# Microseismicity Study Of The Central Ionian Islands (Greece) Accompanied By A Focal Mechanism Clustering Investigation

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## INTRODUCTION AND RELOCATION

In the area of central Ionian islands, Greece, the right-lateral Kefalonia Transform Fault Zone (KTFZ) dominates [1], an active boundary with the highest seismic moment rate in the Mediterranean. A dense seismic network in the area since 2014 [2] allows for a detailed investigation of the local fault network.

- A catalog of 16331 earthquakes occurring between 09/2016–01/2020 was compiled

Initially, relocation with the HYPOINVERSE program [3] was performed, using:

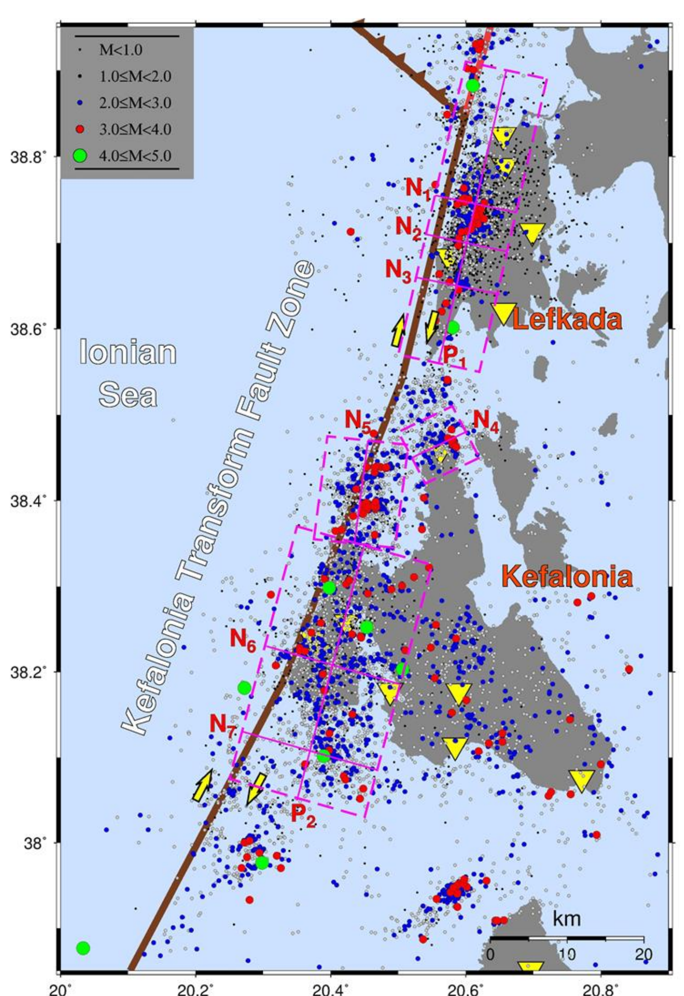
- 1D Velocity crustal model of [4]
- Vp/Vs ratio estimated with the WADATI method
- station time delays to account for lateral crustal variations [5]

The study area was divided into three subareas (map–caption) and relocation was separately accomplished for each subarea with the double difference algorithm (DD) (HypoDD–[6]). The steps followed, were:

- Waveform cross-correlation differential times calculation [7]
- Relocation with the DD method using catalog and cross-correlation differential times

Fault plane solutions were determined by waveform inversion for earthquakes with ML≥3.6

- Inversion was performed in the 0.04–0.10 Hz band, using stations of the central Ionian area along with a few selected stations in western Greece to improve azimuthal coverage.

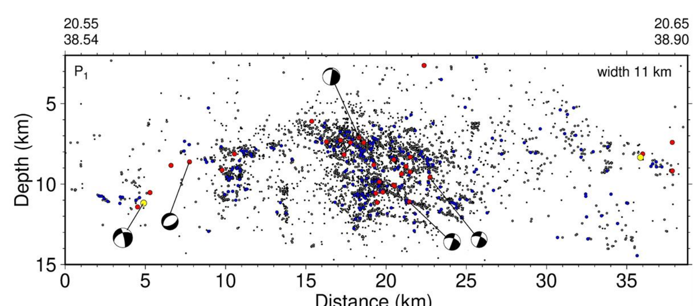


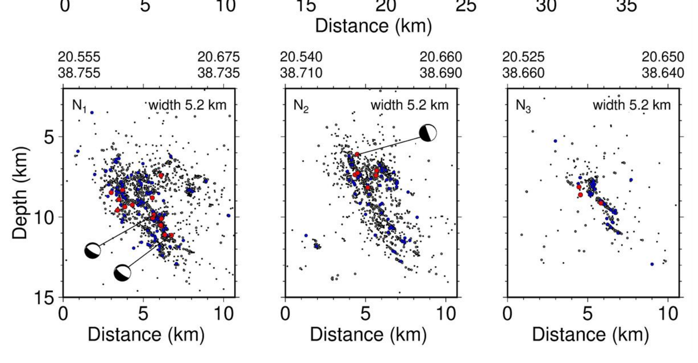

Relocated seismicity for the study area. Inverted yellow triangles depict the stations positions and thick brown lines the active boundary of the KTFZ. Magenta continuous lines represent the surface projections of cross sections of seismicity comprised in the areas defined by magenta dashed lines.

