PS Evolution of Normal Faults: Displacement Patterns in 3D Seismic Data from the Eastern Levant Basin*

Nadav Navon[1], Benjamin Medvedev[1, 2], and Amotz Agnon[1]

Search and Discovery Article #11309 (2020)**
Posted March 16, 2020

*Adapted from poster presentation given at 2019 AAPG Geoscience Technology Workshop, Exploration and Development of Siliciclastic and Carbonate Reservoirs in the Eastern Mediterranean, Tel Aviv, Israel, February 26-27, 2019

 DOI:10.1306/11309Navon2020

[1]Institute of Earth Sciences, The Hebrew University, Israel (navonadav@gmail.com)
[2]Schlumberger Petroleum Services, The Netherlands

Abstract

The continental shelf offshore Israel is densely populated by slump units in the Pliocene -Pleistocene section. The gigantic unit known as the Israel Slump Complex (ISC) and its overburden are incised by thin-skinned fault systems. Quantitative fault displacement analysis presents the relation between the slump units and the evolution of normal faults incising them.

Following standard structural interpretation, slump units and an array of normal faults were mapped in the Gabriella seismic volume, a high-resolution 3D seismic survey (depth-migrated) located 12 km offshore Netanya. The stratigraphic column of the volume includes the post-Messinian section of Saqiye and Kurkar groups. Fault systems are characterized by unrestricted blind faults and restricted growth faults. The Middle-Late Pleistocene progradational settings make distinguishing the two types of faults a challenge.

Fault displacements are analyzed based on ten key horizons using a step-by-step workflow which includes throw-versus-depth profiles, displacement contour diagrams and displacement gradients. Growth stages within the faults are highlighted using expansion indices and restoration models. Combination of these methods proves useful both for growth model classification and accurate fault mapping. Variations in displacement patterns underscore the control of chaotic features, acting to restrict the growing faults.

Two main fault zones are identified: Northern Fault Zone (NFZ) and Southern Fault Zone (SFZ), comprised of N-S and NW-SE striking normal faults, respectively. Four sampled faults yield distinguishable types of growth: (1) Blind fault, where both horizontal and vertical tips close gradually; (2) Restricted growth fault initially evolving as a blind fault, associated with an incision into the ISC at 0.51-0.7Ma; (3) Blind Restricted fault, with two zones of high displacements, associated with the incision of a small slump unit; (4) Blind restricted fault, characterized by high displacement gradients at its deeper part. Maximum displacement zones imply the faults nucleated at 600-700 m depth.

The restricted growth fault is characterized by a shallower maximum displacement zone, interpreted to result from a transition from blind to growth propagation.

We find that chaotic structures control fault activation, which depends on the spatial relation between the structures. This can result either locally with segmented activation within the fault, or with lateral growth initiation on the entire fault. The linkage between proximity to slump units and growth pattern may lie in the compaction potential of the latter.

The research provides empirical evidence for distinguishing a fault growth and blind stages. This can be especially helpful where faults have similar dimensions and ranges of throw values, which result in minor displacement differences. The presented workflow can also be used for illuminating geo-hazards related to fault activation.

