# Spatiotemporal evolutions of two earthquake sequences in South Korea:
## the 2013 Boryeong offshore earthquake sequence and the 2016 Gyeongju earthquake sequence


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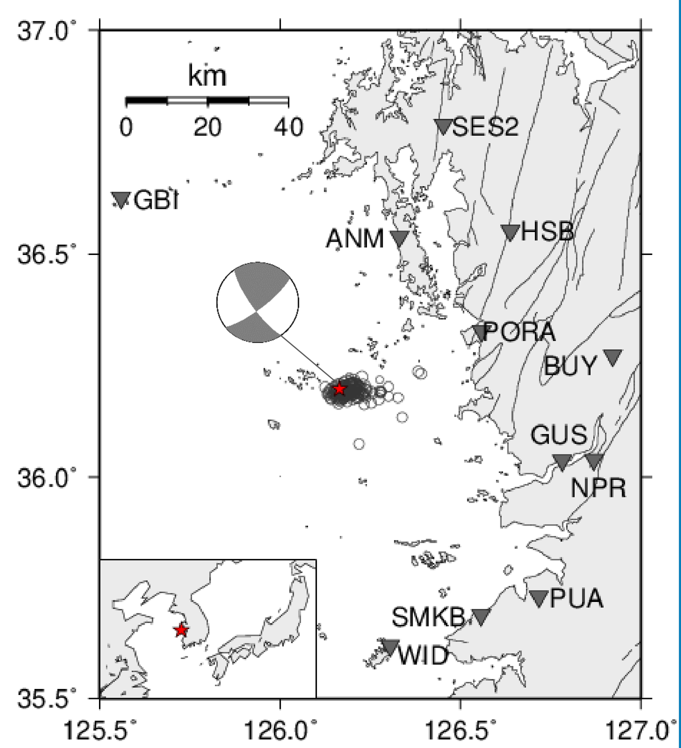
We inspected a distribution of events in spatial and temporal scales for two earthquake sequences of South Korea: the obtained spatiotemporal evolutions suggested a fault geometry in meter-scale without geological information and an expansion of hypocentral area without surface ruptures for the 2013 Boryeong offshore earthquake sequence and the 2016 Gyeongju earthquakes, respectively.

