Quaternary fault map of Israel

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Abstract

The Quaternary fault map of Israel (QFMI) presents faults that show direct and indirect evidence for activity since the beginning of the Quaternary (~2.6 Ma) in Israel, including continuations of large segments to neighbour countries. Faults are classified by: 1) the main strike-slip segments of the Dead Sea transform fault system (DST); 2) faults that have been previously mapped to cross or displace Quaternary sediments; 3) their main branches and the marginal faults of the DST; 4) faults that are associated with instrumental seismicity; 5) subsurface continuations of mapped Quaternary faults. Faults are categorised according to the order of the criteria, i.e., faults are initially examined according to the first criterion, and if they do not match, they are examined according to the second criterion, and so on. The mapped faults within Israel are primarily based on 1:50,000 geological maps of the Geological Survey of Israel (GSI), whilst their continuations beyond the borders and/or offshore are based on scientific publications.

I. Database

As of August 2018, 70 geological map sheets in the scale of 1:50,000 are available for this study (out of the 79 sheets required to cover the whole state of Israel). We also include faults defined as active or potentially active for the Israel Standard 413 "Design provisions for earthquakes resistance of structures" (Sagy et al., 2017). Fault traces from the 1:200,000 scale geological map of Israel (Sneh et al., 1998) are marked where 1:50,000 data are still absent. The 1:10,000 scale geological hazard map of Elat (Wieler et al., 2017) is used for better resolution of both fault location and latest activity in the Elat area. In addition, some faults that have not been mapped (or

not updated yet) crossing Quaternary units in the geological maps are marked here as Quaternary faults based on evidence presented in scientific publications, reports, and theses (Table 3). Offshore and subsurface continuations of faults, as well as faults extending beyond the Israeli borders are marked according to publications (Table 2).

In addition to the geological data, we also consider seismicity from the last ~35 years, which is mainly recorded and monitored by the Geophysical Institute of Israel, relocated as shown by Wetzler and Kurzon (2016), and processed by Sharon et al. (2016), along with updates (details in Sharon, 2018).

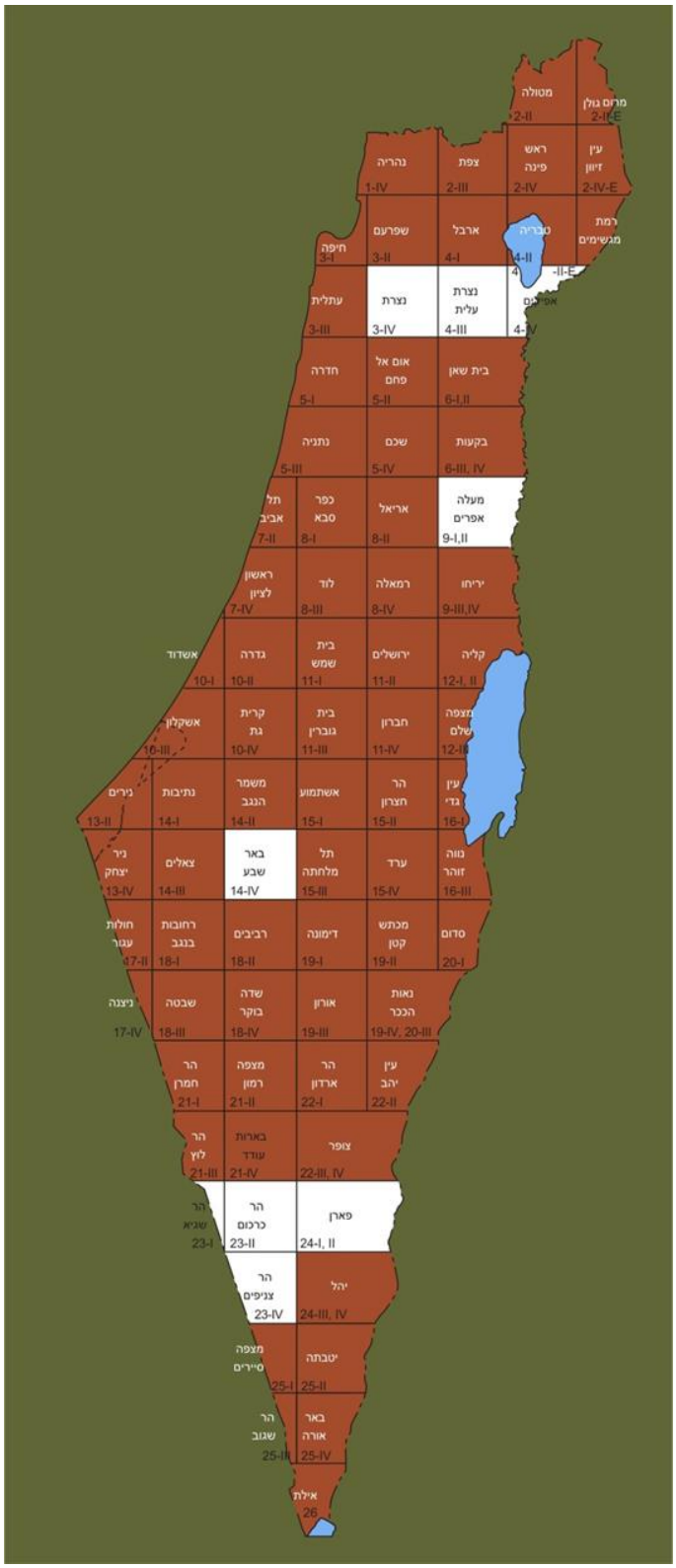
Finally, the QFMI shares some data with previous and present maps of "Active and potentially active faults" for the Israel Standard 413 (Bartov et al., 2009; Sagy et al., 2013, 2016, 2017). However, the QFMI is based on different criteria and it should not be used for the Israel Standard 413 requirements or regulations.