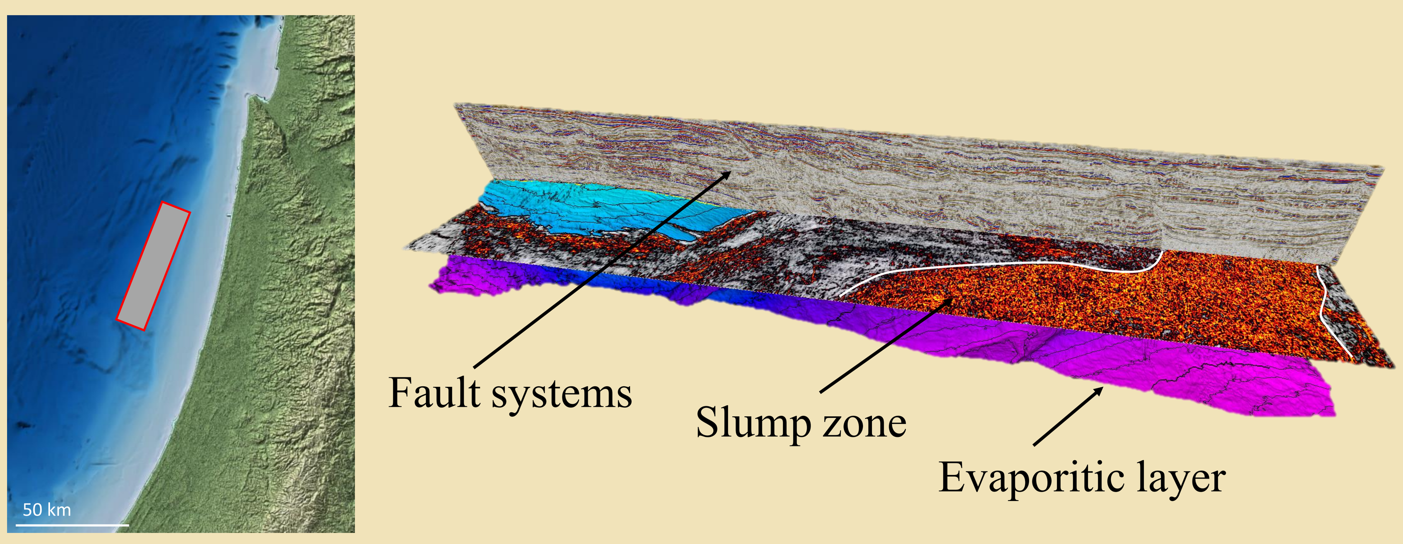
Evolution of Normal Faults: Displacement Patterns in 3D Seismic Data from the Eastern Levant Basin

Nadav Navon[1], Amotz Agnon[1], Benjamin Medvedev[1,2]

1 | Institute of Earth Sciences , The Hebrew University, Jerusalem 91904, Israel
2 | Schlumberger Petroleum Services, Parkstraat 83 Den Haag, the Netherlands

1. Introduction

The Plio-Pleistocene section of “Gabriella” 3D seismic survey (Fig 1), located at the eastern Levant Basin, is incised by numerous fault systems. These consist of growth faults accompanied by synthetic and antithetic faults, some of which overlay the Israel Slump Complex[1] (ISC). Displacement patterns allow to distinguish between post- and syn-depositional faults. We present a workflow to investigate the evolution of these faults by analyzing their displacement patterns.



