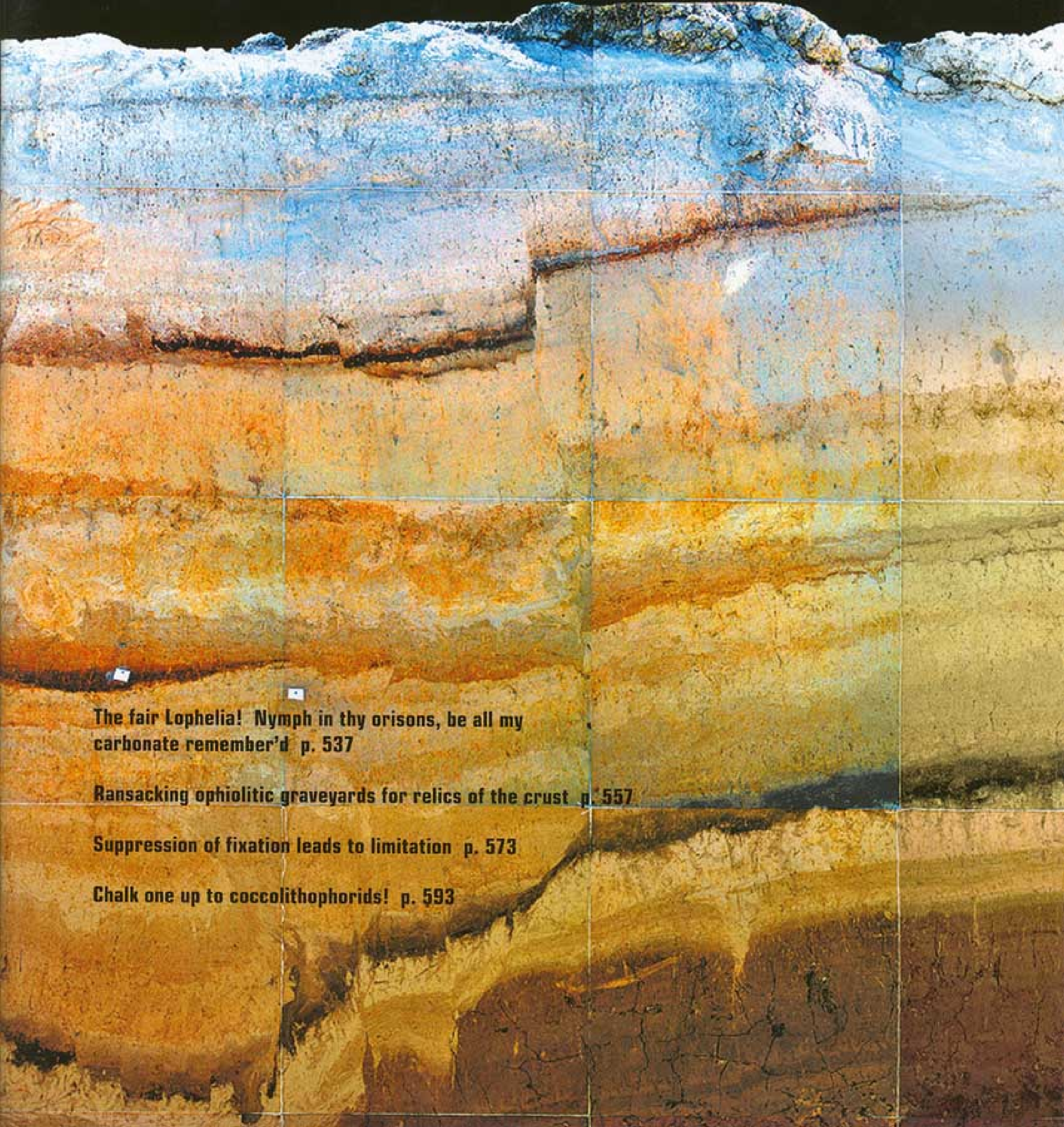
JULY 2005 ■ VOL. 33 NO. 7

THE GEOLOGICAL SOCIETY OF AMERICA

GEOLOGY

ISSN 0091-7613

JULY 2005 ■ VOL. 33 NO. 7 ■ P. 529–616



Sources of the large A.D. 1202 and 1759 Near East earthquakes

M. Daëron* Institut de Physique du Globe de Paris, UMR 7578, 4 place Jussieu, Boîte 89, 75252 Paris, France
Y. Klinger*
P. Tapponnier* Institut de Physique du Globe de Paris, UMR 7578, 4 place Jussieu, Boîte 89, 75252 Paris, France
A. Elias* Institut de Physique du Globe de Paris, UMR 7578, 4 place Jussieu, Boîte 89, 75252 Paris, France, and National Council for Scientific Research, P.O. Box 165432, Ashrafieh, 1100-2040 Beirut, Lebanon
E. Jacques* Ecole et Observatoire des Sciences de la Terre de Strasbourg, 5 rue René Descartes, F-67084 Strasbourg, France
A. Sursock* National Council for Scientific Research, P.O. Box 11-8281, Riad El-Solh, 1107 2260 Beirut, Lebanon

ABSTRACT

The sources of the May 1202 and November 1759, M 7.5 Near East earthquakes remain controversial, because their macroseismal areas coincide, straddling subparallel active faults in the Lebanese restraining bend. Paleoseismic trenching in the Yammoûneh basin yields unambiguous evidence both for slip on the Yammoûneh fault in the twelfth–thirteenth centuries and for the lack of a posterior event. This conclusion is supported by comparing the freshest visible fault scarps, which imply more recent slip on the Râchaïya-Serghaya system than on the Yammoûneh fault. Our results suggest that the recurrence of an A.D. 1202–type earthquake might be due this century, as part of a sequence similar to that of A.D. 1033–1202, possibly heralded by the occurrence of the 1995 Mw 7.3 Aqaba earthquake. The seismic behavior of the Levant fault might thus be characterized by millennial periods of quiescence, separated by clusters of large earthquakes.

