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ORIGINAL ARTICLE

Memory of the Earth and Human Memory of Natural Disasters: the 1953 Earthquake in Western Aragón (Spain)

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Abstract
Occurred in 1953 in Used (Zaragoza province), an earthquake of magnitude 4.7 and intensity VII was the last destructive earthquake in the Aragón region, Spain. The remaining social memory of that event (a type of intangible geological heritage) and its influence on the perception of seismic hazard in the area are explored by means of interviews and a population survey. The results indicate that the memory is lively amongst the population within the epicentral area, both in the generation that experienced it and, to a lesser extent, in the following generations. However, this does not translate into a significant perception of seismic hazard, the latter being more influenced by cultural factors: in the epicentral area it is greater amongst people who did not live through the earthquake, but who have heard familiar stories or have had external information highlighteing its importance. The study of social perception is part of a citizen science project, in which the social memory enters into dialogue with the *Memory of the Earth*, i.e. the record left by that and other previous earthquakes in geology and landscape. The research on the effects of the shake on people, buildings, and environment has benefited from numerous testimonies from the elderly. Reciprocally, such knowledge is scientifically processed and returned to the citizens in the form of scientific outreach products (book, documentary film, talks), with the aim of promoting scientific culture about natural disasters.

Keywords Seismic hazard · Active fault · Population survey · Citizen science · Used · Iberian Chain

Introduction: Scope and Objectives

Geological heritage represents the *Memory of the Earth*, i.e. the record of the Earth's history inscribed in rocks and landscapes (*Declaration of the Rights of the Memory of the Earth*; Martini 1992). Most of that *Memory of the Earth* concerns its remote past, e.g. ancient orogenies or catastrophic faunal extinctions. Their study has relevance for reconstructing the history of our Planet, a cultural resource as important for our present and our future as the history of Humanity itself is. On the other hand, knowledge of Earth history and dynamics is necessary for adequately and efficiently using mineral and energy resources that we humans consider vital for our socioeconomic development.

But the *Memory of the Earth* also deals with events of a more recent past, and the most relevant amongst them undoubtedly are those that refer to natural disasters that recurrently shake cities and countries. Where these phenomena have occurred in the last centuries or decades, they offer the possibility to connect and establish a dialogue with the human memory, either with that individual, personal memory, or with the social memory (the one collected in books, historical documents, or press). The possibility of such a dialogue being established depends on two main factors: (i) the natural recurrence of processes and the elapsed time since the last event and (ii) the extent of individual and social memory, something that is often conditioned by the cultural development of each community. Processes with short recurrence, e.g. river floods, may (or should) be present either in individual memory or in intergenerational memory preserved by oral transmission. On the contrary, processes with secular recurrence require, for the consolidation of their memory, the documentary record.

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Collective memory about catastrophic phenomena, and in general about negative events, tends to be lost too quickly. Concerning, e.g. catastrophic flood events, their memory depends on the presence of eye-witnesses, so that after the latter die out, the historical memory tends to disappear (Fanta et al., 2019). This probably represents a psychological defence mechanism, whereby societies tend to cope with traumatic events by repressing the memory, forgetting the negative; the socio-cultural construction of risk, determined by collective memory, is therefore biased (Páez et al., 2001; Noria, 2015). After the news of a river flood, it is commonplace to hear on radio or television a local official who has been surprised by the phenomenon, claiming that "not even the oldest people in the area could remember such a thing". Societies thus often adopt an "ostrich strategy", closing their eyes to the obstinate reality of natural processes. Our modern, technological *society of knowledge* also makes this mistake, frequently faking the collective memory and demonstrating a worrying lack of scientific culture indeed (Simón, 2015).

In this context, it is understandable that people have difficulties in taking seriously into account the *Memory of the Earth*. Even if our reverence for science nominally gives value to the scientific knowledge that is being achieved about geological processes, our subjective judgements and prescientific notions are often more decisive. This collective attitude does not befit a cultured and wise society.

Natural hazard assessment requires widening the time window of our memory. In the case of earthquakes, for example, such an assessment cannot be based only on the inventory of historical and instrumental earthquakes, but must extend to paleoearthquakes. In intraplate regions where significant earthquakes have large recurrence intervals (in the order of 10^3 years; Liu and Zoback 1997), the latest event could be older than the existing historical documents. In such regions, studying the geological record for identifying active faults and the resulting ancient quakes is therefore a critical task (Allen 1986; Yeats et al. 1997). Paleoseismic events can be identified and dated from both *primary* and *secondary* geological evidences (McCalpin and Nelson, 1996). *Primary* or *on-fault* evidences are usually found at trenches excavated across fault traces, in which relationships between rupture surfaces and sedimentary units are carefully analysed for building a model of the local paleoseismic succession (e.g. Allen, 1986; Pantosti et al., 1993; McCalpin, 2009). *Secondary* paleoseismic evidences are mostly provided by soft-sediment deformation structures (SSDSs) induced by the shake at a distance of the source fault, during or after sedimentation and before complete lithification. Since the pioneer works by Seilacher (1969) and Sims (1973), many others describing regional examples or discussing the methodology for their analysis have been published (e.g. Scott and Price, 1988; Alfaro et al., 1999; Alsop and Marco, 2013; Moretti and Van Loon, 2014; Moretti et al., 2016; Basilone 2017).

The dialogue between Earth's and human memory also demonstrates the complementarity between tangible and intangible geological heritage. As is the case with the cultural heritage in general, geological heritage mostly includes material objects (rocks, fossils, landscapes; Dos Reis and Henriques, 2009), but also intangible entities: customs and folk wisdom, oral traditions, language, myths, and religious ceremonies linked to the geological record (Martini, 2009). Ancient mining techniques (Muntoni et al., 2020), traditional folk wisdom linked to salt pond operations (Mansur and Souza 2011), or orally transmitted accounts of geological processes belong to this category. In particular, chronicles and personal reports of the effects of an earthquake are valuable pieces of immaterial geological heritage. First of all, they represent an essential part of scientific earthquake research, in particular for the location of the macroseismic epicentre and the assignment of intensity. At the same time, they constitute an expression of human perception of natural phenomena, and therefore of high ethno-geological value.

The earthquake occurred on 28 September 1953 in Used (Zaragoza province; see location in Fig. 1), with magnitude 4.7 and intensity VII, was the last destructive earthquake in the Aragón region, Spain. It caused considerable material damage in Used and, to a lesser extent, in other surrounding villages, and a major landslide that cut the main road in the county. The event was widely reported in regional and national press (Fig. 2), and resulted in the death of a girl (Simón et al., 2021). It occurred in a region of low to moderate historical seismic activity, but where geological studies have shown the presence of active, potentially seismogenic faults (Gutiérrez et al., 2009, 2012, 2020; Simón et al., 2012; Peiro and Simón, 2021a, b), i.e. in a region where the geological record provides a wider temporal perspective that provides an adequate explanation to this extraordinary event.