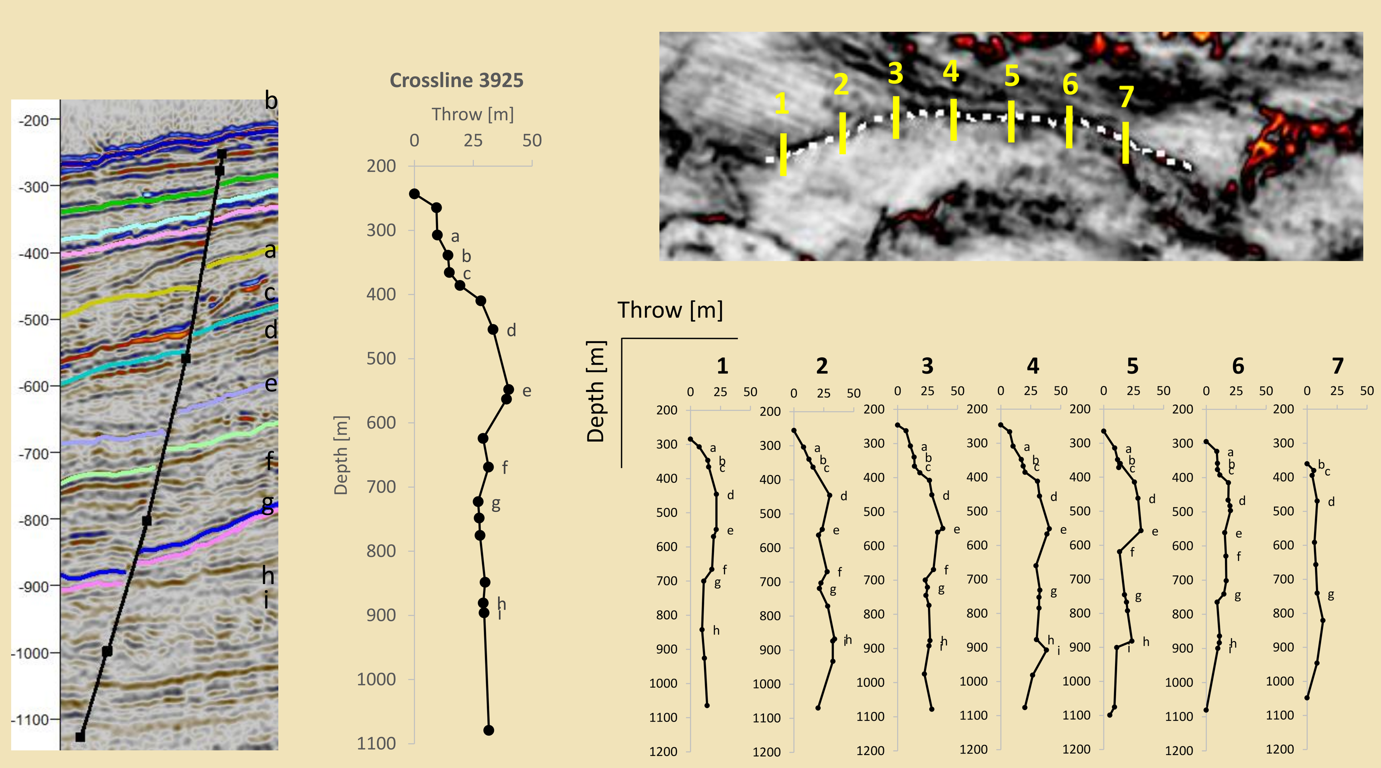
Gabriella Seismic Data

2. Research Goals

- Recapture evolution and propagation history of normal faults based on quantitative displacement analysis.
- Explore the interactions between fault displacement patterns and the chaotic structures incised by them
- Develop a workflow for fault classification in the absence of borehole data and geophysical logs.