Three areas were considered, the Lefkada branch (cross sections P1, N1, N2, N3), the Kefalonia branch (cross sections P2, N6, N7) and the step–over area in between (cross sections N4, N5).

## FAULT COMPLEXITY ALONG KTFZ

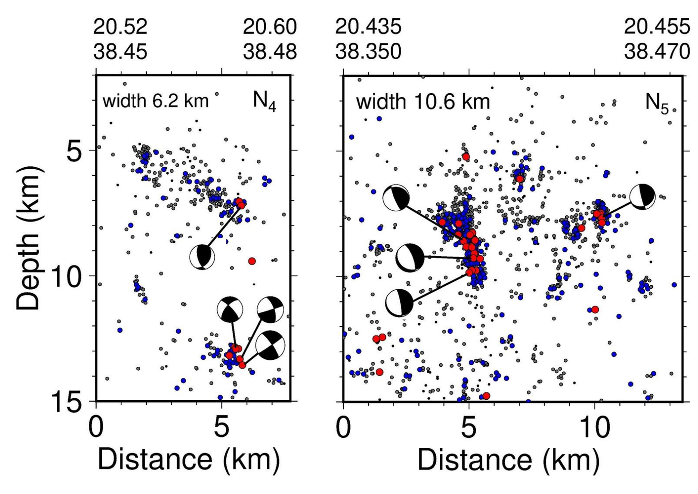
**Lefkada Branch**



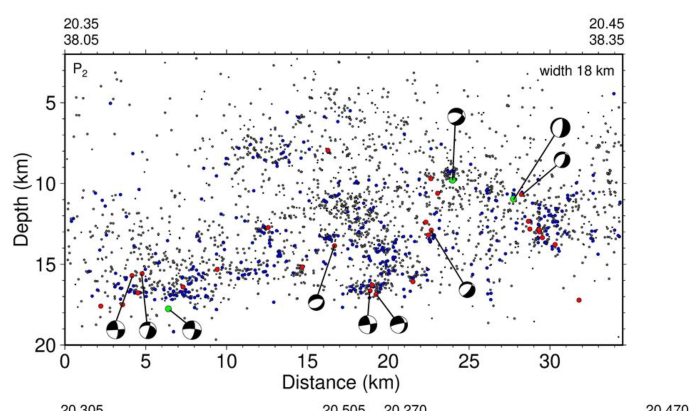

- Narrow, ESE dipping (N1, N2, N3), zone along the western shore of Lefkada
- Seismogenic layer in the depth range ~5–14 km (P1)
- Bulk of seismicity clustered in the center of the Lefkada branch (P1, dist 15–25 km)
- Focal mechanisms show a slightly different dip angle between depths of <9km and depths larger than >10km (N1, N2)

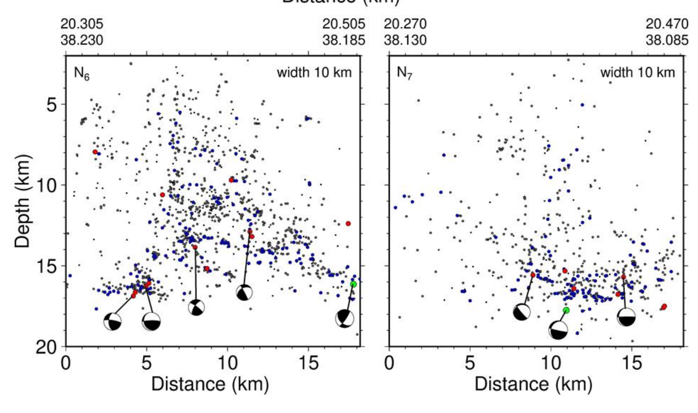
**Step-over area**




- Two clusters at different depths (~7 km and ~12 km) (N4)
- The deeper cluster exhibits reverse slip motion (N4)
- Several E–W striking clusters appear, dipping almost vertically (N5)
- Fault plane solutions manifest left-lateral motion (N5)
- Step over region extends almost 10km along the KTFZ

**Kefalonia Branch**




- Migration of seismogenic layer from ~4–14 km to ~10–19 km at the southern edge of the zone (P2)
- Seismicity is sparser than in Lefkada branch
- Two trends are observed: One dipping to the west, following the trend of the KTFZ (N6, dist ~7–15km) and one dipping almost vertically (N6, dist ~2–8km and N7, dist 0–15km)