Most people who lived through the earthquake are no longer around to recount it, and those who remain mostly were children or teenagers whose memories are fragmentary or biased. At present, it would be unrealistic to search for new data of that earthquake based on oral testimonies (e.g. for refining the macroseismic zonification). However, there have been strong reasons for our research group to undertake an interdisciplinary project focusing on that earthquake. From a scientific point of view, personal and documentary sources of information can contribute to increase our knowledge of the geomorphological-environmental effects of the earthquake, an aspect not studied to date that can now be addressed in the perspective of citizen science. From a social point of

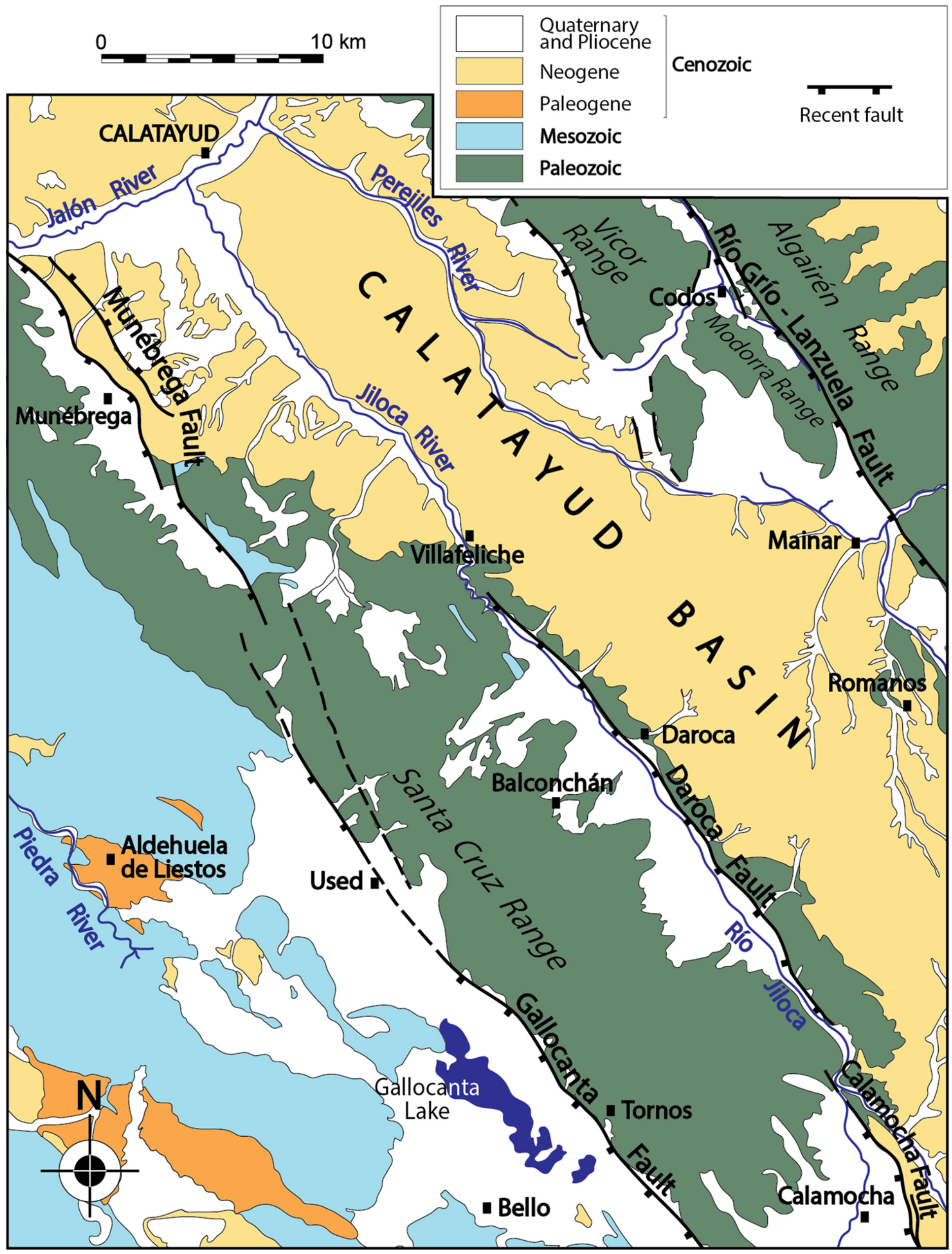

Fig. 1 Geological setting. **a** Location of the study area within the Iberian Chain (inset: location within NE Spain). **b** Geological map of the Used area

view, there is a need to transfer knowledge to the local population, and to deepen the collective perception of seismic hazard.

The objectives of this work are the following:

(1) Establishing a dialogue between the *Memory of the Earth* (record of geological processes interpreted on scientific bases) and the human (individual and social) memory of the Used earthquake of 1953.
(2) Assessing the remaining social memory of the earthquake, comparing the epicentral area with the rest of the Aragón region, as well as between successive generations.
(3) Using human memory for increasing the scientific knowledge of the geomorphological-environmental effects of the earthquakes.
(4) Assessing the influence of human memory on the social perception of seismic hazard.
(5) Developping the social dimension of seismology, implementing an exercise of citizen science, and giving back scientifically processed knowledge to the population in the form of outreach products.

EL NOTICIERO

Año LIII—Núm. 16.601 Zaragoza, martes 29 de septiembre de 1953 Setenta céntimos

Movimiento sísmico en Zaragoza

El fenómeno produjo gran alarma y fueron numerosas las personas que abandonaron sus hogares. — En Huesca y Calatayud fué percibido el sismo intensamente

EL OBSERVATORIO DEL EBRO LO CALIFICA DE TIPO PROXIMO Y DE INTENSIDAD BASTANTE CONSIDERABLE, Y ES UNO DE LOS MAS FUERTES OBSERVADOS EN AQUEL CENTRO

Aproximadamente a las once menos cuarto de anoche se observó en Zaragoza un movimiento sísmico de alguna intensidad.

Sobre todo fué percibido en los pisos altos y en la parte alta de la ciudad.

El temblor de tierra hizo estremecerse durante algunos segundos los muebles, oscilar las lámparas y las vajillas y cristales de los aparadores.

Fueron numerosas las personas que llamaron a nuestro periódico dando cuenta de las sacudidas que, a lo que parece, fueron dos, una más brusca que otra.

En el barrio de la Magdalena, calle de Moncasi, Coso y otros puntos de la población, grupos de vecinos salieron a la calle al instante de apreciarse el movimiento sísmico, llenos de alarma.

Los bomberos recibieron numerosas llamadas de los más variados puntos de la población, hasta el punto de que hicieron un recorrido por las calles, pudiendo apreciar que ningún daño se había producido.

Acerca de la duración del movimiento se oyeron diversas opiniones: mientras unos afirmaban haber sido de cuatro a cinco segundos, algunas personas la hacían llegar hasta más de treinta.

En relación con su intensidad también oímos referencias tan dispares como las de numerosas gentes que no observaron el fenómeno y la de un matrimonio de la calle Madre Vedruna que afirmó que el temblor de tierra les había tirado desde la cama al suelo.

(Pasa a la página cuarta)

Fig. 2 News on the earthquake in *El Noticiero* regional newspaper

Methodology: Documentary Sources

The essential part of this work, dealing with human memory of the 1953 earthquake and perception of seismic hazard, has essentially involved social research. We have first compiled the relevant information that exists in documentary sources: scientific literature, administrative documents, and printed press.

