The Quaternary activity of the Levant fault: progresses and challenges

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The Levant Fault (LF), also named the Dead Sea Fault along its southern section, is a major structure at the scale of the plate tectonics. It is one of the largest active faults of the Oriental Mediterranean basin, along with the North Anatolian Fault and East Anatolian Fault.

The LF is about 1200km-long. It bounds to the West the Arabic plate, allowing for northward motion of the Arabic Peninsula relative to the Sinai micro plate (Figure 1). The southern extremity of the LF links to the spreading center of the Red Sea through the Gulf of Aqaba, formed by a succession of pull-apart basins. To the North, the LF connects to the Taurus-Zagros compressional belt through the complex tectonic system of the East Anatolian Fault.
In 1869, Lartet was the first to describe the structure as a left-lateral fault, later followed by Dubertret (1932) and Quennell (1958) who proposed that the finite horizontal offset is 107km. Freund et al. , in 1968, refined this estimate this estimate by demonstrating that all the igneous and sedimentary rocks of Precambrian to Late Cretaceous age on both sides of the LF are offset by 105km. In the same work, they also argue for a post-Miocene offset of 40-45 km, based on the amount of back-slip necessary to close transtensional basins along the southern part of the LF. Today, this strike-slip model and cumulative offsets are generally accepted.

The results presented here focus on the research accomplished during the past 20 years, and are mostly related to the Quaternary activity of the LF. Such questions as how to map the different segments of the fault, what is the slip-rate during the Holocene and is it the same as the instantaneous slip-rate, how deformation is accommodated through earthquakes, have been looked at in details and major progress have been done.

The structure and the surface expression of the LF, along its southern sections at least, from Aqaba to the south of Lebanon, was well described in the seminal works of Freund et al. in 1981. The northern part, however, and more specifically the Lebanese section, was not so well known. In the recent years, a large effort has been put together to build a map of the active faults of Lebanon. In fact, in Lebanon, the LF bends 25_ eastward relative to the average direction of the LF. Such deflection is responsible for the fault motion to become in part accommodated by compressional deformation, in addition to the strike-slip motion, creating the Lebanon and Anti-Lebanon mountain ranges, which top respectively at 3100m and 2700m. It has been shown that in Lebanon, the displacement is strictly partitioned, with faults being purely strike-slip and other structures only accommodating compression. The Yammouneh fault and the less active Rashaya-Sergaya system are accommodating only horizontal motion. The Shalimar geophysical marine cruise, off-shore Lebanon, has evidenced the presence of an active thrust front that accommodates the compressional motion. The way these different systems connect to each other is not yet well established and the tectonic activity of the several lateral ramps is still under debate.
The slip-rate of the different faults is a part of the debate as it could help to discriminate between the different structures to determinate which one is the most active.

Along the Yammouneh fault, in Lebanon, the horizontal slip-rate has been measured over a time window of ~10 ka by reconstructing and dating offset alluvial fans, yielding a slip-rate of 5.1 ± 1.3 mm/yr. This result is in good agreement with the instantaneous slip-rate determined by GPS for the whole system. Slip-rate along the Rashaya-Sergaya system has been estimated to be about 1.4 ± 0.2 mm/yr, confirming that it is a far less active branch of the fault. From the slip-rates along the strike-slip faults of the system, and the observation of the partitioning of the motion, one can derived a slip-rate on the offshore thrust faults on the order of 3 to 4 mm/yr.
To the south of the Lebanese bend, the geometry of the fault is simpler; south of the Dead Sea the LF is limited to one main segment, almost purely strike-slip, which accommodates most of the deformation. Owing to the one-segment geometry, this section of the fault has been targeted to compare the slip-rate at different time scales. GPS campaigns have allowed to determine the instantaneous slip-rate. Because the southern part of the LF is almost the only place where the fault is not too close from the sea, this section had the potential for a good determination of the far field conditions. The GPS slip-rate along the southern section of the LF is 4.9 ± 1.4 mm/yr. Along this section, several sites show offset alluvial landforms, such alluvial terraces or alluvial fans. Dating and restoring theses landforms to their initial geometry give access to the slip rate of this section of the LF over several time scales, depending on the age of the restored structures. Over the Early Holocene the slip-rate is 4.2 ± 2 mm/yr, in good agreement with the GPS. Over the Pleistocene, however, the value of slip-rate seems to be higher, closer to 7 ± 2 mm/yr. The reason for such discrepancy remains to be understood, that it could be due to an actual slowdown of the Arabic plate over time, as suggested by some regional studies, or that it is due to some bias in the measurements.
One of the questions related to the slip-rate is to determine how the long-term motion is accommodated. The long historical record in the area has allowed for the compilation of catalogues for historical earthquakes. These catalogues, however, even if they attest that the region is seismically active, and the Nuweiba M_w7.3 earthquake in the Gulf of Aqaba, in 1995, was a strong reminder, usually are too short and too inaccurate to help to resolve the return