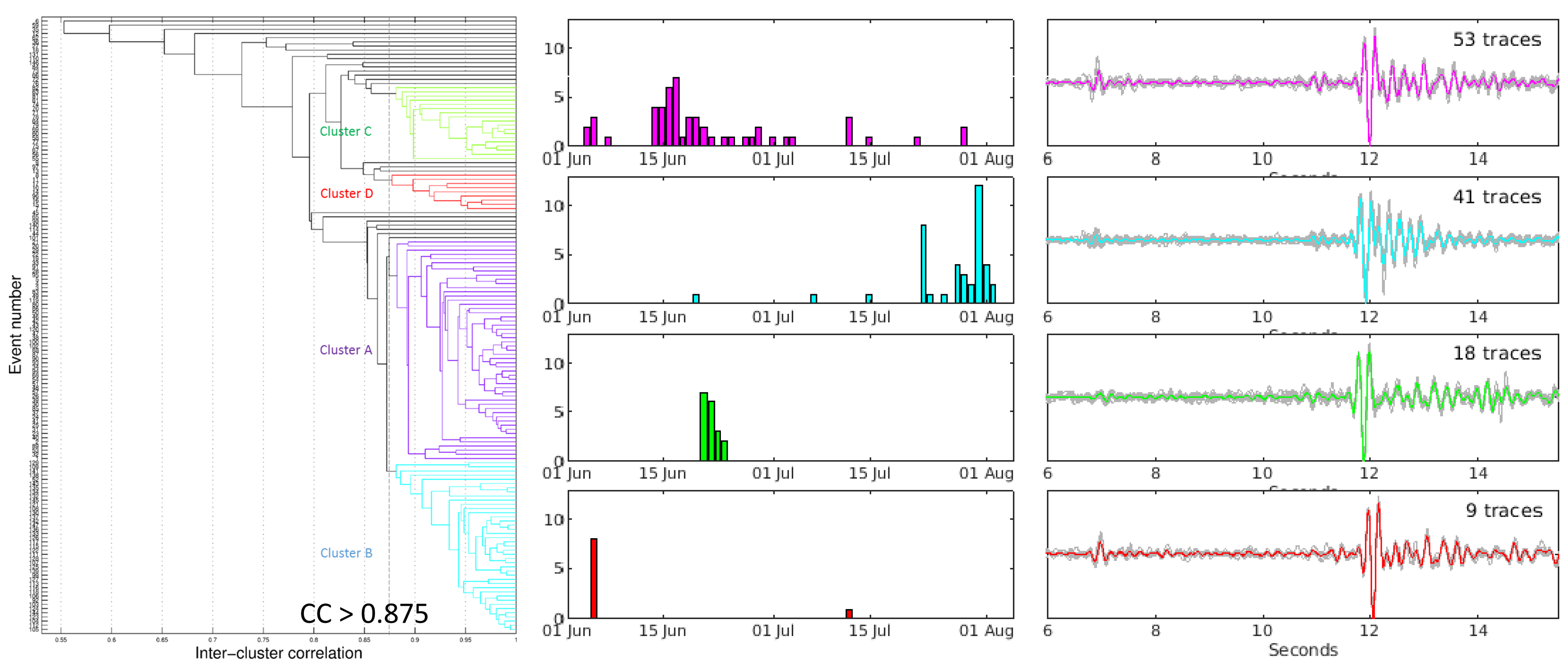

## The 2013 Boryeong offshore earthquake sequence




The 2013 Boryeong offshore earthquake sequence was the consecutive occurrence of 160 earthquakes ($M_L$ 1.3-3.8) over a two-month period in the Yellow Sea, west of the Korean Peninsula. The fault-plane solution for the largest event was computed by the method of Minson and Dreger, 2008.

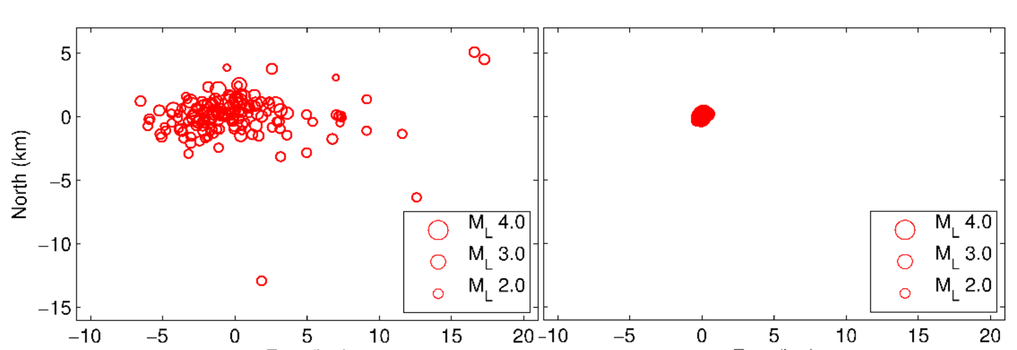
### Hierarchical clustering of waveforms:

based on the dendrogram derived from the maximum cross-correlation coefficients representing the waveform similarity (West, 2013). Waveforms of 149 events recorded by the station PORA were classified by the branch cut of 0.875 (Son et al., 2015). The four events groups formed four distinct segments in spatial scale and showed its own features in temporal scale.