Keywords: Lebanon, Levant fault, historical earthquakes, paleoseismology, event clustering.

INTRODUCTION

The 1000-km-long, left-lateral Levant fault (e.g., Dubertret, 1932; Quennell, 1959; Freund et al., 1968; Garfunkel et al., 1981) marks the boundary between the Arabian plate and the Sinai-Levantine block (Courtillot et al., 1987; Salamon et al., 2003). Since Biblical time, it has generated large (M > 7) earthquakes (e.g., Poirier and Taher, 1980; Ben-Menahem, 1991; Abou Karaki, 1987; Guidoboni et al., 2004b). However, the sources of most historical events in the Near East remain unclear. This is particularly true between 33°N and 34.5°N, where the plate-boundary fault system is divided (Dubertret, 1955), owing to transpression within the Lebanese restraining bend (Freund et al., 1970; Griffiths et al., 2000). Recent offshore seismic studies (Carton et al., 2004; Elias et al., 2004) suggest that the strike-perpendicular and strike-parallel components of motion are accommodated by discrete features east and west of Mount Lebanon (3090 m): the offshore Tripoli-Beirut thrust (Tapponnier et al., 2001), and the Yammoûneh and Râchaïya-Serghaya faults, respectively (Fig. 1). The latter strike-slip fault, which follows the Anti Lebanon Range (2630 m) east of the Beqaa Plain (1000 m), merges with the former at the southern tip of the Hula basin. By linking the Jordan Valley fault with the Missyaf fault, the Yammoûneh fault ensures the continuity of the plate boundary across Lebanon.

Seismic hazard evaluation in this region depends on a better understanding of the seismic potential of the various strands and segments of the Levant fault system. On the basis of new paleoseismic data and geomorphic observations, we propose a reassessment of the sources of arguably the two strongest historical earthquakes (A.D. 1202 and 1759) that devastated the Beqaa Plain and surrounding areas. The Yammoûneh fault has usually been believed responsible for both the May 1202 and November 1759 earthquakes (e.g., Ambraseys and Barazangi, 1989; Ben-Menahem, 1991). Our results indicate instead that the paired October and November 1759 events ruptured the Râchaïya-Serghaya system rather than the Yammoûneh fault. Although historical data alone are inconclusive, paleoseismic dating and comparison of geomorphic observations remove the ambiguity.

MACROSEISMIC CONSTRAINTS ON THE 1202 AND 1759 EVENTS

The effects of the 1202 and 1759 earthquakes were assessed by Ambraseys and Melville (1988) and Ambraseys and Barazangi (1989), respectively, using first-hand accounts. The 20 May 1202 earthquake shook western Syria and the Crusader states, toppling 31 columns of the Jupiter temple in the city of Baalbek (Ben-Menahem, 1991), which was destroyed. The cities of Nablus, Acre, Safed, Tyre, Tripoli, and Hamah, among others, were severely damaged (Fig. 1). Rock falls in Mount Lebanon killed 200 people. Shaking was felt throughout the Mediterranean and Middle East, as much as 1200 km away.

The seismic sequence of 1759 affected roughly the same region (Ambraseys and Barazangi, 1989). The smaller 30 October shock ruined Safed, Qunaitra, and many villages nearby, killed 2000 people, and triggered a seismic wave in Lake Tiberias (Ben-Menahem, 1979). The second, larger shock on 25 November destroyed all villages in the Beqaa. Baalbek was ruined. Three of the last nine columns of the Jupiter temple (Ben-Menahem, 1991) and three columns of the Bacchus temple collapsed. Safed, Ras Baalbek, and Damascus were damaged, and the earthquake was felt as far as Egypt and Anatolia, 1100 km away.

The areas of maximum destruction of the 1202 and November 1759 events overlap, covering an elongated, 150–200-km-long, south-southwest–trending zone centered on the Beqaa plain (Fig. 1). Historical accounts of damage thus imply that the events originated on the Yammoûneh or Serghaya fault. Macroseismic isoseismal contours tend to be biased toward populated areas: here, the fertile Beqaa Plain. It is therefore impossible to use such data alone to discriminate between the two faults.

SURFACE FAULTING

The identification and localization of surface faulting associated with the 1202 and 1759 events provides additional clues to determine the faults involved. Archeological and paleoseismic investigation (Ellenblum et al., 1998) showed that the 1202 earthquake caused 1.6 m of left-lateral displacement of fortification walls at Vadum Jacob (Fig. 1). A later 0.5 m offset may correspond either to the October 1759 event or to the last large regional event of 1 January 1837 (Ambraseys, 1997). The castle at Vadum Jacob is located south of the junction between the Yammoûneh and Râchaïya-Serghaya faults, so the question of which fault took up slip to the north during either event remains open. On the Serghaya fault, in the southern Zebadani valley in Syria,

*E-mails: daeron@ipgp.jussieu.fr; klinger@ipgp.jussieu.fr; tappon@ipgp.jussieu.fr; elias@ipgp.jussieu.fr; eric.jacques@eost.u-strasbg.fr; asursock@cnrs.edu.lb.

