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THE 9 JULY 551 AD BEIRUT EARTHQUAKE, EASTERN MEDITERRANEAN REGION

RYAD DARAWCHEH and MOHAMED REDA SBEINATI
Atomic Energy Commission of Syria,
P.O. Box 6091, Damascus, Syria

CLAUDIO MARGOTTINI
Italian Agency for New Technology, Energy and Environment,
S.P. 67 – Via Anguillarese,
301 – 00060 S. Maria di Galeria, Rome, Italy

SALVATORE PAOLINI
Italian Agency for New Technology, Energy and Environment,
P.O. Box 65 – 00044 Frascati, Rome, Italy

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Analysis of the Byzantine primary and secondary sources for identifying the historical earthquakes in Syria and Lebanon reveals that a large earthquake ($Ms = 7.2$) occurred in July 9, 551 AD along the Lebanese littoral and was felt over a very large area in the eastern Mediterranean region. It was a shallow-focus earthquake, associated with a regional tsunami along the Lebanese coast, a local landslide near Al-Batron town, and a large fire in Beirut. It caused heavy destruction with great loss of lives to several Lebanese cities, mainly Beirut, with a maximum intensity between IX–X (EMS-92). The proposed epicentre of the event is offshore of Beirut at about 34.00°N, 35.50°E, indicating that the earthquake appears to be the result of movement along the strike-slip left-lateral Roum fault in southern Lebanon.

Keywords: Seismology, historical earthquakes, historical primary sources, Lebanon.

1. Introduction

Studying a moderate to large historical earthquake in any region, when historical sources are available, should lead to the assessment of the parameters of that earthquake (i.e. date, coordinates, intensity and magnitude) and consequently the definition of a possible causative fault. This assessment together with others for many historical earthquakes in the region, then, will be used in the earthquake hazard assessment for particular sites, on both local and regional scales.

This paper deals with the 551 AD earthquake, the event that is described as probably the highest magnitude event in the Eastern Mediterranean Region [USGS-UNESCO, 1993].

Several pre-1900 AD catalogues mentioned this earthquake such as those of Bonito [1691] and Perrey [1850]. Also it is listed in the 20th century catalogues: Sieberg [1932] presented the first scientific study on this event when he described its effects in eastern Mediterranean region. Amiran [1952], using a noncontemporary source, had considered the event to be of grade ≥ 9 (MCS). Ben-Menahem [1979] used earthquake catalogues to place the earthquake's epicentre off coast of Beirut. While Plassard and Kogoj [1981] reviewed four historical sources to describe, especially, this event of Beirut. Abou Karaki [1987] had considered this event as a duplicated one and the real date, according to him, was in 1156 AD resulted from dating error between Hejira and Gregorian calendars, without presenting any evidence. Russell [1985] defined the path of destruction from Palestine through northwest Arabia by providing two noncontemporary sources and discussing another contemporary one. In addition, he noted that the destruction at Jerash, Nebo, Petra and Lijjun (today in western Jordan) caused by the 551 AD earthquake, that were proposed by Crowfoot [1938]; Saller and Bagatti [1949]; Hammond [1981] and Parker [1982; 1983] may be an interpretive error. Recently, Ambraseys *et al.* [1994] cited that this earthquake was in Palestine and felt across a large area. Also they suggested that the earthquake's epicentre is in the Jordan Rift Valley. Meanwhile, Guidoboni [1989] and Guidoboni *et al.* [1994] presented three historical original texts of the earthquake, showing the affected area along the Lebanese coast and indicating, in the same time, that the epicenter is located offshore of Beirut. Table 1 shows the available parameters of the earthquake as assessed by some of aforesaid authors. Although most of these series of the related works are valuable, we believe that the earthquake should be re-appraised for two reasons. Firstly, when reviewing the results of Guidoboni *et al.* [1994] and those of Ambraseys *et al.* [1994], we see that there is a clear discrepancy between them, with regard to the location of the epicenter. Secondly, no author has assessed the complete parameters of this earthquake.

Hence, the purpose of this paper is (1) to assess the complete parameters of the earthquake by analyzsing the macroseismic data based on original sources and applying modern methods of intensity and magnitude determinations, (2) to demon-

Table 1. Parameters of the 9 July 551 earthquake from the previous literature.

