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The eastern Alps earthquake of 25 January 1348: new insights from old sources

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ABSTRACT The eastern Alps earthquake of 25 January 1348 is one of the few powerful earthquakes located in central Europe, and it is also one of the better-known European earthquakes of the Middle Ages. Its many studies, by different researchers, rely on almost the same collection of historical data, but set out different earthquake scenarios, from which various epicentres and seismic sources are derived. We tried to find a common solution by focusing on the main sources available on the most damaged areas, trying to accurately identify as many earthquake-affected localities as possible, and re-considering all data homogeneously and transparently, in order to allow fruitful criticism and facilitate the work of future researchers. Our study increases the number of earthquake-affected localities, checks the effects in Carniola and confirms the epicentral location proposed recently and included in the latest Italian earthquake catalogue, i.e. in the Camporosso saddle, next to the border with Carinthia and Carniola.

Key words: 1348 earthquake, Villach, eastern Alps.

Experience and learning are the basis of knowledge that regulates human activities, reducing the weight of the imponderable and the margin of risk every time we have to make decisions.

Ezio Mauro, La Repubblica, 23 October 2020

1. Introduction

The eastern Alps earthquake of 25 January 1348 is one of the few very strong earthquakes located in central Europe. Its major effects affected a wide area, divided today between Austria, Italy, and Slovenia. Its shaking was perceived as far west as Strasbourg (France) and possibly as far south as Pisa (Italy). The news of its occurrence spread all over Europe, as witnessed by the vast number of contemporary chronicles that recorded it. The 1348 earthquake is also one of the better-known European earthquakes of the Middle Ages. Most medieval earthquakes have a very poor set of historical data [no more than 10 macroseismic data points (MDPs) each, and in a few cases, no data points at all] but the 1348 earthquake data set includes 46 MDPs according to Hammerl (1994), or 56 MDPs, according to Guidoboni and Comastri (2005).

Up to the 1800s, the 1348 earthquake was taken as a landmark by scholars, from Konrad von Megenberg (14th cent.), author of the first German-language natural history, to many others (Manetti, 15th cent.; Lycosthenes, 1557; Ligorio, 1570-1571; Ragor, 1578; Sardo, 1586; Rash, 1591;

Bonito, 1691; Pilgram, 1788; Hoff von, 1840; Perrey, 1848; Mallet, 1853-1854; Mercalli, 1883; Baratta, 1901). In the second half of the 1800s, several monographic studies were made (Mitteis, 1862; Hoernes, 1878, 1901; Höfer von Heimhalt, 1880; Hann, 1903; Radics von, 1903; Till, 1907). Modern seismological studies, started after the 1976 Friuli earthquake (Slejko, 2018), led to the drafting of several scenarios of the 1348 earthquake (Ambraseys, 1976; Drimmel, 1980; Gentile *et al.*, 1985). On the historical side, it is worth mentioning the in-depth study by Borst (1988). During the last decade of the 20th century, Austrian and Italian researchers resumed the study by carrying out extensive surveys of medieval European records. The most relevant are Christa Hammerl's doctoral thesis, written in the German language (Hammerl, 1992) and its English summary (Hammerl, 1994), which was the reference study for the Italian intensity database (Stucchi and Monachesi, 1997), and the work begun by Boschi *et al.* (1997, 2000) and resumed by Guidoboni and Comastri (2005). This latter was included in the earthquake catalogue of the Mediterranean area (Guidoboni *et al.*, 2018).

Although all these studies largely rely on the same set of historical data, each interprets them in its own way, setting out different earthquake scenarios, from which different epicentres and seismic sources are derived. Finding a solution is critical because the 1348 earthquake is the crucial event for assessing the maximum possible magnitude in the seismogenic zone of the eastern Alps area where it took place. In this work, we analyse principally the contributions of Hammerl (1994) and Guidoboni and Comastri (2005).

Some years ago, in the frame of the compilation of the Italian earthquake catalogue CPTI15v1.5 (Rovida *et al.*, 2016), some of the authors of the present work released a preliminary report about this event (Caracciolo *et al.*, 2015). It is still the reference study for the CPTI15v3.0 catalogue (Rovida *et al.*, 2021). Caracciolo *et al.* (2015) was 'only an extreme and circumscribed summary, which anticipates the conclusions being drawn up and published', and though it did significantly increase the 1348 earthquake data set, it also left several unresolved questions. The new study presented here goes beyond this commitment because it not only completes the preliminary report, describing its criteria and methodology, and discusses the issue thoroughly, but is above all a revision of the results. Moreover, in this work, we introduce and discuss other aspects, such as the geophysical and tectonic aspects, which were absent in Caracciolo *et al.* (2015).

Up to the mid 1900s, the 1348 earthquake used to be associated with Villach, a town in Carinthia (currently a State or *Land* of Austria), which contemporary sources name as the region that was most heavily damaged by the quake. Later studies located the earthquake close to the present boundary between Italy, Austria, and Slovenia or shifted the epicentre to the south, at the edge of the Friuli Plain (Fig. 1). Similarly to the case of the earthquake of 1511 (Camassi *et al.*, 2011), considerable uncertainty remains about the location, as well as for the magnitude value of the event (Table 1). Although most of the proposed locations refer to the border area of the three cited countries, they do not identify a possible seismogenic source because of the complex tectonic environment with two main systems in this region: the pre-Alpine overthrusts to the south and the Alpine vertical faults to the north with the Gail Line (letter a in Fig. 1) acting as a boundary between the two systems. In any case, the high magnitude of the 1348 earthquake makes it reasonable to think that it should be associated with a large fault such as the Gail Line (letter a in Fig. 1) or the Fella-Sava Line (letter b in Fig. 1). Conversely, taking into account the 1348 earthquake's very wide distribution of damage, it could be associated with the Gemona-Kobarid Thrust (letter c in Fig. 1), located farther south than the previously cited faults, as proposed by Galadini *et al.* (2005).

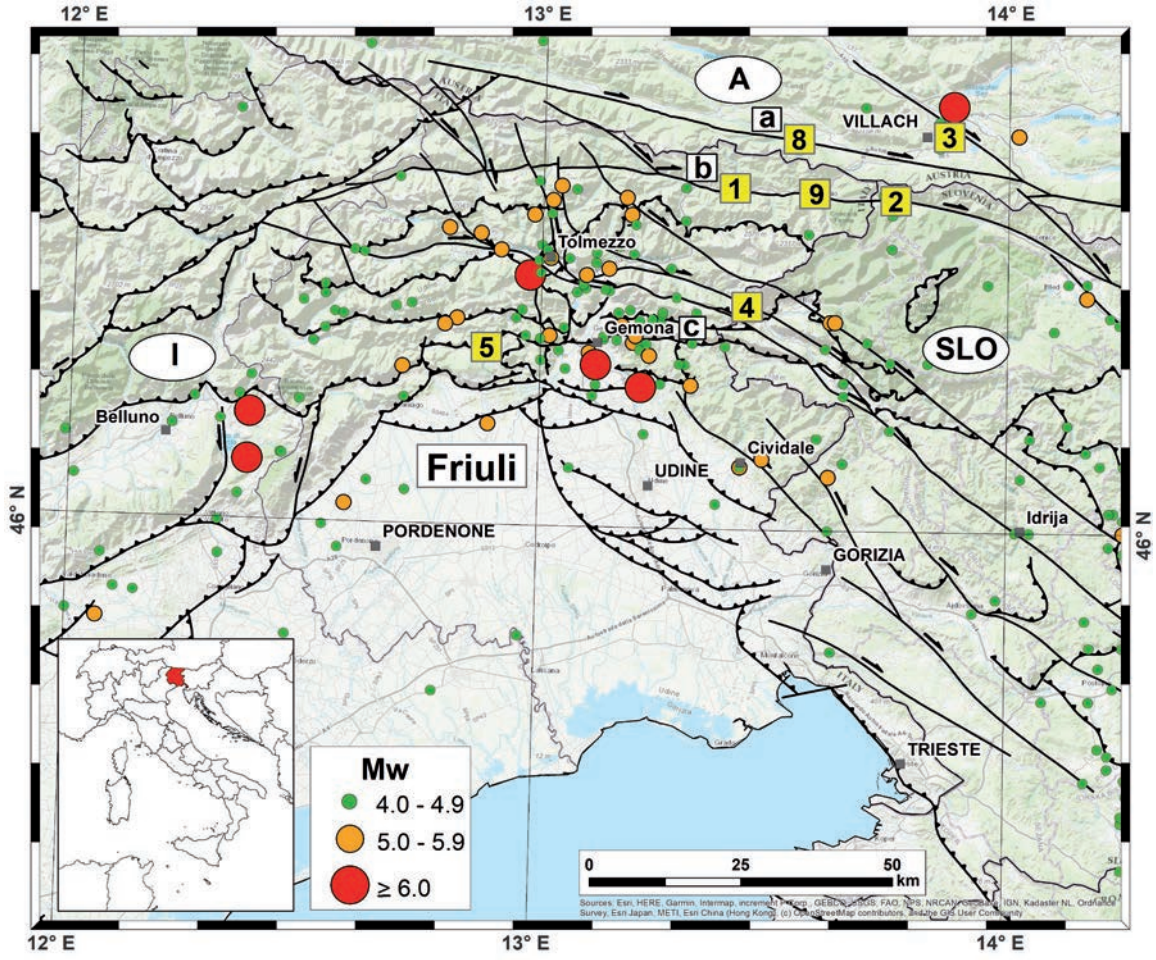

Fig. 1 - Seismotectonic map of the eastern Southern Alps and western External Dinarides. Red circles indicate events with an M_w larger than, or equal to, 6.0, yellow circles events with an M_w between 5.0 and 5.9, and green circles events with an M_w between 4.0 and 4.9. The earthquake epicentres (1000 - 2017) are taken from Rovida *et al.* (2021) and the faults (black lines) from Galadini *et al.* (2005): a = Gail Line; b = Fella-Sava Line; c = Gemona-Kobarid Thrust. The epicentres proposed for the 1348 earthquake according to different authors are shown with yellow squares, the numbers refer to the references in Table 1: 1 = Ambraseys (1976), 2 = Bartole *et al.* (1976), 3 = Gentile *et al.* (1985), 4 = Boschi *et al.* (1995), 5 = Hammerl (1994) [according to the interpretation of DOM 4.1 (Stucchi and Monachesi, 1997)], 8 = Guidoboni *et al.* (2018), 9 = this study. The red area in the inset map of Italy shows the Friuli - Venezia Giulia region.

