UNKNOWN ACTIVE FAULT REVEALED BY MODERATE EARTHQUAKES AND AFTERSHOCKS IN N-NE KARABURUN, WEST OF THE CITY OF IZMIR, TURKEY

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I

ABSTRACT

The Aegean Sea and its surrounding area (Greece and western Turkey) comprise one of the most seismically active plate boundary regions. We used Cepstral Stacking Method (CSM), developed by S.S. Alexander, to determine focal depths in Izmir (north of Karaburun shoreline). Where focal depth and source mechanism are important for active fault identification was provided by three 24 May 1994 earthquakes, all close to magnitude 5, that occurred in northern Karaburun shoreline area, west of the city of Izmir. The focal mechanism of the first of these three events was reported by International Seismological Center bulletin and relative locations of these events are well constrained by the large number of observing stations. Since a focal mechanism solution gives two possible fault plane orientations, the spatial distribution of aftershocks associated with the events or other evidence has to be considered to infer the correct strike direction and fault plane of the active fault. Because depth was poorly constrained or could not be determined in the standard hypocenter determinations, usually arbitrary depths were assigned. In addition, the estimated depths of other events may not be accurate, although they are mostly within the crust. Such poor depth estimations adversely affect active fault identification, particularly for dipping faults like those in northern Karaburun shoreline area, and, therefore, seismic hazard and risk assessments. We identified an active fault located in northern Karaburun, Aegean Sea (west of Izmir Bay) by applying CSM method for 3 earthquakes occurred on May 24, 1994. In the same area, a recent earthquake occurred on May 1st 2012 with many ongoing aftershocks validates our early interpretations of predicted fault geometry of N-NE of Karaburun shoreline area; located on a WNW-striking normal fault dipping SW whose surface trace lies further north under the water where it was never mapped before, which was also supported by the seismicity pattern because of its termination approximately where the fault plane projects to the surface.

CEPSTRAL STACKING METHOD (CSM)

$$s(t) = f(t) + af(t-t_0) + bf(t-t_1)$$

$$FT|s(t)| = F(\omega)|1 + ae^{i\omega t_0} + be^{i\omega t_1}|$$

S(t)=Observed earthquake signal
a and *b*= *amplitude and* polarity of delayed signals
FT= Fourier Transform
w=circular frequency;
t,t0 and t1 indicates P -pP and -sP delays

and

$$P(\omega) = F(\omega)F^*(\omega)[1 + ae^{i\omega t_0} + be^{i\omega t_1}][1 + ae^{-i\omega t_0} + be^{-i\omega t_1}]$$

$$= F(\omega)F^*(\omega)\ [(1+a^2+b^2) + 2a\cos[\omega t_0] + 2b\cos[wt_1] + ab\cos[\omega(t_1 - t_0)]]$$

Then

$$C(u) = [(1+a^2+b^2)\ \delta(t) + 2a\ \delta(t-t_0) + 2b\delta(t-t_1) + ab\ \delta(t+t_0+t_1)] \bullet |F(\omega)F^*(\omega)|^{IFT}$$

or

$$C(u) = |\{\log[F(\omega)F^*(\omega)]\} + \log[(1+a^2+b^2)] + 2a\ \cos[\omega t_0] + 2b\ \cos[\omega t_1] + ab\ \cos[\omega(t-t_0)]|^{IFT}$$

If the logarithm of the power spectrum is transformed instead of the power spectrum (whitens the spectrum used for the cepstrum)