List of 1:50,000 used geological map sheets (as of August 2018)

Sheet 1-IV: Nahariyya - Sneh Amihai, 2004;
Sheet 2-II: Metulla - Sneh Amihai, Weinberger Ram, 2003.
Sheet 2-II-E: Merom Golan – Mor Doron, 1987 (Digital editing, 2006)
Sheet 2-III: Zefat – Levitte Dov, Sneh Amihai, 2014
Sheet 2-IV: Rosh Pinna - Sneh Amihai, Weinberger Ram, 2006 (Partly revised, 2013)
Sheet 2-IV-E: En Zivan – Mor Doron, 1987 (Digital editing, 2006)
Sheet 3-I: Hefa (Haifa) – Karcz Ia'aqov, Sneh Amihai, 2011.
Sheet 3-II: Shefar'am - Sneh Amihai, 2008 (Partly revised, 2013)
Sheet 3-III: Atlit - Segev Amit, Sass Eitan, 2009.
Sheet 4-I: Arbel - Bogoch Ron, Sneh Amihai, 2008 (Partly revised, 2014)
Sheet 4-II: Teverya - Sneh Amihai (Editor), 2008.
Sheet 4-II-E: Ramat Magshimim – Mor Doron, 2012.
Sheet 5-I: Hadera - Sneh Amihai, Sass Eitan, Bein Amos, Arad Arnon, Rosensaft Marcelo, 1996 (Partly revised, 2014).
Sheet 5-II: Umm El Fahm - Sass Eitan, Dekel Ami, Sneh Amihai, 2013.
Sheet 5-III: Netanya - Ilani Shimon, 2016.
Sheet 5-IV: Shekhem – Cook Philip, 2000.
Sheet 6-I, II: Bet She'an – Hatzor H. Yosef, 2000.
Sheet 6-III: Beqa'ot- Mimran Yaakov, Shaliv Gadi, Sakal Emanuel, Sneh Amihai, 2014.
Sheet 7-II: Tel Aviv - Sneh Amihai, Rosensaft Marcelo, 2008.
Sheet 7-IV: Rishon LeZion - Sneh Amihai, Rosensaft Marcelo, 2004.
Sheet 8-I: Kefar Sava – Hildebrand–Mittlefehldt Nurit, 2011
Sheet 8-II: Ariel - Sneh Amihai, Shaliv Gaby, 2012.
Sheet 8-III: Lod - Yechieli Yosef, 2008.
Sheet 8-IV: Ramallah – Shachnai Emanuel, 2000.
Sheet 9-III: Jericho - Ze'ev Binyamin Begin, 1974.
Sheet 10-I: Asdod - Sneh Amihai, Rosensaft Marcelo, 2004.
Sheet 10-II: Gedera - Sneh Amihai, 2004.
Sheet 10-III: Ashqelon - Sneh Amihai, Rosensaft Marcelo, 2008.
Sheet 10-IV: Qiryat Gat - Sneh Amihai (Editor), 2008.
Sheet 11-I: Bet Shemesh - Sneh Amihai (Digital editing), 2009.