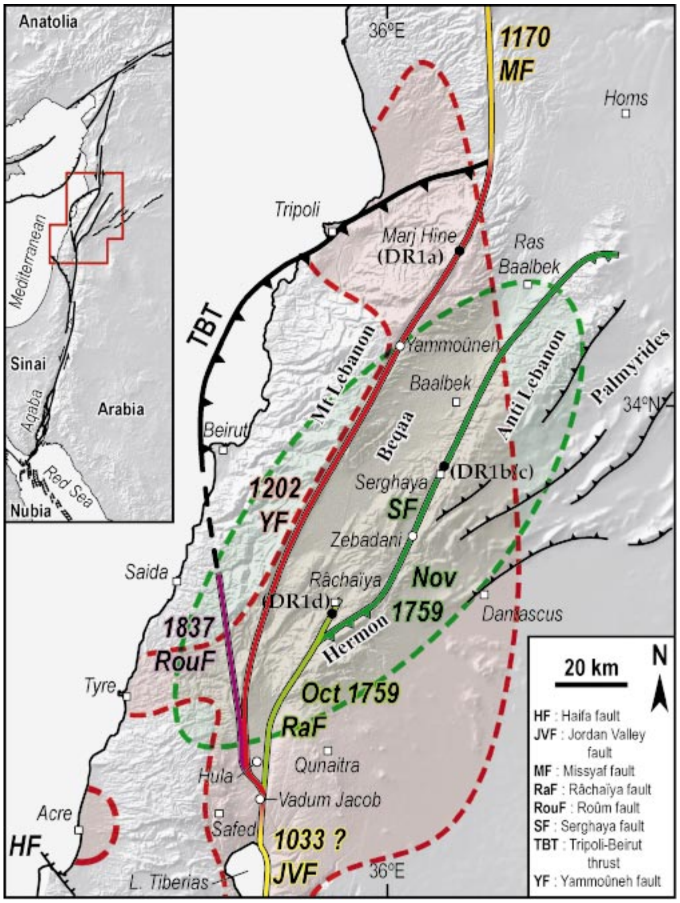


Figure 1. Schematic map of main active faults of Lebanese restraining bend: bold colored lines show maximum rupture lengths of large historical earthquakes in past 1000 yr, deduced from this study and historical documents (see discussion in text). Bold dashed lines enclose areas where intensities ≥VIII were reported in A.D. 1202 (red) and November 1759 (green) according to Ambraseys and Melville (1988) and Ambraseys and Barazangi (1989). Open symbols show location of cities (squares) and sites (circles) cited in text. Black dots mark location of field photographs shown in Figure DR1 (see footnote 1). (Inset: Levant transform plate boundary.)

Gomez et al. (2001) described evidence of recent faulting in the form of a persistent free face 0.5 m high on a scarp cutting soft lacustrine sediments. Trenching in this area, Gomez et al. (2003) exposed a colluvial wedge with modern ^{14}C ages, implying that the latest seismic event postdates A.D. 1650. They interpreted this event to be one of two eighteenth century earthquakes (A.D. 1705 or 1759), but could not discriminate between the two.

Historical sources concerning surface disruption witnessed at the time of the earthquakes are ambiguous. The 1202 Mount Lebanon rock falls might hint at stronger shaking on the west side of the Beqaa, hence on the Yammoûneh fault, but comparable shaking to the east might have gone unreported. Ambraseys and Barazangi (1989, p. 4010) mentioned 100-km-long surface ruptures in the Beqaa in November 1759, but stated that ''the exact location and attitude of (these ruptures) is [sic] not possible to ascertain today.'' Nevertheless, they inferred the Yammoûneh fault to be the most likely candidate. Building on this inference, Ellenblum et al. (1998) referred to Ambraseys and Barazangi (1989) as quoting a description of ground breaks on the Yammoûneh fault by the French ambassador in Beirut. Our own investigation of the French sources cited by Ambraseys and Barazangi (1989, p. 4010) yielded only a second-hand account by the French consul in Saida: ''One claims that [. . .] on the Baalbek side (or possibly: near Baalbek) pulling toward the plain the earth cracked open by more than [~6 m] and that this crack extends for over twenty leagues (~80 km)'' (Archives Nationales, Paris, B1/1032/1959-60). The wording suggests that this rupture took place on one side of the Beqaa, and the mention of Baalbek points to the east side, thus to the Serghaya fault.

The inference that the 1759 earthquakes might be due to slip on the Râchaïya-Serghaya fault and the 1202 event on the Yammoûneh fault is qualitatively supported by comparing the preservation of scarps and mole tracks along the two faults. Data Repository Figure DR1[1] shows the freshest seismic surface breaks we studied in the field. On the east side of the Marj Hîne basin, the Yammoûneh fault juxtaposes Cretaceous limestones with Quaternary colluvial limestone fanglomerates. The surface trace of the fault is marked by a classic coseismic scarplet (fault ribbon: e.g., Armijo et al., 1992; Piccardi et al., 1999) that is fairly weathered (Fig. DR1A; see footnote 1). North of Serghaya, one strand of the Serghaya fault shows a scarplet of comparable origin, between limestone and limestone colluvium, but with a relatively unaltered surface and lighter color (Fig. DR1B; see footnote 1). This scarplet marks the base of a prominent slope break many kilometers long, at places only tens of meters above the valley floor, hence not due to landsliding. On the Râchaïya fault, we found fresh mole tracks in unconsolidated limestone scree (Fig. DR1D; see footnote 1), while none are preserved on the Yammoûneh fault. The fault ribbon north of Serghaya, which testifies to down-to-the-west normal faulting, fits well the French consul's description. Such evidence complements that of Gomez et al. (2001) at Zebadani, implying that the latest earthquakes on the Râchaïya-Serghaya fault are younger than on the Yammoûneh fault (Tapponnier et al., 2001).

PALEOSEISMIC EVIDENCE

To test the inference that the 1202 earthquake is the latest event to have ruptured the Yammoûneh fault, we investigated the paleoseismic record of this fault by trenching lacustrine deposits in the Yammoûneh basin, on the eastern flank of Mount Lebanon (Figs. 1 and DR2 [see footnote 1]). The floor of that closed pull-apart basin used to be flooded each year by meltwater from karstic resurgences (Besançon, 1968). The lake was artificially dried 70 yr ago, and is now a cultivated plain. Aerial photographs and high-resolution satellite images show that the trace of the active strike-slip fault shortcuts the pull-apart (Fig. DR2; see footnote 1). This geometry is clear from changes in soil color and vegetation, as well as inflections or offsets of gullies. Trenching on the east side of the paleolake (Fig. DR2; see footnote 1) confirmed the location of the main fault, which cuts a finely stratified, subtabular sequence of lake beds (Fig. 2). Here, we summarize information relevant to the 1759 and 1202 events in the shallowest part of one trench (Kazzâb trench).

