PSEvaluating Hydrocarbon Migration Paths Using Fault Displacement Distributions*

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Abstract

The analysis of displacement distributions on an extensional faults system is explored to evaluate hydrocarbon migration paths in a productive area located on the northern flank of the San Jorge Basin, Argentina. In this area, most hydrocarbon traps are located in the footwall of north-dipping normal faults, where reservoirs are folded and sealed against low permeability-hanging wall units. Postulated charging mechanisms include lateral migration from a proven southward kitchen and vertical migration through faults from a hypothetical deep-seated local source pod.

The throw of the reservoir section has been measured along 123 seismic sections, crossing eighteen faults, six of which accounts for most of the total displacement. Additionally, five levels were mapped over the deep and shallow segments along the main faults.

Single fault throw profiles are symmetric with greater values at its center and zero at the fault tips. Fault-displacement contours have elliptical shapes with maximum values centered at the reservoir section. Some faults have a deep segment with another zone of maximum displacement that has both lateral and upwards gradients to zero. The aggregated throw profile shows three sectors with displacement variations that are similar to those of a single isolated fault. These sectors are separated by an accommodation zone formed by an overlapping belt of relay ramps, and by a transfer zone with high angle faults that served as magmatic conduits.

Displacement-fault length plots suggest that isolated faults may have linked early in the propagation history. At the same time, transfer zone development facilitates the emplacement of igneous dikes and sills. Oil and gas bubble maps show that both fault juxtaposition seals and igneous dikes have acted as barriers for south to north horizontal migration. This configuration made possible the charge of existent fields but risked the charge of traps located behind the barriers and far from the kitchen.

Displacement contour maps reveal that faults initially nucleated close to the reservoir section and propagated downwards, but did not connect with pre-existent faults. Consequently, vertical migration from a hypothetical deep-seated source pod seems to be unlikely.

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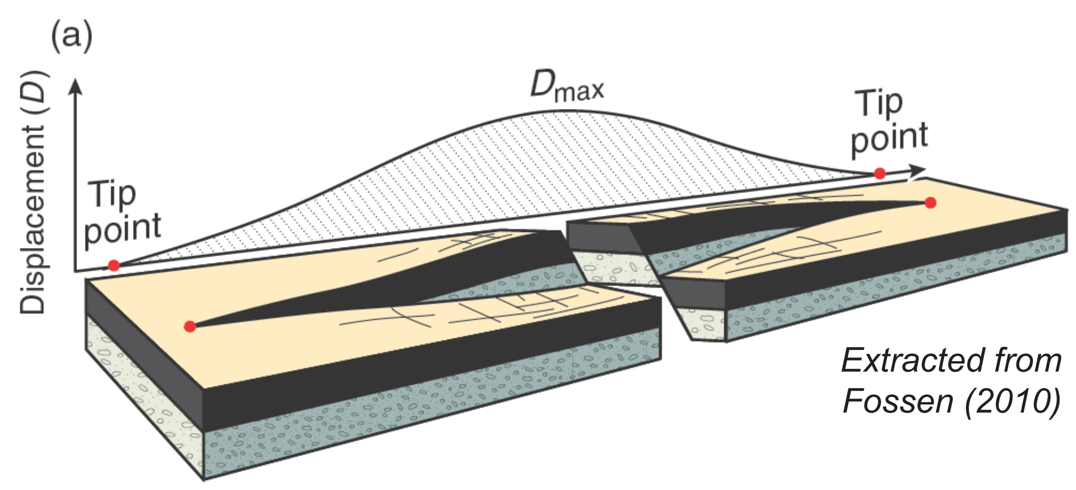
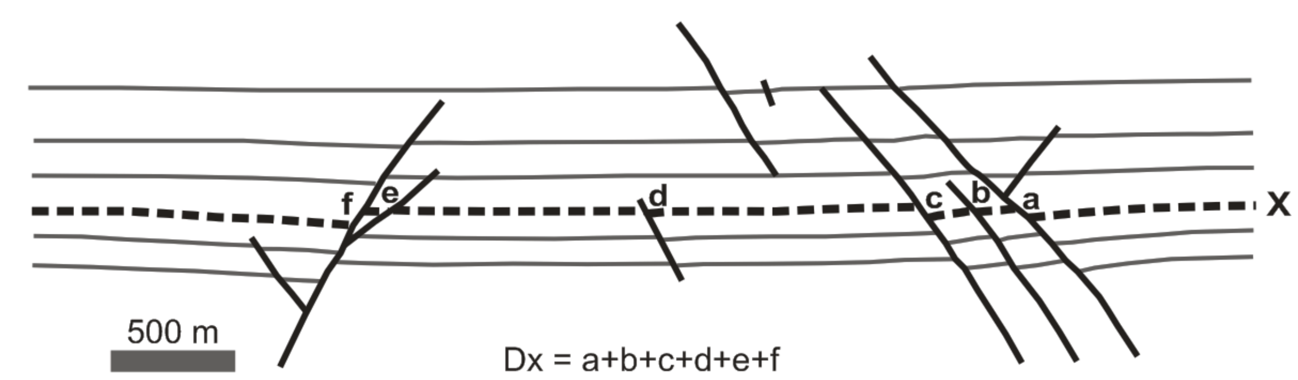
MAIN CONCEPTS

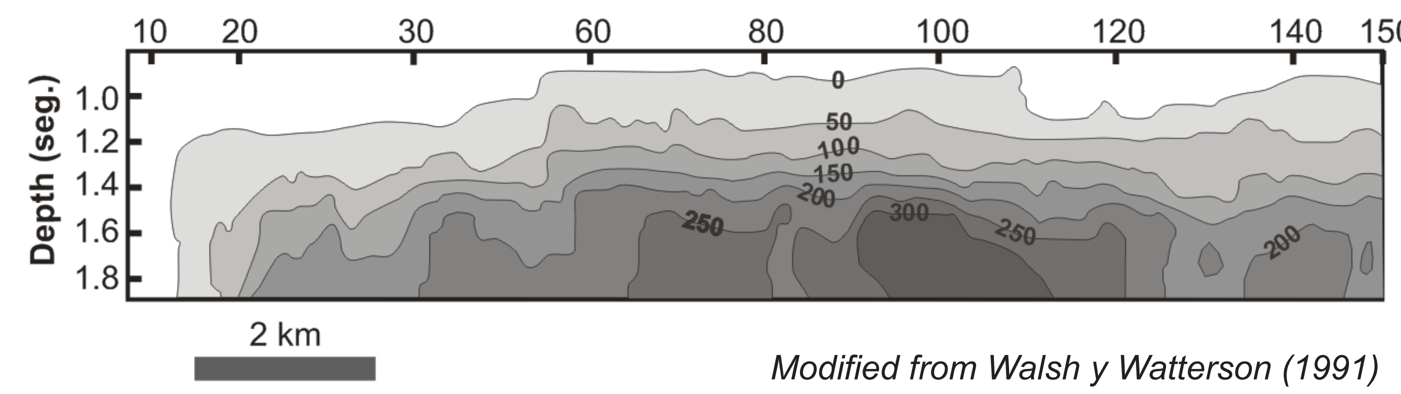
- Displacement maps have elliptical contour lines with maximum values near the center and zero at the tip lines.
- Displacement profiles have maximum values in the central part of the fault trace and they gradually decrease toward the tips.



Extracted from Fossen (2010)

Aggregated displacement

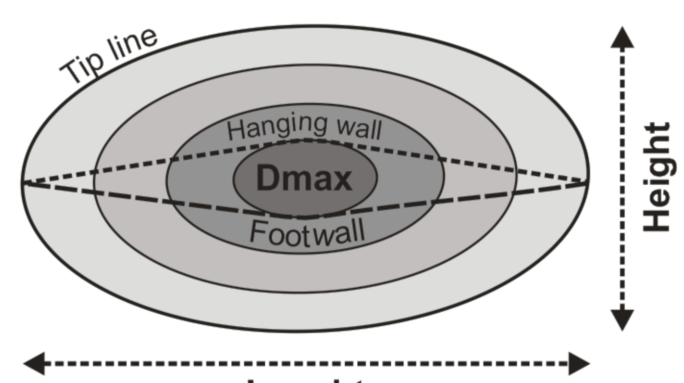




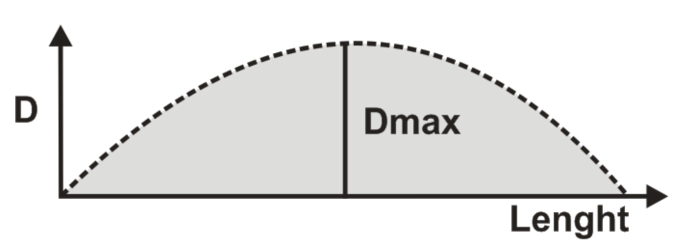
Modified from Walsh y Watterson (1991)