Author(s)	Date	Epicenter °N-°E	Intensity (I)	Magnitude (M)
Sieberg [1932]	551, July 9	/	/	/
Ben Menahem [1979]	551, July 9	/	I0=XI–XII (MM)	$M_L = 7.8$
Plassard & Kogoj [1981]	551, July 6	/	I=XII (Lebanese scale)	/
Russell [1985]	551, July 9	/	/	/
Ambraseys *et al.* [1994]	551, July 9	32.0–36.0	I Ω VI (MSK)	/
Guidoboni *et al.* [1994]	551, July 9	/	I=X (EMS)	/

strate the expected causative fault of the event and (3) to present an account of this event at the cities of the Lebanese coast in general and in Beirut in particular, in a region that has shown relative seismic quiescence during the 20th century.

2. Seismotectonic Setting

The area where the 551 AD earthquake occurred is located in the northern flank of the Arabian plate. This platform is bounded by the left-lateral strike-slip, north–south oriented Levant fault system (LEF) from the west, and by the Bitlis Suture system and the left-lateral strike-slip East Anatolian fault system from the north [Best *et al.*, 1990]. The relative left-lateral movement along the LEF is estimated at around 4–6 mm/year [Barazangi, 1983]. This movement causes collision of Arabian plate with the Eurasian plate. The LEF extends for about 1000 km from the Gulf of Aqaba to the border between Syria and Turkey near Antakya. Its extension in Lebanon consists of two main strike-slip left-lateral faults namely the Yammouneh fault (YAF) of N30°E, which runs through the western Bekaa Valley, and the Roum fault (ROF) that strikes N07°W in southern Lebanon. The ROF extends for more than 50 km from the Hula depression to the city of Beirut. The northernmost part of the YAF in Syria trends again N–S defining the significant strike-slip left lateral Al-Ghab fault (GHF) and intersects the East Anatolian fault system just north of Antakya [Ambraseys and Barazangi, 1989]. Figure 1 shows the main faults of the LEF zone in Lebanon and Syria.

The seismic instrumental monitoring during the 20th century reveals that there is a moderate earthquake activity in Lebanon and western Syria [Sbeinati, 1994]. This activity is concentrated along the main segments of the LEF in Lebanon and western Syria. Two recent moderate earthquake activities occurred due to the ROF and felt widely in southern Lebanon and western Damascus. The first one represents by the double shocks of March 26, 1997 (at 04:22 and 13:20 GMT) of duration magnitude 4.9 and 4.5, respectively [Darawcheh and Sbeinati, 1998], whereas the second event is the shock of June 20, 1999 (at 10:44 GMT) of duration magnitude 3.4 [Sbeinati and Darawcheh, 1999]. Clearly this shows that the ROF is capable and active. Historically, the northern extension of LEF is the site of numerous large earthquakes ($Ms \geq 6.5$) [Ambraseys and Barazangi, 1989; Mouty *et al.*, 1998] with return period of 200–350 years [Ambraseys and Barazangi, 1989].

The importance of the 551 earthquake lies in the fact that Lebanon and western Syria have generally shown relatively seismic tranquillity in the 20th century and most important cities and economical pools are located in the vicinity of the YAF, GHF and ROF.

3. Methodology and Sources of Information

The methodology of study of the historical earthquakes is now available in the literature (e.g. IAEA [1987]; Ambraseys *et al.* [1983, 1997]; Vogt [1993]; Stucchi [1994]).