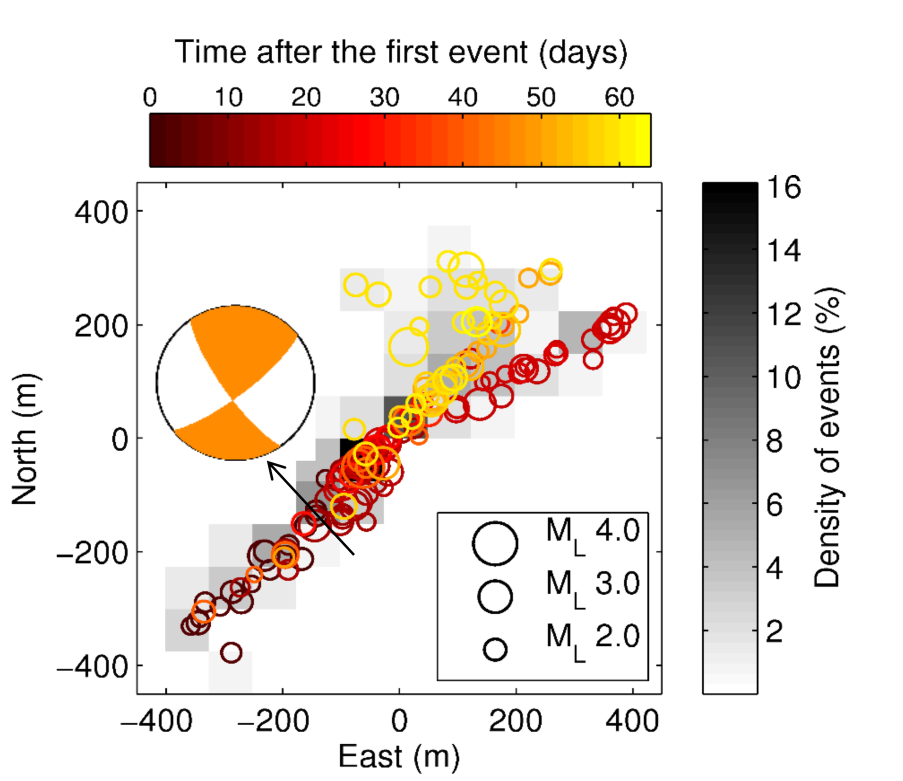



### Migration of epicenters:

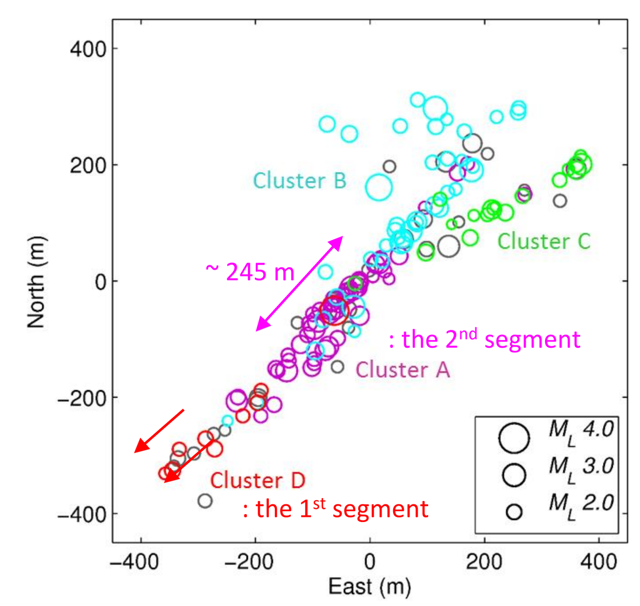
the relocated 149 epicenters formed a clear lineament in map view, which proceeded mainly toward NE (Son et al., 2015). The sequence, however, had a backward migration toward SW at first and produced the largest event that occurred after a pause of the sequence.