Beneath the 25-cm-thick cultivated soil, the upper 2–3 m of the sequence consists mostly of compact, homogeneous, white calcareous marls, with buff to brown layers, 5–200 mm thick, richer in silts and clays. Some of the lighter colored layers contain small (1–4 mm diameter) freshwater shells. A few of the layers are contorted and cloudy owing to liquefaction of probable seismic origin. Several layers contain abundant charcoal fragments (0.5–3 mm), of which 30 of 200 have already been dated. The 75-m-long trench exposes spectacular faulting within a rather narrow (<2 m wide) zone. Figure 2 shows two north-facing trench walls, <1 m apart. Owing to minor dip slip, the lake beds are sharply cut and vertically offset by fault splays, with local tilt and/or thickness changes. The effects of two seismic events are visible

[1]GSA Data Repository item 2005110, Figures DR1 and DR2 and Table DR1, field photographs of the Yammoûneh, Serghaya, and Râchaïya faults, satellite image of Yammoûneh paleolake and fault, and accelerator mass spectrometer radiocarbon data, is available online at www.geosociety.org/pubs/ft2005.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

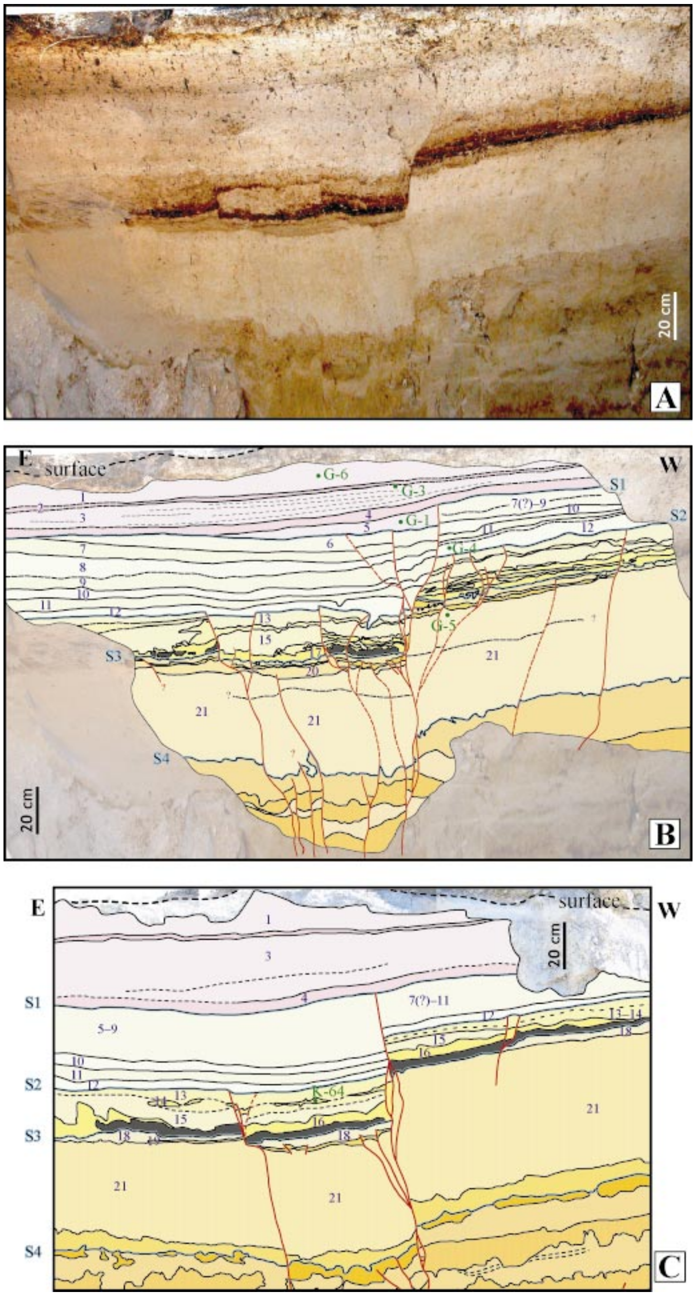


Figure 2. Photograph (A) and log (B) of wall of shallow Kazzâb-2002 trench, and log (C) of Kazzâb-2001 trench. K23, K24, and K29 were sampled on part of Kazzâb-2001 wall outside area shown here.

on both walls, in the uppermost 80 cm. The latest one (S1), marked by a subvertical principal splay, occurred after deposition of layer 6 and before that of layer 4. Layer 6, which is clearly visible on one wall, is preserved only east of the fault, suggesting it was eroded to the west after coseismic uplift. Unit 5, which tapers rapidly eastward, is most likely a type of subaquatic colluvial wedge (redistributed lake mud) emplaced shortly after S1. The penultimate event was recorded as multiple splays (S2) cutting layers 13–16 over a width of 1 m and terminating at the base of layer 12. Layer 11 shows no disruption. Hence we interpret S2 to have occurred between the emplacement of layers 12 and 11. Older events, e.g., S3 and S4, will be discussed elsewhere.

The timing of S1 is constrained by accelerator mass spectrometry radiocarbon dating of samples K23, G3, G1, and K24 (Fig. 2 and Table DR1 [see footnote 1]). Samples K23 (A.D. 1295–1410) and G3 (A.D. 1272–1412) clearly postdate the event. Sample K24 (A.D. 780–1001), from a paleochannel that is clearly capped by layer 4 (and likely by layer 6) to the east, predates the event. Sample G1 (A.D. 864–1002) comes from postseismic wedge 5, which likely contains samples from redistributed layers predating the event. Thus, the latest ground-breaking earthquake occurred between A.D. 864–1001 and 1295–1410. The only possible candidate for this event is the 1202 earthquake, since macroseismic damage for other large Near East events near that time was clearly located either well south (A.D. 1033) or well north (A.D. 1157 and 1170) of the Beqaa (e.g., Ben-Menahem, 1991; Meghraoui et al., 2003; Guidoboni et al., 2004a, 2004b). Any event postdating A.D. 1400 would have disrupted layer 2, and can be safely ruled out.