This uncertainty in the location of the 1348 event plays an important role in the seismic hazard assessment of the territory because, together with the earthquakes of 1511 (Camassi *et al.*, 2011) and 1976 (Slejko, 2018; Tertulliani *et al.*, 2018), the 1348 earthquake represents the largest event to occur in the region and it is fundamental both as a design earthquake in risk scenarios and as a source definition for probabilistic seismic hazard assessment. To quantify the last statement, the influence of different locations of the two historical earthquakes has been investigated to identify the variability of the expected ground motion considering two major towns affected by those events, Tolmezzo and Udine (Fig. 2a). Four of the proposed earthquake locations have been taken into account for the 1348 and 1511 earthquakes (Table 1): they remain associated with different seismogenic zones (see the black

boxes in Fig. 2a) according to the regional seismic hazard assessment (Slejko *et al.*, 2011). The computed seismic hazard, in terms of expected peak ground acceleration (PGA) for different annual exceedance probabilities, shows a near coincidence of results for high probability but noticeable differences can be seen for probabilities lower than 0.0004 (i.e. return periods longer than 2475 years) both for Tolmezzo (Fig. 2b) and Udine (Fig. 2c). When considering the Italian seismic hazard map (http://esse1-gis.mi.ingv.it/), no difference is found in the computed seismic hazard curves of the two sites of Udine and Tolmezzo (green dashed lines in Figs. 2b and 2c). This is because both towns are inside the same wide source of the Italian seismogenic zonation (red boxes in Fig. 2a), and even considering the different epicentres in Table 1, the seismic hazard curves would not change notably. The need for a good knowledge on the historical earthquakes is, then, strongly motivated although the influence produced in seismic hazard, as pointed out by this analysis, is marginal but of interest in specific cases [e.g. risk analysis (Carulli *et al.*, 2003), retrofitting intervention priorities (Grimaz *et al.*, 2016)].

Table 1 - Different epicentres proposed in literature for the 1348 and 1511 earthquakes.

Ref.	Authors	1348			1511		
		Lat.	Lon.	Mag.	Lat.	Lon.	Mag.
1	Ambraseys (1976)	46.50	13.40	6.6	46.20	13.60	6.4
2	Bartole *et al.* (1976)	46.50	13.75	6.8			
3	Gentile *et al.* (1985)	46.60	13.85	5.7			
4	Boschi *et al.* (1995)	46.333	13.433	7.3			
5	Hammerl (1994)*	46.254	12.883	6.7			
6	Fitzko *et al.* (2005)				45.87	14.07	6.6
7	Camassi *et al.* (2011)				46.209	13.216	6.3
8	Guidoboni *et al.* (2018)	46.580	13.541	7.1	46.198	13.431	7.0
9	This study	46.504	13.581	6.6			

*According to the interpretation of DOM 4.1 (Stucchi and Monachesi, 1997).

The 1348 earthquake is also crucial for assessing the maximum possible magnitude in the seismogenic zones of the eastern Alps and for implementing efficient measures of emergency planning of civil protection. With the exception of the zonation used for the most recent seismic hazard map of Italy (Gruppo di Lavoro, 2004; Stucchi *et al.*, 2011), where the seismogenic zones are very large, the locations of the 1348 and 1511 earthquakes are crucial for the zonation design, as seen before, and, although their direct contribution to hazard can be limited (Fig. 2), both the 1348 and 1511 earthquakes considerably condition the maximum possible magnitude for the related seismogenic sources and, consequently, the identification of the design earthquake for risk assessment.

For this reason, it is necessary to ensure that their size and location are established as accurately as possible, i.e. from a macroseismic scenario as complete and reliable as possible. This paper describes the efforts made, in the last few years, to solve some of the still open questions by: a) focusing on the main historical sources that deal with the most damaged areas (Friuli, Carinthia, and Carniola); b) trying to correctly identify as many of the earthquake-affected localities named in these sources as possible; c) re-considering all the available data in a homogeneous way; d) keeping track, as fully and transparently as possible, of the whole process, in order to allow fruitful criticism and to facilitate the work of future researchers.

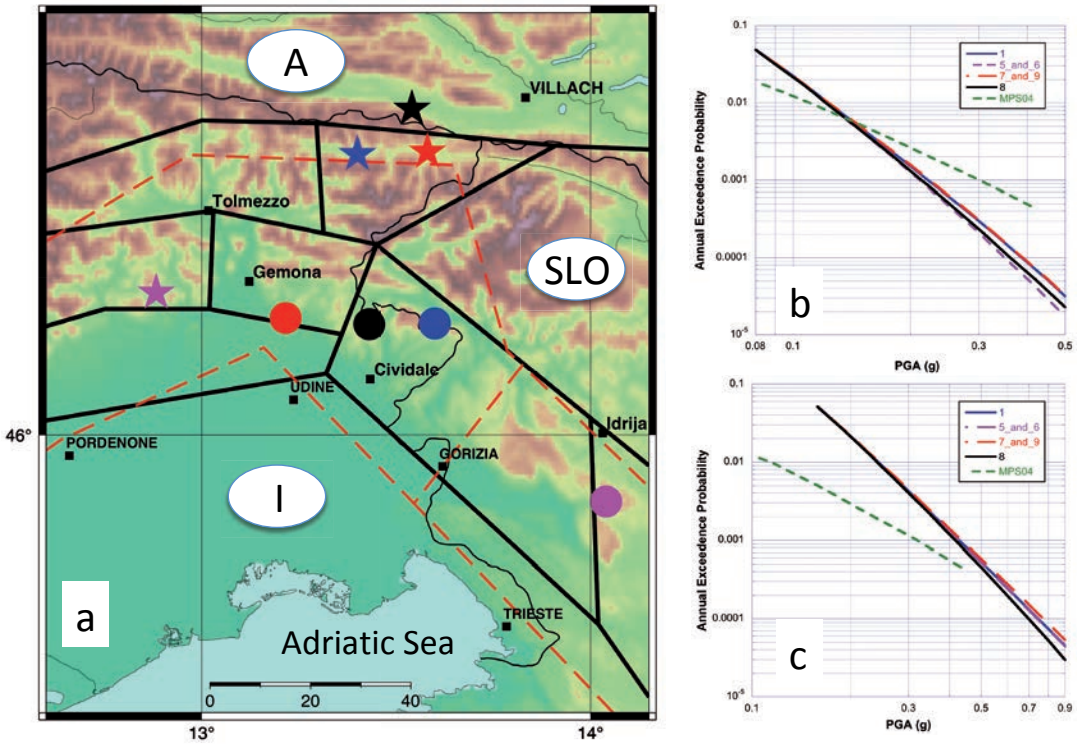

Fig. 2 - Influence of different locations for the epicentres of the 1348 (stars) and 1511 (circles) earthquakes in the expected ground motion, in terms of PGA (in g) vs. annual exceedance probability, at two main towns in Friuli: a) epicentres according to different authors: blue = n. 1 in Table 1 (Ambraseys, 1976), violet = n. 5 in Table 1 (Hammerl, 1994) for the 1348 event and n. 6 in Table 1 (Fitzko *et al.*, 2005) for the 1511 event, black = n. 8 in Table 1 (Guidoboni *et al.*, 2018), red = n. 9 in Table 1 (this work) for the 1348 event and n. 7 in Table 1 (Camassi *et al.*, 2011) for the 1511 event; b) seismic hazard curves for Udine according to the different epicentres of Table 1; c) seismic hazard curves for Tolmezzo according to different epicentres of Table 1. The black boxes in panel a indicate the seismogenic zones used for the regional seismic hazard assessment (Slejko *et al.*, 2011) while the red ones are those used in the Italian seismic hazard map (Stucchi *et al.*, 2011). The green dashed lines in panels b and c show the seismic hazard curves according to the Italian seismic hazard map (http://esse1-gis.mi.ingv.it/).

2. The framework

2.1. Seismotectonic framework

The area affected by the 1348 earthquake (Fig. 1) represents the north-eastern portion of the deformed margin of the Adria microplate (Anderson and Jackson, 1987; Slejko *et al.*, 1989), caused by the anticlockwise rotation of Adria against the Eurasian plate, where the Periadriatic Lineament [whose segment in the study area is called the Gail Line (letter a in Fig.1)] represents the boundary between the two plates and related tectonic systems (Southern Alps and Alps). Moreover, the area comprises the hinge zone between the eastern sector of the Southern Alps and the north-western part of the External Dinarides (Carulli *et al.*, 1990). Both systems reflect in shape and in geodynamic evolution the effects of the cited collision between Adria and Europe. The Southern Alps gradually pass towards the east into the Dinaric orogenic belt and the southern parts of these mountain chains (Carnian and Julian Prealps) face southwards on the Friuli Plain (i.e. the eastern end of the Po Plain), which can be considered as their foreland basin.

The Southern Alps orogenic belt is composed of closely-spaced, E-W oriented, generally south-verging overthrusts (Fig. 1). The southernmost overthrusts, in the maximum shortening zone, developed in response to the more recent N-S oriented compressional stresses (Zanferrari *et al.*, 2000). The recent activity of these tectonic lines is amply documented by geological data (Carulli *et al.*, 1980; Zanferrari *et al.*, 1982) and high-precision topographic measurements (Talamo *et al.*, 1978). The north-western edge of the Southern Alps is characterised by the presence of E-W oriented faults, among which the Gail Line (letter a in Fig. 1) and the Fella-Sava Line (letter b in Fig. 1) are the most important. The Gail Line represents the eastern segment of the Periadriatic (or Insubric) Lineament; it is a system of E-W oriented, sub-vertical mostly normal dislocations and is a very strong tectonic separation between the south verging thrust belt of the Southern Alps, unaffected by Alpine metamorphism, and the metamorphic nappe building of the Alps (Transalp Working Group; 2003). The Fella-Sava line is an E-W oriented, reverse high-angle fault (Castellarin, 1981). According to Carulli *et al.* (1980), morphotectonic evidence connected to post-Pleistocene anomalies of the hydrographic grid support a recent sinistral and dextral transcurrent activity of the Gail and Fella-Sava lines, respectively. Conversely, according to Doglioni (1999), both the Gail and the Fella-Sava lines are potentially active with probable dextral transpressive movements. The Gemona-Kobarid Thrust (letter c in Fig. 1) is an outstanding structural feature whose high-angle ramp bounds to the north the entire Friulian thrust edifice (Galadini *et al.*, 2005).

The tectonic elements of the Dinaric orogenic belt are overthrusts and mostly dextral, sub-vertical faults with direction ranging between NW-SE and NNW-SSE and with a SW vergence.

Thanks to the early settlement of this area (some towns, such as Belluno, Cividale, and Trieste, already existed in Roman times and flourished in the Middle Ages) the historical seismicity of the eastern Alps is comparatively well known (e.g. Bonito, 1691; Baratta, 1901). The eastern Alps and western Dinarides have a long history in instrumental data collection too, some seismographic stations (e.g. Trieste, Ljubljana, Pula, Padua, Venice, Treviso) having been operating since early 20th century (Sandron *et al.*, 2014). Thanks also to studies on regional seismicity (e.g. Slejko *et al.*, 1989), the latest Italian earthquake catalogue (Rovida *et al.*, 2021) gives a creditable overview of the seismically most active areas. Major seismicity occurs along the piedmont belt, from Cividale to Belluno, reaching its maximum in central Friuli (Fig. 1). Minor seismicity occurred in southern Austria and western Slovenia (Del Ben *et al.*, 1991). Not considering the 1348 event, the only strong historical earthquake located in the proximity of the cited Gail Line occurred in 1690 (Barbano *et al.*, 1994), while a few small magnitude events are reported along the close River Fella valley (Poli *et al.*, 2002).

Owing to the regional tectonic regime (mostly overthrusts), a direct association of earthquakes to faults is very difficult and, consequently, seismicity was more easily associated with fault systems and wide zones were generally proposed as seismogenic sources [see the most recent zonations in Slejko *et al.* (2011)] and used for seismic hazard assessment.