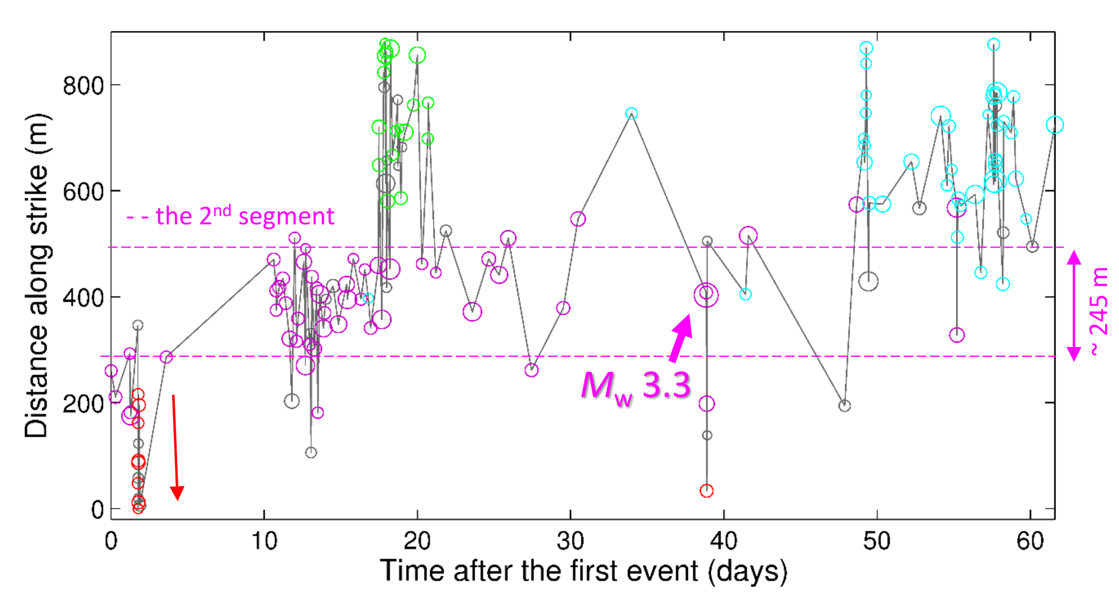



(a) : catalog (b): relocated




(c): on enlarged map with the fault solution of the largest event ($M_L$ 3.8, $M_w$ 3.3)



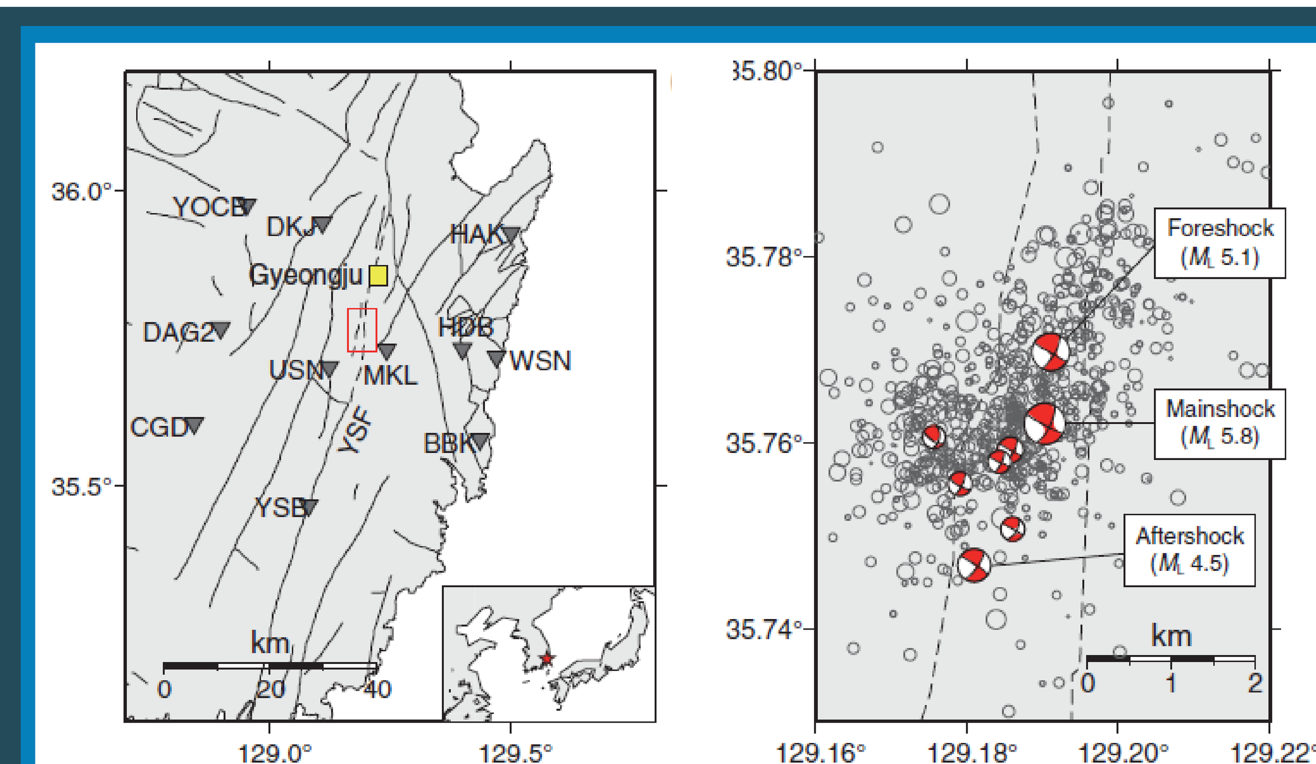




The epicenters was relocated by double-difference technique for $L_g$-phases (Waldhauser and Ellsworth, 2000; Schaff and Richards, 2004; Son et al., 2015)