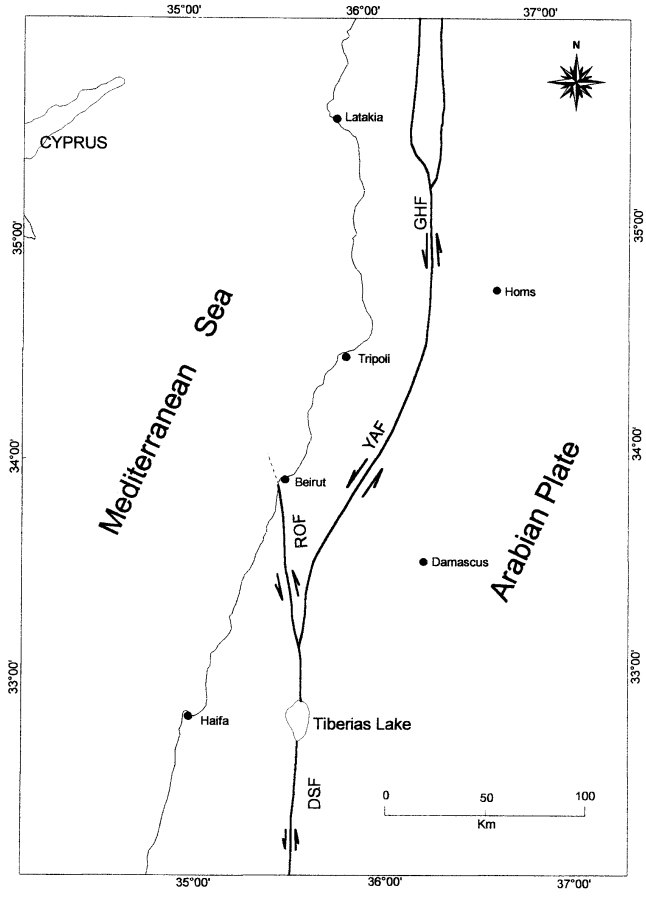

Fig. 1. The main faults of the Levant fault zone in Lebanon and Syria. Note that YAF: Yammouneh Fault; ROF: Roum Fault; GHF: Al-Ghab Fault; DSF: Dead Sea Fault.

In short, we have retrieved the relevant macroseismic data from the available historical sources from two depositories, the Vatican and Pontificio Istituto Orientale, then we reviewed and studied these macroseismic data; in order to reassess the parameters of the earthquake (i.e. date of the earthquake, epicentral location, epicentral intensity and locality intensity, focal depth and macroseismic magnitude) using some relevant rules.

The sources of information for our earthquake are well-known chroniclers who lived in the time of the event. They are Malalas (Mal.) (ca. 491–578 AD), Agathias (Agath.) (ca. 532–580 AD) and John of Ephesus (John Eph.) (ca. 507–586 AD). In addition, there is an itinerary dated to ca. 560–570 written by a traveller named Antoninus Placentinus (Anton.) who visited a part of the affected region shortly after the earthquake. Also, we used an account named De Fragmentis Historicis Tuscolanis (Frag. Hist. Tusc.) dated back to 6th/7th century written by anonymous

chronicler. Normally these sources exist only in quotation by later writers (see historical sources of the references). With the exception of the last source, these sources are documented in Guidoboni *et al.* [1994]. Also we used the late 9th century AD source Chronicon pseudo-Dionisyaum (Chron. pse. Dionis.) despite it is the late one, as it mentioned localities that not reported by the above-mentioned sources.

Although there are problems in some of these sources, they contain good descriptions of the 551 AD earthquake with its physical effects.

We avoided using noncontemporary, but Byzantine sources that are attributed to Theophanes (ca. 758–818), Georgius Monachus (9th century AD), Georgius Cedrenus (ca. 1081–1118) and Michael the Syrian (1126–1199 AD), since they derived their materials from original ones and consequently add no further information.

However, we believe that the historical information available about the earthquake is barely sufficient to allow us to construct the earthquake including its parameters.

4. The Earthquake: Analyses of Data

The exact date of this event is doubtful, and still not very clear. The date reported in the *Chronographia* of Theophanes seems to be the most reliable, being probably extracted from one of the earlier versions of Malalas. Nevertheless, the same Malalas chronicle was largely used from the posterior authors, but with errors and misinterpretations, such as John of Ephesus (year 558/559), or the anonymous authors of the Chronicon pseudo-Dionisyanum (552/3 and 558/9).

Other authors, in example Agathias Scholasticus, are too vague.

In the year 551 AD, July 9, there was a destructive earthquake occurred during the reign of the Byzantine Emperor Justinian (ca. 527–565) along the entire Lebanese littoral. The earthquake destroyed several cities in Maritima (modern Lebanese coast). The affected cities were Berytus [John Malalas, John of Ephesus, Agathias Scholasticus, Antoninus Placentinus, De Fragmentis Historicis Tuscolanis, Chronicon pseudo-Dionisyanum] which is modern Beirut, Tripolis [John Malalas, Antoninus Placentinus, De Fragmentis Historicis Tuscolanis, Chronicon pseudo-Dionisyanum] which is modern Tripoli, Sidon [John Malalas, De Fragmentis Historicis Tuscolanis, Chronicon pseudo-Dionisyanum] which is modern Saida, Byblus [John Malalas, Antoninus Placentinus, De Fragmentis Historicis Tuscolanis, Chronicon pseudo-Dionisyanum] which is modern Djbil, Botrys [John Malalas, De Fragmentis Historicis Tuscolanis] which is modern Al-Batron, and Tyrus [John Malalas, De Fragmentis Historicis Tuscolanis, Chronicon pseudo-Dionisyanum] which is modern Tyre or Sur, to an extent that they received financial assistance from the Emperor for reconstruction [John Malalas]. Moreover, there is a 6th/7th century AD source (De Fragmentis Historicis Tuscolanis) added that 101 towns, not named in the source but located in the vicinity of these cities, fell down, and a great myriad of men and animals were killed in them. With the exception of Beirut, detailed description is lacking for other affected Lebanese cities and regions. In Berytus, most

