Analysis of static stress variations in the 2013 Valencia Gulf (NE Spain) seismic sequence

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Abstract

The role of static stress transfer is assessed during the seismic sequence that took place in the Valencia Gulf in September and October, 2013, while and after gas injections were conducted in the area to develop an Underground Gas Storage (UGS). We compute Focal Mechanism (FM) solutions for the 8 main events (M_L 3.5 - 4.3), and build a 3D model of the area both with FM faults and the mapped structures around the gas reservoir. Coulomb stress changes (ΔCS) are tracked on all faults in the model using COULOMB software. Our analysis supports two main facts: 1) static stress transfer would have acted as a destabilizing trigger in the sequence, and 2) deeper sources than the mapped faults around the reservoir.

Introduction 1

The Castor UGS (Fig.1a) was ideated to store gas in the depleted Amposta Oil Field [1], roughly in between 1.7 and 2.5 km beneath the seabed (Fig.1b). Natural seismicity in the area is very low, but several faulting structures have been identified (Fig.1c).

During the third injection stage of cushion gas, seismic activity increased to more than 30 events/day. After the well shut-in, seismicity reactivated itself towards the end of the month. 8 events of M_L 3.5 – 4.3 occurred (Fig.1d), for which FMs were computed by employing [2]'s method.

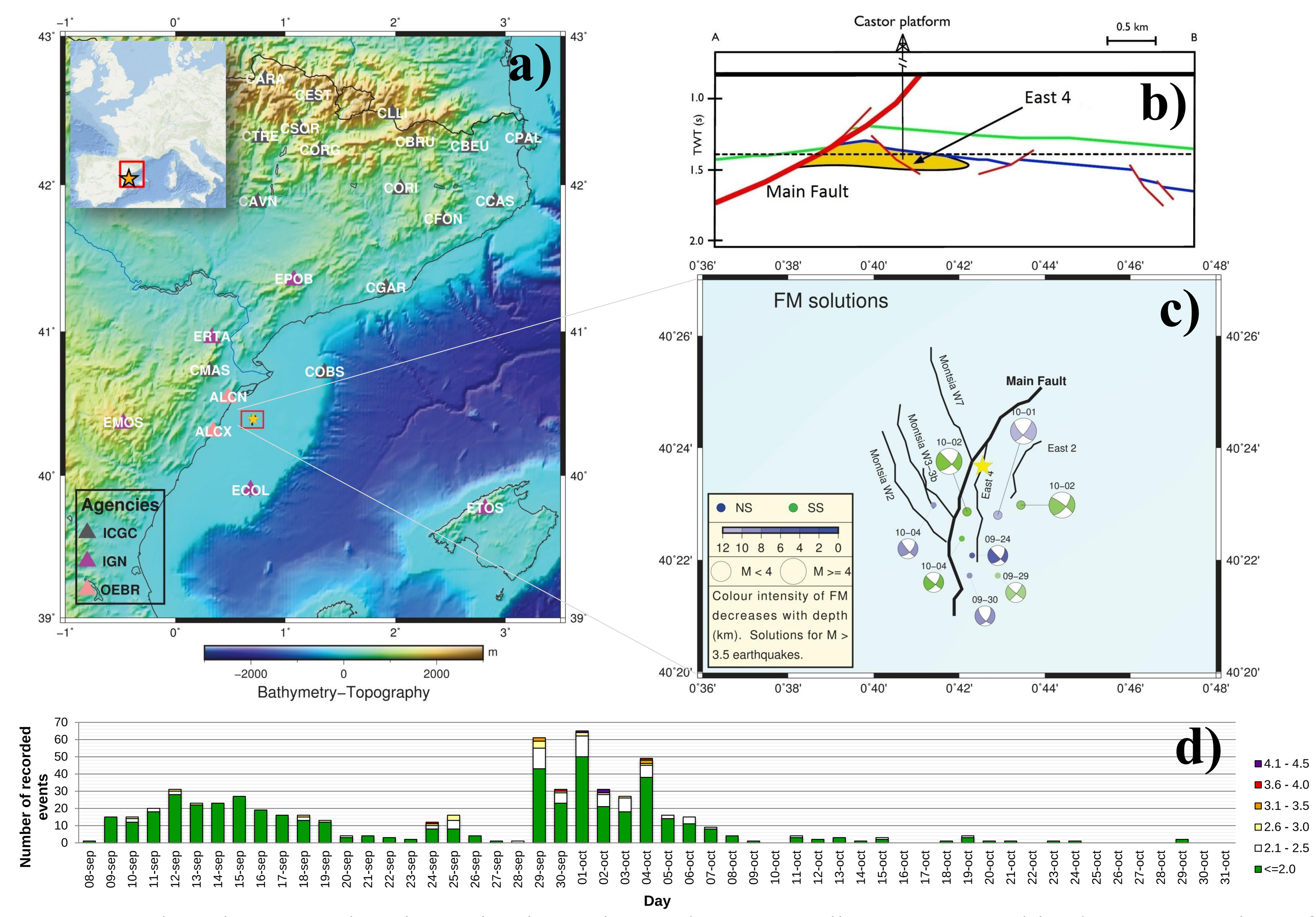