$$(t_{pP} - t_p) = 2h\ .\ \eta_p$$

$$(t_{sP} - t_P) = h\ (\eta_p - \eta_s)$$

$$h = \frac{(t_{pP} - t_P)}{2\eta_P}$$

$$h = \frac{(t_{sP} - t_P)}{\eta_P + \eta_S}$$

$$\eta_p = \left(\frac{1}{\alpha^2} - v^2\right)^{1/2}$$

$$\eta_s = \left(\frac{1}{\beta^2} - v^2\right)^{1/2}$$

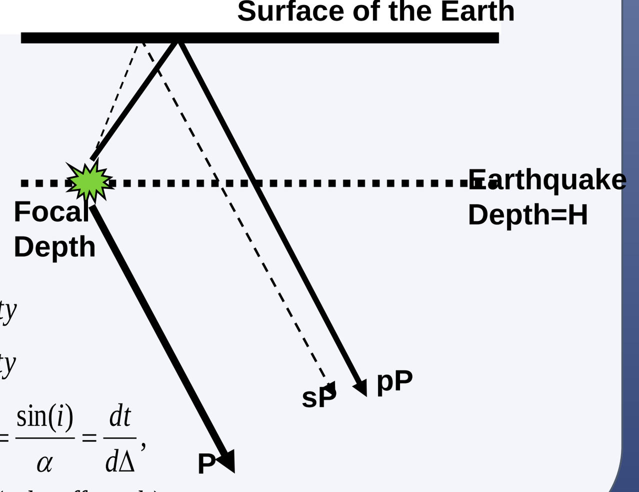
$\alpha = P-wave\ velocity$

$\beta = S-wave\ velocity$

$v = Ray\ parameter = \frac{\sin(i)}{\alpha} = \frac{dt}{d\Delta},$

$i = incidence\ angle\ (take\ off\ angle)$

h = *source depth*
η = *slowness*



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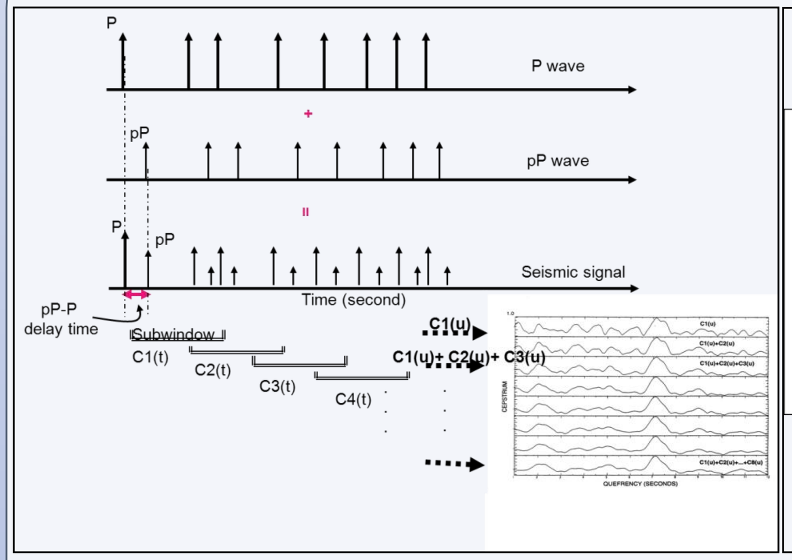
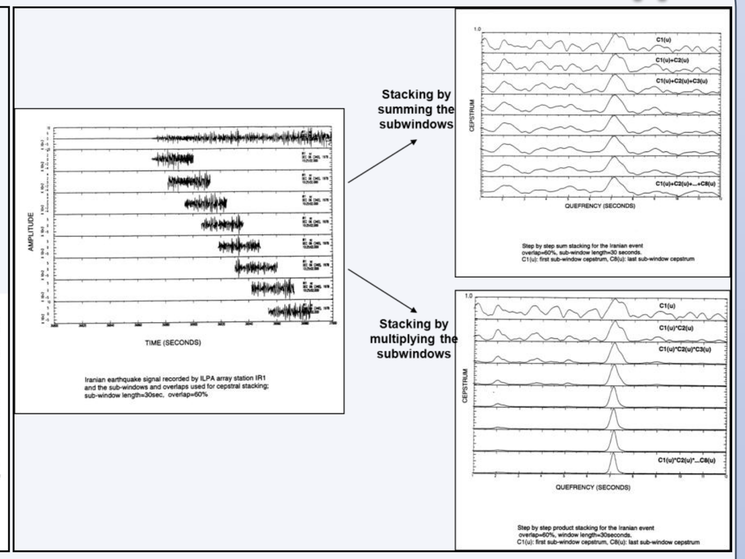
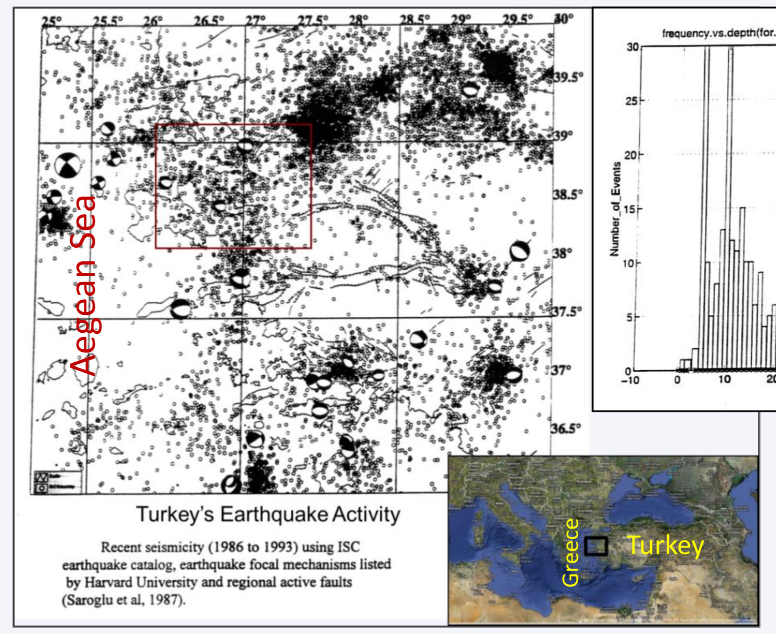
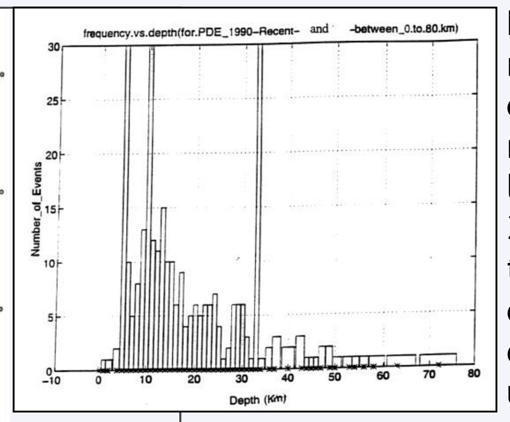