of the buildings including the famous structures fell down with the loss of a great number of people under the debris [Agathias Scholasticus]. The Bishop of Beirut (an eyewitness of the earthquake) said that there were 30,000 deaths due to the earthquake, except the foreign residences [Antoninus Placentinus]. This figure is probably reasonable for a city that was flourishing to the extent it was called pearl of the Phoenician coast at that time. Nevertheless, John of Ephesus reported that the survivors were exhausted by the thirst due to the destruction of the city aqueduct. He added that there was a large fire, continuing for almost two months. The School of Law, one of the outstanding features in Berytus and one of the important centers for legal studies in the Byzantine Empire during that time was destroyed to the extent it was temporary transferred to Sidon [Agathias Scholasticus]. On the other hand, it was mentioned that at the time of the earthquake the sea retired for a mile then returned drowning many ships [John Malalas]. More details about this phenomenon in Beirut are supplied by John of Ephesus. He says: "before the earthquake happened, the sea retired roughly two miles, then the people were rushed in the seabed to find wealth at the sunken ships, then an immense wave returned, flooding the shore and drowning ships as well as the people who were in the seabed and along the coast". Although this last detailed description is somewhat strange and it is difficult to verify its reality, obviously the earthquake was associated with a tsunami. The horrible news of Beirut have reverberated across the entire Empire to an extent that the 6th century Hellenistic poet from Spain John Barbacallus wrote a verse elegizing Beirut [cited in Hitti, 1972]. Based on Beirut's available data, the intensity can be assessed as IX–X (EMS-92). Historical sources, from the other side, have mentioned that Beirut was in chaos and easily conquered by the Persians, Byzantines and Arabs in the year 600 AD [Collinet, 1925].

The city of Sidon suffered with a large number of deaths [John Malalas]. The process of transferring School of Law from Beirut to Saida [Agathias Scholasticus] gives an impression that the degree of damage in Saida was less than that in Beirut. Therefore, a seismic intensity range VII–VIII in Saida may be assigned. In the town of Botrys, a part of Mount Lithoprosopos broke off and fell into the sea forming a harbour [John Malalas]. This description indicates that there was a local landslide. The cities of Byblus, Tyrus and Tripolis were also destroyed with their inhabitants [John Malalas, Antoninus Placentinus, De Fragmentis Historicis Tuscolanis, Chronicon pseudo-Dionisyanum]. Tyre was also destroyed with its inhabitants [John Malalas, De Fragmentis Historicis Tuscolanis, Chronicon pseudo-Dionisyanum]. A similar fate befell the town of Trieris [Antoninus Placentinus], modern Shikka. Although the description is very short, intensity range of IX–X has been allocated to these former towns for geographical considerations. When Antoninus arrived at the island of Antharidus near Syria during his way to the Holy Land, which is probably the sole island of Aradus (modern Arwad) belonging to Syria and not Antaradus (modern coastal city of Tartus), he was silent about the earthquake's effects at the island. Taking into consideration that the earthquake was felt farther north at Antioch (as it will be shown later on) and that this island is very small that did not

allow him to observe any effect, it is believed that Aradus should has only felt this earthquake. The end 8th century chronicle [Chronicon pseudo-Dionisyanum] mentioned that Sarepta (modern Sarfand) was also destroyed with its people. Despite this source is a very late one and so should be treated with caution, this earthquake probably damaged or destroyed Sarepta as it lies between Sidon and Tyre. If this is so, this indicates an intensity range VII–VIII?