time of earthquakes on specific fault segments. In Lebanon, where the last 2 large events, in 1202 and 1759, are well documented, a lot of paleoseismological work has been done to establish which fault was responsible for which event. In that case, it has been possible to show without ambiguities that the 1202 earthquake occurred on the Yammouneh fault while the 1759 event broke the Rashaya-Sergaya segment. The paleoseismological work along the Yammouneh fault actually exposed evidences for 14 paleoearthquakes, with a return time close to 800 yrs. Works along the coast, documenting and dating uplifted shorelines have also allowed to identify one paleoearthquake, the 551AD earthquake, which was widely described in the historical document and which paleoscarps are still visible on the seafloor. Along the southern segments, also some large historical events are known, up to day it has remained an open challenge to find a good site for paleoseismology which would enable to establish a long earthquake chronology.

Among the pending open questions is also the behavior of the northern part of the LF, north of the Lebanese bend. In general, this fault as been less studied in the recent years. The population in this area, mostly Syria and southern Turkey, however, keeps growing, making the demand for a better understanding of the seismic behavior more and more urgent. The contradictory results published in the recent years show that the GPS slip-rate is very slow, whereas the slip-rate determined from paleoseismology seems to be rather faster than the slip-rate determined elsewhere along the fault. Such differences remain to be understood and present a serious challenge to the scientific community.

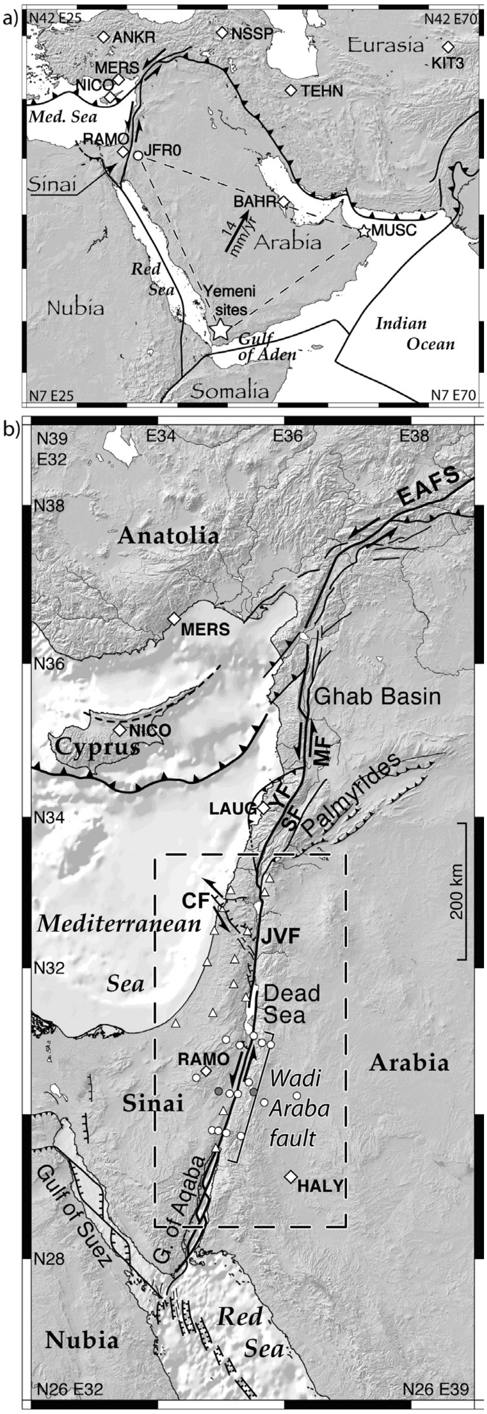

Figure 1:
a) General position of the Levant Fault with the velocity vector of the Arabic plate relative to Nubia.

b) Detailed map of the Levant fault. The white triangle and circles are indicating some of the GPS points measured in the region. YF Yammouneh Fault, SF Sergaya Faault, CF Carmel Fault, JVF Jordan Valley Fault, MF Missyaf Fault, EAFS East Anatolian Fault System.