### Did the 2nd segment generate the largest event, $M_w$ 3.3?

| | The largest event ($M_w$ 3.3) | Events on the 2nd segment (Cluster A) |
|---|---|---|
| Length | ~245 m (fault rupture length , L, derived from Leonard, 2010) | ~ 245 m (maximum distance among Cluster A excluding top 10 %) |
| Location | where the most events occurred, where the Cluster A occurred, | where the area including the $M_w$ 3.3 |
| Waveform | CC > 0.875 between the event of $M_w$ 3.3 and events in Cluster A ( the $M_w$ 3.3 itself is included in Cluster A.) | |

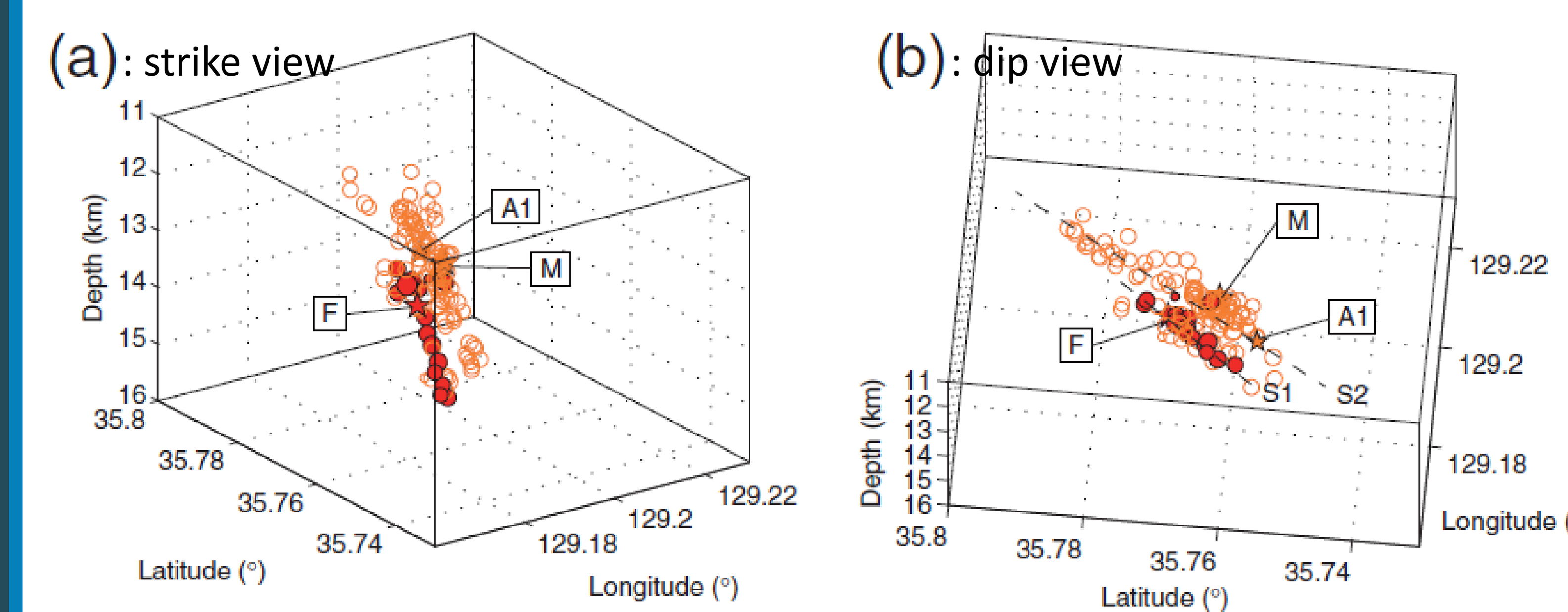
## The 2016 Gyeongju earthquake sequence