3. Methods

1. Throw vs. Depth plots (T-Z plots)

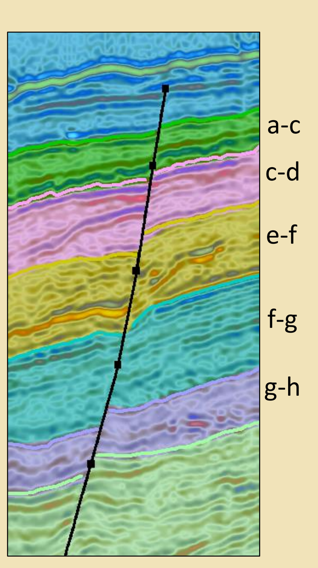


Key horizons a-i followed by displacement measurements

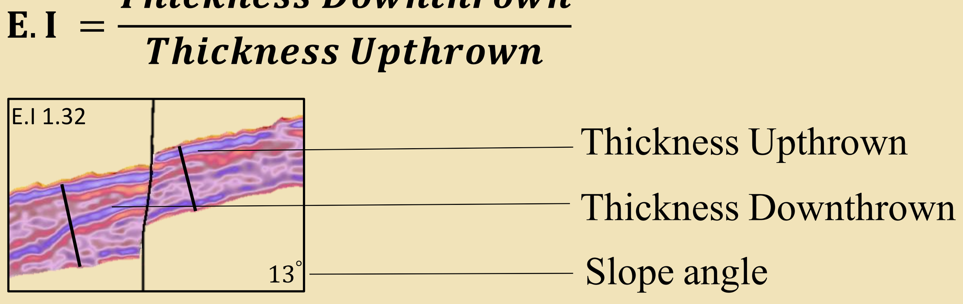
T-Z plots along a fault surface

↓

2. Expansion Index (E.I)

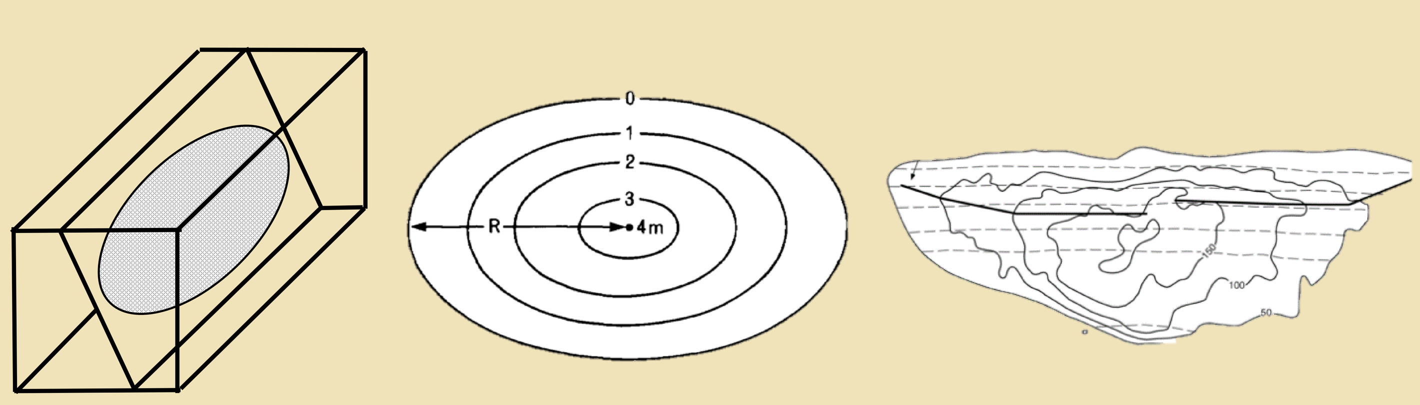


$$E.I = \frac{Thickness\ Downthrown}{Thickness\ Upthrown}$$



↓

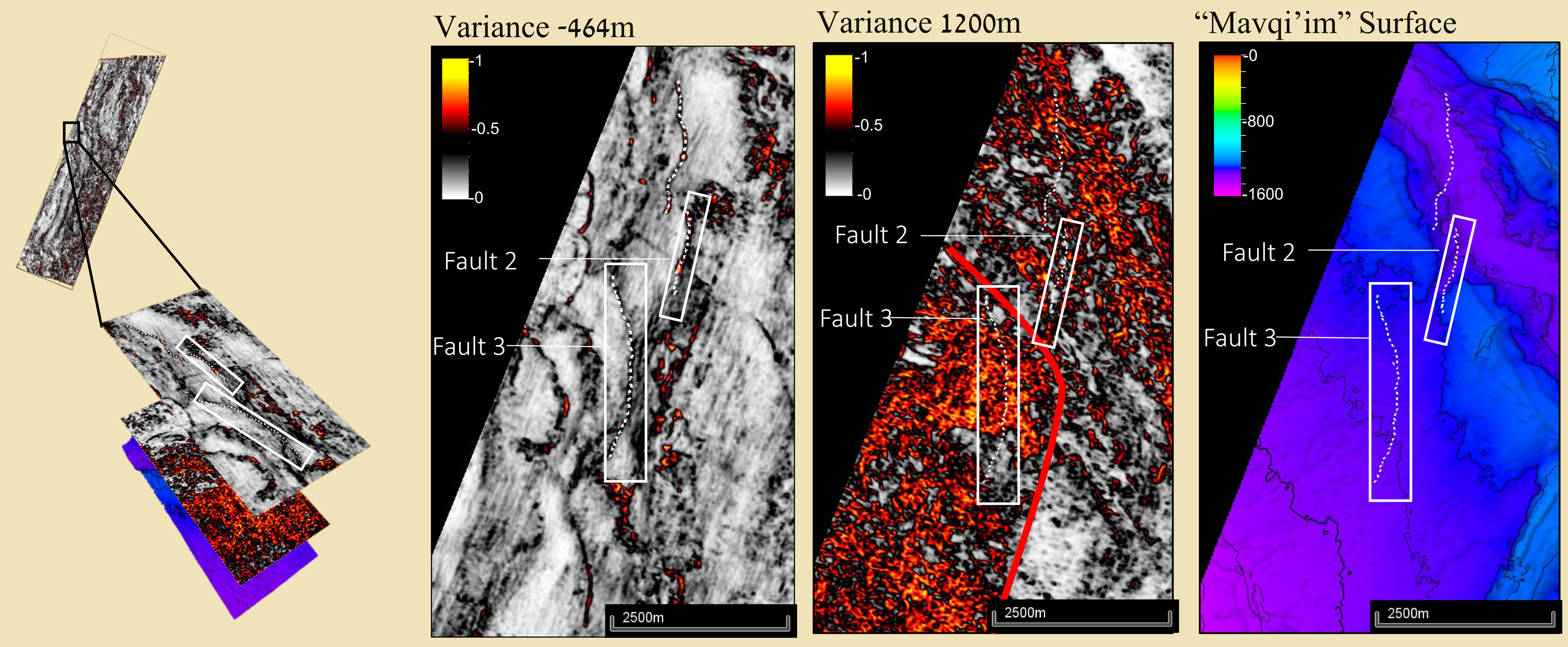
3. Displacement Contour Diagram (DCD)



The isolated model for DCD patterns for post[2]- and syn-depositional[3] faults. Modified after Walsh and Watterson (1990) and Childs et al., (2002).