Concerning scientific literature, there is an only monograph published a few years after the earthquake (Rey Pastor and Bonelli, 1957), apart from occasional mentions in articles on regional active faults and seismotectonics (Gracia and Gutiérrez, 1996; Gutiérrez et al., 2009, 2020; Samardjieva et al., 1999) and the logical inclusion in official seismic catalogues (Mezcua and Martínez-Solares 1983; IGN, 2021).

Scientific (unpublished) and administrative documents have been obtained from the following institutions: Observatori Fabra, belonging to the Reial Academia de Ciències i Arts de Barcelona; Institut Cartogràfic y Geològic de Catalunya (ICGC); Instituto Geográfico Nacional (IGN); Instituto Geológico y Minero de España (IGME); civil registry and archive of the Used municipality; Archivo de la Diputación Provincial de Zaragoza (provincial council); Archivo Arciprestal de Daroca (ecclesiastical archive of Daroca archpriesthood); and Demarcación de Carreteras del Estado en Aragón, Ministerio de Transportes (state roads, ministry of transport, Spanish government).

Printed news was recovered from local, regional, and national papers, mainly *Heraldo de Aragón* and *El Noticiero* (Zaragoza; Fig. 2), *ABC* (Madrid), and *El Correo Catalán* and *La Vanguardia* (Barcelona). These journals were accessed at the Archivo-Hemeroteca Municipal de Zaragoza (archive of the Zaragoza municipality), archive of the Observatori Fabra-Reial Academia de Ciències i Arts de Barcelona, and a dossier previously compiled by IGN.

Second, an interview campaign was conducted with older people who lived through the 1953 earthquake in Used and other villages in the epicentral zone. Significant direct testimony was obtained from a total of 19 informants, which are cited in the "Acknowledgements" section. The information obtained concerns the effects of the shake on people, buildings, and environment.

Third, we carried out a population survey focused on assessing the degree of knowledge and social memory of the 1953 earthquake amongst the population of the epicentral area and the rest of Aragón (as a result of either personal experience or oral transmission), as well as the social perception of seismic hazard. Table 1 shows the template used for such survey. The latter was carried out on-site amongst the inhabitants of affected villages, in addition to being distributed in web format through social networks and other electronic media. A total of 198 responses were collected.

Table 1 Template used for the population survey on the memory and perception of seismic hazard

<table>
<tr><td colspan="4">GENDER: Man Woman</td><td colspan="2">AGE:</td></tr>
<tr><td colspan="6">LOCALITY OF RESIDENCE:</td></tr>
<tr><td colspan="6">Level of education: Primary Secondary University Other</td></tr>
<tr><td colspan="6">1) Do you know if an earthquake occurred in your locality some decades ago? YES NO
Can you remember in which year?</td></tr>
<tr><td>2) Why do you know it?</td><td>You lived through the seism</td><td colspan="2">Your family told you about it</td><td>You know it from other sources</td><td>You do not know it</td></tr>
<tr><td colspan="6">3) Can you remember any other earthquake in your zone in the past? YES NO
If YES, where did it occurred?</td></tr>
<tr><td colspan="6">4) Do you consider that your locality is under significant seismic hazard? YES NO</td></tr>
<tr><td colspan="6">5) Which of the following natural disasters do you consider most likely to occur in your locality?</td></tr>
<tr><td colspan="2">a) Flooding</td><td colspan="4">b) Karst subsidence</td></tr>
<tr><td colspan="2">c) Landslide</td><td colspan="4">d) Earthquake</td></tr>
</table>

In parallel with the social research, geological work has been carried out to understand the seismotectonic framework of the Used earthquake (possible seismic source, geodynamic context…) and its geoenvironmental effects. Different methodological approaches, mostly structural and geomorphological, have been used for exploring the record of seismogenic fault activity in rocks and landscape. The structural study is based on recognizing and mapping the main structures in aerial photographs and satellite orthoimages, complemented with field surveys involving outcrop-scale observations. The geomorphological study is focused on mapping and reconstructing planation surfaces for being used as markers of vertical deformation, as well as landforms linked to fault mountain fronts (linear escarpments, triangular facets, alluvial fans). Intensive field surveys have been carried out searching for evidence of slope unstability resulting from seismic shaking (landslides, falling blocks…), on the basis of indications provided by aged informants.

Geological, Geographical, and Social Setting

The geological region in which the 1953 earthquake took place (Fig. 1a) is the so-called Aragonese Branch of the Iberian Chain. The latter extends for more than 400 km in a NW–SE direction, from Sierra de la Demanda, in the Burgos province, to the Mediterranean Sea, in Castellón and Valencia. It is an intraplate chain located within Iberia, which resulted from inversion of several Mesozoic basins (Liesa et al., 2018) during Paleogene to early Neogene compressional episodes (Liesa and Simón, 2009), under the convergence with the European and African plates (Álvaro et al., 1979; Capote et al., 2002).

The area surrounding Used includes a series of mountain ranges (Santa Cruz, Algairén) and depressions (Calatayud, Gallocanta), which largely follow the general NW–SE direction of the chain (Fig. 1b). The Calatayud basin was onset under the compressional regime during late Palaeogene time, and is infilled by alluvial and lacustrine sediments mainly of the Lower Miocene. It is bounded at its SW margin by the Palaeozoic Ateca-Daroca massif, both being separated by the Daroca thrust (Julivert, 1954; Colomer and Santanach, 1988; Casas-Sainz et al. 2018). The latter was subsequently inverted into the Daroca extensional fault, which sinks the Daroca half-graben with respect to the Neogene infill of the Calatayud basin (Julivert, 1954; Gracia, 1992; Gutiérrez et al., 2008). Within and SW of the Paleozoic massif, a second large extensional structure, the Munébrega-Gallocanta fault zone bounds the Munébrega and Gallocanta Plio-Quaternary half-grabens.

The Grío, Perejiles, Jiloca, and Piedra rivers, tributaries of the Jalón river and, finally, of the Ebro Basin, drain most of the area. Nevertheless, the centre of the Gallocanta depression remains endorheic, hosting the Gallocanta lake (considered as the largest natural lake in Spain, 14.4 km^2) and La Zaida lake. The latter is submitted to artificial management for agricultural use in alternate years, through a sluice gate built in the sixteenth century.

With an average altitude exceeding 1000 m a.s.l., the area has an extreme continental climate, with average minimum temperatures in winter of 0–1 °C (absolute minimum of – 30 °C in the Calamocha Observatory), and average maximum temperatures in summer around 30 °C. Although rainfall is relatively low (400–500 mm/year), the high altitude allows the soil to keep moist enough for fairly regular cereal harvests.

The municipality of Used, as well as the rest of villages in the southern sector of the epicentral area of the 1953 earthquake, belongs to the Campo de Daroca county. The northern sector belongs to Comunidad de Calatayud, whilst other more marginally affected areas belong to the neighbouring counties of Jiloca (Teruel province) and Molina de Aragón (Guadalajara, Castilla-La Mancha region). With the exception of the city of Calatayud, all of them are located in rural Spain and have suffered a severe depopulation process since the mid-twentieth century. Overall population density is 6.7 inhabitants per km^2.