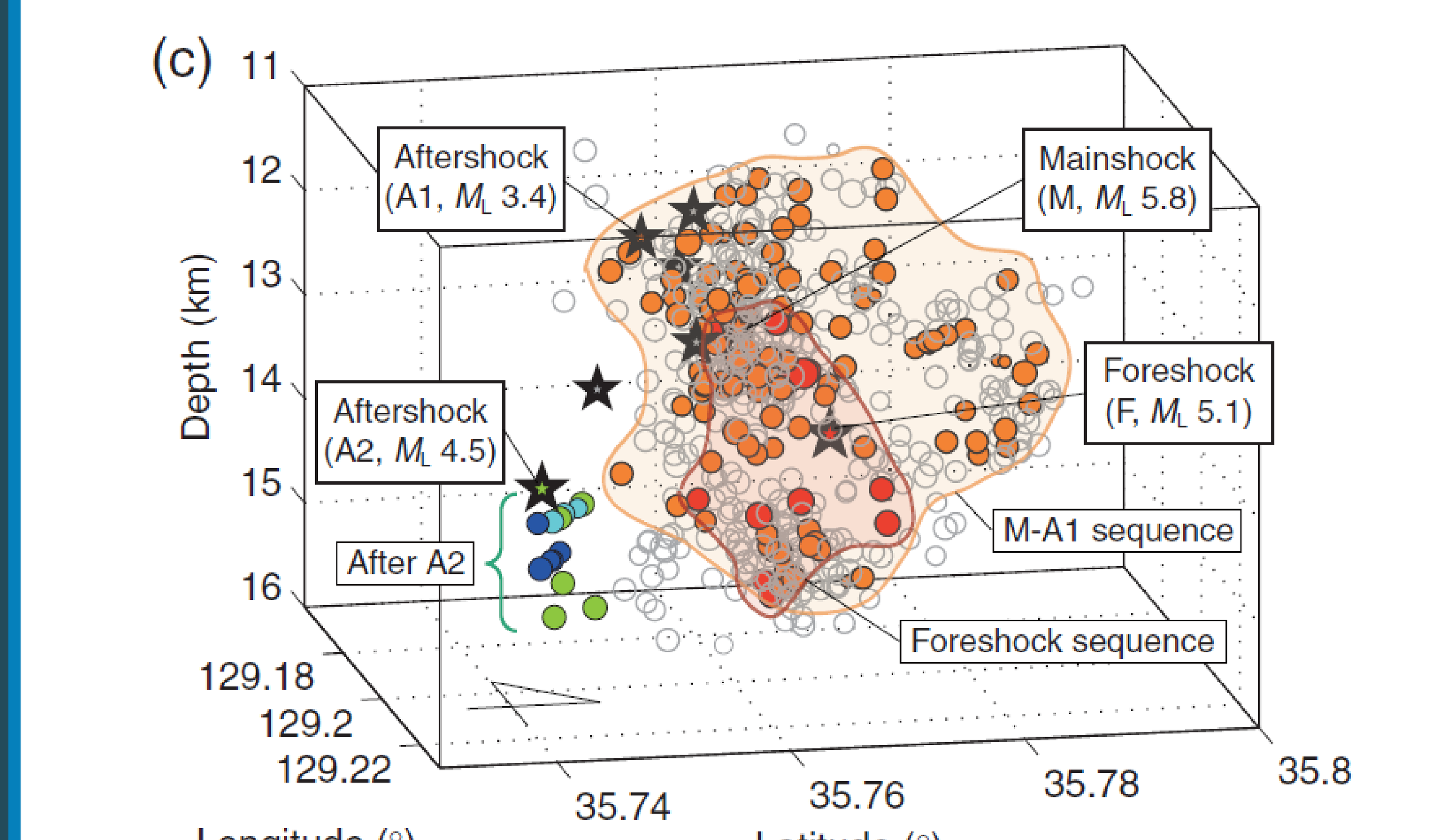



The 2016 Gyeongju earthquakes, including the $M_L$ 5.8 (the largest instrumentally recorded in South Korea), occurred around the Yangsan fault system, which is the most prominent set of lineaments on the Korean Peninsula. Catalogued 536 events are shown with the moment tensor solutions of the eight major events determined by the TDMT inverse technique (Minson and Dreger, 2005)

### Expansion of Hypocentral area:

the spatiotemporal distribution of the fore-main-aftershock sequence, composed of 536 hypocenters relocated by the double-difference technique (Waldhauser and Ellsworth, 2000; Son et al., 2018); which is comparable to the rupture area extent from Uchide and Song (2017).