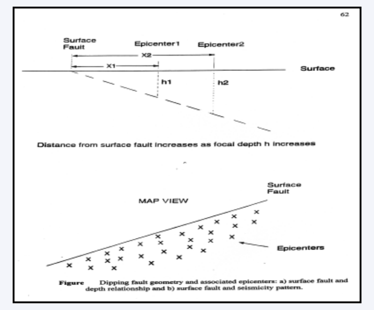
Length of the sub-window has to be greater than the sP - P window to assure that each sub-window has a signal with these delays in it. Otherwise the method fails.

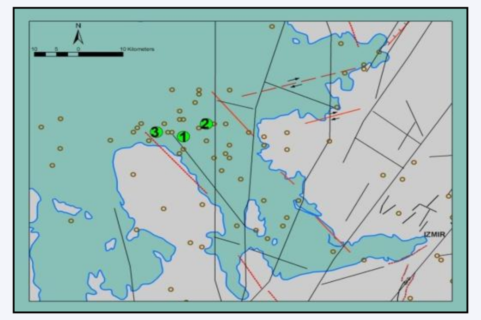
1994 and 2012 Earthquakes and their CSM Analysis in Northern Area of Karaburun Area





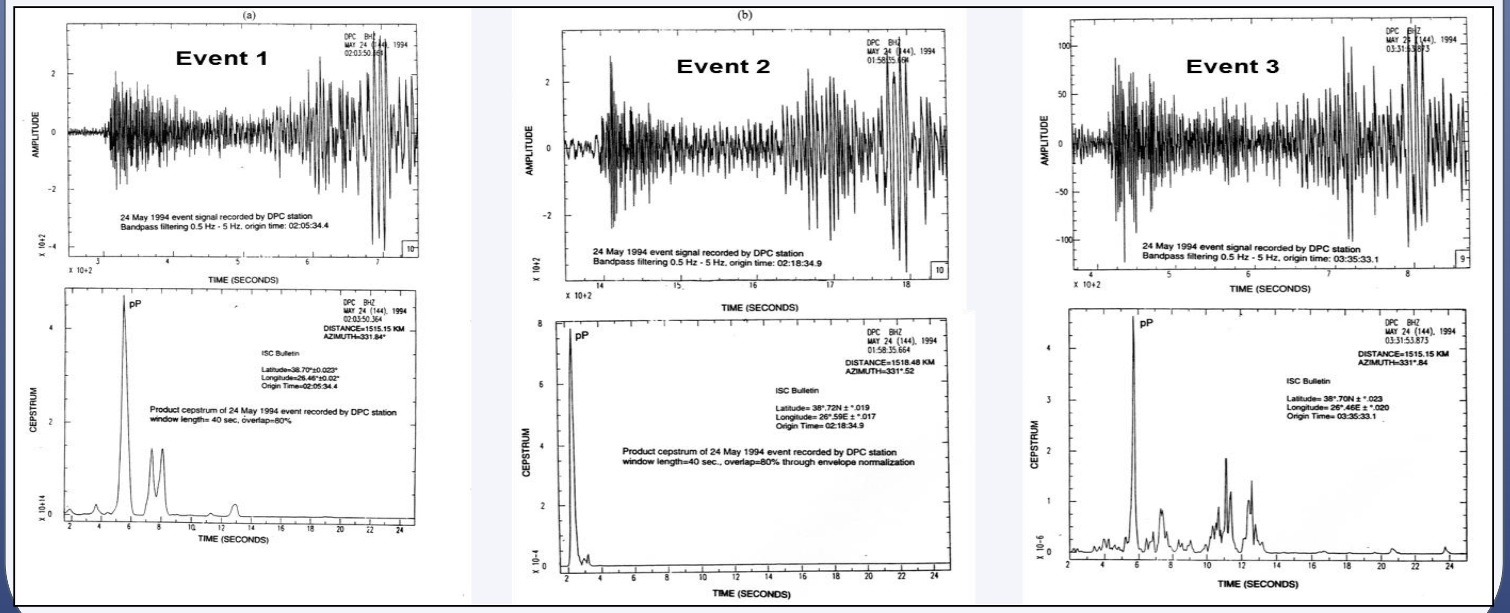
Histogram showing the reported depths of past earthquakes in the region. Note that the large peaks at 5, 10 and 33 km result from fixing the depth in hypocenter determinations and these depths are therefore undetermined.