2.2. Historical context

A little knowledge of the geopolitical context of the 1348 earthquake can help to appreciate the qualities of the records that describe its effects. The area most severely affected by the earthquake was a political and cultural patchwork. It was governed by several rulers, both lay and ecclesiastic: the Dukes of Carinthia and Carniola, the Patriarch of Aquileia, the Count of Gorizia, the German bishops of Freising and Bamberg (Fig. 3). The inhabitants belonged to several ethnic groups and spoke different languages (German, Italian, and Slav dialects).

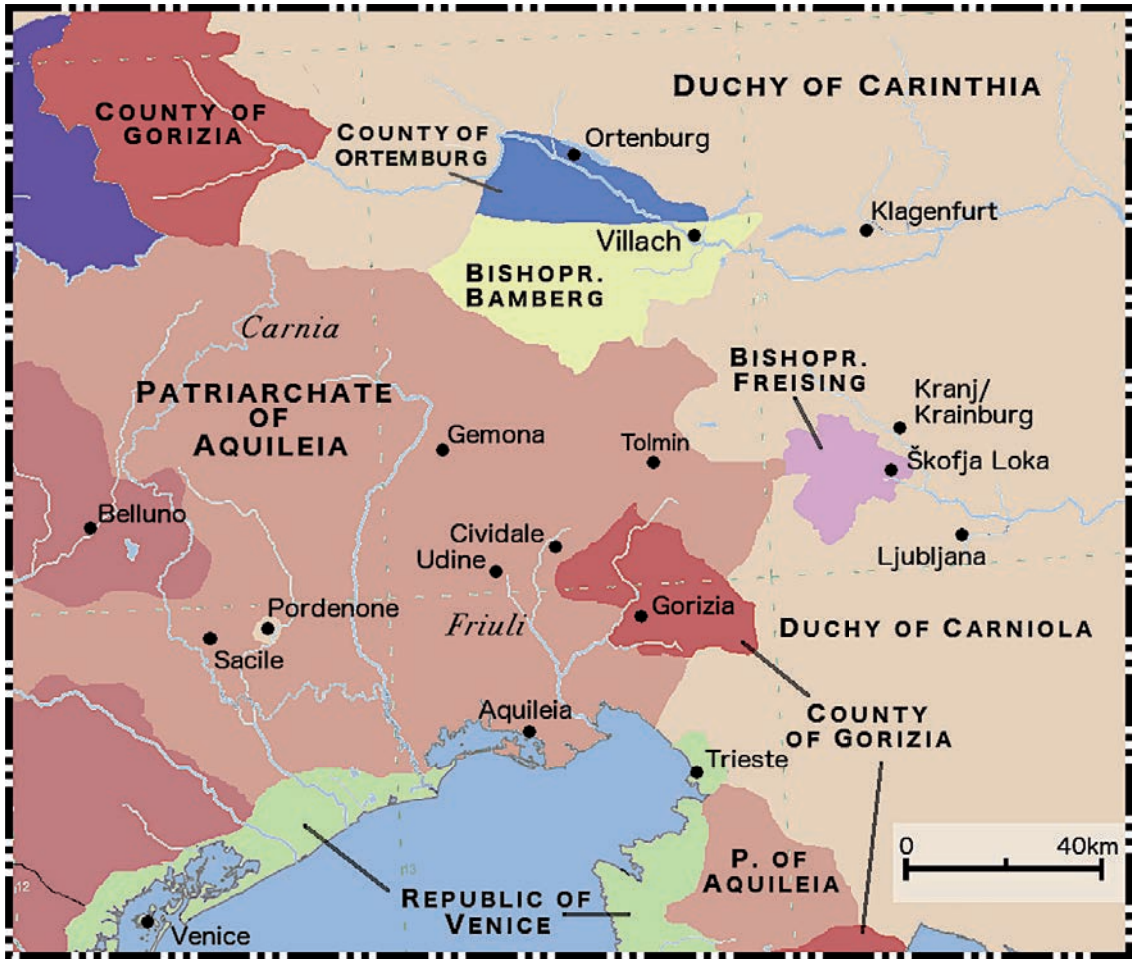

Fig. 3 - Political jurisdictions of the area most affected by the earthquake, in the first half of the 14th century.

No first-hand account of earthquake effects in this region seems to have survived. However, by some means or other, descriptions of these effects did reach contemporary (or nearly so) chroniclers, who lived outside the most affected area and who preserved these accounts by transcribing or by summarising them in their writings. During this process, the original texts (that could have been written in Latin or in any of the other languages spoken in the area) could have been translated, shortened and maybe distorted. Another layer of complexity was added by the plague pandemic known as 'the Black Death', that swept over Europe days, weeks or months (according to the cases) after the earthquake, taking a toll of possibly millions of victims and causing severe social and economic upheavals. It is difficult to evaluate how heavily the plague conditioned the availability of historical sources about the 1348 earthquake. Nonetheless, our understanding of what actually happened in the area most affected by this earthquake must be based on reports written by people who lived outside it, but somehow managed to collect information coming from there and preserved it for posterity. Of these second-hand reports, one was written up a few weeks after the earthquake (Villani, 14th cent.), another a few years after (Matthias von Neuenburg, 14th cent.-a, 14th cent.-b), the last a few decades later (Detmar von Lübeck, 14th cent.). If we wish to make the most of them, we have to sharpen our investigation tools as best we can.

3. Toward a new scenario

The studies by Hammerl (1992, 1994) and Guidoboni and Comastri (2005) are based more or less on the same set of sources, but they interpret them in different ways. Hammerl (1994) identifies 46 affected localities (MDPs) and proposes an epicentral location in northern Friuli (n. 5 in Fig. 1) instead of in the area of Villach (southern Austria), because the author believes that reports of particularly heavy damage in Villach could have been exaggerated by mistaking the consequences of a massive, earthquake-triggered landslide on the nearby Dobratsch Mount for seismic effects. Guidoboni and Comastri (2005) identify 57 affected localities (MDPs) and confirm the traditional epicentral location of the earthquake in southern Austria, near the Friuli border (n. 8 in Fig. 1), though they suggest that a different solution could be possible, pointing out that "the identification of the epicentre is (...) considerably hampered by the lack of data for the Slovenian area".

The identification of place names mentioned by the sources is a crucial issue for the interpretation of the 1348 earthquake, but neither Hammerl (1992, 1994) nor Guidoboni and Comastri (2005) explain either how they identified each place name or why they disagree in the identification of some important places (see Fig. 4). Both Hammerl (1992, 1994) and Guidoboni and Comastri (2005) derive most of their information from Villani (14th cent.) and Matthias von Neuenburg (14th cent.-b), two chroniclers that give long lists of earthquake-affected localities. A third source giving information on many localities is the chronicle by Detmar von Lübeck (14th cent.). Hammerl (1992, 1994) uses it sparingly, but Guidoboni and Comastri (2005) do not use it at all because they do not consider it a 'primary source'.

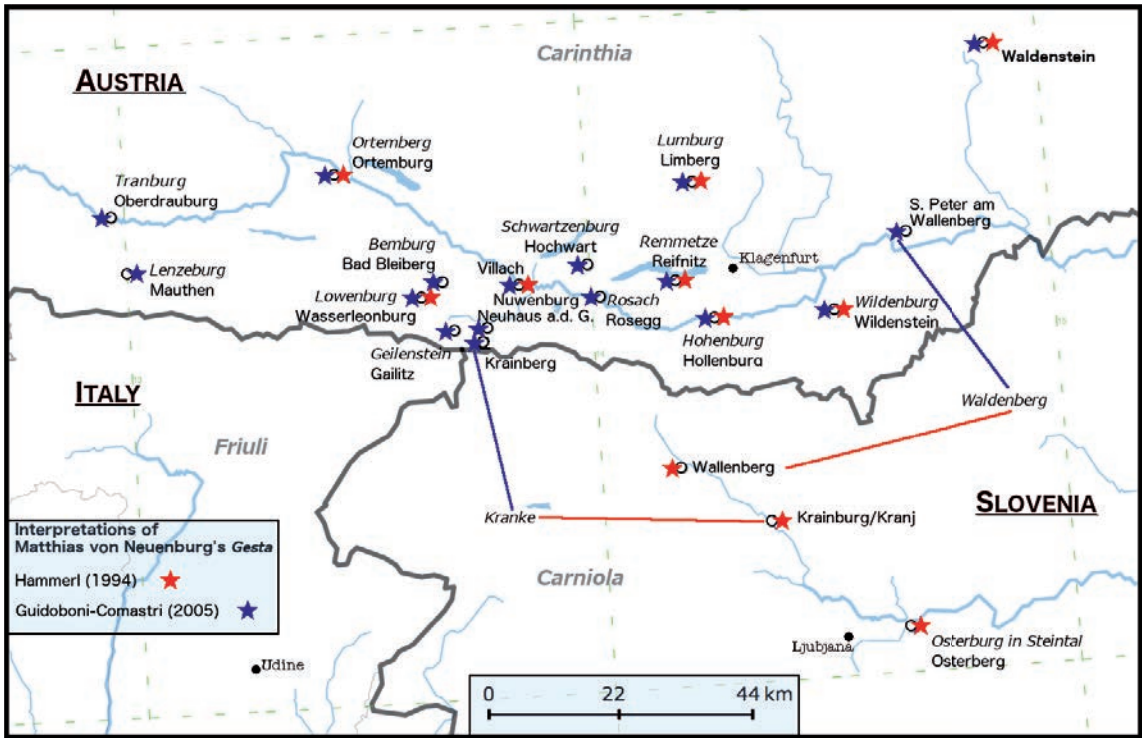

Fig. 4 - Location of the toponyms mentioned in Matthias von Neuenburg (14th cent.-b) according to Hammerl (1994) (blue stars) and to Guidoboni and Comastri (2005) (red stars).

Considering the scenario proposed in the cited studies and by an unpublished paper by Hammerl (1993), and focusing on the most damaged zones (Carinthia, Carniola, and Friuli), we note that more than half of the localities (16 MDPs out of 28) are derived from Villani (14th cent.), Matthias von Neuenburg (14th cent.), and Detmar von Lübeck (14th cent.) (Fig. 5), that none of the cited studies exploited these three sources to the full, and that some of the place names they mention still remain unidentified. In our study, we tried to do both things.

Fig. 5 - Distribution of the damaged localities in Carinthia, Carniola, and Friuli, and their historical sources according to Hammerl (1993). Full circles indicate localities identified only by the three most important sources: Villani (14th cent.), Matthias von Neuenburg (14th cent.-b), and Detmar von Lübeck (14th cent.). Empty circles indicate localities identified by other sources.

Identifying the localities affected by the 1348 earthquake on a modern map is a tricky task. Most place names quoted by the three main sources mentioned above are distorted or altered to some extent. Understandably so: medieval records were written and copied by hand, which can easily lead to mistakes, particularly when names are translated from foreign languages and the transcriber has no direct knowledge of the country described. Furthermore, some localities could have been named differently by different ethnic/linguistic groups that lived there and ruled over it. Finally, an additional complexity is that many localities mentioned by the original sources changed their names in the following centuries: sometimes it is comparatively easy to connect a cited toponym with its modern homologue, but in other cases the interpretation is controversial or a satisfactory solution impossible. To avoid making decisions that may seem arbitrary or perplexing, we will clarify here the criteria that we followed:

a) considering each source as a composite document with an internal logic. Chronicles are often the

result of mixing, translating, cutting up and the recombination of many texts: knowing how each of them was compiled can help identify the present homologues of the toponyms mentioned in it;

b) checking whether the identified localities were already in existence in 1348, to avoid making anachronistic choices;

c) checking the relevance of localities. When there were two or more likely candidates for identification with one of the place names mentioned in the sources, we opted for the one that was most important in 1348 (because it was more likely to attract the attention of potential witnesses);

d) considering how the source describes each locality. In the case of multiple choice, knowing whether the source describes the locality as a town, castle, village, tower, monastery and so on, can help decide which is the best modern homologue. It is also worthwhile checking whether the mentioned name was related to a human settlement or some other type of geographical feature.