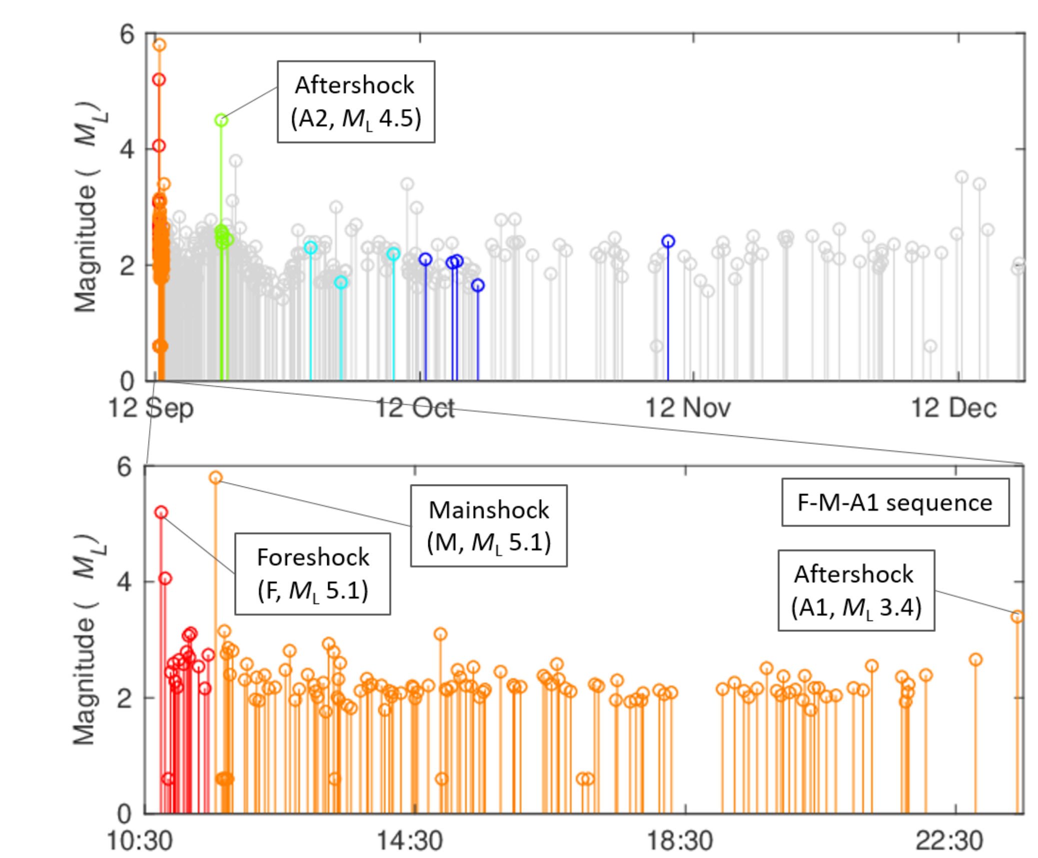

The circles and area represent each sequence: red for the foreshock sequence, orange for the M-A1 sequence, and light green, cyan, and blue for the part of the events in the A2-A3-A4-A5 sequence.

**Foreshock sequence:** the foreshock zone covered depths of 13–15.3 km, during ~50 min with a length of 2 km in map view.

**The mainshock** occurred at the top of the hypocentral area of the foreshocks, 1 km south of the largest and first foreshock (F).

**M-A1 sequence:** The aftershocks, occurring within 12 hours, then widened the hypocentral area in the strike direction by ~1 km toward NNE and expanded it toward the surface. In this sequence, the strike of fault plane inferred from the hypocenter distribution was shifted slightly from S1 to S2 after the mainshock.

**After A2**: the hypocentral area was finally stretched in the strike direction over ~1 km toward SSW by the largest aftershock ($M_L$ 4.5) that occurred 7 days after the mainshock and following events.





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