Ideal, isolated fault

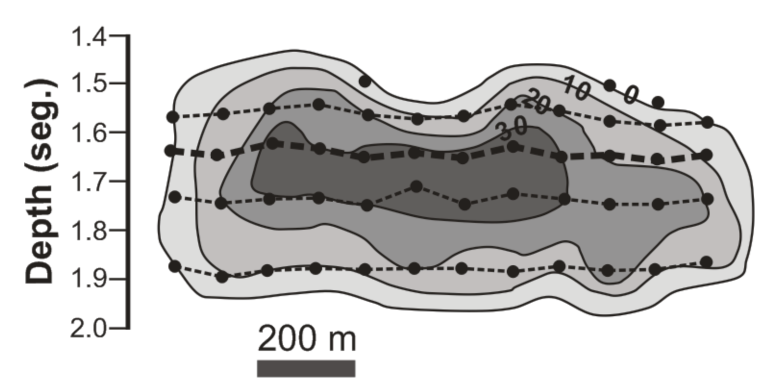
Displacement maps



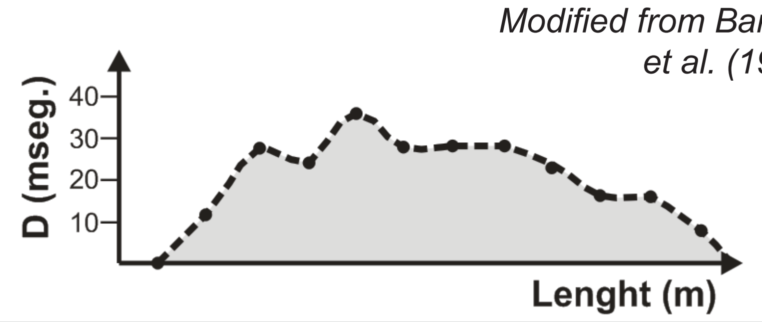
Displacement profiles



Normal fault from the North Sea



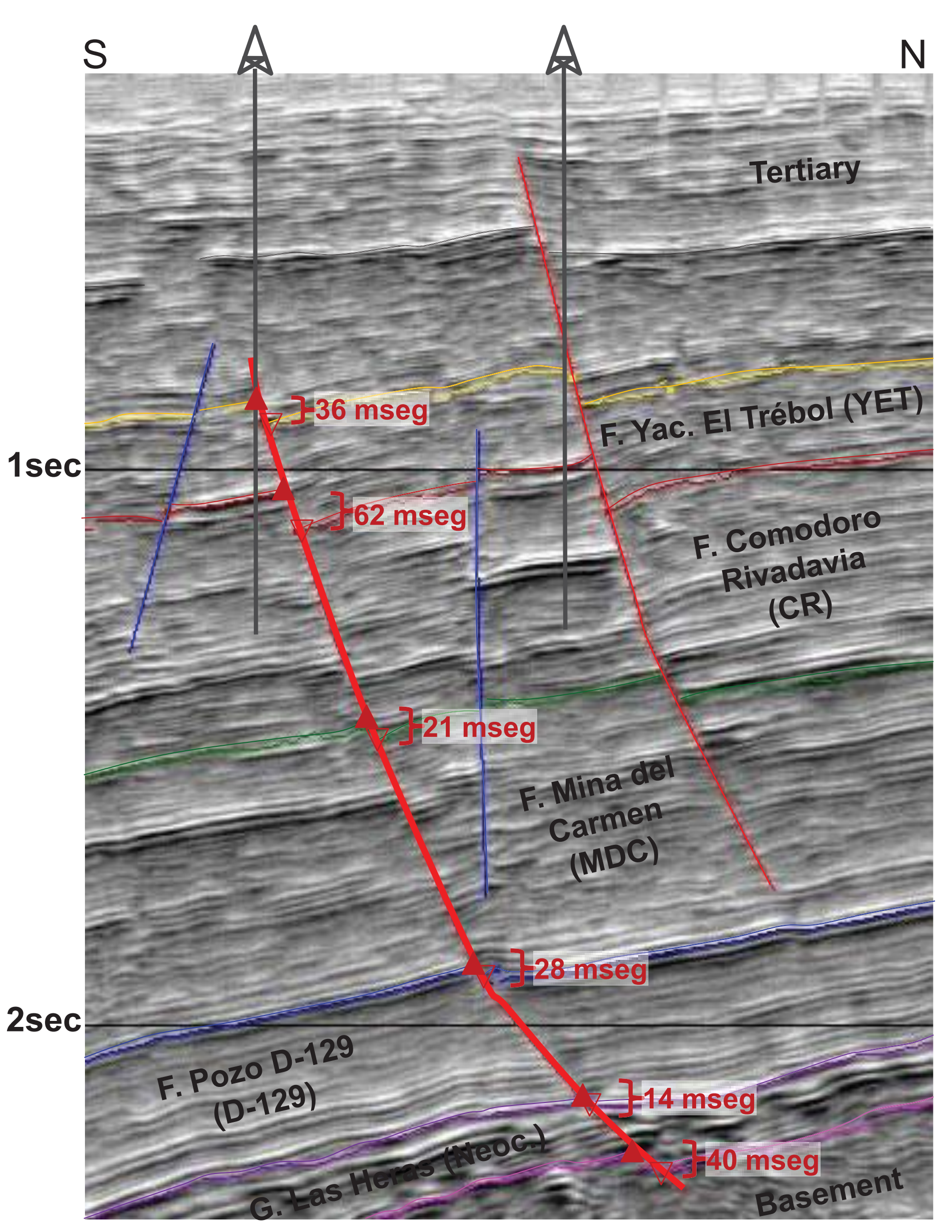
Modified from Barnett et al. (1987)



- Aggregated displacement maps (and profiles) are constructed by summing the throw on selected faults along each horizon.
- The displacement distribution shows a regularity similar to that on a single fault, implying a kinematic coherence requiring a high degree of synchronous movement, as opposed to sequential development, on individual elements in the array.

CONSTRUCTION TECHNIQUE

Cross Line 2345



Data exported from the seismic interpretation

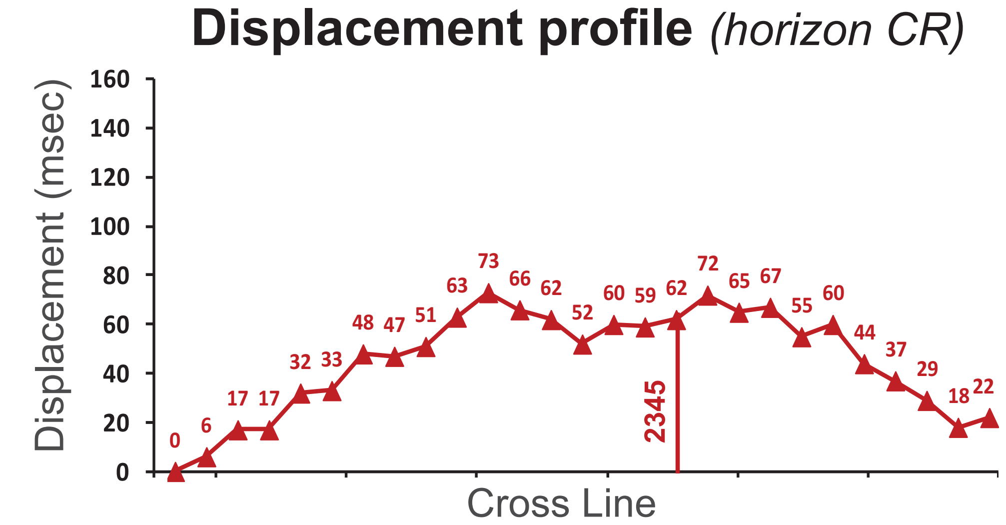
Hz	Block	XLN	Z (twt)
YET	Footwall	2275	882
YET	Footwall	2280	887
YET	Footwall	2285	883
YET	Hangingwall	2275	882
YET	Hangingwall	2280	892
YET	Hangingwall	2285	899
...	...	...	...
CR	Footwall	2265	1074
CR	Footwall	2270	1071
CR	Footwall	2275	1071
CR	Hangingwall	2265	1074
CR	Hangingwall	2270	1077
CR	Hangingwall	2275	1088
...	...	...	...
MDC	Footwall	2270	1524
MDC	Footwall	2275	1517
MDC	Footwall	2280	1515
MDC	Hangingwall	2270	1524
MDC	Hangingwall	2275	1535
MDC	Hangingwall	2280	1532
...	...	...	...

Input data for profile

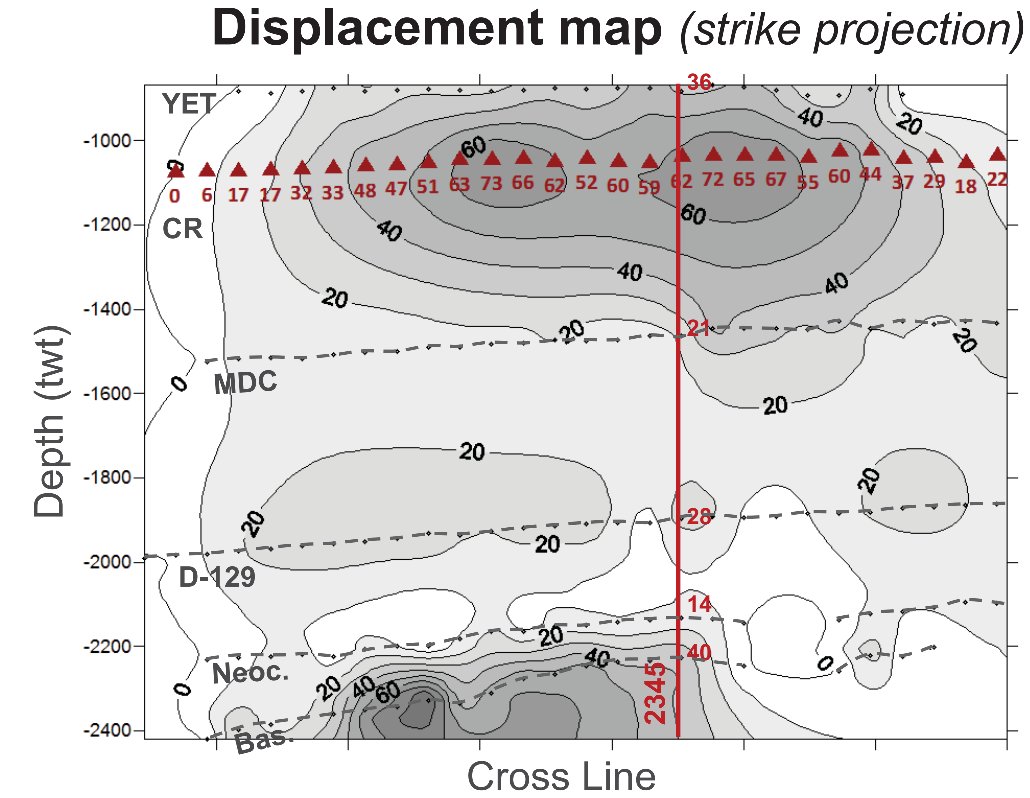
Footwall			
Hz	XLN	Z (twt)	D (twt)
YET	2275	882	0
YET	2280	887	5
YET	2285	883	16
...	...	...	...
CR	2265	1074	0
CR	2270	1071	6
CR	2275	1071	17
...	...	...	...
MDC	2270	1524	0
MDC	2275	1517	18
MDC	2280	1515	17
...	...	...	...