SUMMARY AND DISCUSSION

Our results put to rest the inference that the Yammoûneh fault might not be the main active branch of the Levant fault system in Lebanon (Butler et al., 1997). They provide evidence of coseismic slip on the Yammoûneh fault in A.D. 1202, and show that this segment of the fault has remained locked since then. Because the size of the November 1759 event implies that it ruptured the surface, our data preclude that it took place on the Yammoûneh fault. Because the 1759 earthquake sequence comprised two large events and because of the new evidence we found—in the form of well-preserved mole tracks—of a recent, large event south of Râchaïya, the only other large fault system adjacent to the Beqaa (Râchaïya-Serghaya) is the most plausible source. We propose that the 30 October 1759 earthquake was caused by slip on the shorter (<50 km) Râchaïya fault, and the larger-magnitude 25 November event was caused by slip on the longer (<130 km) Serghaya fault, in keeping with the evidence of recent movement on both (Tapponnier et al., 2001), and the French consul's letter. Our results thus build on those of Gomez et al. (2003) by lifting the ambiguity between the 1705 and 1759 shocks.

We interpret the occurrence of two events in 1759 and the month-long delay between them as a classic earthquake triggering example. Such triggered delayed rupture may be due to the presence of the Mount Hermon asymmetric push-up jog, a geometric irregularity that prevented immediate rupture propagation along the entire Râchaïya-Serghaya fault system. Though not unique, this scenario is in keeping with scaling laws (Wells and Coppersmith, 1994; Ambraseys and Jackson, 1998) that predict (2-sigma) magnitudes of 6.4–7.3 and 7.0–8.0 respectively, compatible with those derived from historical accounts (6.6 and 7.4; Ambraseys and Barazangi, 1989) and from the ~2 m stream channel offset attributed to the last event on the Serghaya fault at Zebadani (7.0–7.2 for the November 1759 event; Gomez et al., 2003).

With its fine lacustrine sequence, midway along the Yammoûneh fault, the Yammoûneh basin is particularly useful for understanding the timing of ancient Lebanese earthquakes. We have investigated this sequence down to 11 m depth: 2–3 m beneath the topsoil is a major stratigraphic transition, of probable climatic origin, from the calcareous marls to an ~8-m-thick clay unit. We have identified and mapped 10 event horizons down to this transition, which we dated as 11 ka (onset of the early Holocene climatic optimum).

Our results have critical implications for the assessment of seismic hazard in the area. On the Missyaf segment of the Ghab fault (Fig. 1), there is paleoseismological and archaeological evidence for three earthquakes since A.D. 70 (Meghraoui et al., 2003), the A.D. 1170 event being the latest. In Lebanon, the classic inference of a ~550 yr recurrence time for large events on the Yammoûneh fault (A.D. 1202 to 1759) must be revisited. The penultimate ground-breaking event (S2) in the Kazzâb trench postdates A.D. 261–537 (Table DR1; see footnote 1), such that the quiescence interval prior to 1202 lasted 800 ± 140 yr at most. This is to be compared with the time elapsed since then

(803 yr), and with our preliminary finding of an ~1 k.y. average recurrence time for previous events since 13 ka. The earthquake sequence of the eleventh to twelfth centuries (e.g., Poirier and Taher, 1980; Ben-Menahem, 1991; Abou Karaki, 1987; Guidoboni et al., 2004a, 2004b; Ambraseys, 2004), which ended with the 1202 event, might thus represent a concatenation of successively triggered earthquakes, analogous to those observed on the North Anatolian and Kunlun faults in the past 100 yr. Likewise, the Levant fault might exhibit millennial periods of quiescence separated by clusters of events rupturing its entire length in a couple of centuries. One might speculate that the 1995 Mw 7.3 Aqaba earthquake (Klinger et al., 1999) heralds the onset of such a clustered sequence.

Therefore, we should be prepared for the occurrence of a large destructive event similar to that of 1202 during the coming century in Lebanon. Given the rate of 5.1 $\pm$ 1.3 mm/yr derived from cosmogenic dating of offset fans along the Yammoûneh fault (Daëron et al., 2004), such an earthquake could produce 3–5 m of coseismic slip, and untold damage in areas vastly more populated today than in medieval times.

ACKNOWLEDGMENTS

We thank the National Council for Scientific Research (Lebanon), the Institut National des Sciences de l'Univers (Centre National de la Recherche Scientifique, France), and the French Ministère des Affaires Etrangères for support. Without additional funding by the Coopération pour l'Evaluation et le Développement de la Recherche (Ministère des Affaires Etrangères) and by the Institut de Physique du Globe de Paris, this work could not have been accomplished. We also thank G. Seitz and M. Kashgarian, from the Center for Accelerator Mass Spectrometry (AMS) (Lawrence Livermore National Laboratory, USA), for ^{14}C sample processing and AMS dating, A. Charbel and R. Jomaa for logistical help in the field, and two anonymous reviewers for constructive criticism. This is International Geological Correlation Programme contribution 2030.

REFERENCES CITED

Abou Karaki, N., 1987, Synthèse et carte sismotectonique des pays de la bordure orientale de la Méditerranée: Sismicité du système de failles du Jourdain–Mer Morte [Ph.D. thesis]: Strasbourg, Université Louis Pasteur de Strasbourg.

Ambraseys, N.N., 1997, The earthquake of 1 January 1837 in southern Lebanon and northern Israel: Annali di Geofisica, v. XL, p. 923–935.

Ambraseys, N.N., 2004, The 12th century seismic paroxysm in the Middle East: A historical perspective: Annals of Geophysics, v. 47, p. 733–758.

Ambraseys, N.N., and Barazangi, M., 1989, The 1759 earthquake in the Bekaa valley: Implications for earthquake hazard assessment in the Eastern Mediterranean region: Journal of Geophysical Research, v. 94, p. 4007–4013.