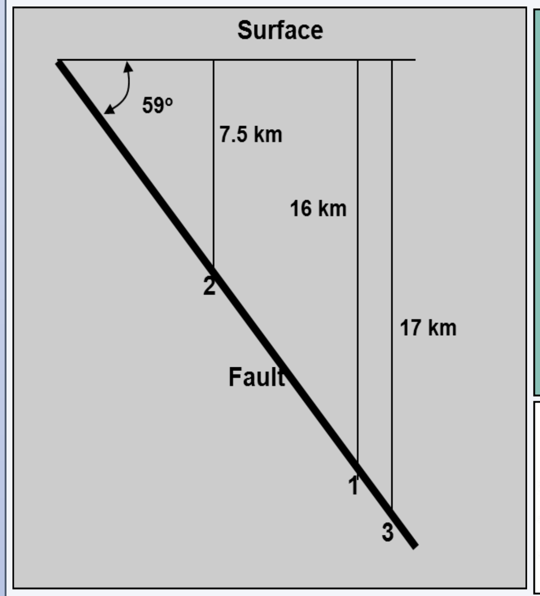


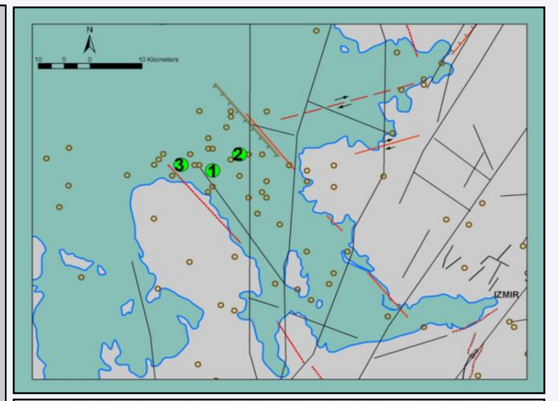
- Focal depth are not well reported, compared to epicenters
- Epicenter distribution, CSM depths can help resolve the best fault plane solution

CSM Depth Solutions for 3 events recorded in 1994 (Figures from Cakir (1997))