Input data for map

Displacement profile *(horizon CR)*



Displacement map *(strike projection)*



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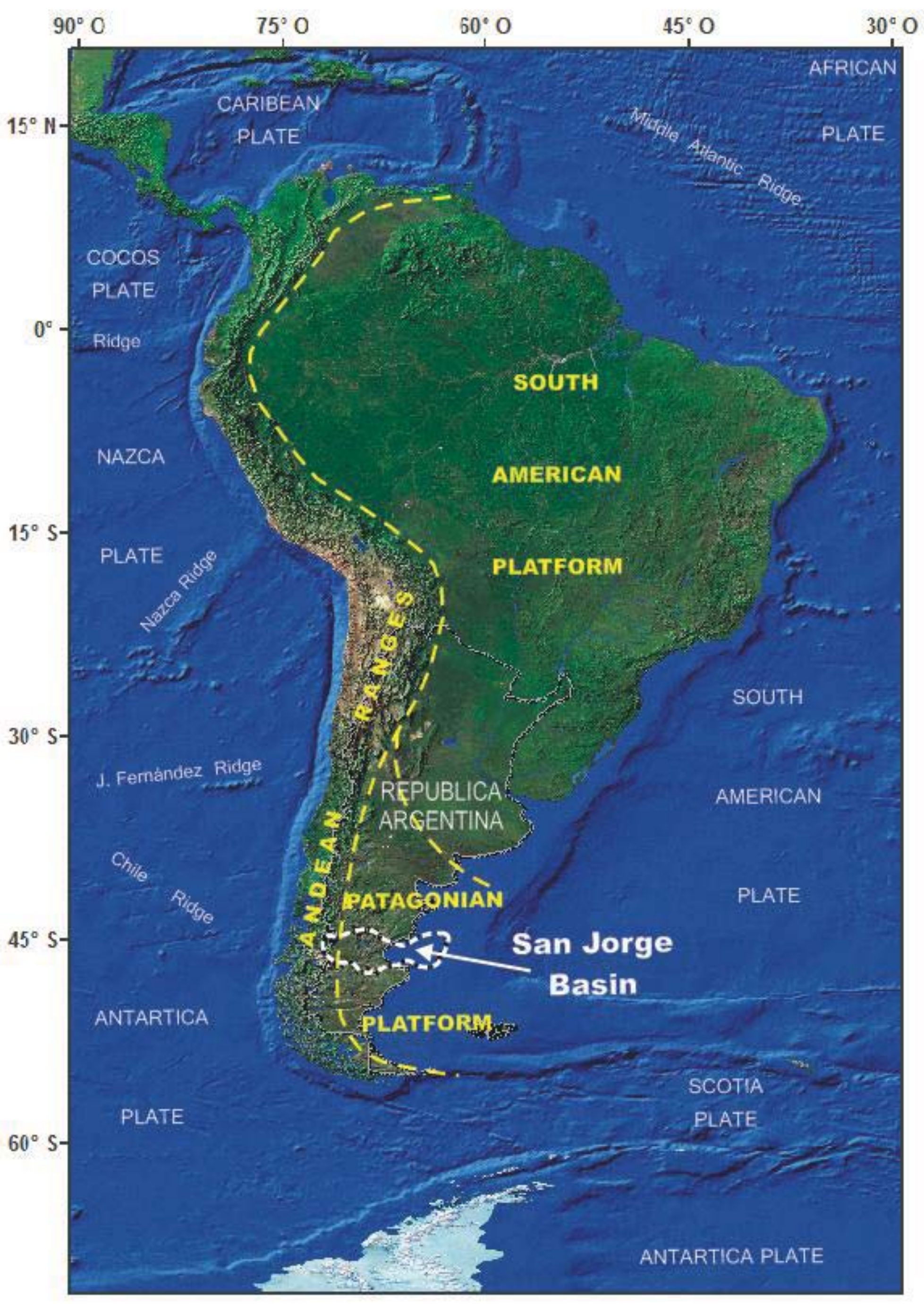
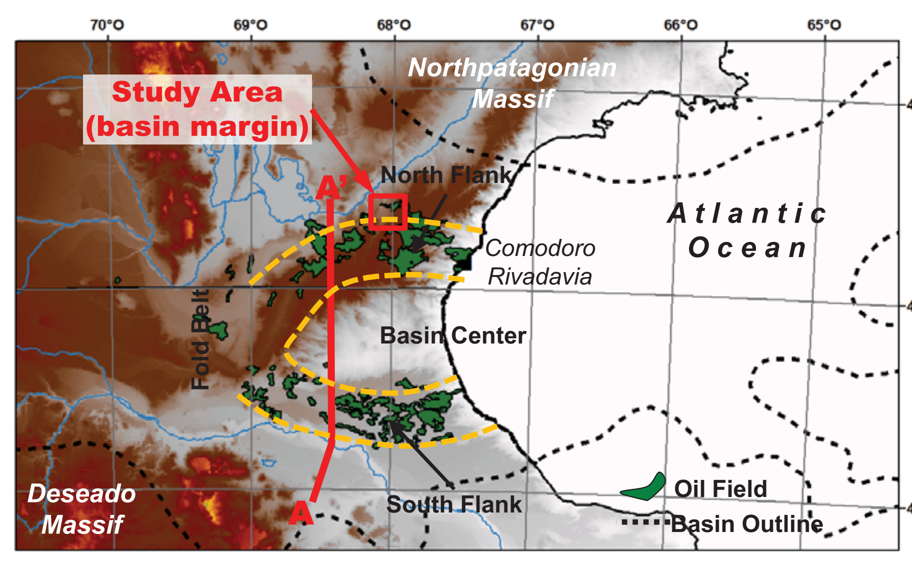
BASIN OVERVIEW



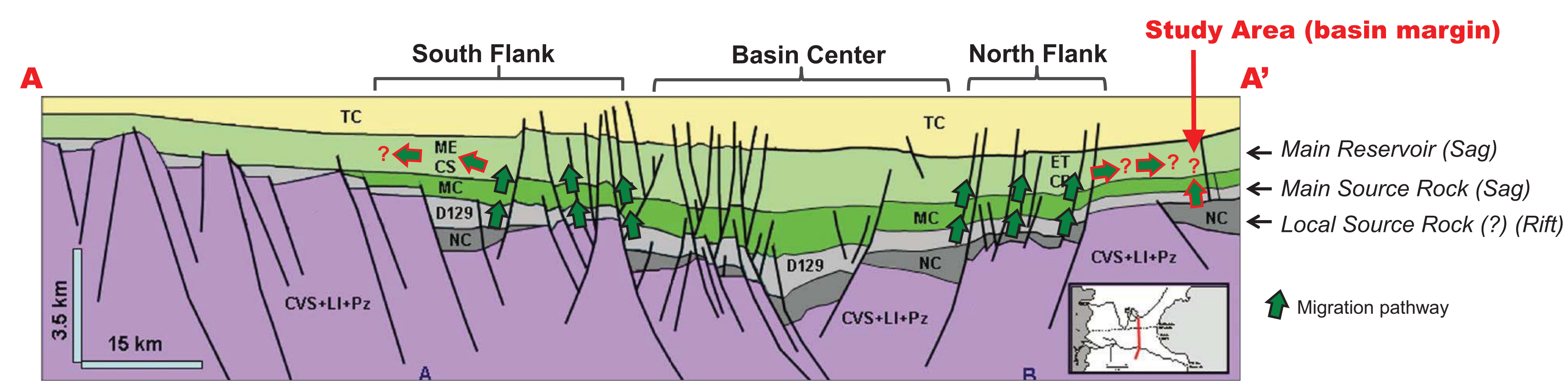
PRODUCTION SUMMARY

- The first commercial oil well was drilled in 1907,near Comodoro Rivadavia city. Since then more than 35000 wells have been drilled.
- Total cumulated production is 5072 Mboe (mostly oil) and total remaining PP reserves are 7872 Mboe (IHS).



GEOLOGICAL SETTING

- Jurassic to Tertiary intracratonic and mainly extensional basin.
- Syn-rift sediments overly the economic basement filing the graben and half-graben structures. Some of them have local source rock pods.
- The regional sag was filled with fluvial-lacustrine sediment, where the main source rock and most prolific reservoirs are developed.
- A compressive event occurred in the Late Tertiary, forming a fold belt in the west.
- Most of the oil was found in a half-elipse that encloses the basin center. The fields are associated to structural traps with a minor stratigraphic compound related to pinch-out of the fluvial deposits.
- Main migration paths are vertical and through the faults, with a high degree of compartmentalization. Lateral migration may occur at the basin margins through amalgamated sandstone bodies.



Modified from Sylwan et al. (2008)

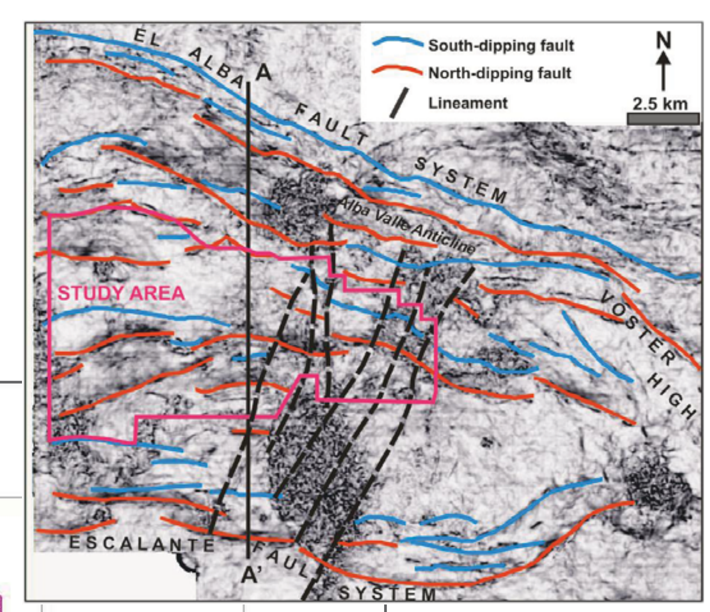
LOCATION AND OBJECTIVES

PETROLEUM GEOLOGY

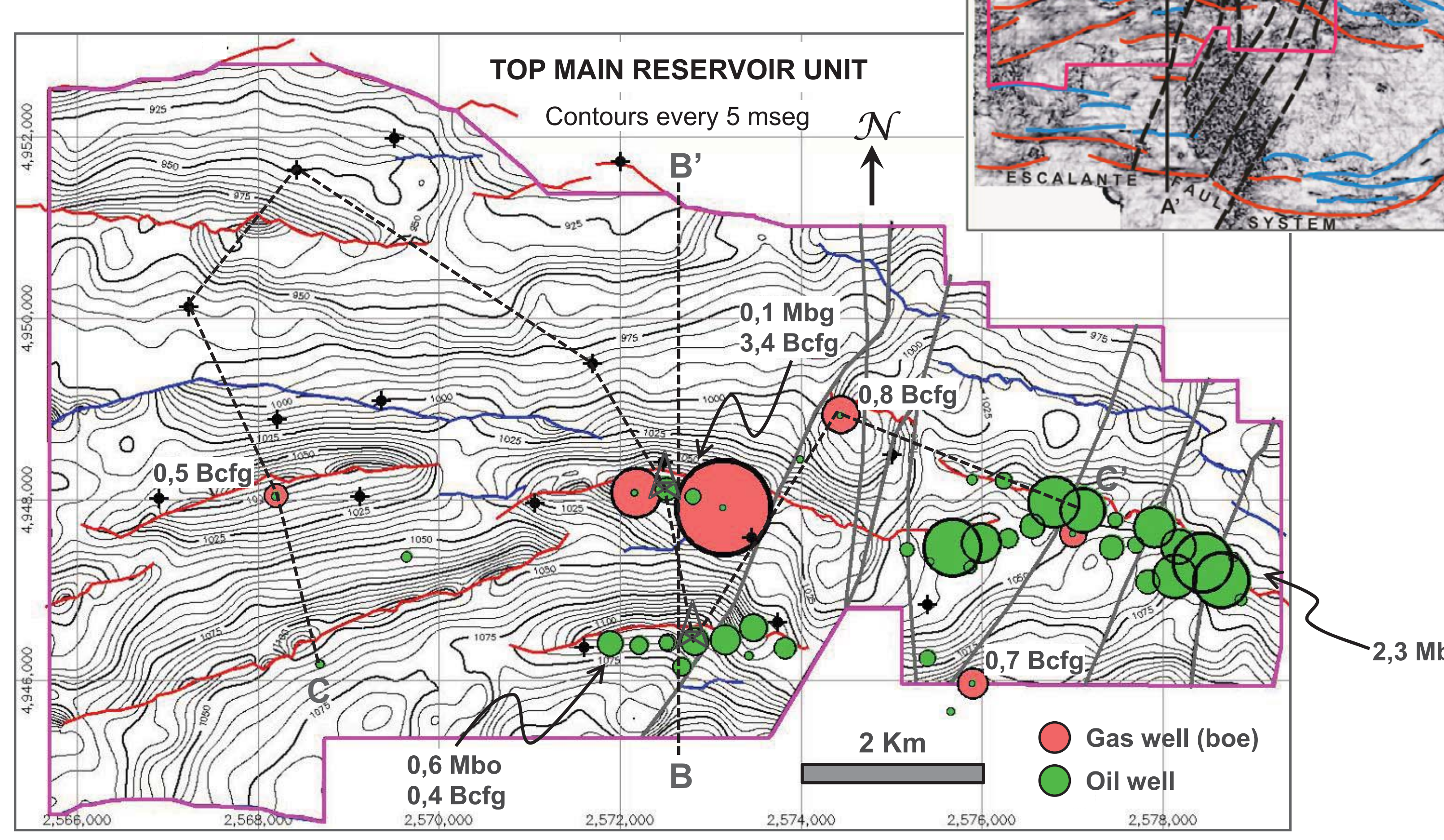
- The study area is located at the northern margin of the San Jorge Basin, in a region known as Manantiales Behr.
- Most of the faults dip towards the basin margin, allowing the development of footwall traps.
- The eastern sector has NNE-SSW to N-S oriented lineaments that seem to play a role on the configuration of the traps.
- Main source rock is immature and with low TOC (lake margin facies).
- A local source rock pod has been invoked as a possible source of the hydrocarbons, allowing the charge of traps located far from the proven kitchen (Bellosi *et al*. 2002; Jalfin *et al*. 2002).
- Vertical migration paths through the fault plane are needed to connect the deep seated source rock with the shallow reservoir levels above.