4. Results

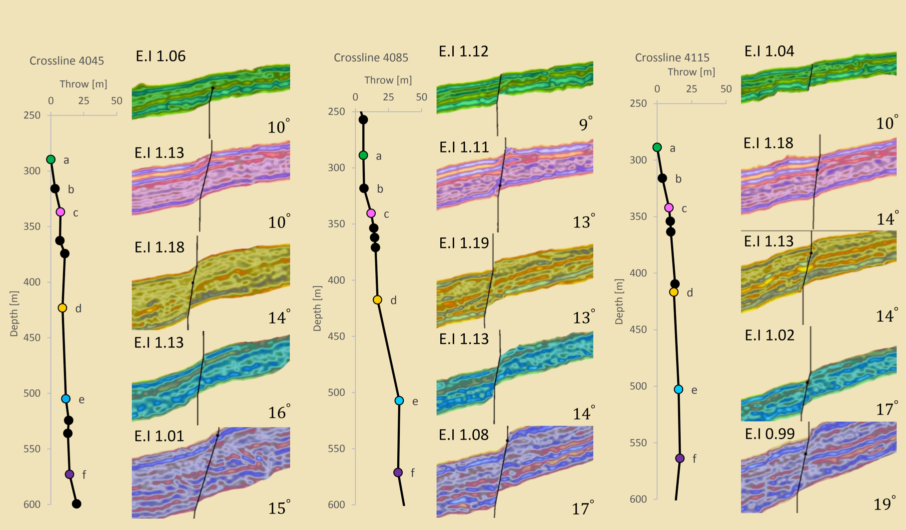
Seismic Interpretation



Fault traces from -464m and projected down to -1200m depth and to “Mavqi’im” structural map. Only Fault 3 incises both the ISC head scarp and the evaporitic layer.