Economy of the zone is mainly based on rain-fed agriculture, with a lesser contribution of farming, small industries (mainly in the agri-food sector), construction, and services (mostly commerce and tourism). Industry and services are mainly concentrated in the county seats: Calatayud, Daroca, and Calamocha.

Memory of the Earth: Tectonic Framework of Seismicity at the Central Iberian Chain

Since the beginning of the Late Miocene, the central-eastern Iberian Chain underwent an extensional tectonic regime linked to rifting of the Valencia Trough (Vegas et al. 1979; Simón, 1982; Roca and Guimerà 1992). Onshore extensional deformation was accommodated by a large network of Neogene-Quaternary grabens (Maestrat, Teruel, Jiloca, Gallocanta, Munébrega), whose bounding faults mostly represent the negative inversion of previous contractive faults (Álvaro et al., 1979). The last stage of tectonic activity started by the mid-Pliocene (approximately 3.8 Ma ago), under a crustal stress regime characterized as a multidirectional or radial extension (σ_1 vertical, $\sigma_2 \approx \sigma_3$) with prevailing ENE-WSW σ_3 trajectories (Simón, 1982, 1989; Arlegui et al., 2005; Liesa et al., 2019). This stress field has remained up to the present day (Herraiz et al., 2000).

Along the central Aragonese Branch, the main extensional faults activated since mid-Pliocene time trend NW–SE to NNW-SSE (Fig. 1b). They are grouped into three major alignments: Río Grío-Pancrudo (Gutiérrez et al., 2013; Peiro and Simón, 2021a, 2021b), Munébrega-Gallocanta (Gutiérrez et al., 2009), and Daroca-Calamocha (Gracia, 1992; Gutiérrez et al., 2008, 2020). All these faults dip towards SW, making the NE margins of half-graben basins, and show traces that exceed 15 km in length (88 km in the case of the Río Grío-Pancrudo; Peiro and Simón, 2021a). The Río Grío-Pancrudo fault zone has undergone vertical displacement of ~300 m during the last 3.5 Ma, with net slip rate close to 0.09 mm/a. Vertical displacement of ~20 m of a sedimentary level dated to 66.6 ± 6.5 ka gives a more recent slip rate approaching 0.30–0.36 mm/a (Peiro and Simón, 2021b). The Munébrega fault also shows evidence of Late Pleistocene activity: vertical displacement of about 7 m in an alluvial unit initially dated to 72 ± 6 ka (Gutiérrez et al., 2009) would result in a vertical slip rate of approximately 0.1 mm/a. Such dating has been recently revised and brought forward to 241 ± 50 ka, which diminishes the slip rate to 0.02–0.04 mm/a (Gutiérrez et al., 2020). At the Daroca fault, offset of an erosional-aggradation pediment dated to 329 ± 43 ka provides a vertical slip rate of 0.02–0.06 mm/a (Gutiérrez et al., 2020). For the Calamocha fault, a throw of about 210 m for the Late Pliocene–Quaternary stage (long-term slip rate of 0.06 mm/a), as well as evidence of recurrent movement during the Pleistocene, have been reported (Martín-Bello et al., 2014).

The activity of these faults is probably responsible for the earthquakes that occasionally affect the region. Most of them have their epicentre in the transition from the Iberian Chain to the Ebro Basin (Algairén, Herrera, and Oriche mountain ranges) and to the Castilian Plateau (Gallocanta-Molina de Aragón highlands). The most important recent earthquakes, apart from the 1953 one, were those of Cimballa (1912, intensity VI–VII), Calatayud (1944, intensity VI, magnitude 3.8), and Herrera de los Navarros (2011, intensity IV–V, magnitude 4.1).

It can be assumed that the 1953 earthquake was caused by one of these large faults. However, it is not easy to know which exactly was, due to high uncertainties in both location of the epicentre (see Fig. 3) and focal depth: either 7.3 km (Rey Pastor and Bonelli, 1957), 15 km (Samardjieva et al., 1999), or 31 km (J. V. Cantavella and J. Fernández, personal communication on an unpublished calculation based on *Hypocenter* software). Most of the focal depths attributed to earthquakes in the region are between 5 and 15 km, i.e. within the brittle upper crust. Geophysical exploration of the eastern Iberian crust indicates that the detachment level for the main extensional faults is located at a depth of 13–15 km (Roca and Guimerà, 1992). Below this level, deformation becomes more ductile and the frequency of earthquakes sharply decreases. Consequently, only the focal depths calculated by Rey Pastor and Bonelli (1957) and Samardjieva et al. (1999) are compatible with the geodynamic framework. Combining those parametres with the average dip of the fault plane (65 to 75° in shallow levels, decreasing in depth), the epicentre should be geometrically located between 2 and 15 km SW of the fault trace responsible for the earthquake. Consequently, the fault most likely to have caused the 1953 earthquake was the Daroca fault. The elongation of isosists along that fault (Fig. 3) is consistent with this interpretation.

In summary, despite this sector of the Iberian plate is characterized by low to moderate seismicity, it hosts a number of active faults, for which the geological record shows evidence of recurrent displacement during the Quaternary, and should be therefore considered as potentially seismogenic. Such knowledge of active faults based upon the *Memory of the Earth* is increasingly guiding seismic hazard