III



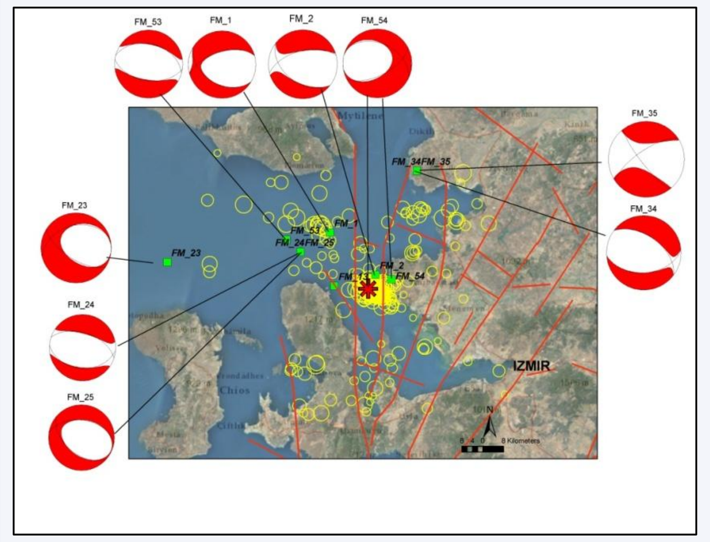


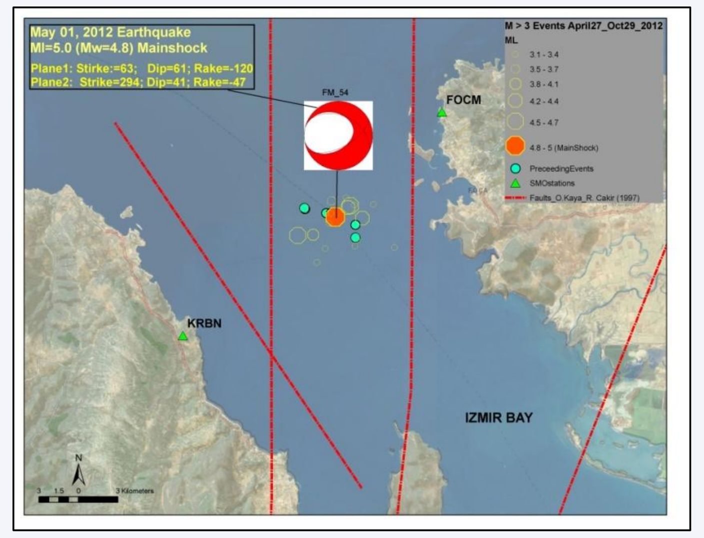
Depth estimates by ISC and by Alexander's Cepstral Stacking Method.

Event	Depth (km)ISC	ISC (pP-P) (km)	(pP-P) Cepst. Stack (km)
1	10	16	16.0
2	10	13	7.5
3	0	11	17.0

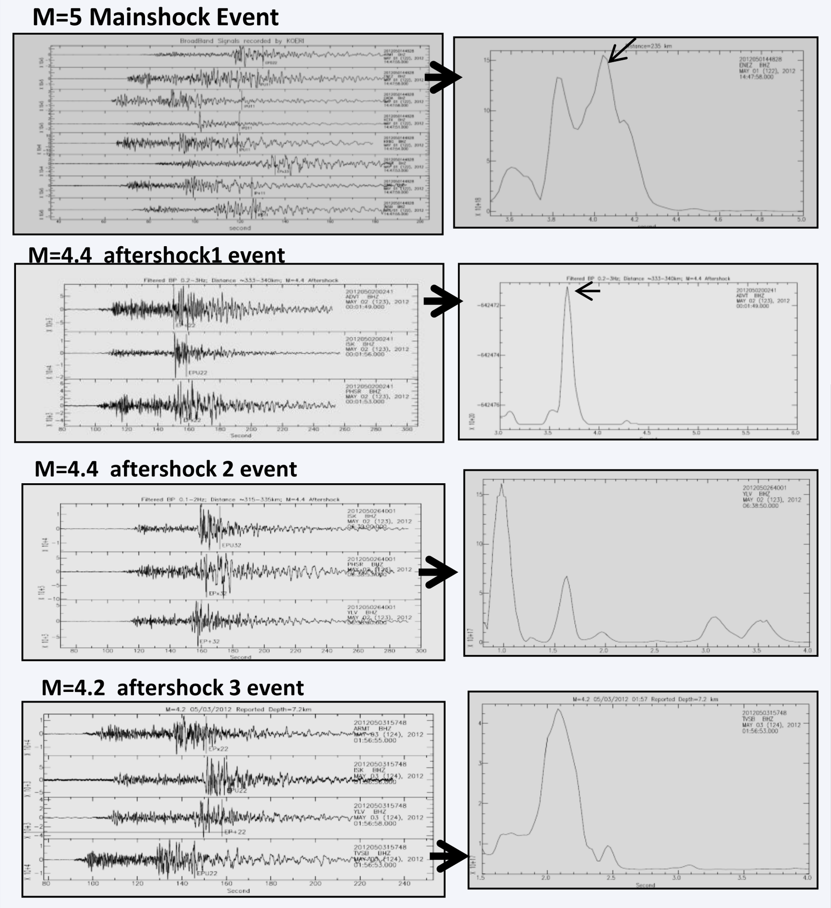
the surface projection of the fault (line close to red line active fault) with hatching showing dip direction. In this case the CSM depths from the mainshock and its aftershocks defines the fault rupture surface with depth as well as its projected surface location, which independently was identified as a likely active fault. (Cakir, 1997)