These criteria would have been of little use without referring to bibliographic tools for the identification and characterisation of toponyms, such as the work of Valvasor (1689) and Dehio (2001). Beside these, other tools proved useful: Kohla (1953), Kohla *et al.* (1973) and Zdovc (2010).

We distinguish the toponyms mentioned in the sources according to whether they can be interpreted in two or more ways (Table 2); whether the relationship with modern localities is deduced from linguistic characteristics and from the internal logic of the source (Table 3); whether the relationship with the currently recognised localities is hypothetical (Table 4).

Table 2 - Place names with more than one possible identification with modern localities (small caps indicate our choice). Legend: G&C = Guidoboni and Comastri (2005); H = Hammerl (1992, 1994); Hf = Hofmeister (1924-1940). Sc = special case; IB = isolated building; TE = territory.

Toponym mentioned in the source	Source	Possible location (places chosen are in small caps)	Author of alternative identification*	Sc	Lat. N (°)	Lon. E (°)	Country
Achelberch	Detmar v. Lübeck	AICHELBERG		IB	46.644	13.96	A
		Aichelburg		IB	46.611	13.513	A
Bemburg	Matthias v. Neuenburg	BLEIBURG			46.588	14.798	A
		Bad Bleiberg	G&C		46.625	13.678	A
		Bamberg		TE	-	-	A/I
Geilenstein	Matthias v. Neuenburg	MOUNT GERLITZEN		TE			A
		Kolovec-Gerlochstein	Hf		46.193	14.641	SLO
		Gerlitzen	G&C				A
Krancke	Matthias v. Neuenburg	KRANJ - KRAINBURG	H		46.239	14.356	SLO
		Krainberg	G&C	IB	46.532	13.757	A
Lümburg	Matthias v. Neuenburg	LIEMBERG	G&C, H	IB	46.751	14.233	A
		Khünburg		IB	46.633	13.41	A
Remmetze	Matthias v. Neuenburg	REIFNITZ	G&C, Hf, H		46.606	14.183	A
		Ribnica [Reifnitz]	Hf		45.739	14.728	SLO
Rathberch	Detmar v. Lübeck	RADOVLJICA			46.344	14.173	SLO
		Ratzenegg		IB	46.661	14.190	A
Tranburg	Matthias v. Neuenburg	KARNBURG	Hf		46.684	14.315	A
		Oberdrauburg	G&C		46.748	12.971	A
		Kranj - Krainburg			46.239	14.356	SLO
Waldenberg	Matthias v. Neuenburg	WEIDENBURG		IB	46.648	13.058	A
		Wallenberg / Pusti-Grad	H	IB	46.930	14893	A
		S. Peter a. Wallersberg	G&C		46.658	14.690	A
Waldenstein	Matthias v. Neuenburg	WILDENSTEIN		IB	46.549	14.513	A
		Waldenstein			46.930	14.893	A
Wildemburg	Matthias v. Neuenburg	WALLENBERG / PUSTI-GRAD	H	IB	46.327	14.169	SLO
		Wildenstein	G&C	IB	46.549	14.513	A

Table 3 - Place names for which a likely relationship with current localities can be established. Legend: Sc = special case; IB = isolated building.

Toponym mentioned in the source	Source	Localisation proposed in this study	Sc	Lat. N (°)	Lon. E (°)	Country
Holenberch	Detmar v. L.	Hohenburg	IB	46.852	13.41	A
hus Nye	Detmar v. L.	Neuhaus (near Tržič)	IB	46.365	14.311	SLO
Nyenberch	Detmar v. L.	Neuhaus an der Gail	IB	46.553	13.771	A
Ragni	Villani	Radendorf		46.548	13.389	A
Tyner	Detmar v. L.	Tainach		46.635	14.538	A
Wartemburg	Matthias v. N.	Wernberg	IB	46.623	13.929	A

Table 4 - Place names for which only a hypothetical relationship with current recognised localities can be established. Legend: Sc = special case; IB = isolated building.

Toponym mentioned in the source	Source	Possible identification	Sc	Lat. N (°)	Lon. E (°)	Country
Derzmola dat hus Schaym	Detmar v. L.	Domžale	IB	46.144	14.598	SLO
hus Tyli	Detmar v. L.	Tolmin	IB	46.184	13.734	SLO
Landemburg	Matthias v. N.	Landskron	IB	46.642	13.897	A
Lentzeburg	Matthias v. N.		IB	46.642	13.897	A
Schellenburg	Matthias v. N.	Schaumburg	IB	46.79	14.291	A

4. Critical re-evaluation of the three main sources

4.1. Villani's Cronica

Giovanni Villani, a Florentine merchant and administrator who died of the plague in the summer of 1348, wrote a world chronicle, at the end of which there is a description of the 1348 earthquake. This description is based on a letter written shortly after the event, by some Florentine traders stationed in Udine (central Friuli), that gives information on several localities on the Friulian and Carinthian sides of the Alps, most of them located along two major trade routes linking Udine with Bavaria, on one side, and with Villach and Feldkirchen on the other (Hammerl, 1994).

Hammerl (1994) derives from Villani (14th cent.) information on earthquake effects in *Sancille* (Sacile) (we will indicate in *italics* the place names mentioned in the sources), *La Muta* (Mauthen), Udine, *Santo Danielle* (San Daniele), Ragogna, *Gelmona* (Gemona), *Vencione* (Venzone), *Tornezzo* (Tolmezzo), *Lemborgo* (Wasserleonburg), *Vedrone* (Federaun), Villach, *Dorestagno* (Arnoldstein), *Osgalche* (Ossiach), and *Verkir* (Feldkirchen). Guidoboni and Comastri (2005) identify other toponyms mentioned by Villani (14th cent.) *La Muta* (Mauthen) and *Tranburg* (Oberdrauburg); the place which Villani (14th cent.) names *Destrafitto* was associated with the Strassfried castle (near Arnoldstein), nowadays in ruins. The *Ragni* castle was identified with Rain: yet there is neither castle (or ruins) nor hamlet of this name. Probably *Ragni* stands for Radendorf (*Radna vas* in Slovenian) (Table 3). Finally, Guidoboni and Comastri (2005) associated the place name *La Croce* with the Alpine pass of Monte Croce Carnico: yet there is probably a misunderstanding

in Villani's *Cronica* (14th cent.) because this toponym corresponds to an Alpine pass without any human settlement.

In Villani (14th cent.), the description of damage for each place, although brief, is longer than in the other chronicles. For example, "it has fallen the Patriarch's palace and other houses", at Udine; "San Daniele's castle has fallen, and there have died many men and women"; "more than half of the houses have been damaged and fell", at Gemona, and so on. We have to point out that when Villani (14th cent.) mentions castles but not the respective towns (as in the case of San Daniele and Tolmezzo), we cannot assign any value in the macroseismic scale but only indicate a 'description code' according to the procedures adopted for the compilation of the Italian macroseismic database DBMI15 (Locati *et al.*, 2021). Villani (14th cent.) devoted more time to describing the effects at Villach, as also Matthias von Neuenburg (14th cent.-a, 14th cent.-b) did in both his texts.

4.2. Matthias von Neuenburg's texts

Matthias von Neuenburg, a lawyer in the service of the Archbishop of Strasbourg, described the 1348 earthquake twice, in a *Chronica* written shortly after the event, and in a biography of his late master: the *Gesta Bertholdi*, written after 1353. The *Chronica* description is brief and names only a few affected localities; the *Gesta* description is longer and includes many more localities, yet without details of the damage.

Some of the toponyms quoted in the *Gesta* were located in Slovenia by Hammerl (1992, 1994), while Guidoboni and Comastri (2005) placed all of them in Carinthia (Fig. 4).

Both texts start with the same introductory paragraph. Then, the *Chronica* describes the effects in Villach, while the *Gesta* gives a first list of damaged castles, starting with *castrum Osterburg in Valle Steintal,* which Hammerl (1994) identifies as Osterberg, a castle of Carniola whose ruins exist today near Podgrad, in the Ljubljana municipality (Valvasor, 1689). Then, two coupled localities come, *Lentzeburg* and *Rosach*. The latter is certainly to be associated with Rosegg; Guidoboni and Comastri (2005) identified the former (without explaining how) with Mauthen. We can tentatively identify *Lentzeburg* with the Landskron castle, near Villach, yet further research is needed on this account (Table 4). This first list of the *Gesta* includes other four toponyms: *Ortemberg*, which both studies identify with the Ortemburg castle, *Waldenberg*, identified by Hammerl (1994) with the Carniolan castle of Wallenberg and by Guidoboni and Comastri (2005) with Sankt Peter am Wallersberg; we, instead, identify it with the castle of Weidenburg (Dehio, 2001), midway between Ortemburg and Villach (Table 2). Then, comes *Schwartzenburg*, which Guidoboni and Comastri (2005) identify with the castle of Hochenwart. The fourth place, *Schellenburg*, was not recognised by the previous studies; we suggest a link with Schaumburg, but further research is needed (Table 4).

The *Gesta*, then, describes the earthquake effects in Villach, following almost *verbatim* the *Chronica*. It, then, gives another list of eight toponyms: *Waldenstein*, identified by previous studies with Waldenstein (Wolfberg District), while we suggest an association with Wildenstein. We also prefer to identify *Wildemburg* with Wallenberg/Waldenberk, a Slovenian castle mentioned above. *Hohenburg* is identified with the Hollenburg castle and *Lůmburg* with the Liemberg castle. Since these localities are on the eastern side of Carinthia, near Klagenfurt, we suggest that the following toponyms, whose identification is uncertain, were broadly located in the same area. Accordingly, we identify *Wartemburg* with Wernberg [or *castrum Werdenburch* (Dehio, 2001)] (Table 3); *Remmetze* is identified with Reifnitz by both studies, yet, as Hofmeister (1924-1940) pointed out, there are two Reifnitz, one in Carinthia, and another in Carniola (the latter known in Slovenian as Ribnica) and both were relevant places in the 1300s; therefore, it is not easy to decide which is

the better candidate (Table 2). We identify *Krancke* with Kranj (or Krainburg), the Carniola capital town (Table 2) and *Tranburg* with the Karnburg castle (Hofmeister, 1924-1940; Dehio, 2001) (Table 2). The previous studies made different choices: *Tranburg* was associated with Kranj by Hammerl (1994) and with Oberdrauburg (on the Bavarian border) by Guidoboni and Comastri (2005).

The *Gesta* goes on to mention two castles that were destroyed by landslides: *Lowenburg* by the landslip of the Mount Dobratsch, and *Landenburg*, which to date defies identification. It could be identified with the Landskron castle; yet, as in the case of *Lenzeburg*, a possible link needs further research (Table 4).