Figure 1: a) location map showing seismic stations whose recordings were used in the computation of the FM solutions. **b)** Profile scheme of Castor UGS location, modified from [3] **c)** Mapped faults around the reservoir and obtained FM solutions. **d)** Histogram showing number of recorded events and magnitudes.

We evaluate the following:

i) Could static stress transfer have triggered the felt events in the series?
ii) Is any of the mapped faults likely to have slipped during the sequence?

Method 2

- Nodal Planes (NP) selection criteria: Optimally Oriented Fault Planes (OOFP) and Critical Pore Pressure (CPP).
- Static stress changes assessed via the Coulomb Failure Function (CFF):

$$\Delta CS = \Delta\tau \pm \mu(\Delta\sigma - \Delta u)$$

- Only static stress redistribution is considered (no fluid flow, since data are not public).
- Calculations are made in COULOMB [4].
- ΔCS are tracked both on FM and mapped faults (Table 1).

Table 1: Summary of all modeled faults.

Name	Slips?	Strike	Mean dip	Rake	Base depth [km]	Event size (M_w)	Tracked ΔCS?	Acts as
FM 1	Y	41.4	54.5 (SE)	-6.1	5.2	3.6	Y	S & R
FM 2	Y	39.1	79.9 (SE)	-5.1	8.25	3.6	Y	S & R
FM 3	Y	32.0	56.5 (SE)	-30.4	8.25	3.9	Y	S & R
FM 4	Y	39.6	75.6 (SE)	-20.7	11.25	4.1	Y	S & R
FM 5	Y	45.0	64.8 (SE)	0.0	5.25	4.2	Y	S & R
FM 6	Y	40.0	65 (SE)	8.8	6.25	4.0	Y	S & R
FM 7	Y	45.0	60 (SE)	-9.5	8.25	3.7	Y	S & R
FM 8	Y	37.9	67.7 (SE)	-5.4	3.25	3.6	Y	S & R
East 4	N	6	35 (SE)	-10	2.5	—	Y	R
East 2	N	221	38 (NW)	-10	2.5	—	Y	R
M W2	N	140	42.5 (SW)	-150	2.3	—	Y	R
M W3	N	159	40.5 (SW)	-150	2	—	Y	R
M W3b	N	142	44.5 (SW)	-150	2	—	Y	R
M W7	N	154	54.5 (SW)	-150	2.3	—	Y	R
MF	N	206	35 (NW)	-10 & -150	3.1	—	Y	R

Results 3

FM faults (evolution on selected NPs)