On the mainland, the earthquake was severe and tremendous in Palestine [John Malalas, De Fragmentis Historicis Tuscolanis], to such an extent that many cities and villages, not named, in both regions of Galilee (modern Aj-Jalil) and Samaria (modern As-Samyra) were destroyed [John of Ephesus, Chronicon pseudo-Dionisyanum]. To the east, similarly happened to the province of Arabia, which is western Jordan today, [John Malalas, John of Ephesus, De Fragmentis Historicis Tuscolanis, Chronicon pseudo-Dionisyanum]. In this regard, archaeological evidences suggest that the 551 AD earthquake is responsible for destruction or damage of a number of historical sites in Arabia (Jerash, Nebo, Lijjun and Petra) [Crowfoot, 1938; Saller and Bagatti, 1949; Hammond, 1981; Parker,1982, 1983]. However, due to the missing of objective evidence we cannot verify any severe damage to these sites.

This event was strongly felt in Syria including regions of Antioch (modern Antakya) and Mesopotamia [John Malalas, De Fragmentis Historicis Tuscolanis]. In the time of this earthquake, Agathias Scholasticus mentioned that Alexandria was felt by an earthquake causing concern and no one remained in his house. We think that it may be the same event.

The total number of deaths is rather difficult to evaluate. However, as a result of the earthquake side-effects (tsunami and fires) we believe that a myriad of people were killed along the Lebanese coast, particularly in Beirut.

The available macroseismic data makes impossible to construct the isoseismal curves for the 551 AD earthquake, from which the earthquake's epicenter can be assessed. Alternatively, we proposed distribution of the damage severity and earthquake intensity (according to EMS-92 [Grünthal, 1993]) for the affected Lebanese cities as shown in Fig. 2. However, we believe that the most probable position of the earthquake's epicentre seems to be a near-field location of Beirut, the locality that has the highest intensity due to this earthquake from one hand, and alternatively, offshore of Beirut on the other hand. The evidences for the latter is as follows: firstly, the earthquake was preceded by a retreating of the sea for a period of time that allowed people to rush downward the exposed bottom of the sea to search for treasures before they felt the land shaking. Secondly, there is the large extent and the severity of the tsunami along the whole Lebanese coast. Considering that there is no evidence that the earthquake affected or even was felt in Cyprus [Pantazis, 1996], we estimate the earthquake's epicentre at 34.00°N and 35.50°E. These coordinate fit with the conclusions of Guidoboni *et al.* [1994].

Locating the earthquake's epicentre near the sole strike-slip Roum fault suggests that the earthquake is the result of its movement. This northwest fault that extends

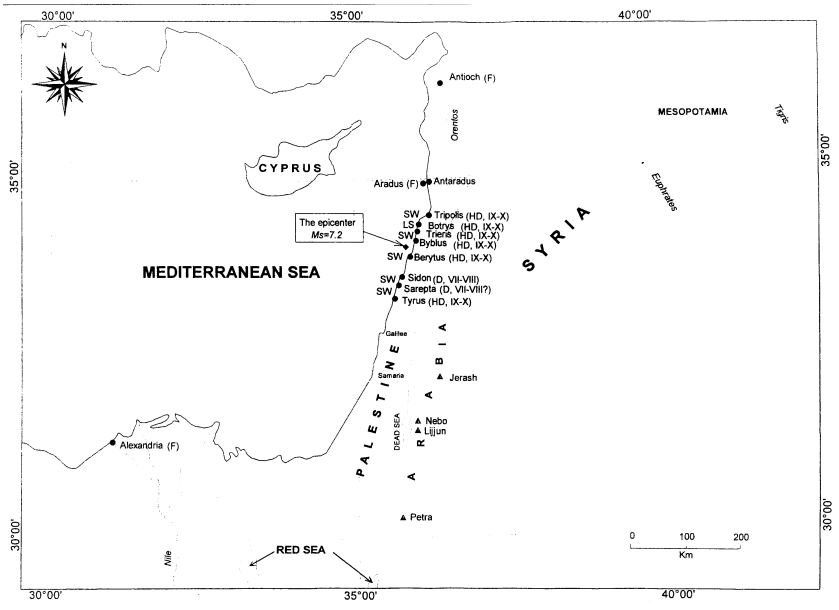

Fig. 2. Distribution of the damage severity and the intensity (EMS-92) for the 9 July, 551 AD earthquake, and its proposed epicentre. Note that F: Felt; D: Damage; HD: Heavy Damage; LS: Landslide and SW: Sea-Wave. Triangles represent possible damaged archaeological sites from the previous literature.

from north of Tiberias Lake to city of Beirut is a branch of a major fault system that forms the western boundary of the Arabian platform of the transform nature. This fact, together with the results of the seismic monitoring in the region during the 20th century suggests that the focal depth is shallow.