Sheet 11-II: Jerusalem - Sneh Amihai, Avni Yoav, 2011 (Partly revised, 2013)
Sheet 11-III: Bet Guvrin - Sneh Amihai, 2016.
Sheet 11-IV: Hevron - Sneh Amihai, Roth Israel, 2012.
Sheet 12-I, II: Qalya - Roth Israel, Burg Avihu, Sneh Amihai, 2008.
Sheet 12-III: Mizpe Shalem – Mor Uri, Burg Avihu, 2000.
Sheet 13-II: Nirim - Sneh Amihai, Rosensaft Marcelo, 2008.
Sheet 13-IV: Nir Yizhaq - Sneh Amihai, Rosensaft Marcelo, 2008.
Sheet 14-I: Netivot - Sneh Amihai, Rosensaft Marcelo, 2008.
Sheet 14-II: Mishmar HaNegev - Sneh Amihai, Avni Yoav, Zilberman Ezra, 2015.
Sheet 14-III: Ze'elim – Zilberman Ezra, 2004.
Sheet 15-I: Eshtemoa - Sneh Amihai, Avni Yoav, 2008.
Sheet 15-II: Har Hezron - Gilat Arie, 1983.
Sheet 15-III: Tel Malhata – Wdowinski Shimon, Sneh Amihai, Avni Yoav, 2012.
Sheet 15-IV: Arad - Hirsch Francis, Burg Avihu, Avni Yoav, 2008.
Sheet 16-I: En Gedi – Raz Eli, 1984.
Sheet 16-III: Neve Zohar – Agnon Amotz, Sagy Amir, 2011.
Sheet 17-II: Holot Agur – Zilberman Ezra, 2002.
Sheet 17-IV: Nizzana - Zilberman Ezra, Avni Yoav, Sneh Amihai, 2011.
Sheet 18-I: Rehovot BaNegev – Zilberman Ezra, 2002.
Sheet 18-II: Revivim - Starinsky Avraham, Zilberman Ezra, Braun Moshe, Sneh Amihai, 2010.
Sheet 18-III: Shivta - Sneh Amihai, Avni Yoav, Bartov Yosef, Zilberman Ezra, Braun Moshe, Lasman Noah, Weinberger Ram, 2011.
Sheet 18-IV: Sede Boqer - Avni Yoav, Weiler Nimrod, 2013.
Sheet 19-I: Dimona – Roded Reuven, 1996.
Sheet 19-II: HaMakhtesh HaQatan – Hirsch Francis, 1995.
Sheet 19-III: Oron - Roded Reuven, 1982.
Sheet 19-IV, 20-III: Neot Hakikar - Yechieli Yosef, Elron Ehud, Sneh Amihai, 1994.
Sheet 20-I: Sedom - Agnon Amotz, Weinberger Ram, Zak Israel, Sneh Amihai, 2006.
Sheet 21-I: Har Hamran - Zilberman Ezra, Avni Yoav, 2004.
Sheet 21-II: Mizpe Ramon - Zilberman Ezra, Avni Yoav, 2004.
Sheet 21-III: Har Loz - Avni Yoav, 2001.
Sheet 21-IV: Be'erot Oded – Avni Yoav, 2017.
Sheet 22-I: Har Ardon - Avni Yoav, Bartov Yosef, Sneh Amihai, 2016.
Sheet 22-II: En Yahav - Sneh Amihai, Eyal Amir, Eidelman Amir, Bartov Yosef, 2014.
Sheet 22-III: Zofar – Baer Gideon, Soudry David, Bar Oded, Sneh Amihai, 2014.
Sheet 24-III, IV: Yahel - Ginat Hanan, Lifshitz Avi, 2008.
Sheet 25-I: Mizpe Sayyarim - Ginat Hanan, 2008.
Sheet 25-II: Yotvata - Ginat Hanan, 1994.
Sheet 25-III: Har Seguv – Segev Amit, Beyth Michael, 2000.
Sheet 25-IV: Be'er Ora – Beyth Michael, Segev Amit, Bartov Yosef, 2000.
Sheet 26: Elat – Beyth Michael, Eyal Yehuda, Garfunkel Zvi, 2000.

Locations of 1:50,000 geological map sheets used for the present map (as of August 2018



Brown: locations of published 1:50,000 sheets.
White: unpublished sheets.