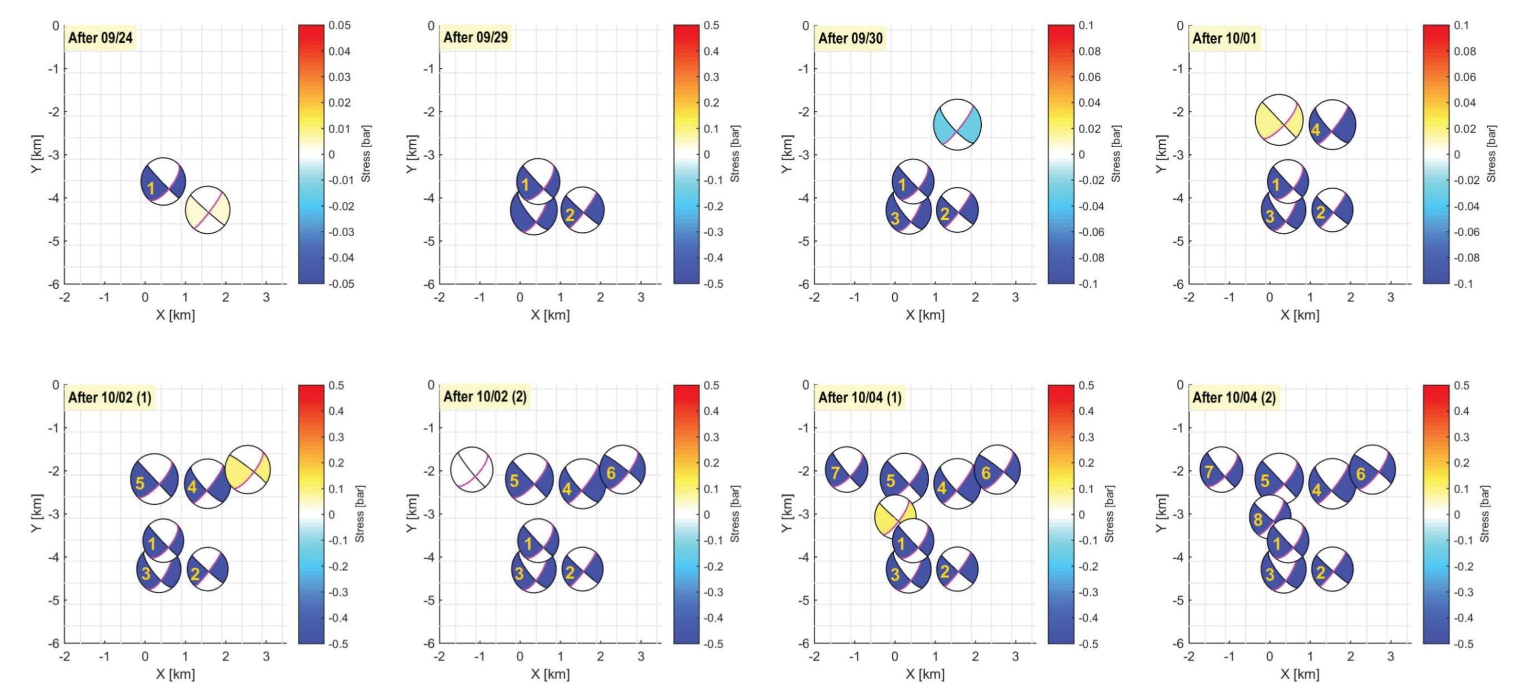

Figure 2: Cumulative Coulomb stress resolved on the NPs. Slipping nodal planes are shown in pink. Note that colorbar scale changes for each step of the series.

Mapped faults

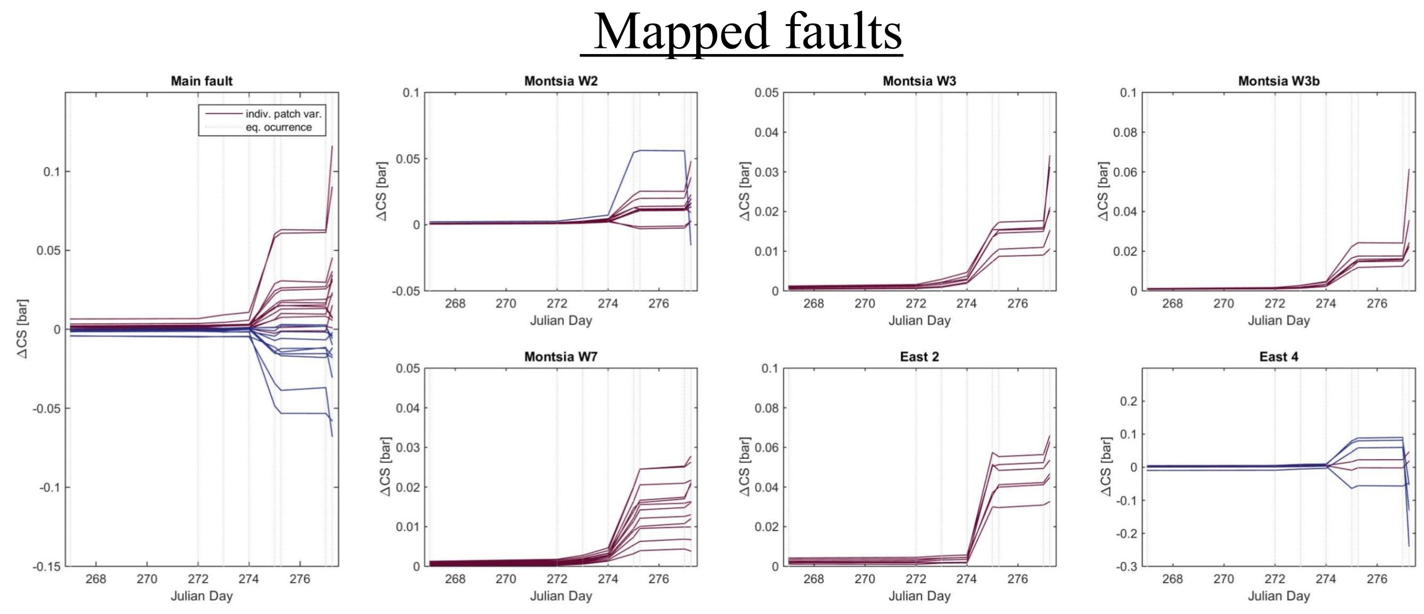

Figure 3: Time series showing ΔCS as tracked on each patch of the mapped faults.