May 01, 2012 Ml=5 Earthquake and its afterhocks



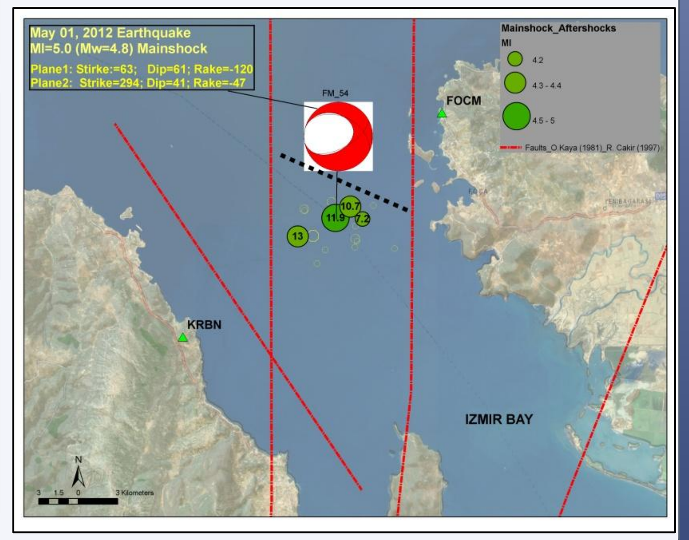


Important earthquake focal mechanisms reported in the ISC Bulletin (Int Seis Cent Online Bull., 2010). Note that all local and surrounded earthquakes show E-W trending normal fault behaviors. (After Kaya,1981 and Cakir, 1997)



See panel ***I*** *for the complete analytical calculation using the depth phases.*

M=4.4 Aftershock ReportedDepth=13km; EvName=2012050200241					
Stations	Distance	Azimuth	Cepstral Peak1	Cepstral Peaks2	CSM Depth (km) (for Vp=6km/s)
ADVT	333	52	2	3.7	6 or 11.1
ISK	339	36	2	3.6	6 or 10.8
PHSR	340	13	1.9	3.4	5.7 or 10.2



IV

CONCLUSIONS

- The recently-developed Cepstral Stacking Method (CSM) provides very accurate depth estimates for crustal earthquakes using one or more regional seismic stations.
- NE-SW trending major faults (older) controls the E-W (younger) trending faults in the area
- CSM depths, epicenter distribution can be used to pick the best fault plane solution given in focal mechanism solutions
- Three events recorded in 1994 indicating the same or nearby location of the same fault system
- 2012 events show the fault is very active and seismic activity is in the depth range 2-17 km
- Abrupt termination of the seismicity shows E-W faults are segmented by the older NE-SW strike slip oriented faults verifying Kaya's (1981) geologic structure model for the region.
- Uses of CSM depth calculations for one or more regional recordings include more accurate hypocenters of events, fault rupture geometry from multiple aftershocks, and discrimination between shallow explosions and crustal earthquakes.
- Results of applying this combined approach to earthquakes in the Aegean region have illustrated its potential usefulness for accurately characterizing the current active tectonic regime.
- If there are several well-recorded earthquakes at different depths on a given fault, the fault can be mapped in three dimensions and related to the tectonic stress regime prevailing in the area.
- For events large enough to have well-defined focal mechanisms both the fault geometry and slip at the hypocenter can be determined.
- Relative locations of regional events with these depth constraints give accurate hypocenters that define the active fault regime for any tectonically active region, such as the Aegean Region.
- Recent M=5 May 01, 2012 earthquake verifies the earlier interpretation of fault location and its orientation (Cakir, 1997).
- Preceding events (M 3-3.6) occurred at the May 01, 2012 mainshock location that may be characteristic for similar faults in this area.

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(***) Prof. Dr. Orhan KAYA [1937- 2002]

"Orhan Kaya was a dedicated scientist and a devoted teacher. He was a unique person because of his modest and tender nature and was one of the pioneering figures in the development of Earth Sciences in Turkey not only for his individual contributions but also for his influence on his colleagues and students. Kaya published many interesting scientific papers and abstracts, and his long-lasting contributions to the Earth Sciences community in Turkey will always be remembered."

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