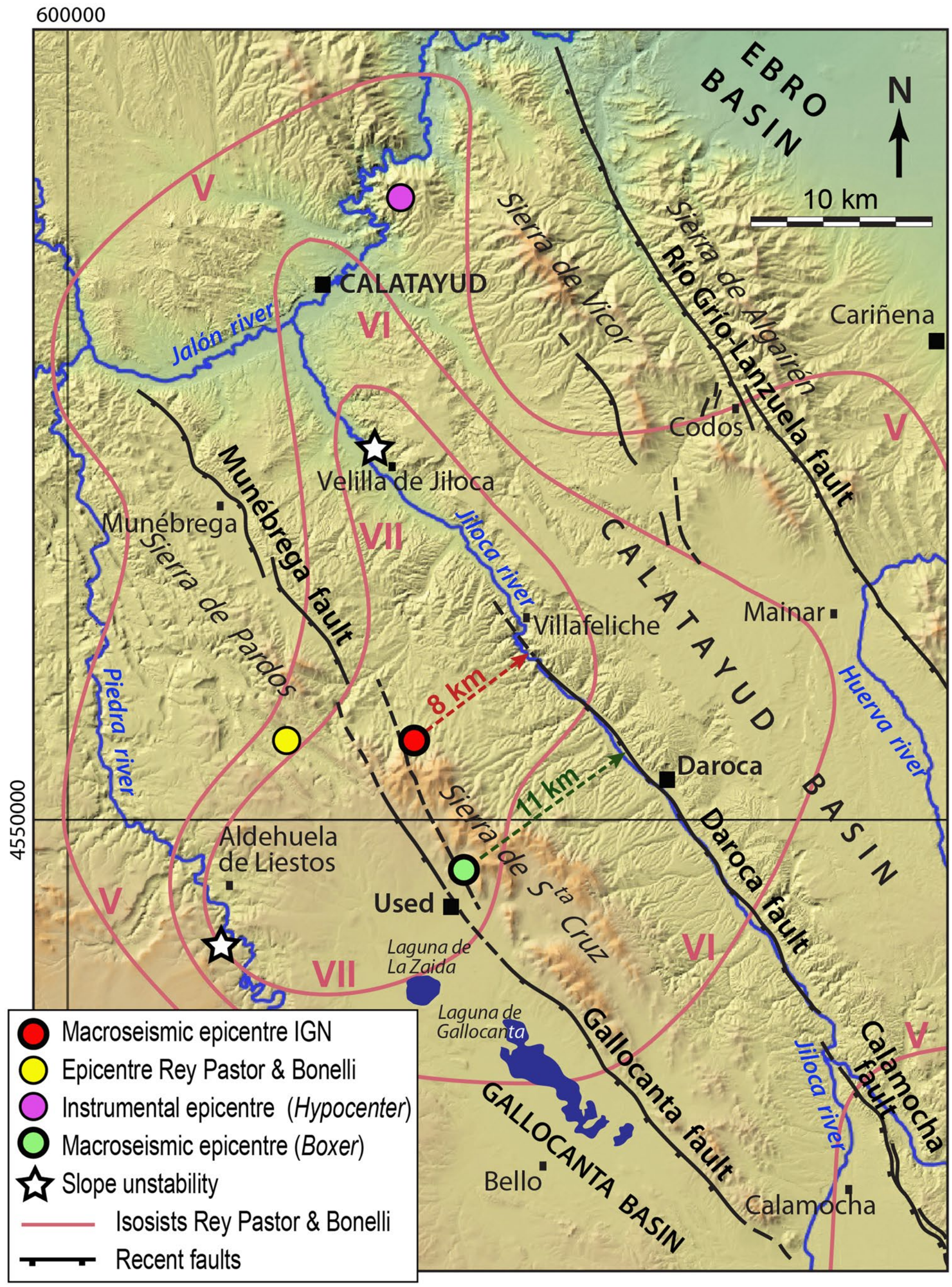

Fig. 3 Synthetic seismotectonic map. The compatibility between distinct locations proposed for the epicentre and potential source faults is analysed. From the available data, the most probable seismogenic source was the Daroca fault

assessment in scientifically advanced countries. In Spain, it has given rise to new hazard maps elaborated by IGN (Martínez Solares et al., 2013). These should soon replace the obsolete map currently considered in seismic codes (Ministerio de Fomento, 2002), in which a null seismic hazard level is assigned to the entire Iberian Chain.

A recent case in the region illustrates how using the geological record of prehistoric earthquakes can provide the basis for more rational seismic hazard assessment. In 2012 the Aragón regional government presented the project for a new hospital in Teruel city, which, according to current regulations, did not initially include any anti-seismic design. The site chosen for it is about 400 m from the Concud fault, which makes the boundary of the Jiloca graben in its southern sector. This is the best-known active fault in the region: it has been object of intense paleoseismological research that have allowed reconstructing a wide succession of 11 events since approximately 74 ka BP, with average recurrence period of 7.1–8.0 ka, total net accumulated slip of about 20 m, and average slip rate of 0.29 mm/a (Lafuente, 2011; Lafuente et al., 2011, 2014; Simón et al., 2016). The maximum expectable earthquake within a 500-year period is estimated to be $M = 5.3 \pm 0.3$, whilst the peak ground acceleration could attain $a_p = 0.105$ g (Simón et al., 2014). In the light of reports written by our research team, IGN and IGME, the Aragón government decided to modify the building project and provide it with anti-seismic design according to the newly proposed seismic parameters.

Human Memory of the Used Earthquake of 1953

Individual and social memory on the 1953 earthquake is enough to reconstruct its effects in Used and the other villages of the epicentral area. Testimonies collected amongst informants who experienced the quake (Fig. 4) illustrate how they felt and reacted. Scientific and administrative documents and press recorded seismological data and numerous consequences derived from the shake.

In Used, there was a general panic; people went out into the streets without knowing what had happened. The doctor and the vet tried to calm them down; despite most people did not know what an earthquake was indeed, they were comforted to see that initially there was no great misfortune. Another thing was to see, the following day, the destruction caused to buildings: almost all of them were damaged and some even collapsed. A wall of the church was cracked and part of the bell tower crowning the frontal façade fell (Fig. 5). A 19-year-old girl, Victorina Liarte, was terrified and went into shock; as a result, she fell seriously ill and died a week later.

The earthquake was strongly felt in other numerous villages of the Daroca and Calatayud counties, although damage to buildings was minor. Special mention should be made of what happened in Daroca. According to the complete and personal account by the correspondent of *El Noticiero* journal "…the ground rippled repeatedly, making the effect of a giant cat crawling under a carpet (…). The walls also shook as if they had been made of paper (…). People walking in the street were shaken (…). In many places, terrified of new movements, they lay down in their clothes". Without going into how accurate this description is, the earthquake caused significant damage in Daroca, and even today noticeable cracks can be observed in façades that were not repaired (Fig. 6).

In addition to *El Noticiero*, other regional and national newspapers reported on the earthquake and its effects, mostly *Heraldo de Aragón* and *Amanecer* (Zaragoza), *El*

Fig. 4 Some people who lived through the earthquake have provided valuable information. **a** Marcelina Ferrer. **b** Santiago Muñoz. **c** Silvina López. **d** Silvestre Gálvez. Photographs: Jorge Brizuela

Fig. 5 Frontal façade of the Used parish church in 1947, showing the bell tower that collapsed during the earthquake of 1953 (source: Archivo Mas)

Correo Catalán and *La Vanguardia* (Barcelona), and *ABC* (Madrid). The press quickly published some of the first data from the seismographs. *El Noticiero* contacted the Ebro Observatory (Tortosa, Tarragona province) only 15 min after the earthquake. The journalist not only received first-hand scientific information, but also contributed to assess the intensity of the earthquake and the possible location of the epicentre. Such interesting conversation constituted a splendid example of collaborative science. The Ebro Observatory had initially attributed to the earthquake an intensity of IV on the Mercalli scale, but the journalist pointed out that in mountains SW of Zaragoza the movement had been more intense. In view of that exchange of information, it was suspected that the epicentre could be located in the Daroca area.

In the days that followed, not only did the press report on the phenomenon, but local institutions and individuals carried out an interesting exercise of citizen science, providing valuable testimonies. Much data collected at the time for evaluation of the seismic intensity is preserved in the correspondence that town councils, parish priests, and individuals maintained with the Fabra Observatory in Barcelona. The informants responded to the call made by Eduard Fontseré, director of the meteorology and seismology section of that observatory, as well as to press announcements published by the Reial Acadèmia de Ciències i Arts de Barcelona, the institution to which it belongs. It is amazing that, in their survey sheets, some informants themselves assigned a Mercalli intensity to the observed effects. According to the overall results, the epicentral intensity was initially estimated to VIII (Fontseré, 1955). Later, and independently, Rey Pastor and Bonelli (1957) used the testimony files collected by the Toledo Observatory (which, unfortunately, we have not been able to locate) and carried out their own field surveys. From these, they (i) located the epicentre more precisely to the north of Used (longitude 1°40′W, latitude 41°08′N), (ii) calculated the focal depth at 7.3 km, and (iii) estimated a maximum intensity of VII (Fig. 3).