Ambraseys, N.N., and Jackson, J.A., 1998, Faulting associated with historical and recent earthquakes in the Eastern Mediterranean region: Geophysical Journal International, v. 133, p. 390–406.

Ambraseys, N.N., and Melville, C.P., 1988, An analysis of the eastern Mediterranean earthquake of 20 May 1202, *in* Lee, W.K.H., et al., eds., History of seismography and earthquakes of the world: San Diego, Academic Press, p. 181–200.

Armijo, R., Lyon-Caen, H., and Papanastassiou, D., 1992, East-west extension and Holocene normal-fault scarps in the Hellenic arc: Geology, v. 20, p. 491–494.

Ben-Menahem, A., 1979, Earthquake catalogue for the Middle East (92 B.C.–1980 A.D.): Bollettino di Geofisica Teorica ed Applicata, v. 21, p. 245–310.

Ben-Menahem, A., 1991, Four thousand years of seismicity along the Dead Sea rift: Journal of Geophysical Research, v. 96, p. 20,195–20,216.

Besançon, J., 1968, Le poljé de Yammoûné: Hannon, v. 3, p. 3–62.

Butler, R.W.H., Spencer, S., and Griffiths, H.M., 1997, Transcurrent fault activity on the Dead Sea Transform in Lebanon and its implications for plate tectonics and seismic hazard: Geological Society [London] Journal, v. 154, p. 757–760.

Carton, H., Singh, S.C., Elias, A., Tapponnier, P., Briais, A., Sursock, A., Jomaa, R., Daëron, M., King, G., and Jacques, E., 2004, Miocene to Quaternary folding and thrusting offshore Lebanon from SHALIMAR seismic profiles: Eos (Transactions, American Geophysical Union), v. 85, abs. T53B-0488.

Courtillot, V., Armijo, R., and Tapponnier, P., 1987, The Sinai triple junction revisited: Tectonophysics, v. 141, p. 181–190.

Daëron, M., Benedetti, L., Tapponnier, P., Sursock, A., and Finkel, R.C., 2004, Constraints on the post ~25-ka slip rate of the Yammoûneh fault (Lebanon) using in situ cosmogenic ^{36}Cl dating of offset limestone-clast fans: Earth and Planetary Science Letters, v. 227, p. 105–119.

Dubertret, L., 1932, Les formes structurales de la Syrie et de la Palestine: Paris, Académie des Sciences Comptes Rendus, v. 195.

Dubertret, L., 1955, Note explicative de la carte géologique du Liban au 1/200 000, Beirut.

Elias, A., Tapponnier, P., King, G., Singh, S.C., Sursock, A., Briais, A., Carton, H., Jacques, E., Daëron, M., and Jomaa, R., 2004, Fresh submarine seismic breaks due to historical thrust earthquakes offshore Lebanon: Eos (Transactions, American Geophysical Union), v. 85, abs. T13C-1382.

Ellenblum, R., Marco, S., Agnon, A., Rockwell, T., and Boas, A., 1998, Crusader castle torn apart by earthquake at dawn, 20 May 1202: Geology, v. 26, p. 303–306.

Freund, R., Zak, I., and Garfunkel, Z., 1968, Age and rate of the sinistral movement along the Dead Sea rift: Nature, v. 220, p. 253–255.

Freund, R., Garfunkel, Z., Zak, I., Goldberg, I., Weisbrod, T., and Derin, B., 1970, The shear along the Dead Sea rift: Royal Society of London Philosophical Transactions, v. 267, p. 107–130.

Garfunkel, Z., Zak, I., and Freund, R., 1981, Active faulting in the Dead Sea rift: Tectonophysics, v. 80, p. 1–26.

Gomez, F., Meghraoui, M., Darkal, A.N., Sbeinati, R., Darawcheh, R., Tabet, C., Khawlie, M., Charabe, M., Khair, K., and Barazangi, M., 2001, Coseismic displacements along the Serghaya Fault: An active branch of the Dead Sea fault system in Syria and Lebanon: Geological Society [London] Journal, v. 158, p. 405–408.

Gomez, F., Meghraoui, M., Darkal, A.N., Hijazi, F., Mouty, M., Souleiman, Y., Sbeinati, R., Darawcheh, R., Al-Ghazzi, R., and Barazangi, M., 2003, Holocene faulting and earthquake recurrence along the Serghaya branch of the Dead Sea fault system in Syria and Lebanon: Geophysical Journal International, v. 153, p. 658–674.

Griffiths, H.M., Clark, R.A., Thorp, K.M., and Spencer, S., 2000, Strain accommodation at the lateral margin of an active transpressive zone: Geological and seismological evidence from the Lebanese restraining bend: Geological Society [London] Journal, v. 157, p. 289–302.

Guidoboni, E., Bernardini, F., and Comastri, A., 2004a, The 1138–1139 and 1156–1159 destructive seismic crises in Syria, south-eastern Turkey and northern Lebanon: Journal of Seismology, v. 8, p. 105–127.

Guidoboni, E., Bernardini, F., Comastri, A., and Boschi, E., 2004b, The large earthquake on 29 June 1170 (Syria, Lebanon, and central southern Turkey): Journal of Geophysical Research, v. 109, no. B07304.

Klinger, Y., Rivera, L., Haessler, H., and Maurin, J.-C., 1999, Active faulting in the Gulf of Aqaba: New knowledge from the Mw 7.3 earthquake of 22 November 1995: Seismological Society of America Bulletin, v. 89, p. 1025–1036.

Meghraoui, M., Gomez, F., Sbeinati, R., Van der Woerd, J., Mouty, M., Darkal, A.N., Radwan, Y., Layyous, I., Al Najjar, H., Darawcheh, R., Hijazi, F., Al-Ghazzi, R., and Barazangi, M., 2003, Evidence for 830 years of seismic quiescence from palaeoseismology, archaeology and historical seismicity along the Dead Sea fault in Syria: Earth and Planetary Science Letters, v. 210, p. 35–52.