Table 1: List of geological formations and units used for the QFMI

Formations	Local sedimentary units	Local volcanic units	Other units*
Arava Fm.	Ahuzam Cgl.	Avital Tuff	Alluvium
Amora Fm.	Amora Salt	Bene Yehuda Scoria	Beach rocks & reefs
Ashmura Fm.	Betlehem Cgl.	Brekhat Ram Tuff	Calcareous sandstone (kurkar)
Garof Fm.	Biq`at Uvda Cgl.	Dalton Basalt	Colluvium
Gesher Bnot Ya'aqov Fm.	Edom facias	Dalton Scoria & Tuff	Dune sand, Sand sheets, Red sands
Hazor & Gadot Fms.	Egel Cgl.	Dalwe flows	Loess, fluvial & eolian
Lisan Fm.	En Awwazim Cgl.	En Awwazim flow	Gypsum
Malaha Fm.	En Feshha Cgl.	En Zivan Basalt flows	Lake sediments
Mazar Fm.	Giv'at Oz Cgl.	Golan Basalt flows (Muweissa and En Zivan flows)	Loam (hamra)
Nevatim Fm.	Karbolet caprock	Hazbani Basalt flows	Neogene-Quaternary conglomerate units, Terrace cgl.
Ortal Fm.	Lot caprock	Keramim Basalt	Playa
Pleshet Fm.	Mahanayim Marl	Meshki Basalt flows	Recent fan
Samra Fm.	Mearat Sedom caprock	Muweisse Basalt flows	Soil
Sede Zin Fm.	Nahshon Cgl.	Neogene Basalts	Tufa, travertine
Seif Fm.	Ramat Gerofit Cgl.	Raqad Basalt	Unnamed clastic unit
Ye'elim Fm.	Ravid Cgl.	Sa'ar Basalt flows	
Ze'elim Fm.	Ruhama Loess & sand	Shievan Scoria	
Zehiha Fm.	Sabkha soil	Yarda/Ruman Basalt flows	
	Si'on Cgl.	Yarmouk Basalt	
	Wadi Malih Cgl.	Yehudiyya & Dalwe Basalt flows	

* Geologic and geomorphic descriptions that appear in 1: 50,000 geological maps for Quaternary deposits.

Table 2: References for faults located beyond Israel borders and/or subsurface faults

Geographic area	Reference
Gulf of Eilat	Ben-Avraham, 1985; Hartman et al., 2014
Arava valley	Calvo, 2002; Le Béon et al., 2012; Sneh and Weinberger, 2014
Sinai peninsula	Sneh and Weinberger, 2014
North-western Negev	Eyal et al., 1992
Dead Sea basin	Ben-Avraham and Schubert, 2006; Sneh and Weinberger, 2014
Jordan valley	Ferry et al., 2007; Sneh and Weinberger, 2014
Gilboa fault (western part)	Sneh and Weinberger, 2014
Carmel fault (eastern part)	Sneh and Weinberger, 2014
Carmel fault (western part)	Schattner and Ben-Avraham, 2007
Zvulun Valley	Sagy and Gvirtzman, 2009
Sea of Galilee	Eppelbaum et al., 2007; Hurwitz et al., 2002; Reznikov et al., 2004; Sneh and Weinberger, 2014
Hula basin	Schattner and Weinberger, 2008
Lebanon and Syria	Weinberger et al., 2009; Garfunkel, 2014; Sneh and Weinberger, 2014

Table 3: References for faults and fault segments* that have been marked based on papers, reports, and theses

Area	Name of fault / group of faults or segments[#]	References
	Arif-Bator	Zilberman et al., 1996; Avni, 1998
	Gerofit	Ginat, 1997
	Gevaot Ziya	Avni, 1998

Southern Israel	Halamish line	Avni, 1998
	Har Seguv	Avni, 1998
	Hiyyon	Ginat, 1997
	Katzra	Avni, 1998
	Milhan	Ginat, 1997
	Mitzpe Sayarim	Avni, 1998
	Noza	Ginat, 1997
	Ovda	Avni, 1998
	Paran	Zilberman, 1985; Avni, 1998; Calvo, 1998; 2002
	Yotam	Wieler et al., 2017
	Zhiha	Avni, 1998
	Zin	Enzel et al., 1988; IEC and Lettis & Associates, 2002; Avni and Zilberman, 2007
	Znifim – Zihor – Barak	Ginat, 1997
	Zofar	Calvo, 2002
Central Israel and Dead Sea area	Jericho	Sagy and Nahmias, 2011
	Masada Plain	Bartov et al., 2006
	Modi'in	Buchbinder and Sneh, 1984
	Nahal Darga (east)	Enzel et al., 2000
	Nahal Kidron (east)	Sagy and Nahmias, 2011
Northern Israel	Ahihud	Kafri and Ecker, 1964; Zilberman et al., 2011a
	Beit Qeshet (western part)	Zilberman et al., 2009
	Ha'on	Katz et al., 2009
	Hilazon	Kafri and Ecker, 1964; Zilberman et al., 2008
	Kabul	Kafri and Ecker, 1964; Zilberman et al., 2008
	Nahef East Fault	Mitchell et al., 2001
	Nesher	Zilberman et al., 2006; 2008
	Tiberias	Marco et al., 2003

* Faults are listed in table 3 if their latest mapping is not updated yet in the 1:50,000 sheets (as of August 2018), or if their definition as Quaternary faults cannot be directly deduced from the geological maps.