Fig. 6 Symmetrical cracks in the façade of a building in Calle Mayor of Daroca town

So far, we have referred to the social memory documentally recorded. But what is the individual memory kept by those who lived through the earthquake? We must bear in mind that the current testimonies by older people may be different from those given by their parents in 1953. Time filters often distort stories. The contrast between both pointviews is exemplified in Calatayud town. *Heraldo de Aragón* emphasized in its 2 October edition the great alarm amongst the population, stating that "only sick people did not leave their homes, (…) and 99% of the neighbourhood took to the streets". However, a present-day, 94-year-old informant lucidly recalled the earthquake in Calatayud but claimed not to have felt any fear.

We wanted to objectify the memory that currently persists in the municipalities more affected by the earthquake, and also to compare it with that in other areas of Aragon. With this purpose, a survey was carried out in person amongst the inhabitants of the epicentral area, in addition to being distributed in web format through social networks and other electronic media. A total of 198 responses were collected, of which 90 belonged to people in the Used-Daroca-Maluenda area (included in isosists VI and VII; Fig. 3), 54 correspond to the rest of the Zaragoza province, and 54 to the Teruel province. Concerning the responses obtained in the epicentral area, 42 were from people over 72 years old (of whom 27 lived through the earthquake and, because of their age, could remember it), 42 were between 40 and 71 years, and 6 were from people under 40.

The results of this survey (Table 2 and Fig. 7a) show that a great majority (81%) of people living in the more affected area who were over 4 years old at the time of the earthquake remember it, generally because they experienced it first-hand. More than half can date it with reasonable accuracy (±2 years). This proportion drops to 71% amongst those aged 40–71, who know about it only from oral transmission within the family (about half of the total in this age group), or from other sources. Within this age segment, only 43% know the approximate date. Amongst those under 40 years of age, for whom the sample is very small, only half knew about the earthquake, generally from sources outside the family.

If we aggregate these results and compare them with those of other areas of Zaragoza and Teruel provinces, we see significant differences. In the Daroca-Used-Maluenda area, 74% of people of all ages are aware of the existence of the 1953 earthquake, whilst only 4% in the rest of the Zaragoza province. In Teruel, 32% of individuals surveyed were aware of the occurrence of an earthquake in their locality; in 13% of the cases, given the approximate date on which they placed it, it was also very probably the 1953 earthquake.

In short, the memory of the earthquake is quite vivid in the municipalities of the epicentral area, both in the generation that lived through it and, to a lesser extent, in younger generations. In areas of the Iberian Chain and the Ebro Basin where it was felt with less intensity, knowledge of the earthquake is logically more limited, but it is noteworthy that it is quite greater in the Teruel province than in Zaragoza province.

Geomorphological and Geoenvironmental Effects of the Earthquake: Dialogue Between Earth's and Human Memory

The most worrying and reported effects of earthquakes are those on people, household goods, and buildings. These are a priority when classifying the degrees of intensity, both in the Mercalli scale and in the current European Macroseismic

Table 2 Results of the population survey on the memory and perception of seismic hazard

		EPICENTRAL ZONE				REST OF ZARAGOZA PROVINCE	TERUEL PROVINCE
	Age	>71	40-71	<40	TOTAL	TOTAL	TOTAL
	N	42	42	6	90	54	54
1) Do you know if an earthquake occurred in your locality some decades ago?	YES (%)	81	71	50	74	4	32
	NO (%)	19	29	50	26	96	68
Can you remember in which year?	RIGHT (%)	57	43	50	51		
	WRONG / DK / NA (%)	43	57	50	49		
2) Why do you know it?	Lived through (%)	64	0	0	30		
	Family (%)	7	47.5	16	26.5		
	Other sources (%)	10	23.5	34	17.5		
	DK / NA (%)	19	29	50	26		
4) Do you consider that your locality is under significant seismic hazard?	YES (%)	2.5	9	0	5.5	2	33
	NO (%)	95	86	50	90	87	54
	DK / NA (%)	2.5	5	50	4.5	11	13
5) Which of the following natural disasters do you consider most likely to occur in your locality?	Flooding (%)	69	67	67	68	70	48
	Karst subsidence (%)	2.5	10	33	8	54	17
	Landslide (%)	40	31	50	37	20	39
	Earthquake (%)	0	7	17	4	2	28

Scale (EMS-98). Scientists consider the latter as a good instrument for damage analysis of current or very recent earthquakes, but it has serious limitations for analysing old earthquakes. Not only does it exclude data on environmental effects, but also on historical-artistic and archaeological heritage. This limitation has been countered by the introduction of an Environmental Effects Macroseismic Intensity Scale (ESI-07), promoted by the International Union for Quaternary Research (INQUA) and published by the Geological Institute of Italy (Michetti et al., 2007).

In the case of the 1953 earthquake, the only observed geomorphological-environmental effects were related to instability of hillsides and slopes. Two relevant cases have been recognized from direct personal testimonies, documents, and press reports, as well as from geomorphological field observations, i.e. thanks to confluence of Earth's and human memory.

The most conspicuous geomorphological effect was the landslide that cut the N-234 road between Velilla de Jiloca and Maluenda, south of Calatayud. Almost all the regional and national newspapers highlighted this event. *ABC* and *Heraldo de Aragón* described it as a "landslide from a nearby mountain, with more than 800 tonnes of earth and stones falling. Some blocks were more than 2 *Tm*, and several of them ended up in the river Jiloca, while others cut off the road to Valencia". The works for removing the collapsed material and opening the road again took 4 days. Older people in both municipalities remember perfectly well what happened. In Velilla de Jiloca, they advised us that, on top of the mountain where the landslide occurred, a large open crack (*La Raja*) does exist "since ever", where they used to play as children.

The collapsed slope belongs to an abrupt escarpment that extends along, and close to, the right bank of the Jiloca river. It is made of horizontal Miocene gypsum and marl beds, deeply cut by a network of fractures with dominant NW–SE and NE-SW directions, in its northern part, and NNW-SSE and ENE-WSW, in its southern part. The escarpment is markedly unstable, as evidenced by its current appearance, with multiple partially disconnected gypsum blocks, some of them modelled in the form of monoliths. Satellite images (Fig. 8a) show how some blocks bounded by two fracture sets are separated from the escarpment without losing their parallelepipedal shape. At the roadside, other blocks that were overturned in the past show steeply dipping bedding (Fig. 8b).