Piccardi, L., Gaudemer, Y., Tapponnier, P., and Boccaletti, M., 1999, Active oblique extension in the central Apennines (Italy): Evidence from the Fucino region: Geophysical Journal International, v. 139, p. 499–530.

Poirier, J.P., and Taher, M.A., 1980, Historical seismicity in the Near and Middle East, North Africa, and Spain from Arabic documents (VIIth–XVIIIth century): Seismological Society of America Bulletin, v. 70, p. 2185–2201.

Quennell, A.M., 1959, Tectonics of the Dead Sea rift: Proceedings, International Geological Congress, 20th, Mexico, p. 385–403.

Salamon, A., Hofstetter, A., Garfunkel, Z., and Ron, H., 2003, Seismotectonics of the Sinai subplate—The eastern Mediterranean region: Geophysical Journal International, v. 155, p. 149–173.

Tapponnier, P., Daëron, M., King, G., Jacques, E., Sursock, A., and Elias, A., 2001, Active faulting and seismic hazard in Lebanon: Journal of Conference Abstracts, v. 6 (EUG XI).

Wells, D.L., and Coppersmith, K.J., 1994, New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement: Seismological Society of America Bulletin, v. 84, p. 974–1002.

Manuscript received 5 November 2004
Revised manuscript received 26 January 2005
Manuscript accepted 5 February 2005

Printed in USA

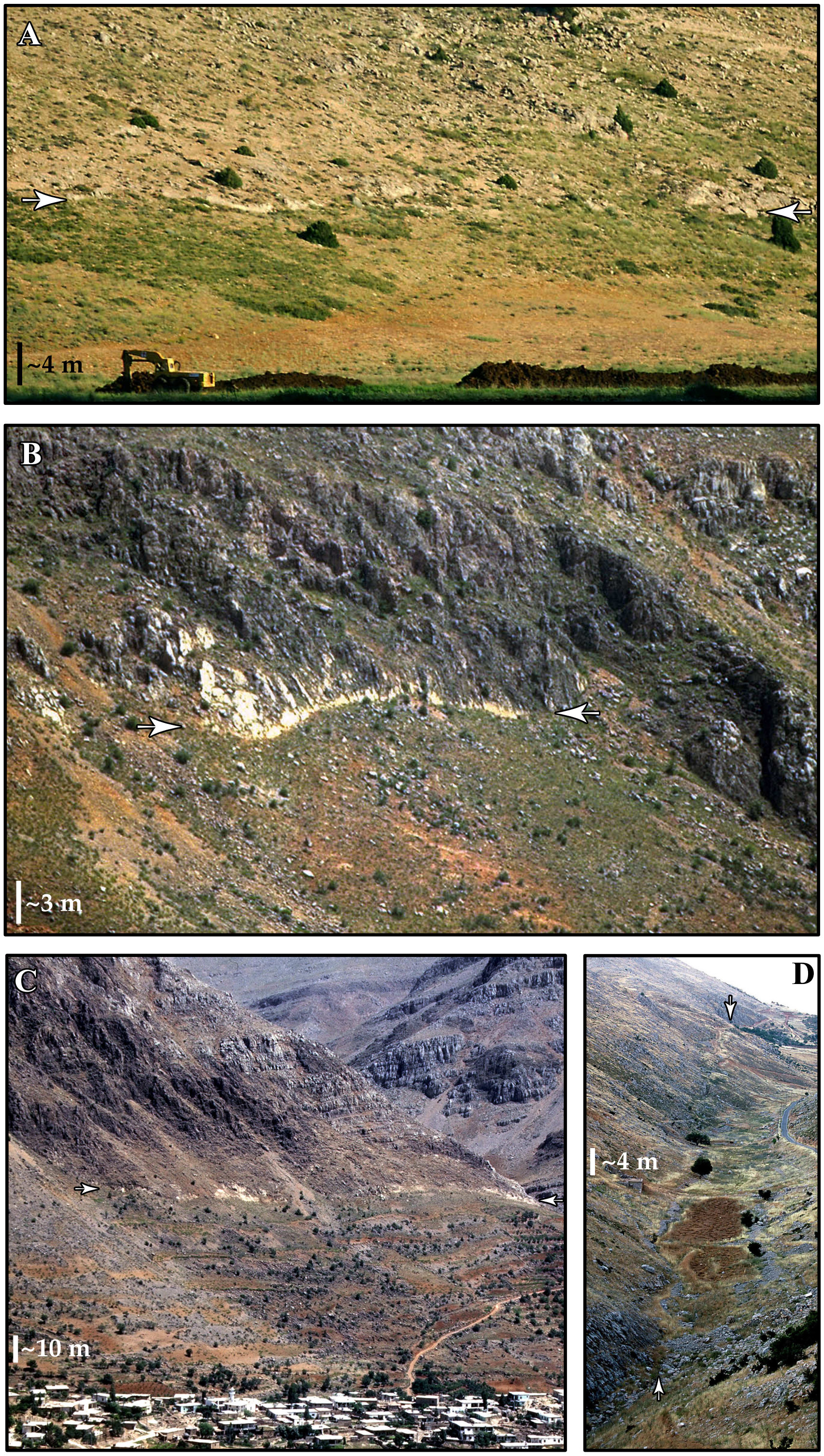


Figure DR1: Comparison of weathered seismic scarplet (highlighted by white arrows) on Yammoûneh fault (A) with fresher seismic scarplet on Serghaya fault (B,C) and well-preserved mole-tracks on Râchaïya fault (D). (locations on Fig. 1)