[#] Fault names are mainly according to the references.

II. Criteria

The primary and secondary criteria for sorting the faults in the QFMI are listed in a descending order of categorisation, meaning that faults are initially examined according to the first criterion, and only if they do not match the criterion, they are examined according to the second criterion, and so on.

Primary criteria

1. Main strike-slip faults of the DST (solid black lines)

Faults of the DST that are identified here based on previous research as main sources for intermediate to large earthquakes.

2. Faults with direct evidence of Quaternary activity (red lines)

Faults that have been mapped offsetting Quaternary formations or that have been interpreted as active at least once since the Quaternary by scientific publications (Table 3) are mapped here. This criterion is mainly related to zones that are covered by Quaternary sediments.

Secondary criteria

Faults that have no field relationship with Quaternary formations consequently show no direct evidence for Quaternary faulting. These next criteria were designed under the rationale that they expand our database with faults that can be reasonably assumed to have been active ever since the Quaternary, based on the following criteria:

3. First order branches and the marginal faults of the DST (yellow lines)

a) First order branches of faults that are mapped following the primary criteria.

b) Faults that border the DST basins, separating Quaternary formations from older rocks and are associated with a sharp topographic boundary of at least a hundred of meters.

c) Faults that emerge from Quaternary sediments that infill the DST valleys and are likely to be branches of the main segments of the DST.

4. Faults associated with recent seismicity (purple lines)

Faults with mapped surface traces of more than 6 km that are associated with intensive seismic activity, measured by gridded earthquake density and seismic moment density values, are assumed here to be Quaternary faults. This criterion is based on scaling relations between fault dimensions and source parameters (Wells and Coppersmith, 1994; Stirling et al., 2002; Mai and Beroza, 2000). For more details see Sharon (2018).

5. Subsurface faults (dashed black and pale blue lines)

   Subsurface inferred continuation of major mapped fault segments, belong to the DST are primarily marked in the QFMI (Table 2). Few other faults, with well-constrained near-surface location inferred from high-resolution seismic data, which offset dated Quaternary units, are also marked (see comment c below).

Supplementary comments

a. The establishment of the database of Quaternary formations, used for this study (Table 1), is a complicated issue as well-defined geochronology for many of the formations has not yet been obtained. In simple cases, late-Quaternary formations can be easily picked from stratigraphy charts and from published papers, while in more complicated cases the age uncertainty is in the order of millions of years. Moreover, the boundary Pleistocene-Pliocene (= Neogene-Quaternary) was shifted in 2009, from ~1.8Ma to ~2.6Ma, thus, some formations that were associated with the Pliocene are now associated with the Pleistocene. Therefore, geological periods attributed to some formations, mentioned in pre-2009 publications, might mislead. In addition, many of the stratigraphic charts of the pre-2009 geological maps are not updated, nor are the formations' geological symbols. Furthermore, as recent research that is involved with dating methods and/or advanced geological interpretations reveals better geochronological constraints, the most up-to-date information is required in order to select correctly formations that were formed during the Quaternary. As much of this information has not been officially published, personal communication significantly aided to obtain the most up-to-date geochronological constraints of the young formations.

b. A fault branch is defined here as a fault that was mapped as splitting at an acute angle from a Quaternary fault. The throw direction of the fault and its branches are also taken into account.
c. While a rich research of the subsurface exists in the Israel area, the exact location and the activity age of inferred faults are usually less constrained. Moreover, if the fault is not inferred in the shallow subsurface, its trace location on the ground is highly uncertain. Therefore, many subsurface inferred faults that exist in the literature are absent in the QFMI. Nevertheless, because of the importance of the DST faults to seismo-tectonic and ground motion maps, inferred continuations of the large DST strike-slip segments are marked by black dashed lines, while other segments of the DST, as well as a few other faults with published details for both their subsurface extension and their Quaternary activity are marked by pale blue dashed lines. Fault segments that are mapped as concealed (mostly by alluvium) in the 1:50,000 maps are marked in the QFMI only if they are the continuation of mapped faults.
d. Faults beyond the Israeli borders are limited to the extensions of mapped faults that are within Israel, and/or the main DST segments.
e. The background for the QFMI is based on the digital elevation model of the Earth produced by the Shuttle Radar Topography Mission (Farr et al., 2007).

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