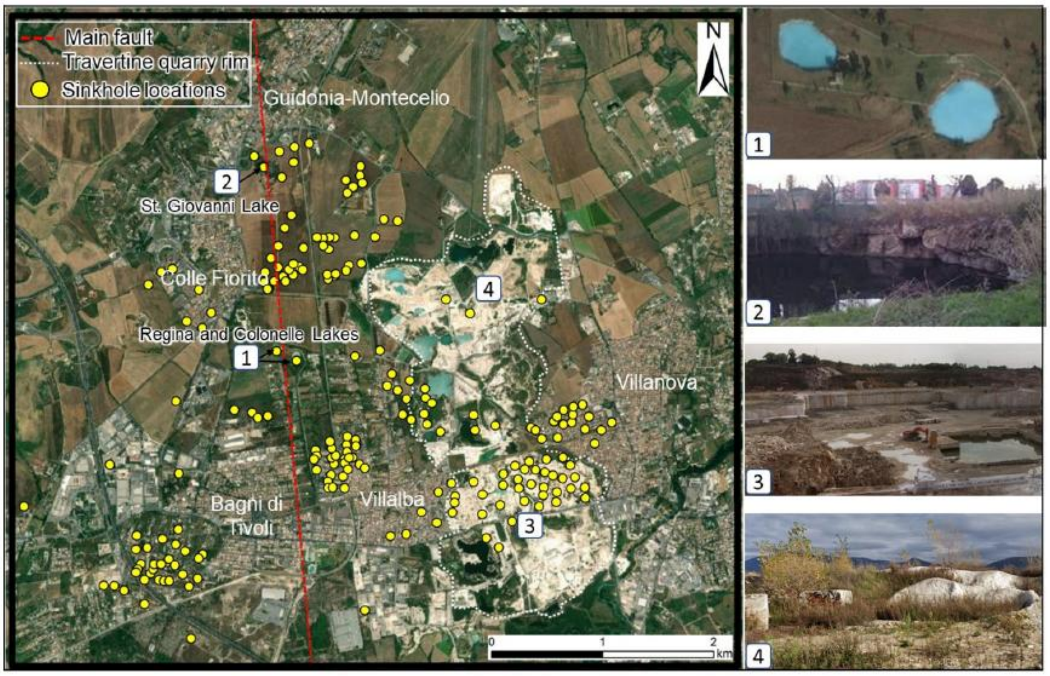

Figure 2. Point-like sinkhole inventory overlapped on orthophoto referred to June 2021. Photos on the left referred to: Regina and Colonnelle lakes (from Bing Maps© Microsoft) (1), St. Giovanni Lake (from Falcioni 2018) (2), Travertine quarrying areas (3) and deposits (from Street View © Google) (4).

Figure A.13. Example of subsidence area (from Bianchini et al., 2022).

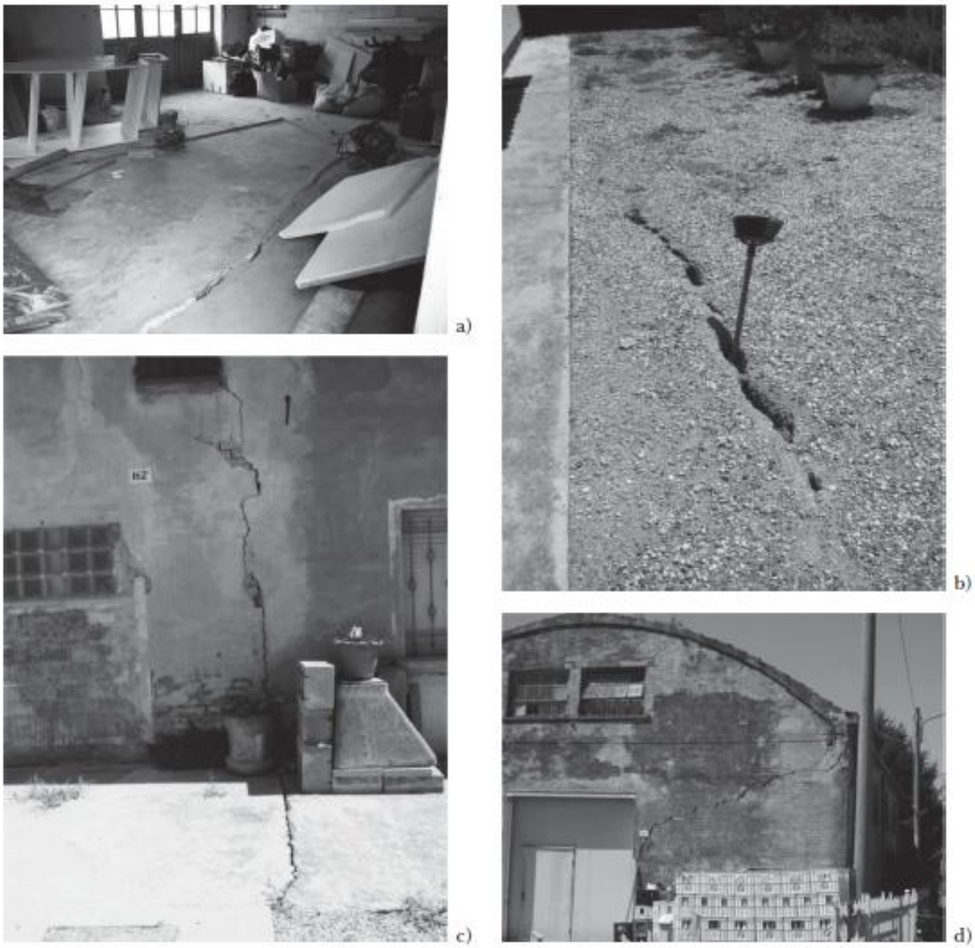

Fig. 2 – Esempi di fratture nel terreno e dissesti agli edifici causati dal sisma nelle aree di indagine A: a); B: b); e C: (c, d).
Fig. 2 – Typical seismic-induced soil fractures and damages to structures observed in areas A: a); B: b); and C: (c, d).

Figure A.14. Example of effects of liquefaction processes (from Tonni et al., 2015).