A second geomorphological effect, verified with considerable reliability, is fall of one or two large rock blocks in Barranco del Montecillo, a narrow, winding canyon embedded in Upper Cretaceous limestones south of Aldehuela de Liestos. An elderly informant, Santiago Muñoz, told us that, as a boy, he worked as a shepherd and regularly led his sheep

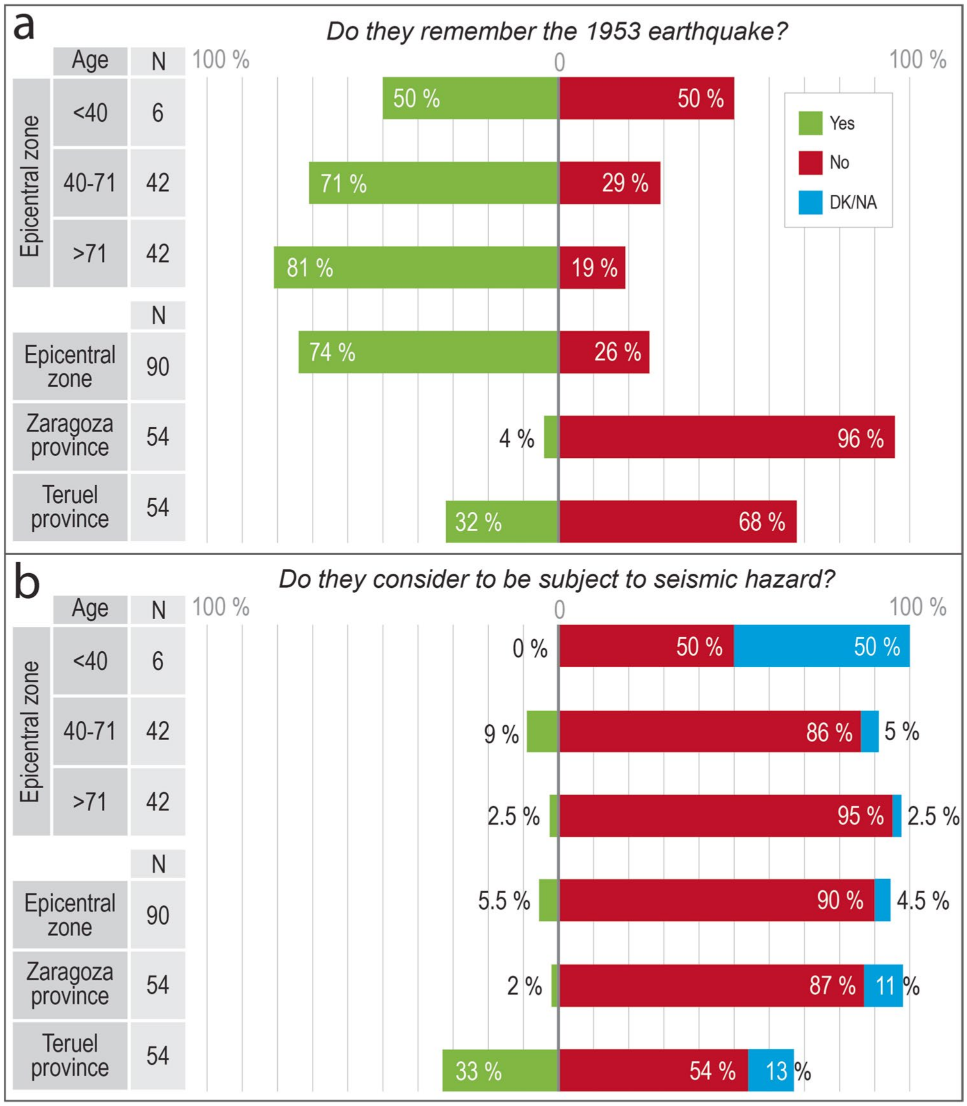

Fig. 7 **a** Results of the survey carried out in the Zaragoza and Teruel provinces exploring social memory on the 1953 earthquake. **b** Idem exploring perception of seismic hazard. Number of individuals interviewed: 198; date: December 2020 to February 2021

along this canyon. Next to one of the meanders, halfway up the slope, there was "a menacing boulder". Years later, at an imprecise date after 1953, he returned to the site and saw that the large rock had indeed fallen to the valley bottom, probably during the earthquake.

We assessed the likelihood of this hypothesis by carefully surveying the area described by the informant. According to his testimony, the boulder (i) was very large, (ii) came from the left slope of the canyon, and (iii) in its fall, it slightly overtopped the bottom and crossed to the right bank. Three candidate blocks were found at the bottom of Barranco del Montecillo. One of them was excluded since it is on the left side of the talweg, and with a fair degree of certainty is already observable on aerial photographs taken in 1947, before the earthquake. The other two blocks are compatible with the description, as they lie on the right bank, and they do not appear on 1947 aerial photographs whilst are observable on those taken in 1957. Particularly, one of these two boulders, about 3 m high, shows internal bedding in a nearly vertical position (Fig. 9). This suggests that it was overturned whilst falling and, with the inertia, it could have surpassed the talweg and risen approximately 1 m on the opposite bank.

Social Perception of Seismic Hazard

How do memory and knowledge on the 1953 earthquake translate into the perception of seismic hazard in the region? The second part of the population survey carried out inside and outside the epicentral area sought to assess the degree of perception amongst the population living in or linked to the Used-Daroca-Maluenda area, making a comparative assessment between successive generations of people and with other areas of Aragon (Table 2 and Fig. 7b). In the area most affected by the 1953 earthquake, the vast majority of people