OBJECTIVES

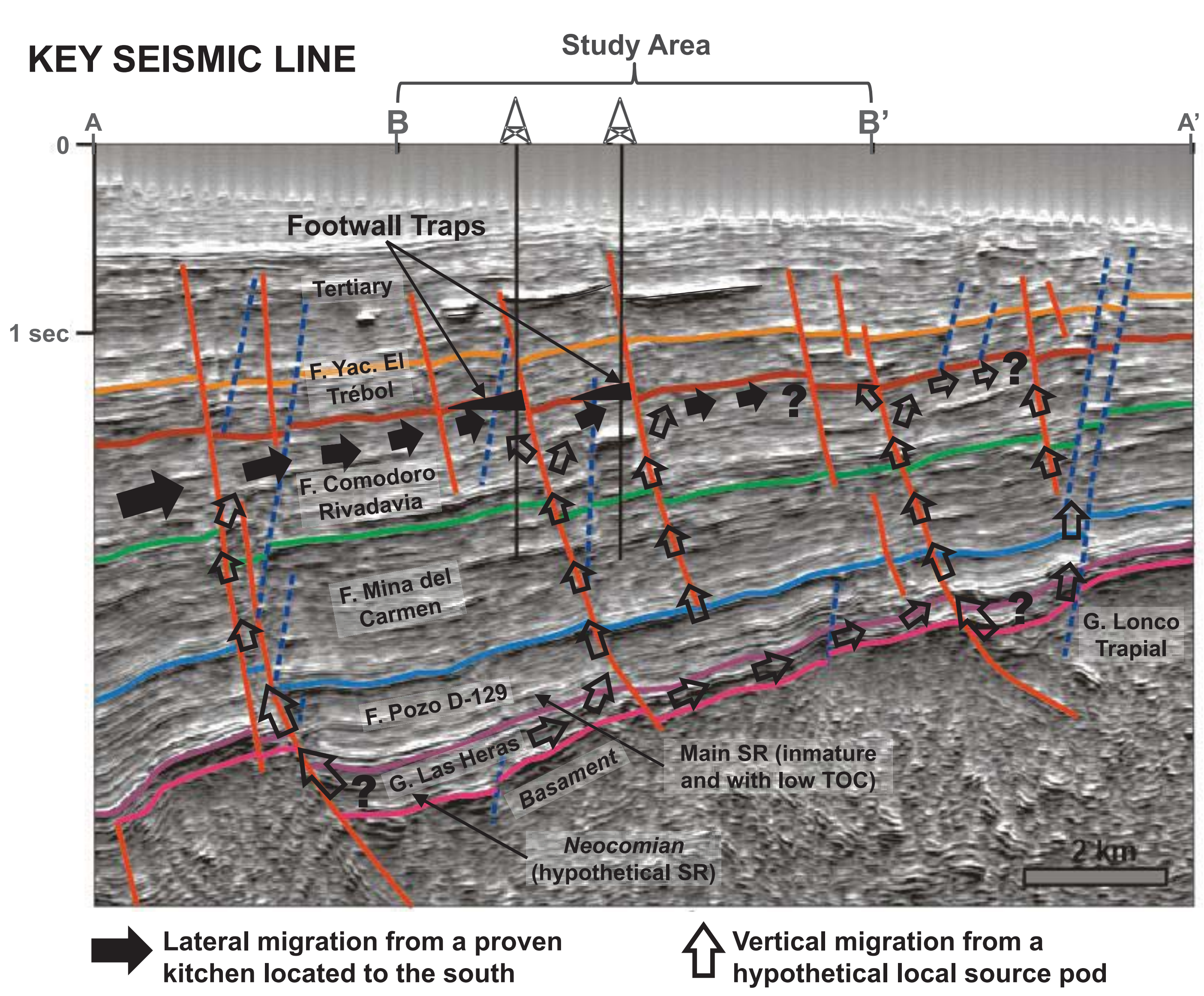
- To analyze the fault slip distribution in order to evaluate the chance of shallow reservoir charge from a deep seated source pod.
- To investigate the nature of the lineaments located at the eastern sector and its relation with the main extensional system.
- To propose a model of hydrocarbon migration and trapping in order to risk undrilled traps.



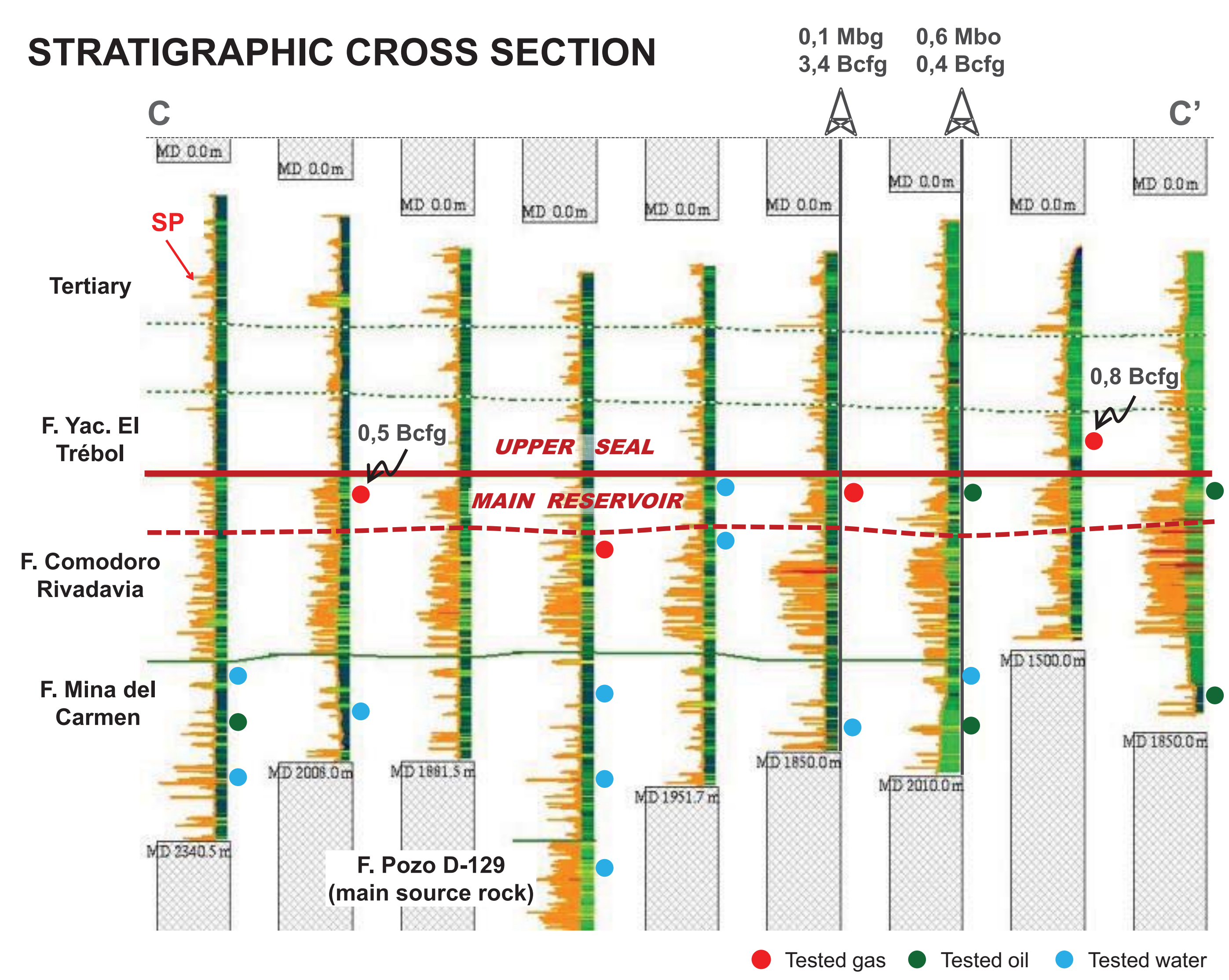
TIME STRUCTURAL MAP and BUBBLE MAP



KEY SEISMIC LINE



STRATIGRAPHIC CROSS SECTION



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FAULT DISPLACEMENT ANALYSIS

RESULTS

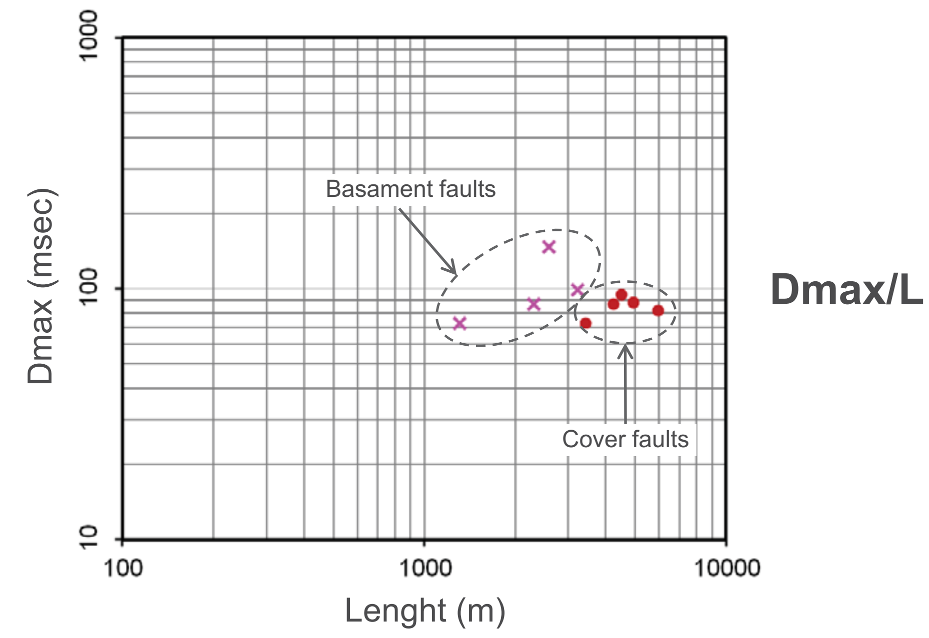
- There are two kinds of faults:

  1) Faults affecting the sedimentary cover and the basement (faults 1, 2 and 5)

  2) Faults that involve only the sedimentary cover (faults 3, 4 and 6)

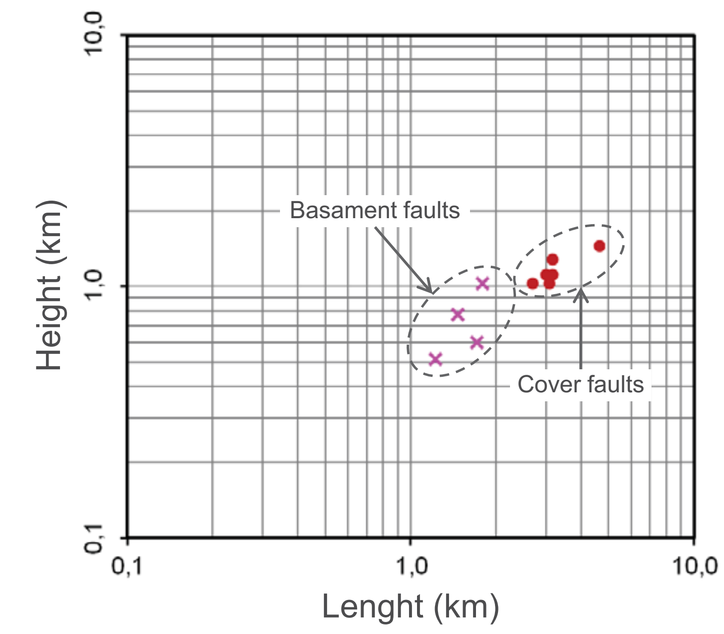
… and both types have proven hydrocarbon accumulations on their footwalls (faults 4 and 6)

- Cover faults have elliptical displacement contours centered at the top of the main reservoir unit.
- Basement faults have semi-elliptical shapes and high throw gradients near the tip-lines.
- Cover faults have little or no connection with basement faults, making the connection difficult between the deep seated hypothetical source rock and the shallow reservoir levels.
- Fault 3 has low variation in the throw values and is belived to have a strike-slip component of movement.
- Basement faults have Dmax/L relationships and aspect ratios that distinguish them from cover faults.