Taking into consideration the above-mentioned effects of the event in the area, we believe that the earthquake is of large size. To assess surface wave magnitude Ms of the earthquake, three methods were used:

1 — Using the Shebalin's nomograph [1974], $Ms = 7.3$ is calculated.

2 — Applying Ambraseys' equation [1988] that correlates between observed length of strike-slip surface fault L (in km) and Ms for the Middle East:

$$Ms = 4.63 + 1.43 \log(L) \tag{1}$$

and assuming that this event may be attributed to the 50-km-long, strike-slip Roum fault, we obtain $Ms = 7.1$.

3 — Adopting the empirical formula of Bonilla *et al.*, 1984 that correlates also between Ms and L for numerous strike-slip faults:

$$Ms = (6.10 \pm 0.25) + (0.70 \pm 0.13) \log L \tag{2}$$

by taking into account the five possible cases (4 with errors and one without errors), Ms has been calculated to be 7.3. The results obtained by the above

reported formulae are scattered between the values $Ms = 7.1$–7.3 which can be assumed as final magnitude.

Moreover these values seems to be reasonable as compared with the historical descriptions of the effects produced by this earthquake.

Although historical sources did not mention occurrence of aftershocks, it is more likely that this large earthquake should be followed by at least one less-magnitude (felt) aftershock. Sometimes this is encountered, as the historical sources report only the larger events.

5. Discussion and Conclusions

The re-appraisal of the 9 July 551 AD earthquake has led to the following conclusions:

1 — Location of three new affected sites: these are the island of Aradus (modern Arwad), the towns of Trieris (modern Shikka) and Sarepta (modern Sarfand).
2 — Estimating the seismic intensities for the previous localities, as well as the towns of Tyrus, Sidon and Botrys.
3 — Assessment of the average surface-wave magnitude of the earthquake (Ms), to be of the order of 7.1–7.3.
4 — Suggesting that the strike-slip left-lateral Roum fault is a possible causative fault of the earthquake.
5 — Locating the earthquake's epicentre at 34.00°N and 35.50°E.

In general, this paper shows that the 9 July 551 AD earthquake represents one of the largest seismic events in and around Lebanon during the Byzantine period. It destroyed several Lebanese coastal cities and chiefly the city of Beirut. The earthquake was associated with a tsunami along the Lebanese coast, with a local landslide near Al-Batron and with an eruption of a large fire in Beirut, continuing for almost two months.

The general conclusions are shown in Fig. 2.

Returning to Fig. 1, the Roum fault (ROF), which seems to be responsible of this earthquake, represents a branch of the major fault system criss-cross Lebanon and western Syria. This major fault system consists of two main faults namely the Yammouneh fault (YAF) and the Al-Ghab fault (GHF), which are both responsible for generating many destructive historical earthquakes in Syria and Lebanon. In this regard, the YAF has generated earthquakes in 1202 ($Ms = 7.5$), 1705 ($Ms = 6.9$) and 1759 ($Ms = 6.6$ and 7.4) [Ambraseys and Melville, 1988; Ambraseys and Barazangi, 1989; Ambraseys and Finkel, 1993; Mouty *et al.*, 1998]. While the Al-Ghab fault has generated destructive historical earthquakes in western and northwestern Syria, such as earthquakes of 1157 ($Ms > 7.0$), 1170 ($Ms > 7.0$), 1404 ($Ms = 7.4$), 1407 ($Ms \sim 7.0$), 1796 ($Ms = 6.6$), 1822 ($Ms = 7.4$), 1872 ($Ms = 7.2$) [Ambraseys and Barazangi, 1989; Mouty *et al.*, 1998]. Taking into consideration that the return

period between these large historical earthquakes that occurred in Lebanon and western Syria is 200–350 years [Ambraseys and Barazangi, 1989] from one hand, and that the region with its urban and economic density, on the other hand, has shown relatively seismic quiescence during the 20th century, we believe that the earthquake hazards of these may be genuine in many cities in the area in the near future. In other words, there may be a probable rupture of one of the aforesaid faults, in the form of a large earthquake ($M \geq 6.5$). This implies that results of these historical earthquake studies must be used in seismic hazard assessment for particular sites and on both local and regional scales for Lebanon and Syria, and that huge efforts of multidisciplinary approaches should be done by architects and engineers by designing structures within acceptable safety margins and strengthening existing structures. And this, in turn, will help in mitigating the seismic risk in our region.

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