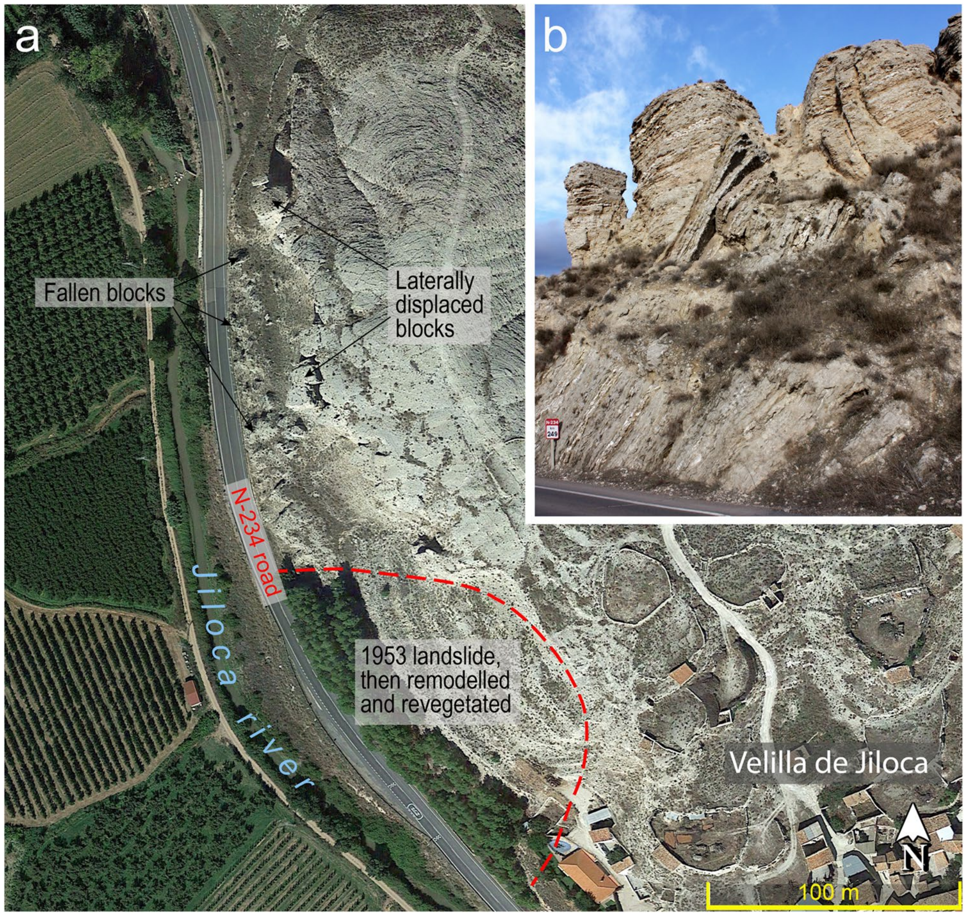

Fig. 8 **a** Vertical *Google Earth* image of the unstable slope in which a landslide triggered by the earthquake cut the N-234 road. **b** Current appearance of the N-234 road slope. Blocks of Miocene gypsum bounded by tectonic fractures are displaced laterally and, in some cases, collapsed and overturned

Fig. 9 Limestone block at the bottom of Barranco del Montecillo, very probably fallen during the 1953 earthquake

do not consider themselves to be subject to significant seismic hazard. Overall, only 5.5% of people do. By age group, this perception is higher amongst people aged between 40 and 71 (9%) than amongst those over 72 (2.5%). Earthquakes worry people much less than other natural disasters that could affect their territory. Ahead of them, and in this order, the danger of floods, landslides, or karstic subsidence are considered much higher. The same order is maintained irrespective of the age range analysed.

If we compare these results with those of the other areas covered by the survey, we notice certain differences. Both in the rest of the Zaragoza and Teruel provinces, those who believe they inhabit an area with a certain seismic hazard are again in the minority, but whilst in Zaragoza they are only 2%, and in Teruel they reach 33%. Compared with the other types of geological disasters, the order of concern in the province of Teruel is similar as in the epicentral area, whilst in Zaragoza the perception of danger of karstic subsidence (a frequent process in the central Ebro basin) prevails over that of slope movement (Table 2).

The main conclusion to be drawn is that the existing social memory of the 1953 earthquake does not translate into a significant perception of seismic hazard. This perception is miniscule and very similar in the area most affected by the earthquake, where it is very largely remembered, and in the rest of the province of Zaragoza, where the memory is almost non-existent. The perception of seismic hazard seems to be more influenced by cultural factors: in the epicentral zone it is higher amongst people who did not live through the earthquake, but who have heard stories within the family and have had external information that has probably highlighted its importance.

This hypothesis is corroborated by the results obtained in Teruel: in spite of having felt the earthquake of 1953 more remotely, there seems to be a slightly greater awareness of it than in Zaragoza, and even though there is no other quake comparable in intensity and proximity in time in the register of the whole province of Teruel, there is a greater perception of the seismic risk. The explanation is probably to be found in the fact that, especially in Teruel city, the seismic phenomenon has been the subject of press reports and social debate due to the above-mentioned issue of the project of new public hospital.

The Outreach Project

One of the main objectives of the present project was promoting scientific culture about natural disasters amongst population, based on their own memory and experience. In this way, knowledge generated has been processed and returned to locals in the form of scientific outreach products. Three tools have been used: a written publication, a documentary film, and public talks. These help them both to consolidate the social memory of the 1953 earthquake and, at the same time, to rationally understand geological processes involved in natural disasters.

The main results of the research work, both those related to geology (evaluation of the fault responsible for the earthquake, geomorphological-environmental effects) and those concerning human memory and social perception, are collected in an outreach style booklet (Simón et al., 2021; Fig. 10a). The latter also summarizes the main seismological data compiled from both scientific literature and unpublished documents. The edition has been promoted by the Zaragoza University in collaboration with local study centres of Daroca (Zaragoza) and Jiloca (Teruel). The printed copies have been distributed free of charge, most of them to the population of Campo de Daroca, Comunidad de Calatayud, and Jiloca counties.

A documentary film, 15 min in duration, shows the essential contents of the project in a synthetic and lively format (Fig. 10b). The narration is supported by drone scenes, documentary images, interviews, and short expert dissertations. The script and documents have been prepared by two of the authors of the present paper (J. L. S., A. P.), whilst filming and editing of the documentary was carried out by Jorge Brizuela.

A number of public talks have been carried out in municipalities of the Campo de Daroca, Comunidad de Calatayud, and Jiloca counties (Used, Daroca, Calamocha, Maluenda…), in which the book has been presented, printed copies have been given to the public attending the event, the documentary

Fig. 10 **a** Cover of the outreach short book: *The 1953 Used earthquake: science and memory*. **b** Photogram of the documentary film, filmed and edited by J. Brizuela: A. Peiro interviewing an aged informant

film has been exhibited, and the chronicle of the project has been released.

Concluding Remarks

Our study on the 1953 earthquake has tried to deepen the knowledge and rescue the memory of what was the last destructive earthquake to occur in Aragon. As Earth scientists, we have first attempted to characterize the tectonic framework in which the quake took place, mostly based on the geological and geomorphological record, i.e. on Earth's memory printed on rocks and reliefs. But we have also been interested in the social memory of that event, complementing scientific knowledge with popular knowledge of it.

The 1953 earthquake caused considerable material damage in Used (Zaragoza province) and, to a lesser extent, in other surrounding municipalities. The event was widely reported in regional and national press. It also produced the death of a girl, a fact that had never been explicitly reported before.

The earthquake was studied at the time by seismologists from the Fabra Observatory in Barcelona and the Instituto Geografico Nacional (IGN) in Madrid, and was assigned a magnitude of 4.7 and an epicentral intensity of VII. Uncertainties in focal location make it difficult to determine which fault in the area was responsible for the earthquake; the Daroca fault is the most compatible one with the available seismologic and tectonic information. The only documented geomorphological-environmental effects are a major landslide that cut the N-234 road and the fall of large boulders in a canyon tributary to the Río Piedra.

Based on direct testimonies from people who lived through it, as well as on a population survey carried out inside and outside the epicentral area, we conclude that the memory of the 1953 earthquake is very much alive in the more affected municipalities, both in the elderly and somewhat less so in younger generations. Nevertheless, that social memory does not translate into a significant perception of seismic hazard, the latter being more influenced by cultural factors than by direct personal experience of the earthquake.

Our study has a citizen science dimension: much information has been provided by the population itself and, after being processed and interpreted, has a return to the inhabitants of the territory in the form of cultural products. It somehow represents a dialogue between the *Memory of the Earth* and the social memory, trying to contribute to the remembrance of the 1953 earthquake not being lost. As stated by Fanta et al. (2019) referring to catastrophic floods, people remember and understand natural processes, but only for a limited period of time. Knowledge that is not repeated often enough fades away from the memory. Therefore, communitary protection from natural disasters cannot uniquely rely on folk memory, but on scientific knowledge. It is necessary to teach people about the occurrence of catastrophic events in the past, which requires exploring their record in rocks and landscapes, i.e. in the geological heritage.

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Code Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

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