The *Gesta* description ends with two toponyms whose identification remains controversial: *Bemburg* and *Geilenstein*. Guidoboni and Comastri (2005) identify *Bemburg* with Bad Bleiberg. This site was associated with a mine from antiquity, but the town of the same name was founded much later than the 14th century (Dehio, 2001). So, it is unlikely that a 1300s source could have mentioned it. Admitting almost the same spelling distortion, we suggest that *Bemburg* indicates the castle and town of Bleiburg, an important centre at that time, though it lies farther eastwards in Carinthia (Dehio, 2001). It is also possible that *Bemburg* did not stand for a specific place but the Bamberger jurisdiction (Table 2).

The last place, *Geilenstein*, is identified by Guidoboni and Comastri (2005) with Gailitz, a hamlet close to the Arnoldstein monastery. Hofmeister (1924-1940) linked it with a castle mentioned by Detmar von Lübeck's (14th cent.) chronicle (see the following paragraph) as the castle of Gerlochstein, in Slovenia. Another possibility is that the mention of *Geilenstein* alludes to a huge landslide caused by the earthquake in the Mount Gerlitzen, above the lake of Ossiach. In this area, according to other chronicles (Anonymus Leobiensis, 14th cent.; Villani, 14th cent.; Andreas von Regensburg, 14th-15th cent.), the 1348 earthquake caused a major landslide (Guidoboni and Comastri, 2005).

4.3. Detmar von Lübeck's chronicle

We will devote particular attention to Detmar von Lübeck's (14th cent.) chronicle because it is the only one to cover all three political and linguistic areas involved in the earthquake (Carinthia, Carniola, and Friuli), because of the important information it provides, and also because earlier studies used it sparingly (Hammerl, 1992, 1994) or not at all (Guidoboni and Comastri, 2005). Detmar von Lübeck (14th cent.) was not an eyewitness to the 1348 earthquake, as his chronicle *was* written from 1385 onwards and far outside the earthquake-affected area, but this is not enough to discard his report, particularly so as, after all, neither Villani (14th cent.) or Matthias von Neuenburg (14th cent.-a, 14th cent.-b) wrote their reports at first hand. In any case, Detmar von Lübeck's (14th cent.) chronicle cannot be dismissed as either unreliable or unimportant. It was the official chronicle of Lübeck, one of the most important German cities of the time (Putzo, 2010), and to write it Detmar von Lübeck could have relied on all the informative potential of the Lübeck city archives, including documents and correspondence collected since the end of the 13th century. For these reasons we can consider it as reliable and analyse it in the same way as other chronicles nearer in time and space to the 1348 earthquake.

Detmar von Lübeck's (14th cent.) description of the 1348 earthquake comprises two main parts and, in the second part, it is possible to distinguish three different fragments (Fig. 6). In the first part, Detmar von Lübeck lists a group of localities placed along an imaginary south-north line (Fig. 7) where several natural phenomena occurred: a fire caused by lightning in Coron and Modon (Koroni and Methoni), two important Venetian colonies in the Peloponnese (Miller, 1908; Heywood, 1986; Bées, 1993); an earthquake (not necessarily the one we are studying) that

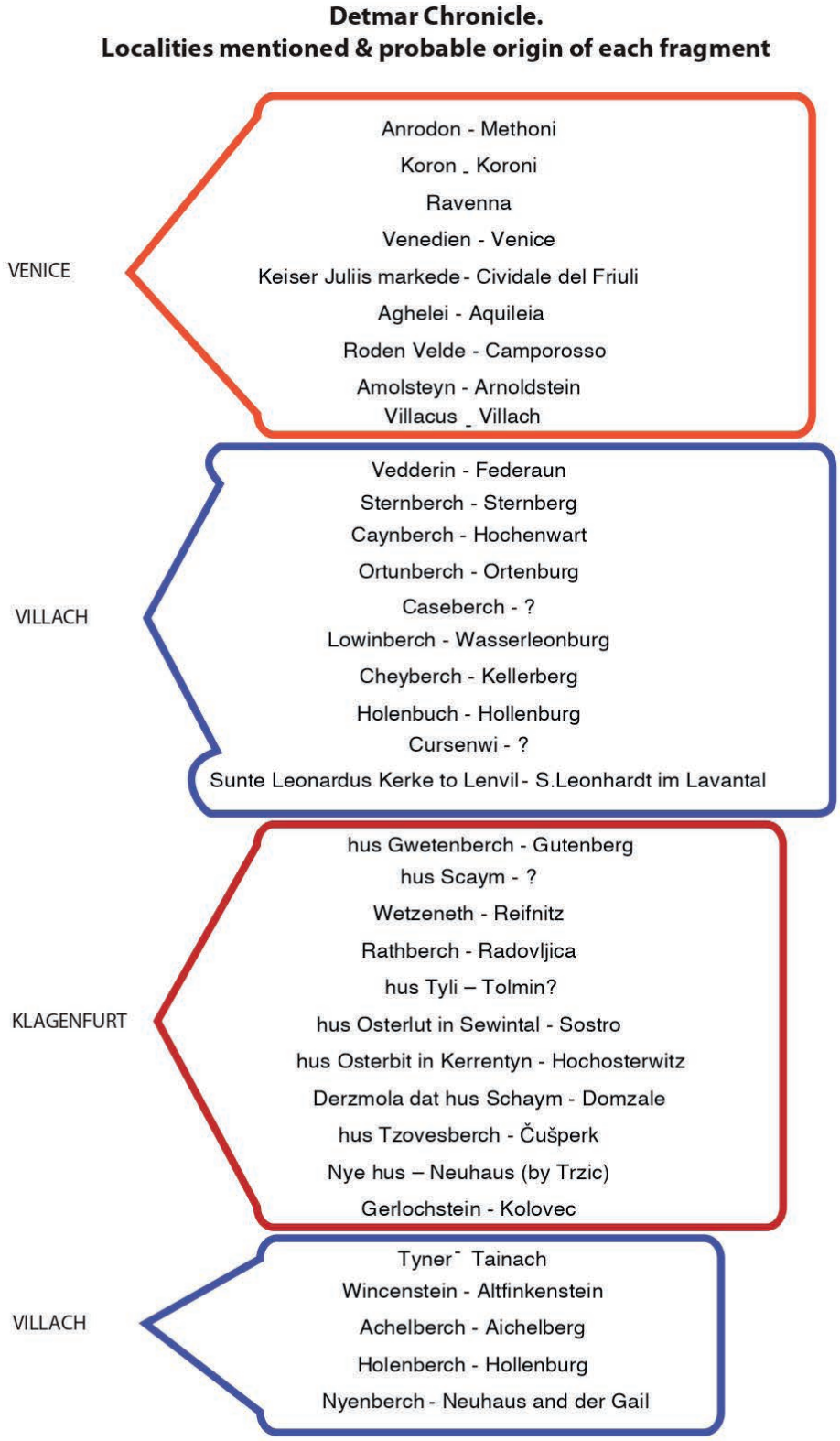

Fig. 6 - Detmar von Lübeck (14th cent.) chronicle: localities mentioned and probable origin of the information.

damaged Ravenna; the plague and the earthquake in Venice; and finally the aftermath of the 1348 earthquake in the most damaged areas. At this point, side by side with Aquileia, Detmar von Lübeck's names another locality: *Kaiser Juliis Markede* (a literal translation of *Forum Julii*, the Latin name of modern Cividale del Friuli), where a large church collapsed ("*vel en grot tempel*"). Excepting a brief and generic allusion to Cividale by a 16th century author (Nicoletti, 16th cent.), Detmar von Lübeck is the only nearly contemporary author to mention this town. Although Guidoboni and Comastri (2005) do not include Cividale amongst their results, the CFTI5Med (Guidoboni *et al*., 2018) contains it without adding any explication.

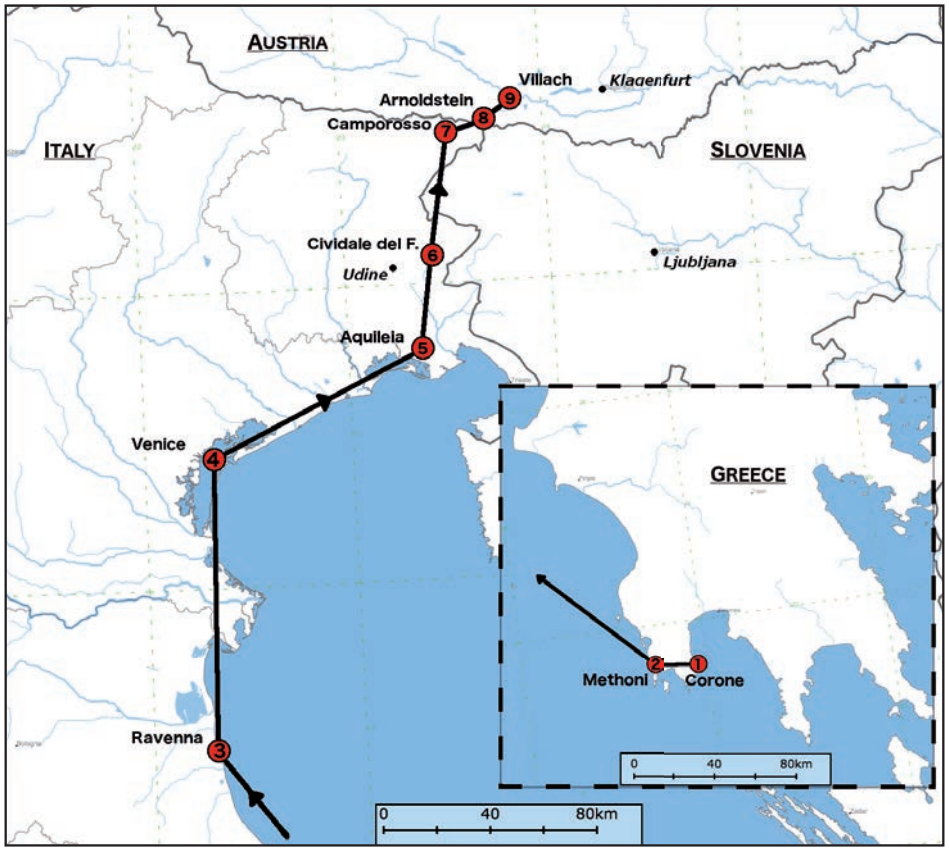

Fig. 7 - First list of localities affected by natural phenomena mentioned by Detmar von Lübeck's (14th cent.). Numbers indicate the order in the text.

Then, Detmar von Lübeck mentions *Roden felde* (Red field or, in Italian, Camporosso), situated on the road to Villach ("*men gheit to Villacum*"). At this point, the text enters the territory under jurisdiction of Bamberg's Bishopric (Fig. 3). Nowadays, the toponym Camporosso may be applied either to the hamlet comprised in the Tarvisio municipality (Camporosso in Valcanale), or to a strip of land of approximately 20 km lying along the Pontebba-Malborghetto-Tarvisio line, which marks the watershed between the Adriatic Sea and the Danubian Basin. Yet, Detmar von Lübeck's narrative seems to refer to the latter because it uses the plural form, "all towns and churches in that land fell (*vellen alle burghe unde keerken*)", which does not fit in a single village or hamlet (Figs. 3 and 8; Table 5). The

text goes on with the damage at the village and monastery of Arnoldstein and Villach. At this point ends the first part of the text, which we can assume originates from Venice, because of its geographical coverage and also because *Roden felde* match the Italian toponym (translated in German), while in German this place is known as Saifnitz (Figs. 6 and 7).