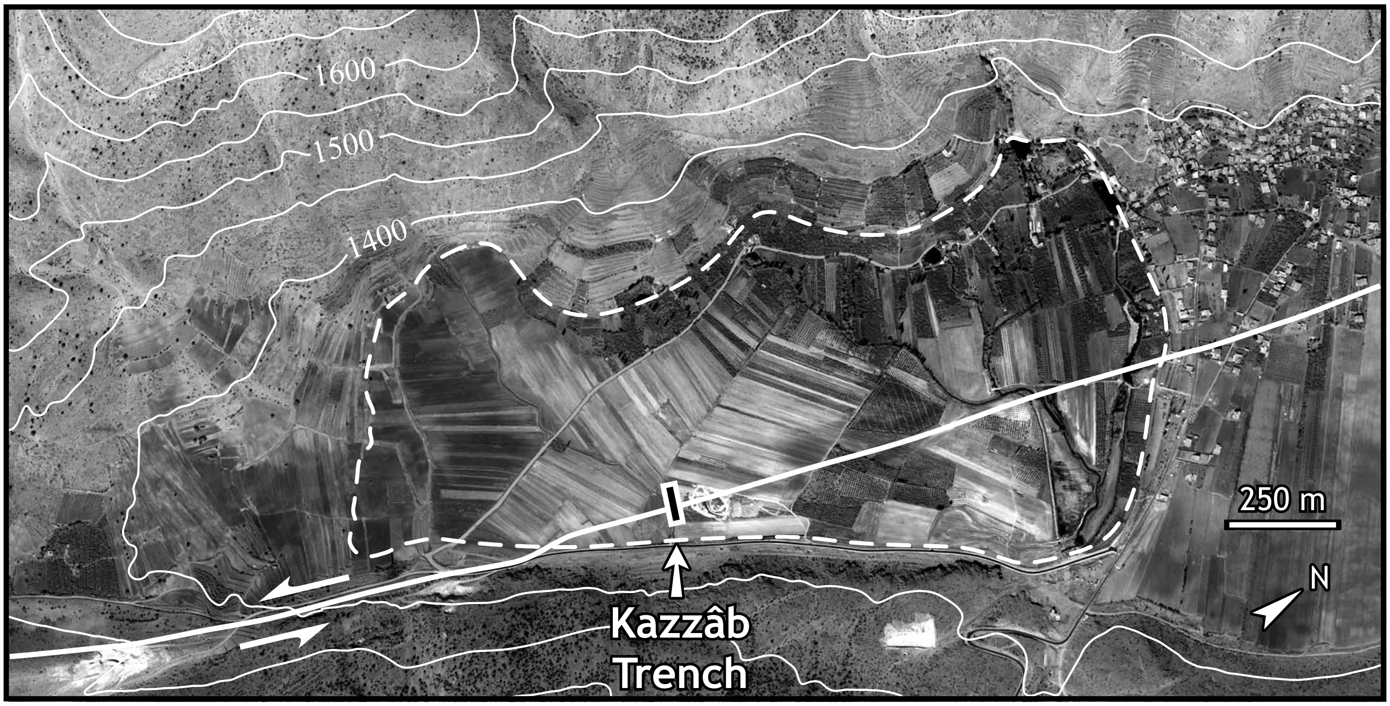


Figure DR2: Satellite image of Yammoûneh paleolake (ancient shoreline dashed). Main strand of Yammoûneh fault (bold white line) cuts across lacustrine deposits. There is little evidence of current strike-slip motion on either side of the basin, where the sedimentary fill abuts the limestone edges. Resistivity measurements were previously interpreted to indicate that the Yammoûneh fault cuts across the basin, offsetting vertically the underlying bedrock (Besançon, 1968).

Sample	Lab number	Material	d^{13}C ‰	Radiocarbon age (BP)	Layer or unit	Calibrated age (95% probability range)
(Y-02) G1	12233	Charcoal	-25.3	1115±35	5 [r]	**A.D. 864 – 1002**
(Y-02) G3	12234	Charcoal	-28.5	650±60	3 (top)	**A.D. 1272 – 1412**
(Y-02) G4	12235	Charcoal	-21.0	1980±90	12 [r]	**202 B.C. – A.D. 241**
(Y-02) G5	12236	Charcoal	-32.6	2000±100	21 (top)	352 – 296 B.C. / **208 B.C. – A.D. 240**
(Y-02) G6	12237	Charcoal	-29.3	718±35	1 [r]	**A.D. 1222 – 1306** / A.D. 1364 – 1387
(Y-01) K23	85982	Charcoal	-25(*)	610±45	2	**A.D. 1295 – 1410**
(Y-01) K24	85983	Charcoal	-25(*)	1125±50	see text	A.D. 780 – 794 / **A.D. 802 – 1001**
(Y-01) K29	85984	Charc. & wood	-25(*)	2055±40	21	**170 B.C. – A.D. 26**
(Y-01) K64	86069	Charcoal	-25(*)	1640±45	14	A.D. 261 – 279 / **A.D. 324 – 537**

Table DR3: Radiocarbon dates
Most of the catchments around the paleolake being steep and short (<4 km), it is unlikely that the dated charcoals were stored for very long before deposition. AMS measurements were made at Van de Graaff laboratory of Utrecht University ('G' samples) and at CAMS of Lawrence Livermore National Laboratory ('K' samples); ages were calibrated using OxCal 3.9 (Bronk Ramsey, 1995; 2001) and calibration curve INTCAL98 (Stuiver et al., 1998); calibrated ages exclude ranges with probability <2%, and bold ages represent most likely range (at least 80%); (*) means d^{13}C was assumed but not measured; [r] is for reworked samples.

References

Besançon, J., 1968, Le poljé de Yammoûné: Hannon, v. 3, p. 3–62.

Bronk Ramsey, C., 1995, Radiocarbon calibration and analysis of stratigraphy: the OxCal program: Radiocarbon, v. 37, n. 2, p. 425–430.

Bronk Ramsey, C., 2001, Development of the radiocarbon program OxCal: Radiocarbon, v. 43, n. 2A, p. 355–363.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., van der Plicht, J., and Spurk, M., 1998, INTCAL98 radiocarbon age calibration, 24000–0 cal BP: Radiocarbon, v. 40, n. 3, p. 1041–1083.