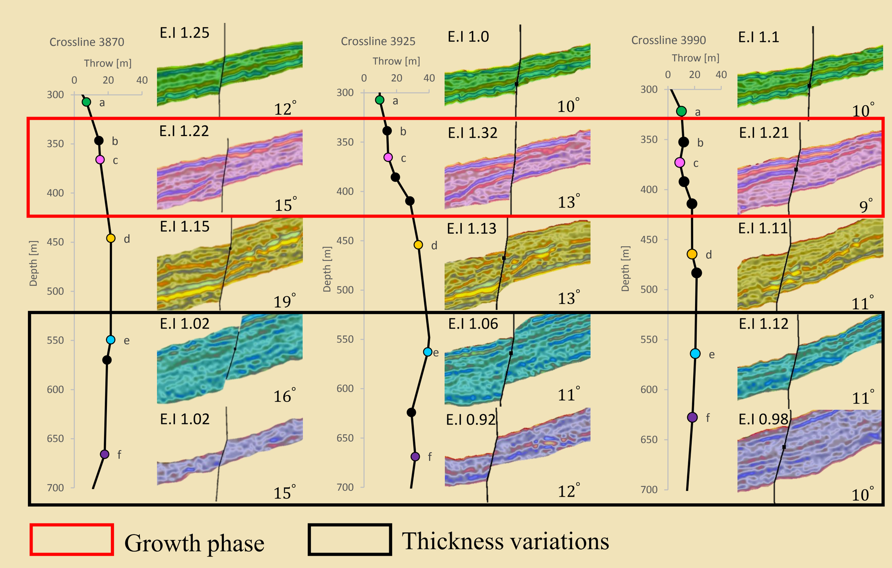
Displacements Analysis

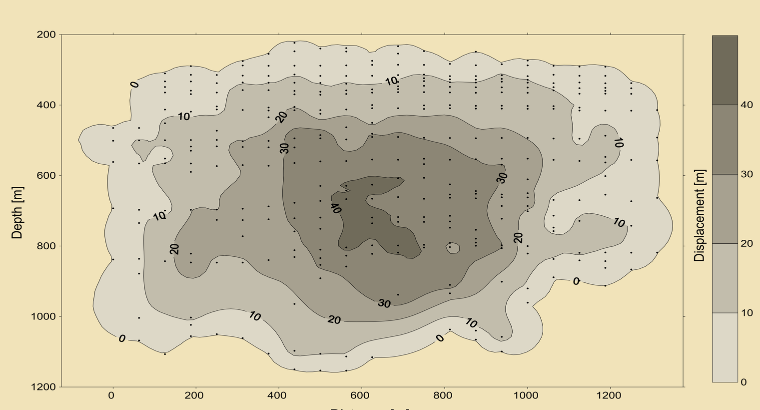
Fault 2- Blind pattern



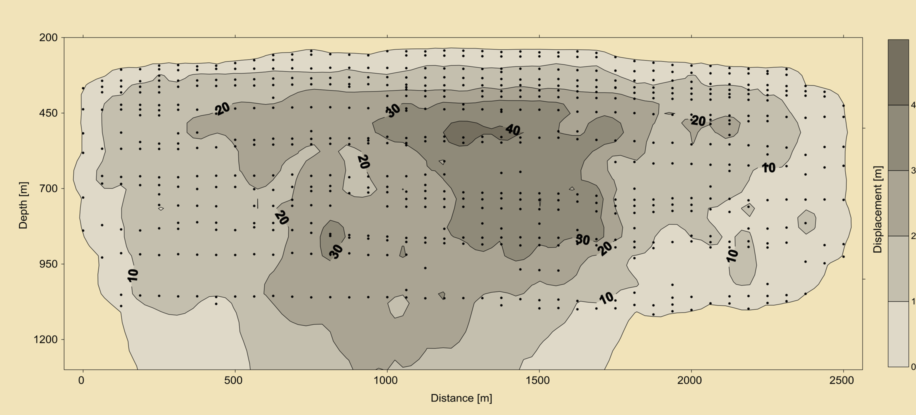
Each panel shows T-Z plot (left) and E.I with relevant seismic section (right).