The second half of Detmar von Lübeck's narrative shows an abrupt change of style. After a short mention of many collapses in *Kerrentyn* (Carinthia) and *Carbonos* (presumably Carniola), Detmar von Lübeck presents another list of 26 toponyms, with very few descriptions of earthquake effects. We suggest that this passage can be broken down into three parts, each reflecting a separate source of information used by Detmar von Lübeck (14th cent.), originally written in different places (Fig. 6).

The first part includes 10 toponyms: *Vedderin*, i.e. Federaun, *Sternberch*, i.e. Sternberg, and *Lowinberch*, i.e. Wasserleonburg, all in the surroundings of Villach. It is also possible to identify *Ortunberch* with Ortenburg and *Holenbuch* with Hollenburg: in 1348 both were important castles, not far from Villach but outside its jurisdiction. Then, comes *Caynberch*, which could correspond to Hohenwart, mentioned by Matthias von Neuenburg (14th cent.-b) as Schwarzenburg (Black Castle, in Slovenian Črni Grad). *Cheynberch* is likely to correspond to Kellerberg, a castle in the Ortenburg jurisdiction, also named by the chronicles by Anonymus Leobiensis (14th cent.) and Andreas von Regensburg (14th -15th cent.), both cited by Dehio (2001). The last place mentioned in this part of the list is the church of Sankt Leonhard im Lavanttal *(Sunte Leonardus kerke to Lenvil*). This building, located outside the fortified burg of Gomarn and relatively far from the epicentral zone, was, like Villach, an enclave of the Bishopric of Bamberg within the Duchy of Carinthia. Detmar von Lübeck (14th cent.) could have had somewhat exaggerated information about this place, because he states that the church was entirely destroyed ("*is al vorstoret*"). But according to Dehio (2001), the church was built only a few years before 1348, and it shows no trace of damage. Moreover, there is no information about the consequences of the earthquake either in the castle or in the village. Arguably, the church suffered only slight damage, overstated during the process of transmission of the news. In this part of the list, there are two toponyms (*Caseberch* and *Cursenwi*) that still defy identification. We think that this fragment was initially written in Villach (Fig. 6).

The second part, including 11 place names, is set apart from the others by the use of a 'semantic marker' (Greimas and Courtés, 1982): the term *hus*, meaning both 'house' and 'fortified house' or 'castle' (Wackernagel, 1878), applied to 8 toponyms. Detmar von Lübeck (14th cent.) does not use it in any other sections, and this could mean this part of the list was based on a separate source. We can identify *hus Gwetenberg* with Gutenberg castle [*Gutenburg* in Matthias von Neuenburg (14th cent.-b)]; *hus Osterlut in Sewntal* with Osterberg in the Sava valley [named by Matthias von Neuenburg (14th cent.-b) as well]; *hus Osterbit in Kerrentyn* with the Hochosterwitz castle in Carinthia; and *hus Tzovesberch* with the Zobelsberg castle. Among the 'hus-less' toponyms, *Gerlochstein* could correspond to the Gerlachstein/Kolovec castle. The last place name in this section is *Tyner*, identifiable as Tinje, the Slovenian name for Tainach or Tinach (Kohla, 1953), a town less than 20 km east of Klagenfurt (Table 3). Even though it is not mentioned, the centre of the area designed by these localities is Klagenfurt. Some of the places named in this fragment are near Klagenfurt or located along, or very close to, the old Roman road that connected Emona (now Ljubljana) to Virunum (close to Maria Saal today) passing through the Loibl Pass. We suggest that the other place names in the same section are located there too: in this case, *hus Nye* could be

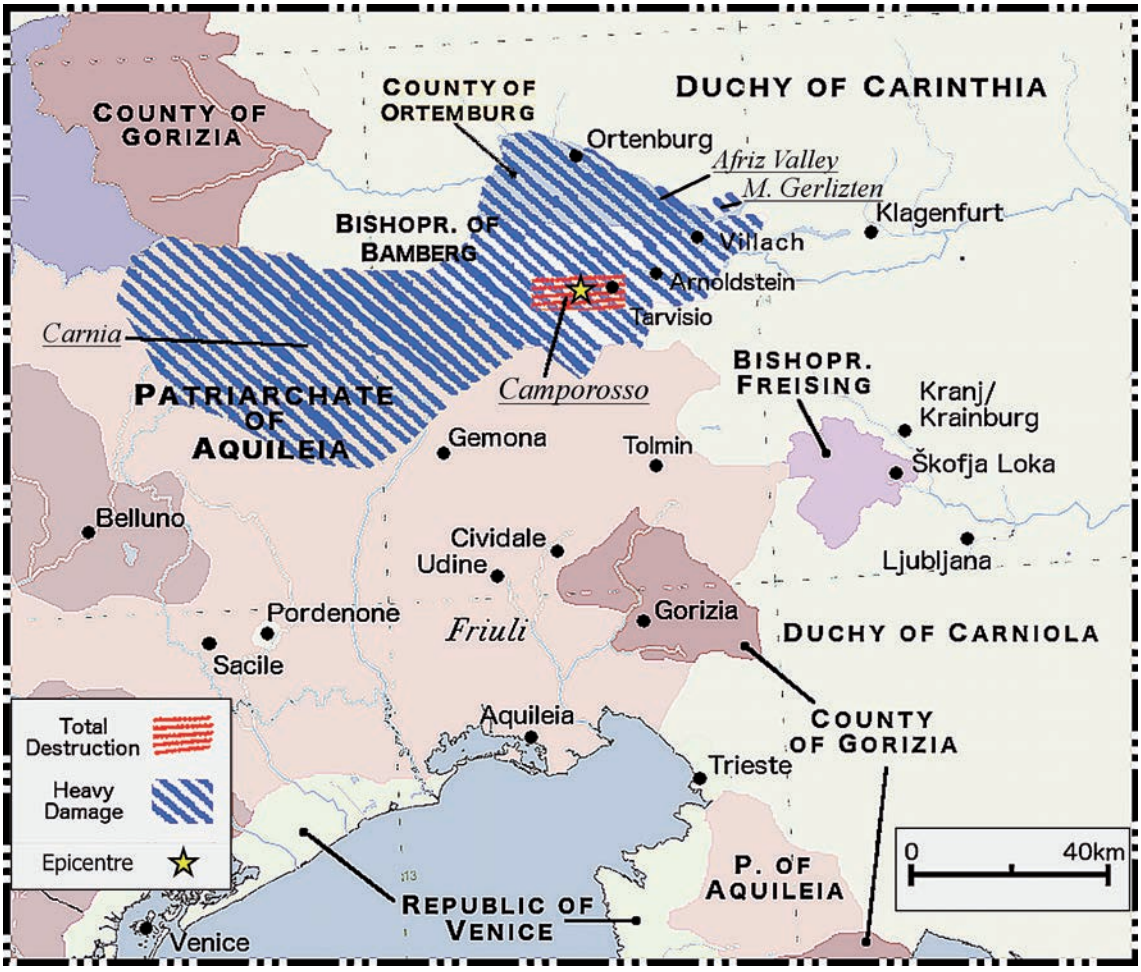

Fig. 8 - Extended areas with heavy and total destruction.

Table 5 - Extended areas included in the new scenario.

Extensive area	Source	Kind of damage	Level of damage
Afritz Valley	Villani (14th cent.)	Earthquake - Landslides - Flood	Heavy Destruction
Bamberg District	Anonymus Leobiensis (14th cent.)	Earthquake - Landslide	Heavy Destruction
Carnia District	Villani (14th cent.)	Earthquake	Heavy Destruction
Ortenburg District	Anonymus Leobiensis (14th cent.)	Earthquake - Landslides - Flood	Heavy Destruction
Camporosso saddle	Detmar von Lübeck (14th cent.)	Earthquake	Total Destruction
Villach District	Villani (14th cent.)	Earthquake - Landslides - Flood	Heavy Destruction
Mount Gerlitzen	Villani (14th cent.) Matthias von Neuenburg (14th cent.-b)	Earthquake - Landslides	Heavy Destruction

Neuhaus castle, near Tržič (as well as Gutenberg castle), and *Derzmola dat hus Schaym* could be Domžale (or Dom-schal in German); this last identification has two linked drawbacks: the reliability of the toponym and the relevance of the village at the time of the earthquake (Table 4). This fragment includes another four, hard-to-identify toponyms: *hus Scaym*, *Wetzeneth*, *Rathberch* and *hus Tyli*. The first could be a duplication of *hus Schaym*, the following two do not have the marker *hus*, so they could be towns, rather than castles. Hofmeister (1924-1940), links *Wetzeneth* with Reifnitz [named *Remmetze* by Matthias von Neuenburg (14th cent.-b), Table 2]. *Rathberch* might correspond to Radmannsdorf, i.e. respectively the German and Italian names of present-day Radovljica [or the Carinthian castle of Ratzenegg near Klagenfurt (Dehio, 2001)] (Table 2). This leaves us with two more place names without clear identification. One is *hus Tyli*. Arguably, Ambraseys (1976) indicated Tolmin amongst the damaged places by this earthquake on the basis of Detmar von Lübeck (14th cent.). Yet, Tolmin is far from the other places mentioned in the same fragment and its link with the toponym is rather weak; moreover, we do not know any other source, which mentions it. Therefore, we consider *hus Tyli* (and Tolmin) as a hypothesis for further research (Table 4). We think that this fragment comes from Klagenfurt, namely the centre of the covered area, while the last fragment comes (again) from Villach (Fig. 6).

The first locality in the last fragment is *Wincenstein*, which corresponds to Finkenstein castle (now Altfinkenstein); *Achelberch* could match either Aichelberg/Eichelberg castle, near Umberg, or Aichelburg castle, near Sankt Stephan im Gailtal (Dehio, 2001) (Table 2). *Holenberch* could be a duplication of *Holenbuch* (mentioned in the first section), corresponding to Hollenburg, or refers to the Hohenburg castle, near Pusarnitz, not far from Villach (Table 3).

The very last toponym named by Detmar von Lübeck (14th cent.) is *Nyenberch*, that could correspond to Neuhaus am Gailtal, an early medieval fortress located in front of the Dobratsch landslide, and likely the same place mentioned by Matthias von Neuenburg (14th cent.-b) as *Nuwenburg* and identified by Guidoboni and Comastri (2005).

Detmar von Lübeck (14th cent.) ends his paragraph devoted to this event by saying that "many other places were affected by the earthquake, but I do not know their names". However, Detmar von Lübeck (14th cent.) himself claims that the earthquake damaged approximately 30 towns in Carinthia and Carniola, but indicates the names of only 26 of them.

5. Results

5.1. Quality of data

To assess the quality of the results, we followed the method suggested by Burton *et al.* (1984) and modified by Musson (1998), that employs three categories of quality (reliability, locational certainty, and veracity), evaluating them by a binary criterion 0/1 that corresponds to a positive/negative answer.

The first category (reliability) evaluates whether the data are adequate to establish the intensity assignment beyond a reasonable doubt, but in our case descriptions of effects are generally poor and insufficient to establish a definite intensity value: therefore, most localities in our data set should be coded 1 for reliability.

The third category (veracity) evaluates whether the data are actually truthful and connected to a

specific earthquake. In our case information is mostly poor, and its veracity is based on the general reliability of each source. Since we chose to use only sources considered as 'truthful', according to Musson's (1998) code, the whole set of data should be marked 0 for veracity (Table 6).