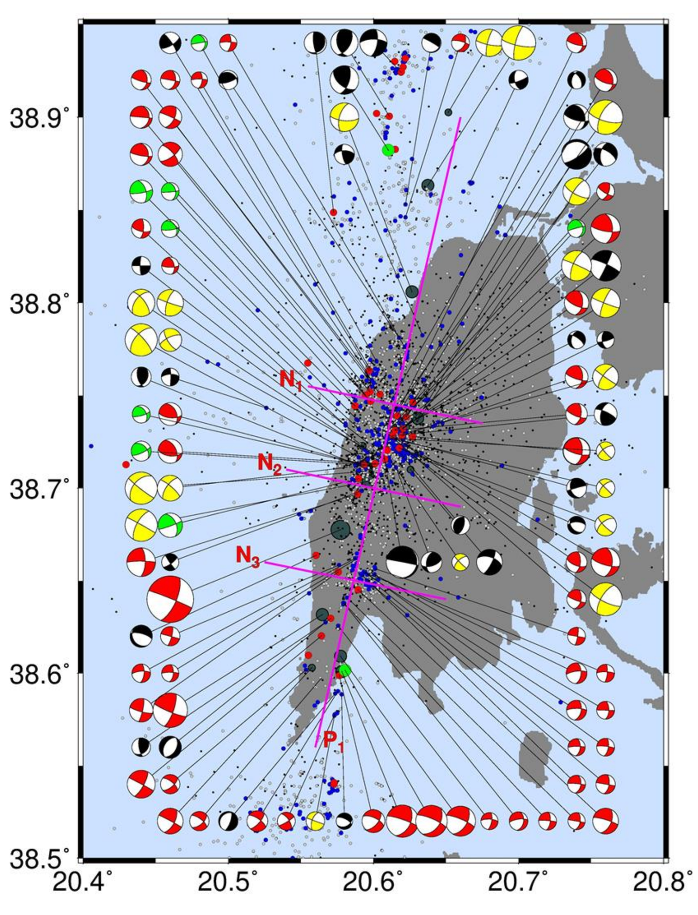
## FOCAL MECHANISM CLUSTERING FOR THE LEFKADA BRANCH

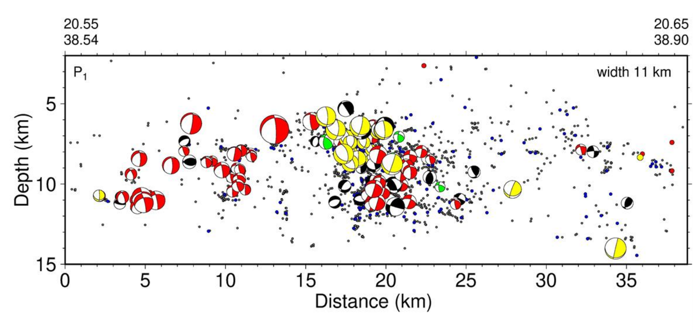
A density-based clustering algorithm, the DBSCAN [9], is applied to quantify the focal mechanism heterogeneity in the study area and identify clusters of events with similar fault plane solutions. The algorithm uses the Kagan angle [10] as a metric for the computation of the distance, d, among the events and two input parameters, the minimum number of neighbors, minPts, and the maximum Kagan angle between any pair of events, ε.

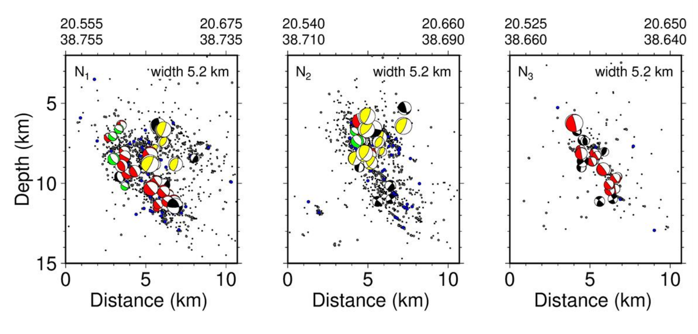
- Earthquakes with at least minPts neighbors, namely with Kagan angle d ≤ ε, are considered core points and define a cluster
- Earthquakes with less than minPts neighbors within distance ε and connected to a core point are called border points
- Events that are not assigned to any cluster are considered noise

For the implementation of the method to the Lefkada branch we considered:

- 80 focal mechanisms determined by the first motion polarity method, using the FPFIT program [11]
- 20 fault plane solutions estimated for the same area in [4] by waveform inversion (gray spheres in map below)