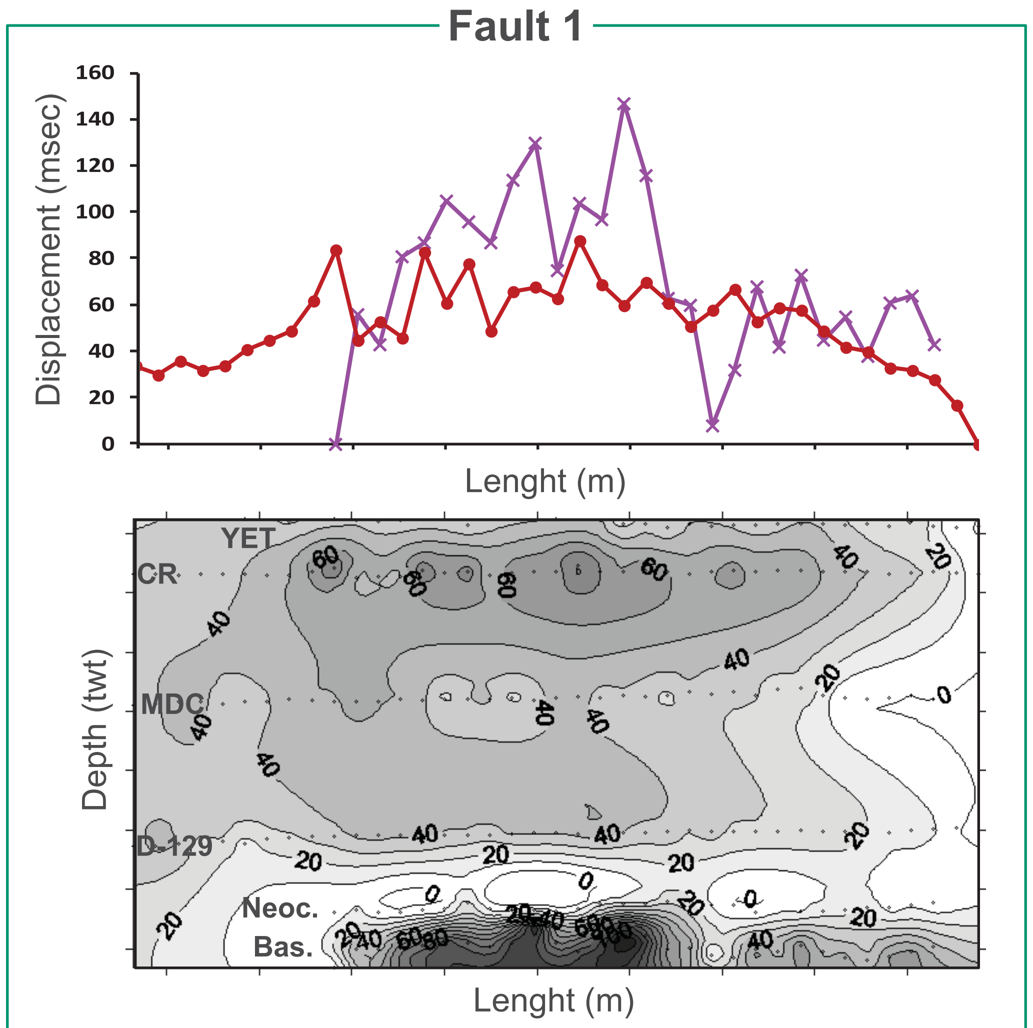


Dmax/L

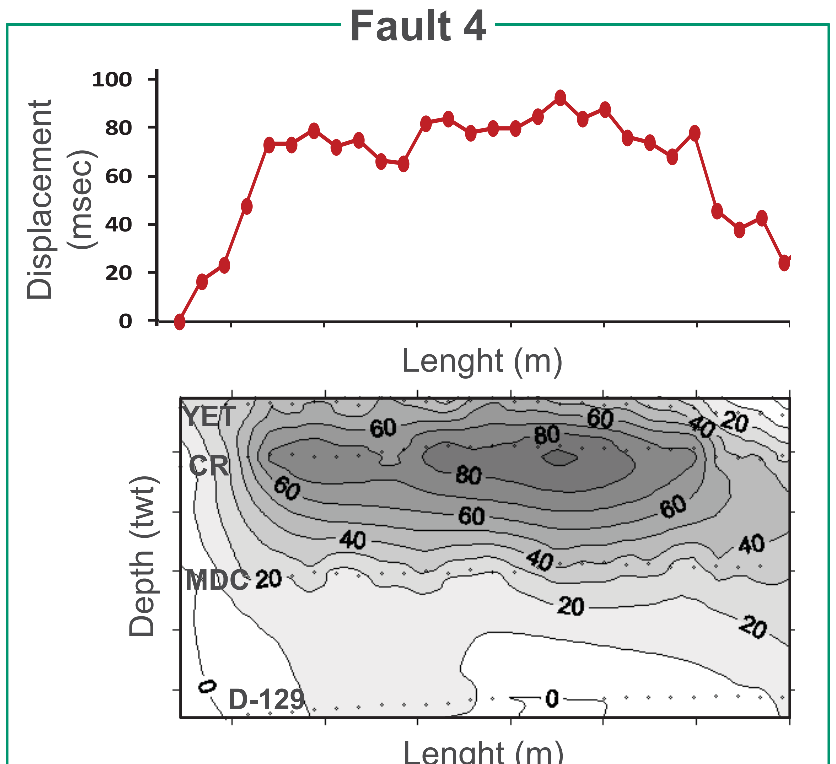
Aspect Ratio



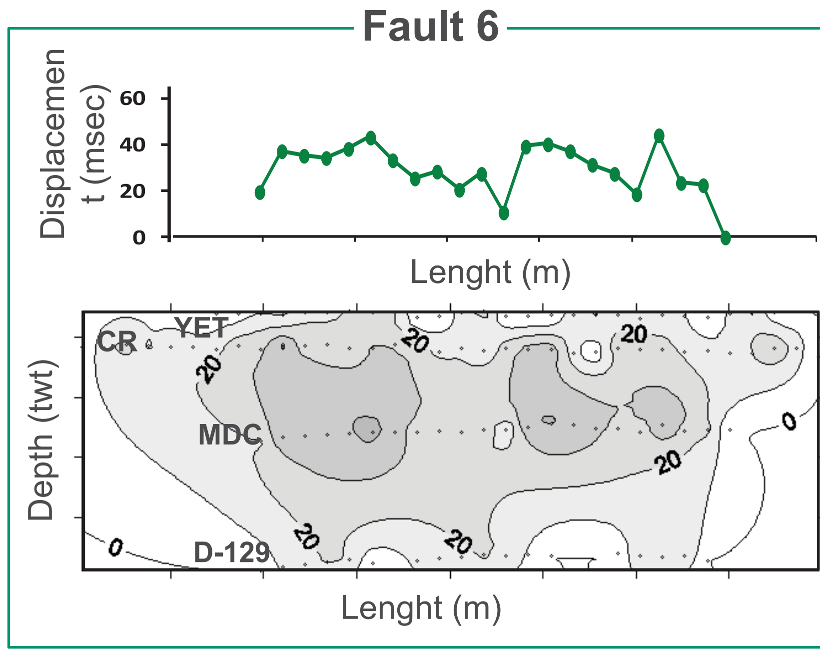
Fault 1



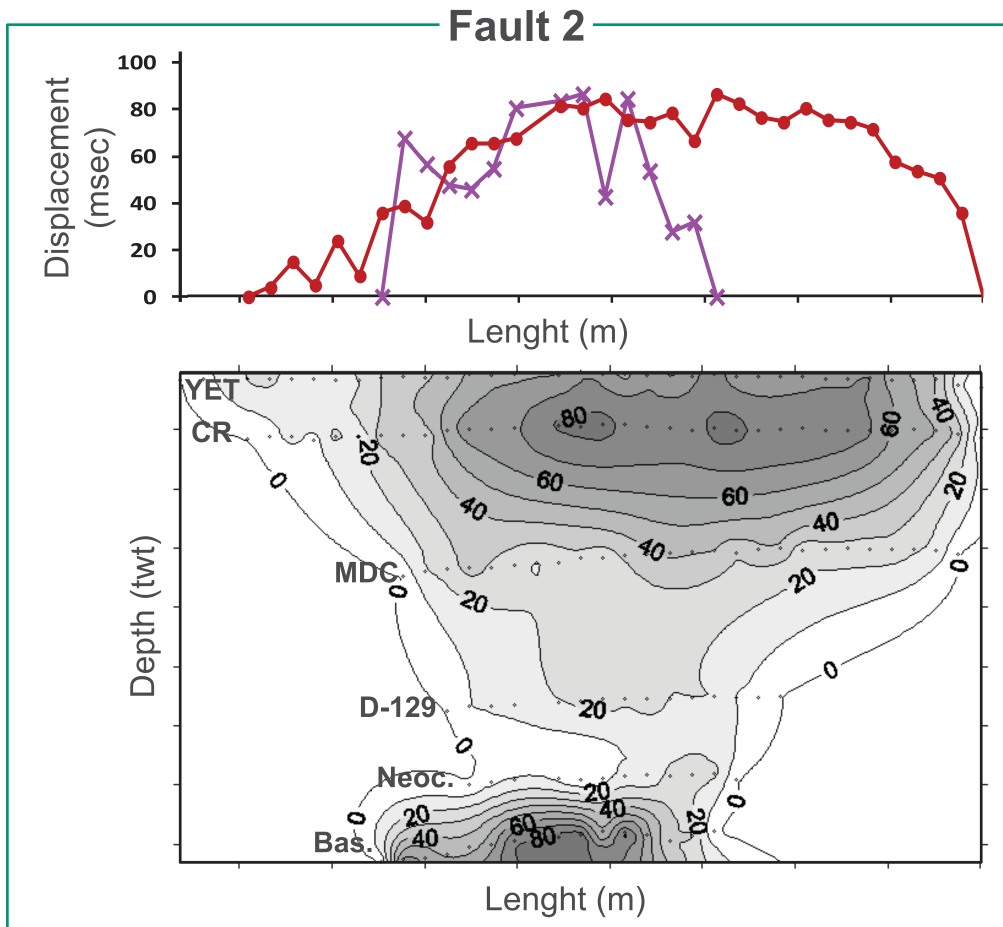
Fault 4



Fault 6



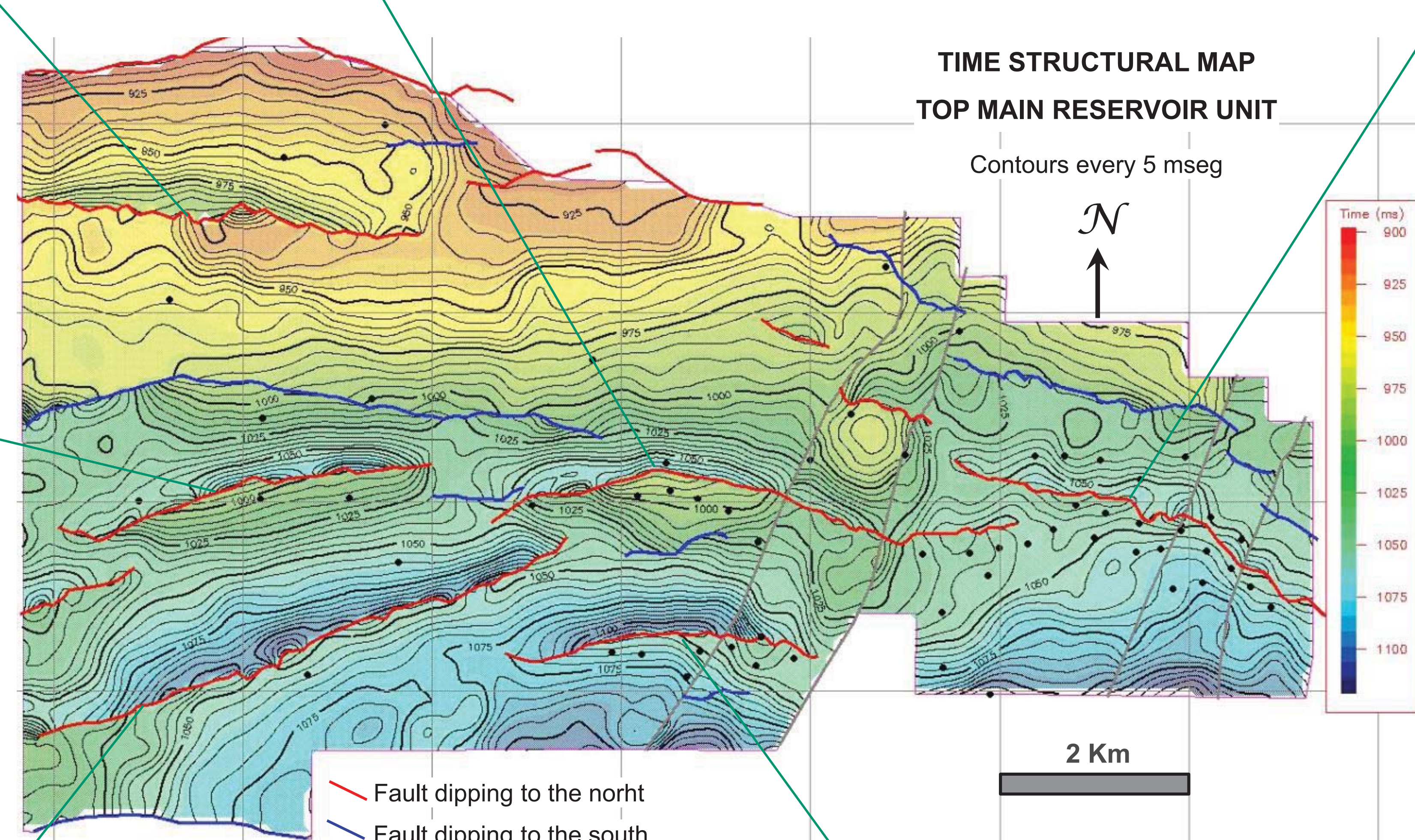
Fault 2



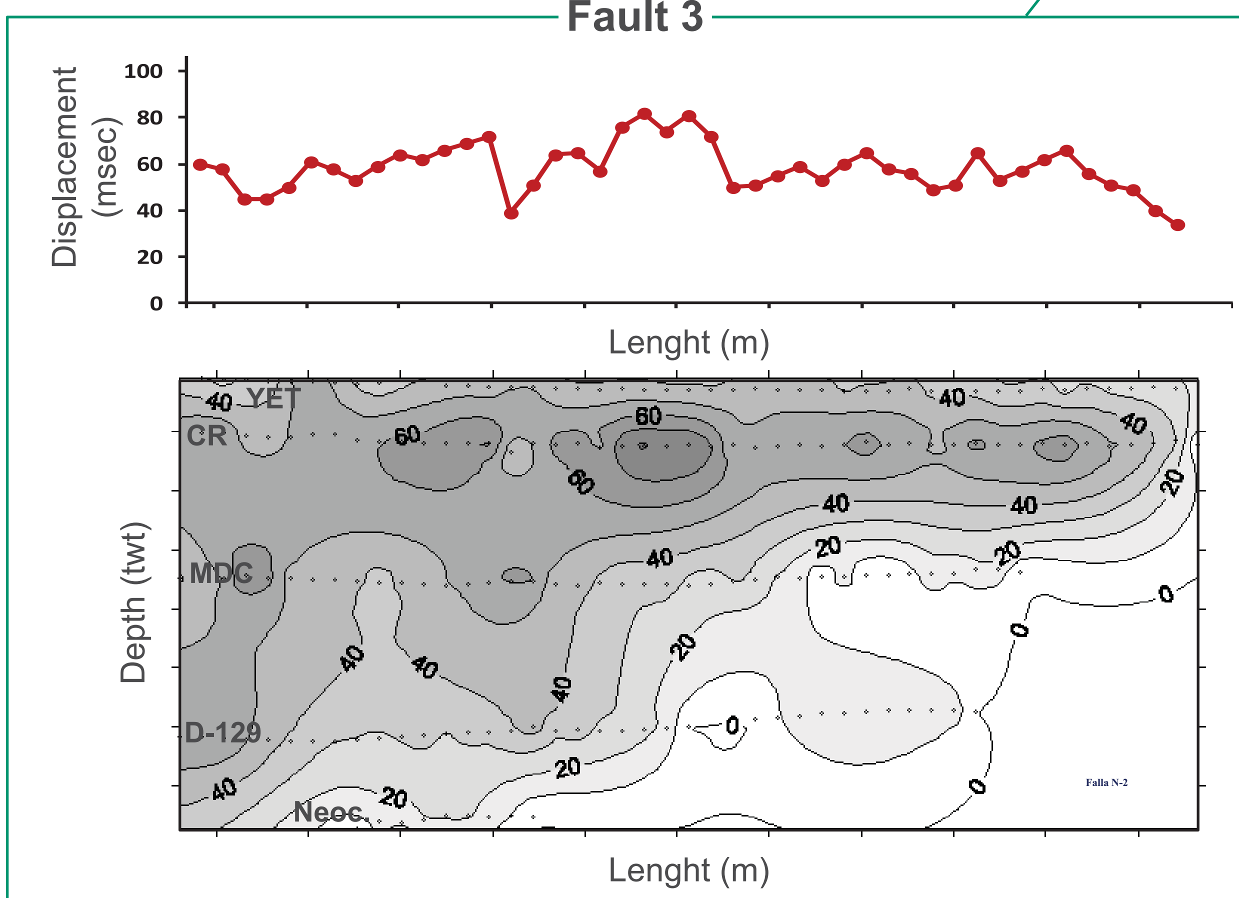
TIME STRUCTURAL MAP

TOP MAIN RESERVOIR UNIT

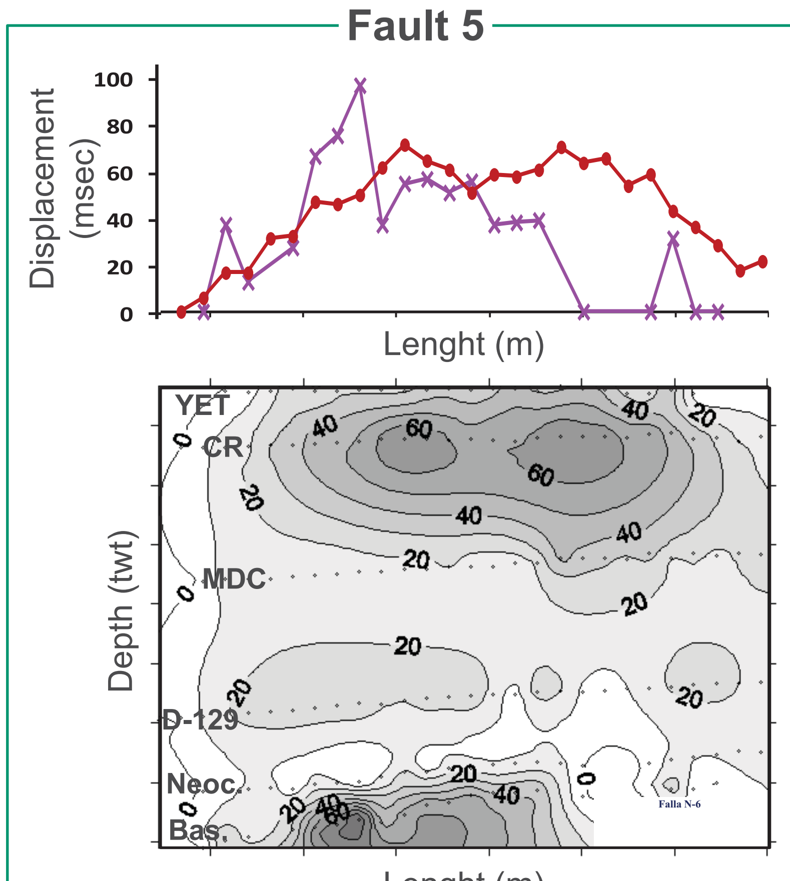
Contours every 5 mseg

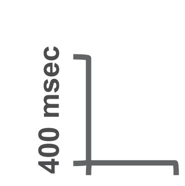


Fault 3



Fault 5





YET: F. Yacimiento El Trébol

CR: F. Comodoro Rivadavia

MDC: F. Mina del Carmen

D-129: F. Pozo D-129

Neoc.: G. Las Heras

Bas.: G. Lonco Trapial

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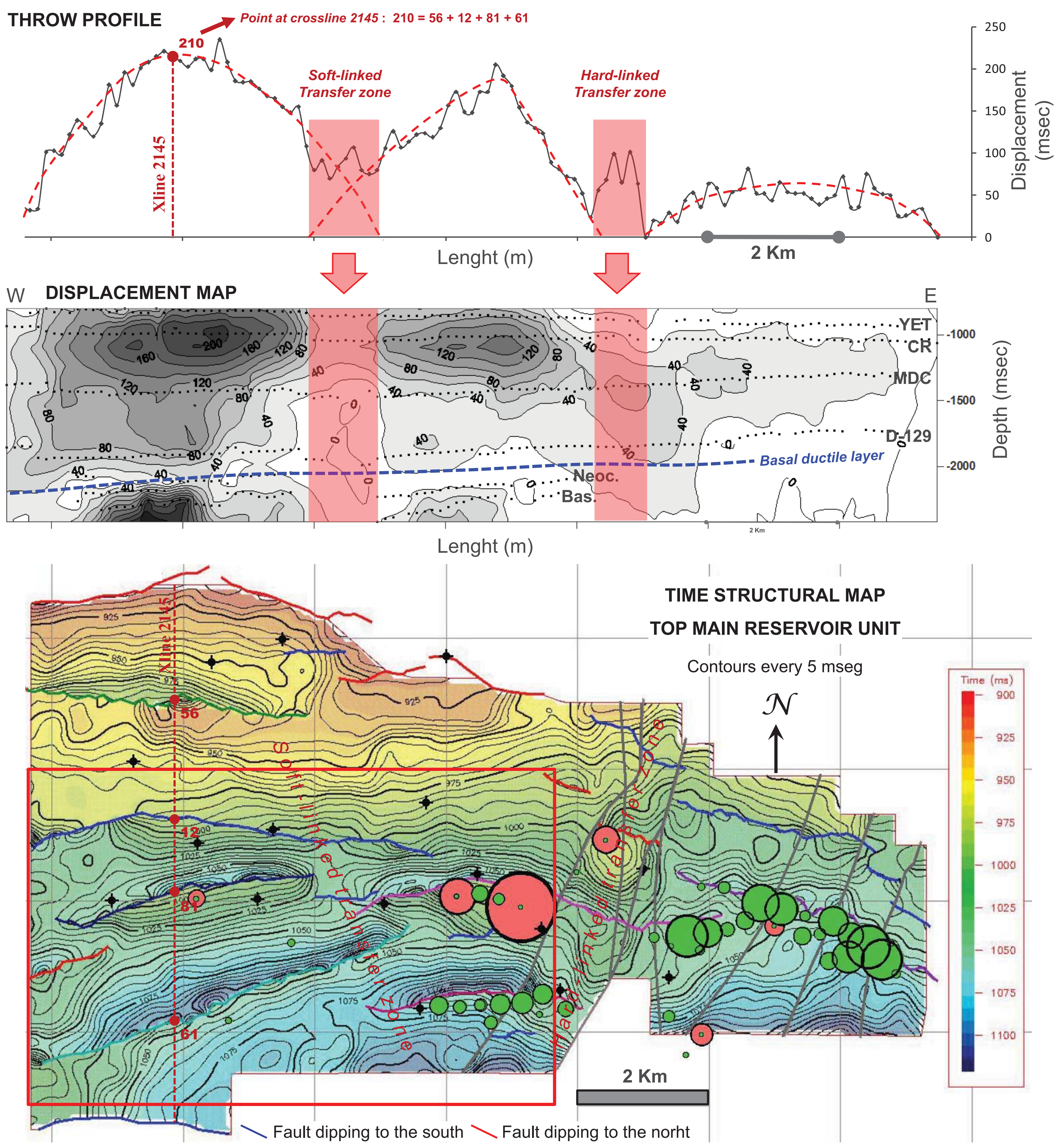
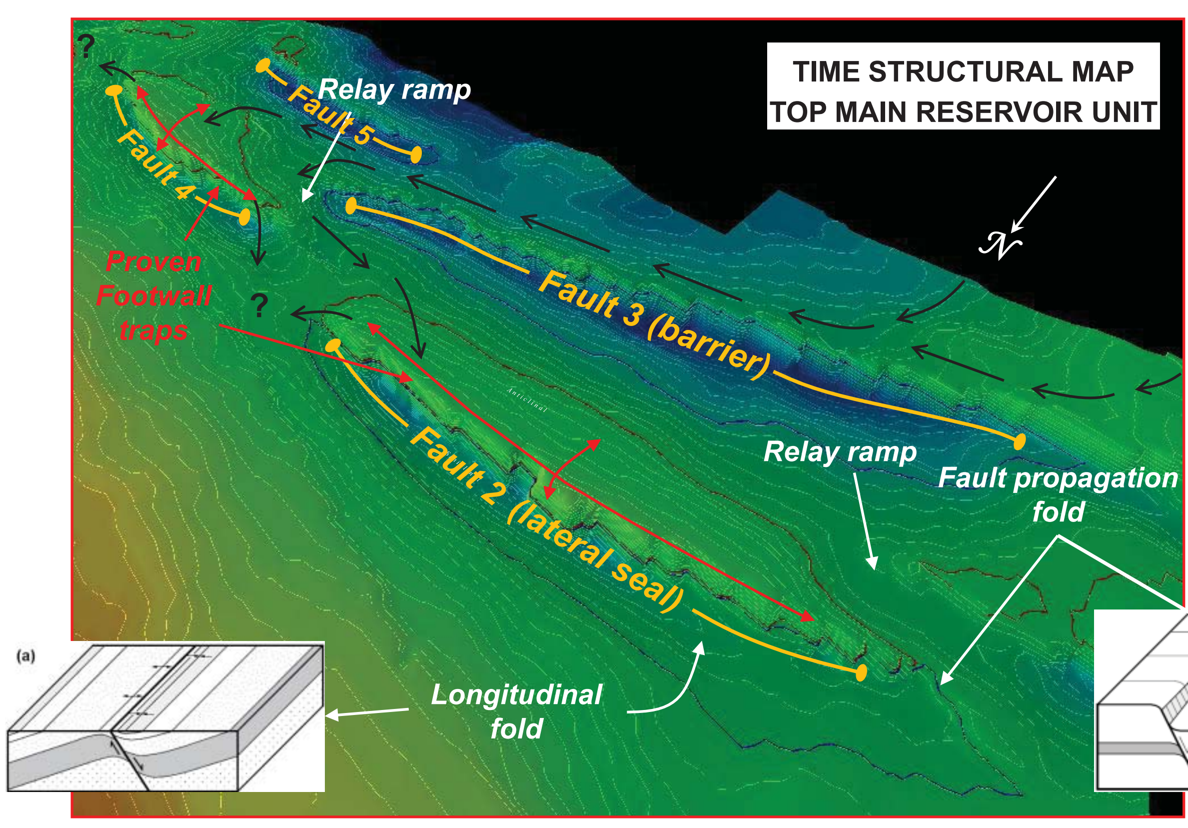
TRANSFER ZONES

- The aggregated throw profile shows three bell-shaped zones with displacement variations that are similar to those shown by single faults.