Discussion 4

Cumulative stress changes on FM faults for the 6th and 8th events (Fig. 2) reach values around 0.1 bar, a commonly used threshold for earthquake triggering [5]. In addition, our results point to positive cumulative ΔCS for 5/7 FM events (71.4 %), which is in accordance with previous findings by [6]. Influence of ΔCS on earthquake occurrences as low as 0.05 bar has already been reported [7], and others' findings support that earthquake triggering is not a threshold process (i.e. any deviation from normal activity might be enough to trigger seismic activity), e.g. [8,9]. Hence, we reflect on static stress transfer to have influenced the occurrence of the studied events. Regarding the mapped faults, a notable ΔCS discharge is resolved on the East 4 fault (Fig. 3, 4), as a result of the last FM fault slip, geometrically compatible and located nearby. Thus, that is the most likely of the mapped faults to have slipped, should one have been activated.

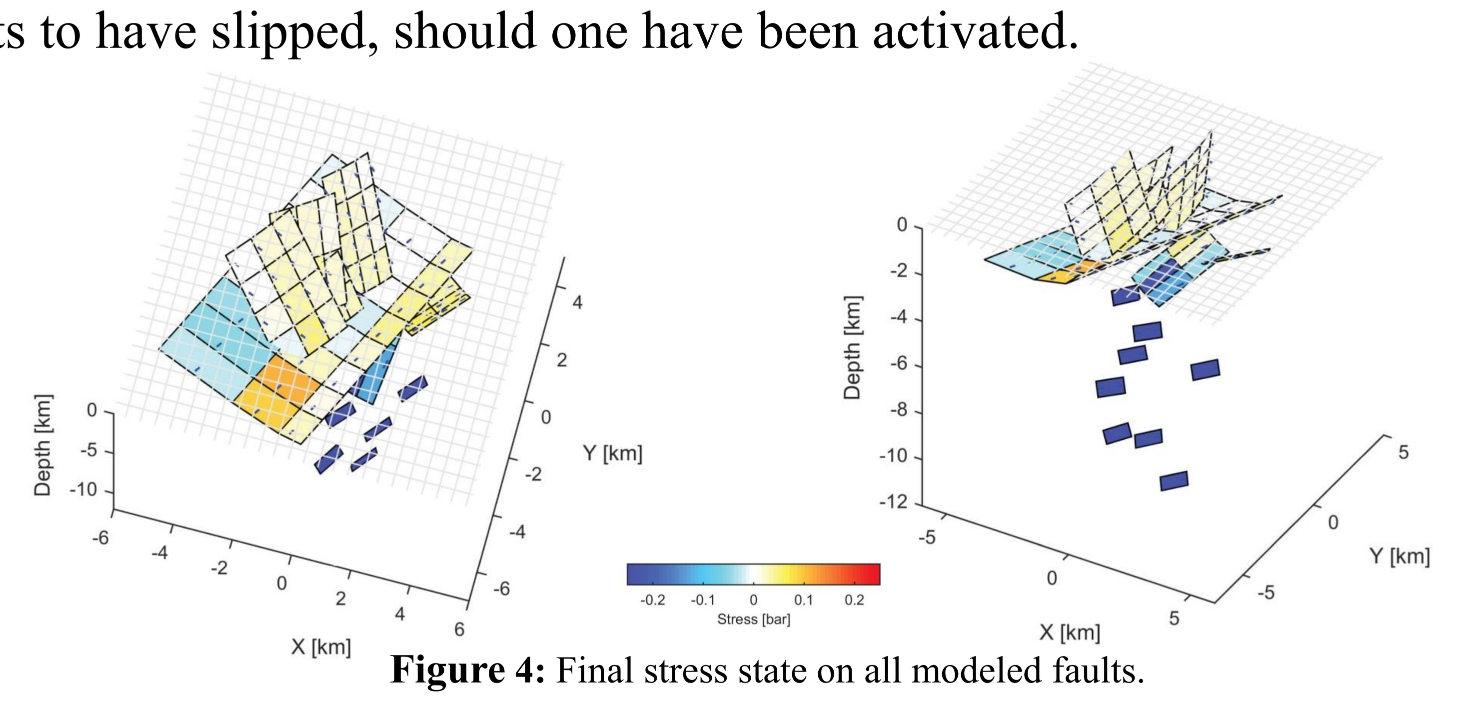

Figure 4: Final stress state on all modeled faults.

Conclusions

I. Static stress transfer is revealed to have played a destabilizing role.
II. The East 4 is the only mapped structure for which activation could be supported. However, our FM solutions point to entirely deeper sources.
III. Coupled modeling with fluid flow is necessary to assess the earthquake's origin.

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