In our case, the crucial aspect of the data set is the category of 'locational certainty', which evaluates whether the data are adequately located. Therefore, the toponyms whose identification is probable but not certain (Tables 2 and 3) will be indicated in Table 6 with an 'x' in the column Q (quality).

Moreover, we hypothesised other possible links between recognisable localities and toponyms mentioned in the sources. As further research is required to identify these localities, we decided not to plot them for the time being. Finally, a few of the localities mentioned in the sources remain unidentified and without any possible identification to this day. These are *Caseberch* and *Cursenwi*.

5.2. Identifying toponyms and assessing damage

We depict the scenario of the zone of the most significant damage based on the three main sources examined here. Many localities have been relatively easily identified (Table 6). Other localities are more difficult to plot on modern maps. Amongst these places, some could be matched with two modern localities: our choices are indicated in small caps (Table 2), and are included in the final intensity list (Table 6) with an 'x' in the quality column (Q).

Table 3 lists a group of place names whose relationship with modern localities is deduced from linguistic features and from the internal logic of the source.

Table 4 lists a group of place names mentioned by the three main sources, whose relationship with modern localities is only hypothetical. They have not been included into the final data set but we consider these cases as starting points for further research.

Matthias von Neuenburg (14th cent.-b) and Detmar von Lübeck (14th cent.) provided a large number of locations with a single and brief description of the damage. In these cases, as well as with isolated buildings (castle, monastery or church), a generic 'description code' has been assigned. According to the procedures adopted for the compilation of the DBMI15 (Locati *et al.*, 2021), we will use the code HD (heavy damage), indicating an intensity larger than, or equal to, 7 for most of the localities indicated by both mentioned chroniclers (rather than the code D, that represents a range of 6-8 grades and includes slight damage). Therefore, when we use the HD code, we do not consider all locations to have suffered in the same way, but that these places have suffered damage equal to, or greater than, grade 7.

The preliminary study by Caracciolo *et al.* (2015) included some localities based on local historiography or of late chronicles without explicit links with original sources [for example Cavitelli (1588), Nicoletti (16th cent.), and Palladio degli Olivi (1660)]. According to Musson (1998), these MDPs were coded with a low level of veracity and reliability. In this paper, to avoid misunderstandings, we prefer to consider them (in a similar way to those of Table 4) as hypotheses, starting points for further research, but not as results. On the contrary, we took into account several localities outside the maximum damage area, information on which is provided by contemporary and reliable sources (Table 6).

Table 6 - Macroseismic data used in this work for drafting a new scenario of the 25 January 1348 earthquake. Legend: Sc = special case; IB = isolated building; MS = multiple settlement; DL = deserted locality; TE = territory; HD = heavy damage; D = damage; SD = slight damage; Q = quality column; x = second rate data.

25.01.1348 Eastern Alps I_{max} = 9-10 - Ep. 46.504 13.581 - M_w = 6.6						
Place name	**Sc**	**Lat. N (°)**	**Lon E (°)**	**Int. (MCS)**	**Country**	**Q**
Villach		46.614	13.845	9-10	A	
Gemona del Friuli		46.279	13.135	9	I	
Mauthen		46.663	13.000	8-9	A	
Oberdrauburg		46.748	12.971	8-9	A	x
Paluzza		46.531	13.017	8-9	I	
Ragogna (San Giacomo)	MS	46.177	12.978	8-9	I	
Venzone		46.333	13.139	8-9	I	
Udine		46.063	13.234	8	I	
Bolzano		46.499	11.352	7-8	I	
Venezia		45.438	12.336	7-8	I	
Padova		45.407	11.875	7	I	
Trento		46.068	11.122	7	I	
Aichelberg / Eichelberg	DL, IB	46.644	13.96	HD	A	x
Altfinkenstein	IB	46.546	13.903	HD	A	
Aquileia	IB	45.768	13.37	HD	I	
Arnoldstein (hamlets)	MS	46.55	13.704	HD	A	
Arnoldstein (monastery)	IB	46.548	13.709	HD	A	
Bleiburg	IB	46.588	14.798	HD	A	x
Čušperk-Zobelsberg	IB	45.885	14.686	HD	SLO	
Federaun	IB	46.571	13.812	HD	A	
Gutenberg	IB	46.362	14.291	HD	SLO	
Hochwart-Hochenwart	IB	46.638	13.995	HD	A	
Hohenburg	IB	46.852	13.410	HD	A	x
Hollenburg		46.547	14.262	HD	A	
Karnburg		46.684	14.315	HD	A	x
Kellerberg	IB	46.674	13.708	HD	A	
Kolovec-Gerlochstein		46.193	14.641	HD	SLO	
Kranj-Krainburg		46.239	14.356	HD	SLO	x
Liemberg	IB	46.751	14.233	HD	A	x
Neuhaus an der Gail	IB	46.553	13.771	HD	A	x
Neuhaus-Tržič	IB	46.365	14.311	HD	SLO	x
Radendorf		46.548	13.389	HD	A	x
Ortenburg	IB	46.794	13.459	HD	A	
Ossiach	IB	46.675	13.984	HD	A	
Podgrad-Ljubljana / Osterberg	IB	46.069	14.638	HD	SLO	
Pusti Grad-Wallenberg	IB	46.327	14.169	HD	SLO	x
Radovljica		46.344	14.173	HD	SLO	x
Ragogna (castello)	MS IB	46.177	12.978	HD	I	

Table 6 - continued.

Reifnitz		46.606	14.183	HD	A	x
Rosegg		46.589	14.018	HD	A	
San Daniele del Friuli	IB?	46.157	13.01	HD	I	
Sternberg	IB	46.626	13.992	HD	A	
Strassfried	IB	46.55	13.65	HD	A	
Tainach		46.635	14.538	HD	A	x
Tolmezzo		46.398	13.019	HD	I	
Wasserleonburg	IB	46.604	13.633	HD	A	
Weidenburg	IB	46.648	13.058	HD	A	x
Wernberg		46.623	13.929	HD	A	x
Wildenstein	IB	46.547	14.521	HD	A	x
Cividale del Friuli		46.093	13.431	D	I	
Costozza		45.469	11.608	D	I	
Feldkirchen in Kä nten	IB	46.724	14.094	D	A	
Hochosterwitz	IB	46.756	14.452	D	A	
Pordenone		45.959	12.658	D	I	
Sacile		45.953	12.499	D	I	
Sankt Leonhard im Lavanttal	IB	46.963	14.800	SD	A	x
Bologna		44.494	11.343	5	I	
Ferrara		44.836	11.618	5	I	
Weihenstephan bei Freising		48.396	11.725	5	D	
Concordia Sagittaria		45.756	12.846	HF	I	
Erfurt		50.975	11.025	HF	D	
Modena		44.647	10.926	HF	I	
Mozzanica		45.476	9.692	HF	I	
Piacenza		45.052	9.693	HF	I	
Pisa		43.718	10.402	HF	I	
Reggio nell'Emilia		44.698	10.631	HF	I	
Verona		45.439	10.994	HF	I	
Frankfurt		50.100	8.683	F	D	
Mantova		45.158	10.794	F	I	
München		48.138	11.564	F	D	
Regensburg		49.014	12.111	F	D	
Strasbourg		48.583	7.733	F	F	
Vicenza		45.548	11.546	F	I	
Würzburg		49.800	9.933	F	D	
Afritz Valley	TE			HD	A	
Bamberg District	TE			HD	I-A	
Camporosso	TE			HD	I	
Carnia	TE			HD	I	
Mount Gerlitzen	TE			HD	A	
Ortenburg District	TE			HD	A	
Villach District	TE			HD	A	

5.3. Environmental consequences of the earthquake

It is not possible to study the eastern Alps earthquake of 1348 without mentioning the enormous landslide of Mount Dobratsch. Few historical earthquakes have such a close link to a landslide as in this case, to such an extent that it has been known as the 'Villach earthquake'. In fact, an important part of Hammerl's (1992) research aimed at severing the association between epicentre and landslide.

However, historical sources allow us to broaden the scene of the environmental upheaval produced by the earthquake. In addition to the landslide of Mount Dobratsch, Villani's correspondents had reported similar phenomena in the Afritz valley (a few kilometres north of Villach) and in the Gerlitzen Mountain, above Lake Ossiach.

Beside the analysis of historical sources, other scientific methods suggest that the huge rock avalanche in the Veliki vhr (Slovenia) could have been caused by the 1348 eastern Alps event (Merchel *et al.*, 2014).

In addition to what the sources tell us about the consequences of the earthquake, it is also worth noting here what they do not mention. Although the earthquake occurred in the middle of winter, the sources do not cite any snow avalanches among the effect of the earthquake. Furthermore, Villani's correspondents had collected information from the northern side of the Alps a few days after the event, with no apparent communication problems caused by the fall of snow.

According to Lendhard (2007), on one hand, the resistance of a slope to the ground motion depends on the geometrical properties of the ground and on its water saturation. On the other hand, an earthquake can trigger a landslide only if the rocks are in unstable conditions. So, we can hypothesise that the 1347-1348 winter was mild, with heavy rains instead of snow, and that the rocky slopes were fragile and at the point of breaking.

5.4. Extended areas

Regarding medieval earthquakes, efforts are not always sufficient to find evidence that clearly indicates the epicentral zone (Gangl, 2003). For this reason, we have used other clues that the sources offer. In the new scenario, we have included some extended areas or 'territories' (TE) instead of single localities, such as the Afritz Valley, the Camporosso saddle and small administrative districts like Villach and Ortemburg (Table 5). According to the code used by DBMI15 (Locati *et al.*, 2021), the effects of the earthquake in all those areas are indicated with HD (heavy damage) in Table 6. Nevertheless, the level of damage is not the same in all these zones. Narrative sources indicate heavy damage, with many castles, churches or hamlets destroyed except for Camporosso. According to Detmar von Lübeck (14th cent.), in the Camporosso area, the earthquake destroyed all churches and hamlets. We consider the difference between 'many' and 'all' to be just as significant as regarding individual locations. The Camporosso saddle, situated in the middle of the other zones, appears to be the area with the greatest damage and coincides with the epicentre calculated with the traditional macro-seismological method (Fig. 8).

5.5. Seismological considerations

To identify clues, if any, about the seismic source of the 1348 earthquake, we used a simplified representation of some intensity maps and mapped the area of the largest ground motion (highest 2 degrees), the area where damage is reported (intensity larger than, or equal to, grade 6), and the area of perceptibility (intensity larger than, or equal to, grade 3), as was done for the 1511 earthquake by Camassi *et al.* (2011).