Fault 3- Growth pattern

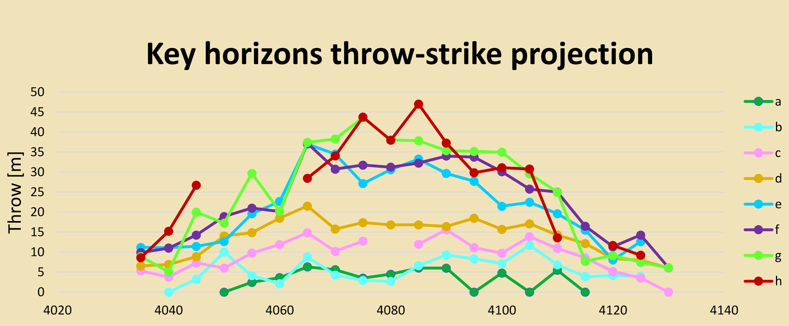




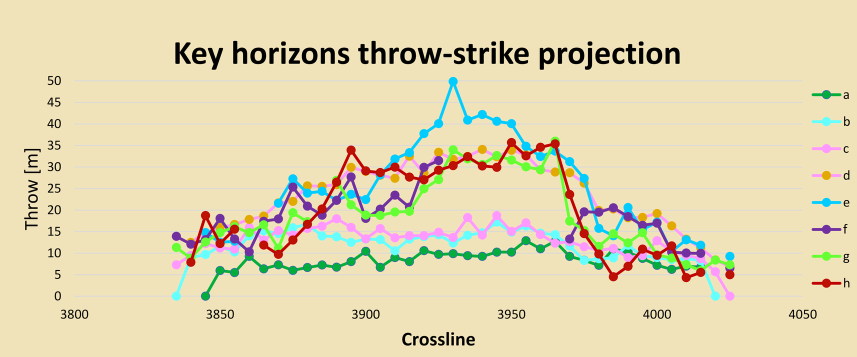
DCD pattern: blind propagation fault



DCD pattern: transition from blind to growth

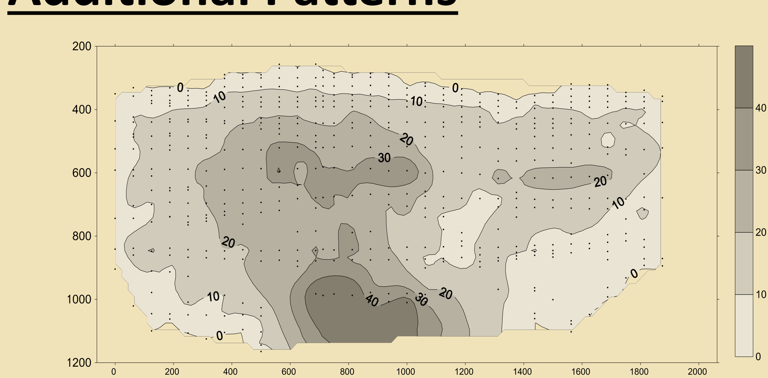


Throw values increase with depth from horizon *a* to horizon *h*.

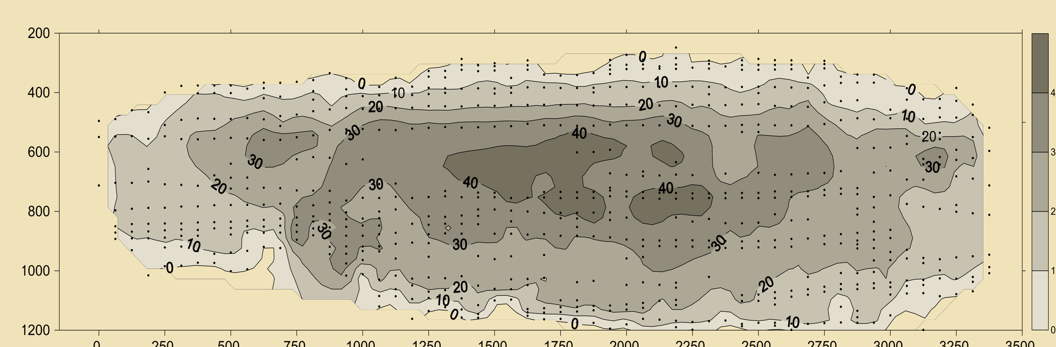


Maximum throw values measured at horizon *e*.

Additional Patterns



DCD pattern: Slump incision



DCD pattern: Vertical restriction, fault linkage.

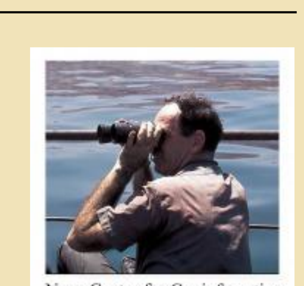
5. Highlights

- A sample of four faults yields four different displacement patterns.
- Chaotic structures control fault evolution, recorded as abrupt changes in displacement values resulting in irregular displacement patterns.
- Combining data from neighboring wells and fault DCDs with allows to estimate the ages of onset and growth phases: 0.5-0.71 Ma.

6. References & Acknowledgments

1. Martinez, J. F., Cartwright, J., & Hall, B. (2005). 3D seismic interpretation of slump complexes: Examples from the continental margin of Israel. Basin Research, 17(1), 83–108. http://doi.org/10.1111/j.1365-2117.2005.00255.x
2. Nicol, A., Watterson, J., Walsh, J. J., & Childs, C. (1996). The shapes, major axis orientations and displacement patterns of fault surfaces. *Journal of Structural Geology*, *18*(2–3), 235–248. http://doi.org/10.1016/S0191-8141(96)80047-2
3. Childs, C., Nicol, A., Walsh, J. J., & Watterson, J. (2002). The growth and propagation of synsedimentary faults. *Journal of Structural Geology*, *25*(4), 633–648. http://doi.org/10.1016/S0191-8141(02)00054-8.

We would like to thank the Schlumberger company for supplying Petrel software; Adira for providing the seismic dataset; Prof’ M. Reshef (Tel Aviv University) for the fruitful conversations and Ecolog Engineering Ltd. for the sponsorship.
The Earth science administration at the Ministry of Energy release the data for this study. The research was conduct at the Neev Center for Geoinfomatics.



Neev Center for Geoinfomatics