- The three zones are separated by two types of transfer zones: 1) a soft-linked transfer zone made up by an overlapping belt of relay ramps; and 2) a hard-linked transfer zone related to high-angle faults that also served as magmatic conduits.
- The geometric coherence shown in the aggregated displacement profile and map for the cover faults suggest a synchronous kinematic evolution.
- The main source rock unit (F. Pozo D-129) acted as a decoupling level, causing that reactivation of pre-existent basement fabric and had little control on the development of faulting in the sedimentary cover.

Aggregated displacement profile and map



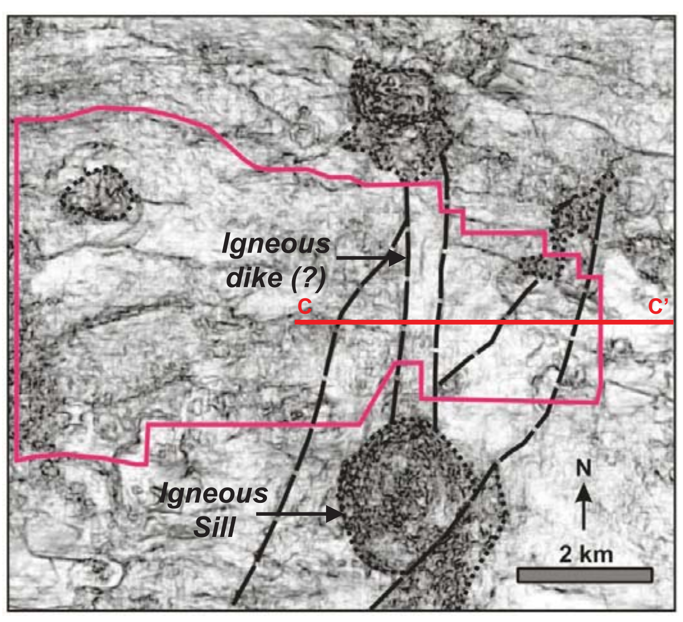
Soft-linked transfer zone



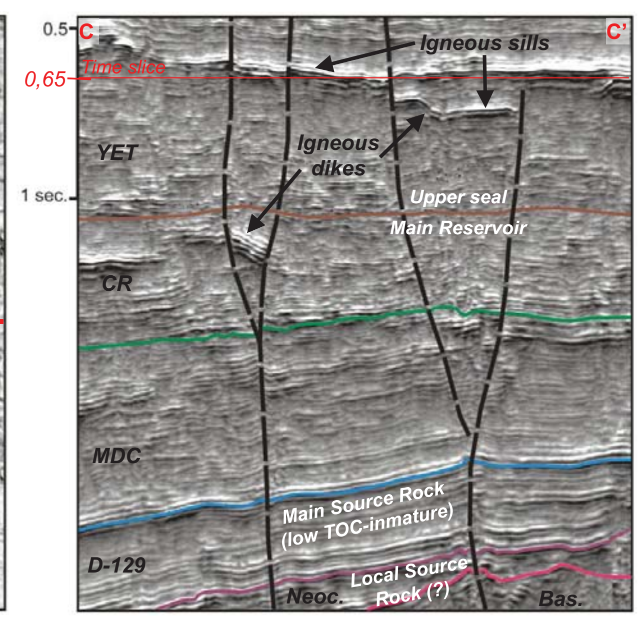
- North-dipping faults are barriers to hydrocarbon lateral migration made by the juxtaposition of footwall carrier beds (reservoir if a trap configuration exists) with hanging wall non-permeable upper seal lithologies.
- Relay ramps are corridors of carrier beds that may allow hydrocarbon migration towards the basin margin.

Hard-linked transfer zone

COHERENCE TIME SLICE AT 650 MSEC



SEISMIC SECTION C-C'



- The N-S to NNE-SSW lineaments are high-angle discontinuities with little or no vertical slip that cut both the basement and the sedimentary cover.
- In map view, the lineaments are connecting circular to irregular zones with low signal to noise ratio which are interpreted to be concordant igneous bodies (sills) intruded into Tertiary units.
- In cross section, the lineaments are also related to discordant igneous bodies (dikes) which may cut through the reservoir section.
- The steep displacement gradients and the low values of throw in the eastern sector are interpreted to be the result of the interference of the extensional faults with the pre-existent lineaments.
- The lineaments may have accommodated the extension through strike-slip and oblique-slip movement allowing the intrusion of igneous bodies in the sedimentary cover.
- The strike-slip fault zones and/or the dikes intruded into the lineaments may have acted as lateral seals that contributed to enlarge the area of the footwall traps.