- Focal mechanism clustering results in Lefkada branch for minPts=4 and Kagan angle=15º
- Three clusters are formed (Red, Yellow, Green)
- Black focal mechanisms denote unclustered data (noise)
- Red cluster contains earthquakes with ESE dipping fault planes (strike of KTFZ) (N1, N2, N3)
- Yellow cluster contains earthquakes at shallower depths with NW dipping fault planes, conjugate ones to the red cluster (N1, N2)
- Green cluster contains a few earthquakes striking NNW and dipping to ENE

## CONCLUDING REMARKS

**Relocation**

- A tightly clustered fault zone is observed in Lefkada branch with features similar to those of the KTFZ
- A step over region spanning 10km along the KTFZ consisting of antithetic E–W striking splay faults
- Focal distribution in the Kefalonia branch outlines a more complex fault network than the Lefkada branch
- A transition zone with the characteristics of the KTFZ along with those of the Hellenic Subduction front can be observed in the Kefalonia branch.

**Clustering**

- Focal mechanism clustering illuminates the fault complexity in the tightly clustered area of the Lefkada branch
- Conjugate faulting is identified in the main cluster of Lefkada
- Results in the Lefkada branch show potential for expansion in the whole region

## DISCLOSURES

This research is co–financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning 2014–2020» in the context of the project “Kinematic properties, active deformation and stochastic modelling of seismogenesis at the Kefalonia–Lefkada transform zone” (MIS–5047845). The software Generic Mapping Tools was used to plot the map of the study area [12].

## ABSTRACT

The central Ionian region (Greece) constitutes the most seismically active area in the Mediterranean, with the main tectonic characteristic being the Kefalonia Transform Fault Zone (KTFZ), consisted of two main branches that are linked by a step-over region. A dense seismic network allows intensive microseismicity investigation, detailing the geometry and kinematics of the major along with secondary structures capable of producing moderate earthquakes, adding to the seismic hazard assessment of the area. Earthquake relocation can highlight the complex geometry of the fault network, while the heterogeneity of the local stress regime can be investigated by analysis of the focal mechanisms.

A catalog of 16331 earthquakes was compiled by manual picking of P- and S- phases. Earthquakes were relocated using a 1D velocity model along with station delays to account for lateral crustal variations, and the application of the double difference method using cross correlation differential times. Fault plane solutions were determined using either waveform inversion or P-wave first onset polarities. A density-based clustering algorithm (DBSCAN) was applied to assess the mechanism variability. The Kagan angle was used as a similarity metric between focal mechanisms and the clustering was controlled by the minimum number of mechanisms with Kagan angle less than a specific threshold.

The relocation detailed the characteristics of several en-echelon secondary faults on the northern (Lefkada) branch, exhibiting minor dip change along depth, while a more complex focal distribution combining the strike-slip characteristics of KTFZ along with plate subduction can be observed in the southern (Kefalonia) branch. Clustering analysis of the fault plane solutions, applied in the northern branch of the KTFZ, revealed detailed features of the small-scale fault structures, showing great potential for an application in the broader region.

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## REFERENCES

[1] Scordilis, E. M., Karakaisis, G. F., Karakostas, B. G., Panagiotopoulos, D. G., Comninakis, P. E., & Papazachos, B. C. (1985). Pure Appl. Geophys. 123, 388–397

[2] Permanent Regional Seismological Network operated by the Aristotle University of Thessaloniki (1981). http://geophysics.geo.auth.gr/the_seisnet/WEBSITE_2005/station_index_en.html

[3] Klein, F. W. (2000). US Geological Survey, Open-File Rep. 02–171 Version 1.0

[4] Papadimitriou, E.; Karakostas, V.; Mesimeri, M.; Ghouliaras, C.; Kourouklas, C. (2017) Pure Appl.Geophys. 174(10), p. 3869–3888.

[5] Karakostas, V.G.; Papadimitriou, E.E. (2010). Acta Geophys. 58, p 838–854.

[6] Waldhauser, F., Ellsworth, W. L. (2000). Bull. Seismol. Soc. Am. 90, 1353–1368.

[7] Schaff, D.P.; Bokelmann, G.H.R.; Ellsworth, W.L.; Zanzerkia, E.; Waldhauser, F.; Beroza, G.C. et al (2004). Bull. Seismol. Soc. Am. 94, p 705–721.

[8] Zahradnik, J., Sokos, E., (2018). Seismol. Res. Lett. 89, p 1137–1145.

[9] Ester, M., Kriegel, H. P., Sander, J., & Xu, X. (1996). In Kdd, 96, pp. 226-231.

[10] Kagan, Y. Y. (1991). Geophys. J. Int., 106(3), p. 709-716.

[11] Reasenberg, P., Oppenheimer, D. (1985). U.S. Geological Survey, Open-File Rep. 85-739.

[12] Wessel, P., W. H. F. Smith, R. Scharroo, J. Luis, and F. Wobbe (2013). EOS Trans. AGU, 94(45), p. 409–410.