In addition to the 1348 earthquake, we have considered three main events which occurred in the study region: the 1511 earthquake, the Gemona 1976 main earthquake, whose source was located on the Susans-Tricesimo Alpine thrusts (Galadini *et al.*, 2005), and the 1998 Bovec earthquake, whose source was associated to the Ravne Dinaric strike-slip fault (Bajc *et al.*, 2001; Zupančič *et al.*, 2001). For the last two earthquakes, an intensity map with a wealth of information is available (Figs. 9c and 9d); conversely, the 1511 intensity map shows a limited number of data points outside the epicentral area (Fig. 9b). The intensity map of the 1348 earthquake (Fig. 9a) actually remains rather poor in information also after this investigation. If a faint similarity can be tentatively suggested between the 1511 and 1976 events, also considering the wider extension of the damage area of the historical event that should suggest a larger magnitude, the few data and the widely spread largest intensities do not support any consideration on the source of the 1348 quake. For the sake of precision, it must be said that neither the similarity nor the larger magnitude of the 1511 earthquake with respect to the 1976 one were proposed by Camassi *et al.* (2011). In summary, the epicentre already proposed by Caracciolo *et al.* (2015) for CPTI15 (Rovida *et al.*, 2021) seems the most convincing based on the present historical investigation and on the seismotectonic considerations cited in our previous chapters and is confirmed by this study (see Table 1).

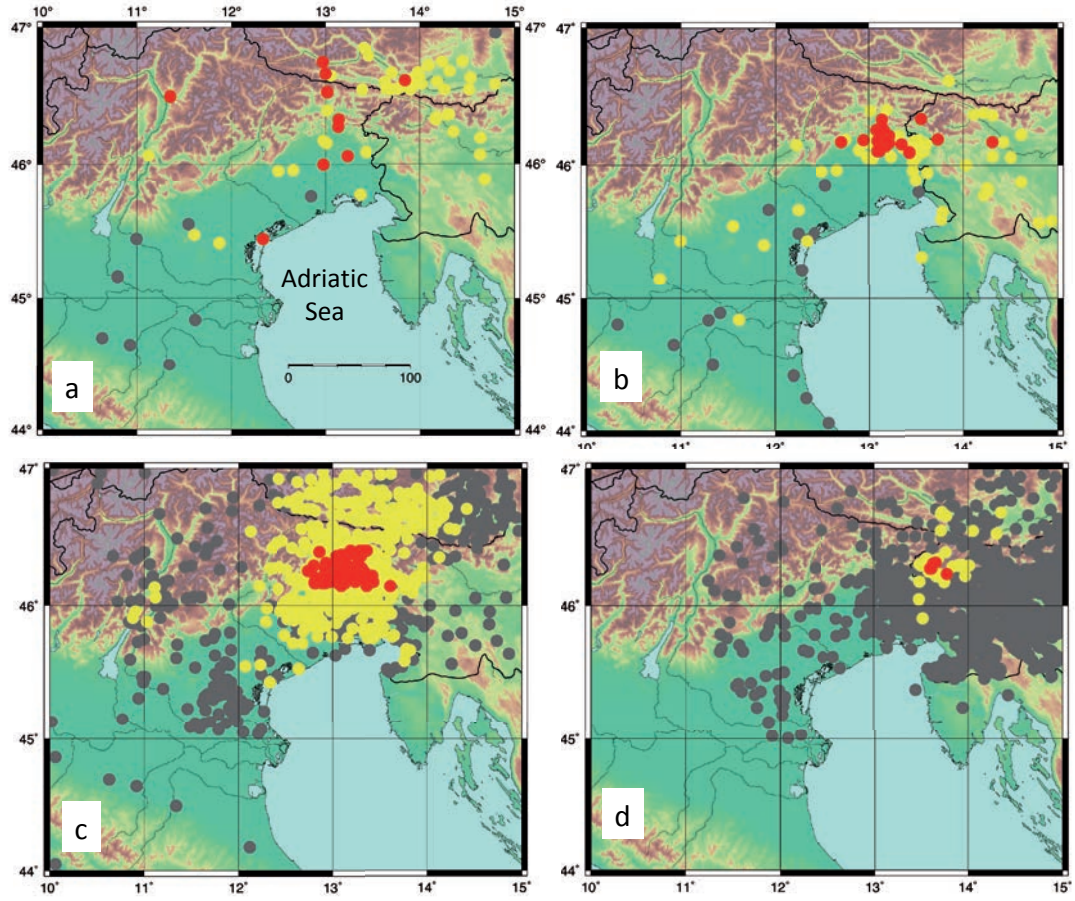

Fig. 9 - Simplified intensity maps, the points with a large intensity (equal to the highest 2 intensity degrees) are mapped in red, those with an intensity larger than, or equal to, grade 6 are mapped in yellow, and those with an intensity larger than, or equal to, grade 3 are mapped in grey: a) 1348 earthquake, MDPs from this study; b) 1511 earthquake, MDPs from Camassi *et al.* (2011); c) 1976 Gemona earthquake, MDPs from Tertulliani *et al.* (2018); d) 1998 Bovec earthquake, MDPs from Zupančič *et al.* (2001). Intensity scale is MCS for the 1348 and 1511 quakes and EMS-98 for the 1976 and 1998 events.

6. Conclusions

At this point, we can indicate the contributions of this work, the open questions and the possible ways for further research. From the quantitative viewpoint, this study increases the number of earthquake-affected places to 74 MDPs (Table 6 and Fig. 10a), with respect to the 46 MDPs of Hammerl (1994) and 57 MDPs of Guidoboni and Comastri (2005). This figure is not a mere 'addition' but the result of a nearly complete revision of the data points, including those mentioned in the preliminary report by Caracciolo *et al*. (2015). In that work, 89 localities were indicated, yet those records were not qualitatively homogeneous. A meaningful part of the present work involved reassessing those records, distinguishing certain, probable and possible data, the latter being considered mere hypotheses for further research, and, therefore, not reliable enough to be included in Table 6. Other points mentioned here were not even considered in the Caracciolo *et al*. (2015) work.

Another important aspect of this study is the corroboration of the effects in Carniola, considering the lack of information in Slovenia lamented by Guidoboni and Comastri (2005). Besides that, this work confirms the epicentral area reported in CPTI15 (Rovida *et al.*, 2021) on the basis of the Caracciolo *et al*. (2015) study. It is located in the southern side of the border between Carinthia and Friuli, not far from the epicentre indicated by Guidoboni and Comastri (2005) and agrees with the proposition of Hammerl (1992, 1994) too, who suggested the epicentral area in Friuli, southwards of Villach (Fig. 10b).

Above all, we would like to emphasise the importance of the reading of historical sources regarding some small areas. According to this analysis, the zone of greatest damage would involve the settlements on the Camporosso saddle, namely the villages of Pontebba, Malborghetto and Tarvisio, that matches well with the epicentral area calculated on the basis of the available MPDs.

In addition to these seismological achievements, we would also like to point out two relevant methodological issues. Despite the limits of space in this type of paper, we sought to make the critical reading of the sources and the identification of toponyms as detailed as possible: that is, the process of building the macroseismic scenario. We think that both issues are crucial for further research as well as useful criticism.

Further studies will hopefully improve the macroseismic information about this event, reconsidering the points not sufficiently reliable or providing additional macroseismic data points. Until now, studies on this earthquake are based almost entirely on the same sources. The archives of both Bamberg and Freising bishoprics, possibly preserve other documents not yet considered. New releases of historiographical studies regarding castles and towns (likely produced not in direct relation with earthquakes) may help to shed new light on the 1348 event as well. These issues are linked with two other seismological aspects of the 1348 earthquake that still remain open: the hypocentre and the magnitude. Although these parameters can be considered sufficiently identified, given the period when the event occurred, they cannot be considered well-constrained because of the still associated large uncertainties. Further clues about the source of the 1348 earthquake could be given by geological investigations (e.g. paleoseismic trenches to date coseismic ruptures). As concerns hazard and risk, it is reasonable to think that specialised scientists working on the 1348 earthquake will need to take good account of the enduring uncertainties.

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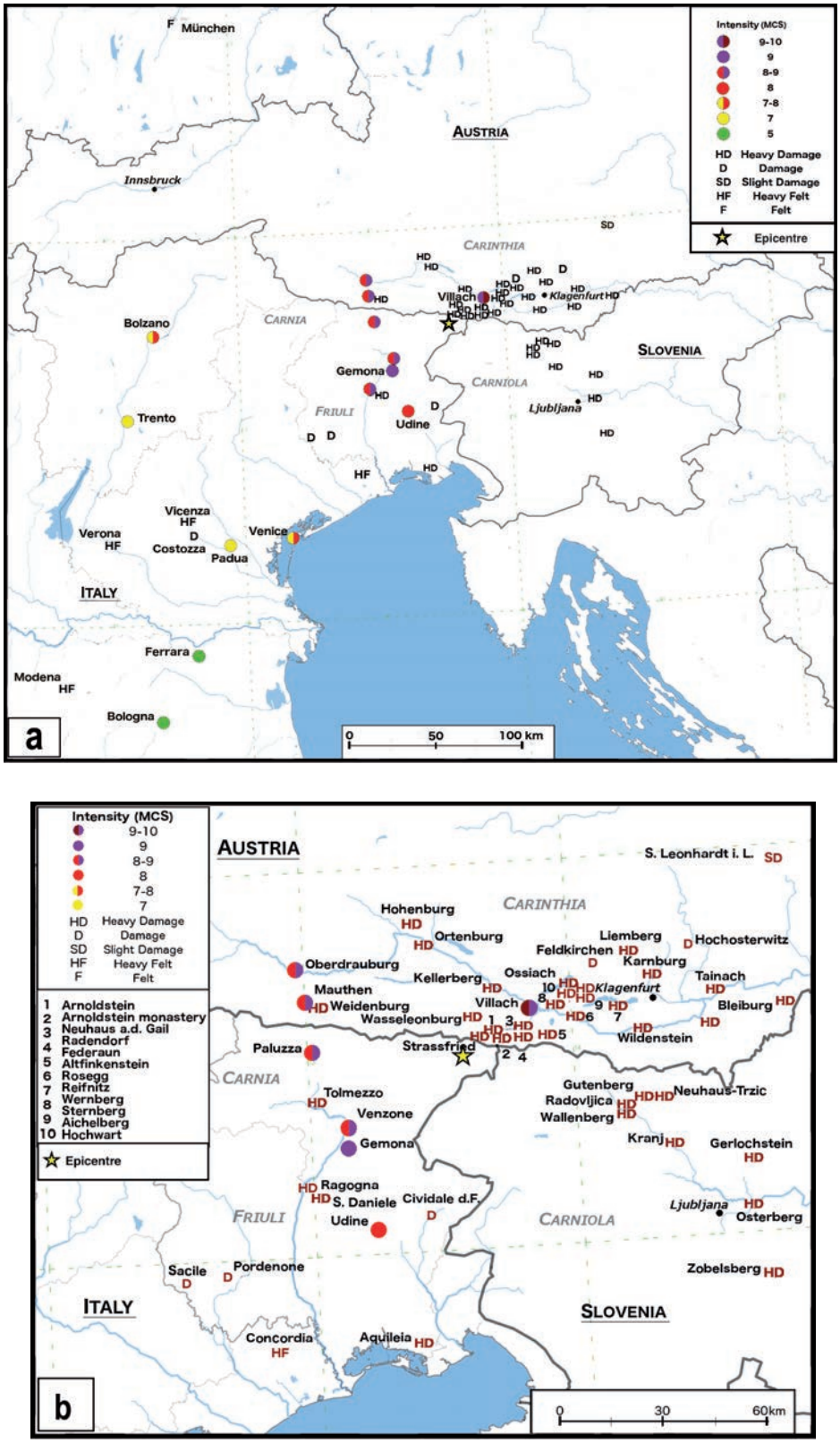

Fig. 10 - New scenario of the 25 January 1348 earthquake: a) larger outlook; b) epicentral area.

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