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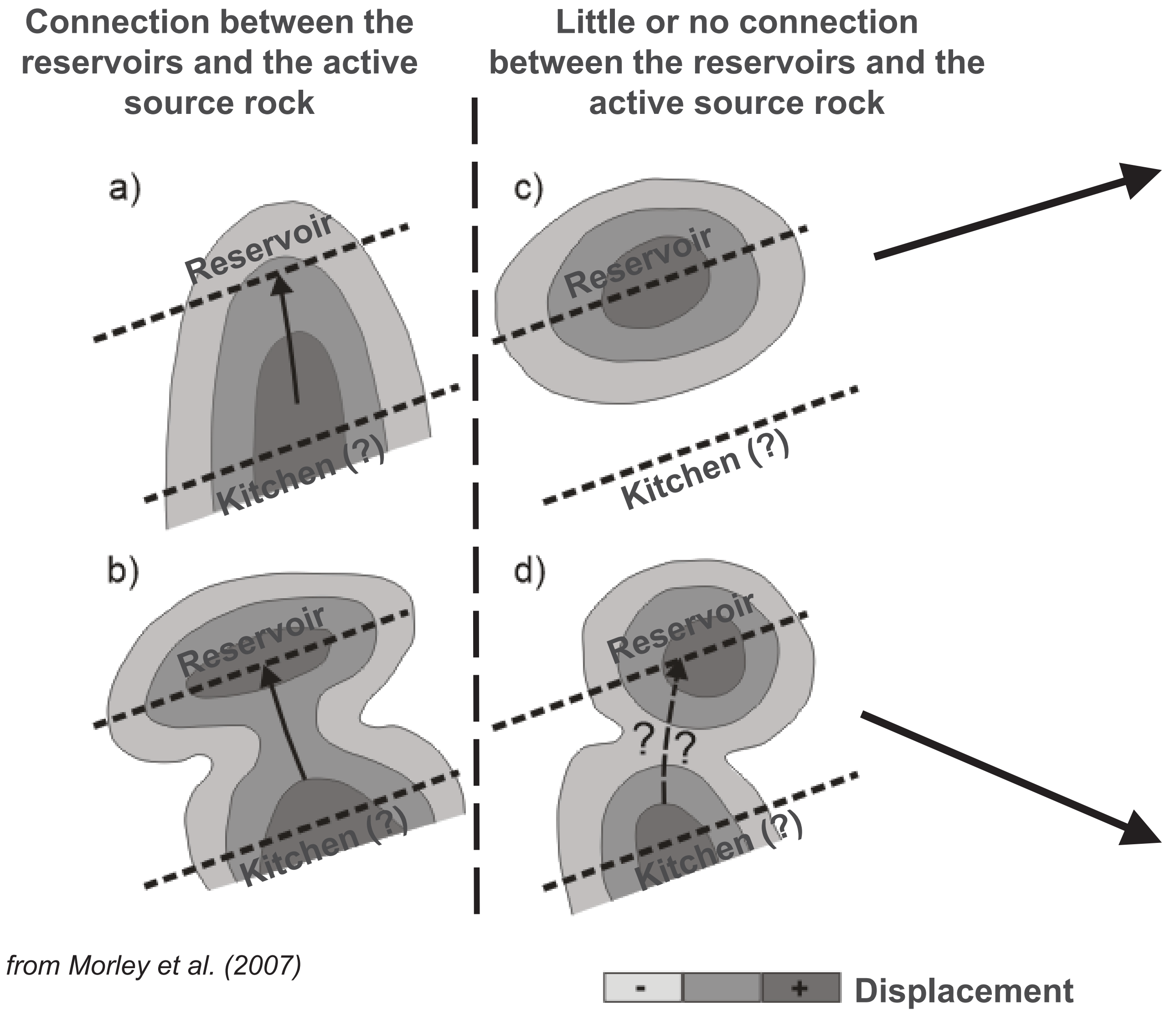
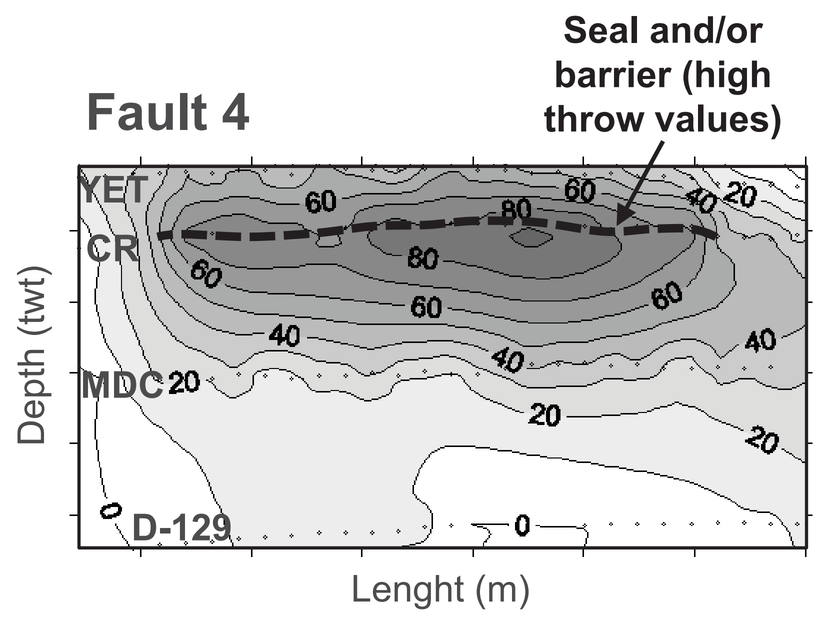
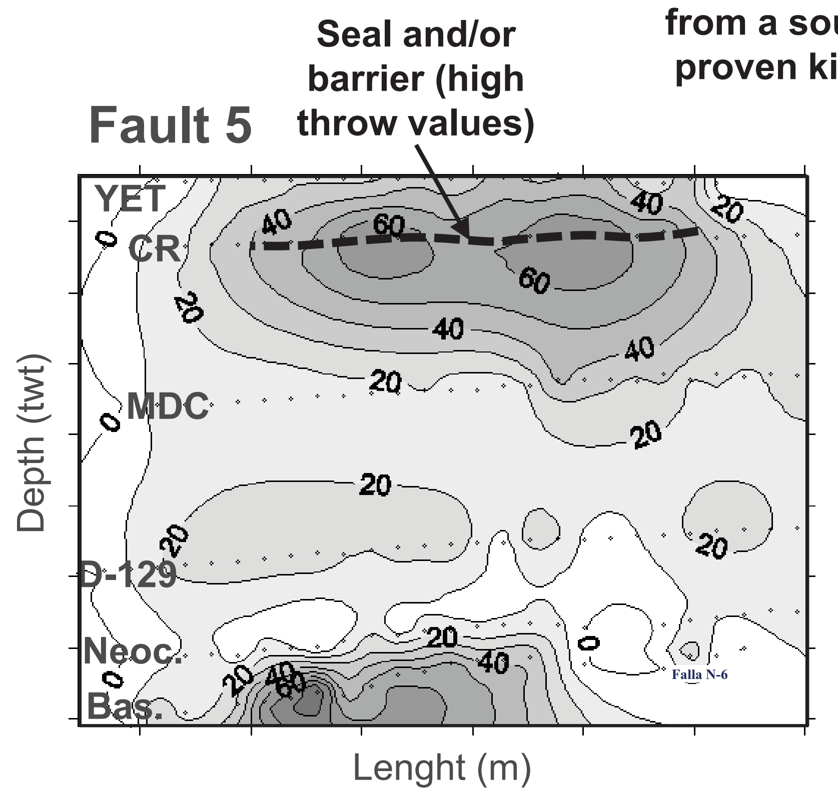
DISCUSION AND CONLUSIONS

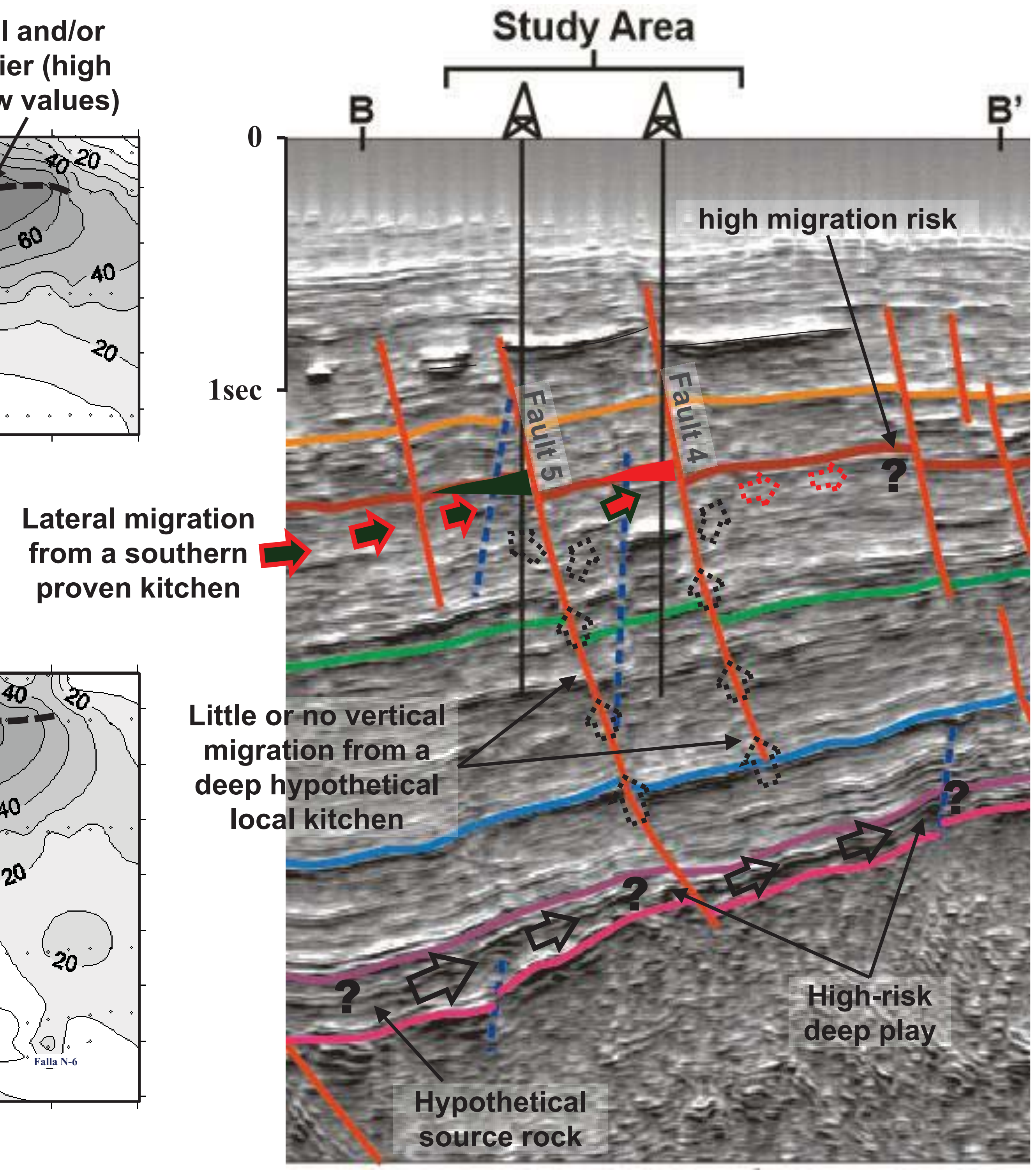
Schematic displacement contour patterns



Modified from Morley et al. (2007)







a) Reactivated basement fault that propagated up into the sedimentary cover.

b) Basement fault that is connected with a younger fault nucleated in the cover.

c) Fault nucleated in the cover that is not connected with pre-existent basement faults.

d) Fault nucleated in the cover that is little or not connected with a pre-existent basement fault.

CONCLUSIONS

- Observed fault displacement contours patterns indicates poor o no potential vertical migration pathways from a hypothetical local deep-seated source pod.
- High throw segments at north-dipping normal faults are barriers/seals to lateral migration trough carrier/reservoir rocks.
- High angle, perpendicular to oblique, transfer faults may have served as magmatic conduits and as barriers/seals to hydrocarbon lateral migration and trapping.
- Observed fluids distribution can be explained considering a structurally driven lateral migration pathway and the spatial distribution of fault-related barriers and seals.
- Undrilled traps located at basin margin are visualized to have a high migration risk because the lack of efficient vertical migration conduits and the longer lateral migration pathways.