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Introduction

Focal mechanisms of earthquakes provide two nodal planes and the question which one is the fault plane is the ‘seismologist’s dream’. It is so because the knowledge of causative faults is of key importance for seismo-tectonic studies. For example, the intermediate-depth earthquakes, like the one studied in this paper, have rarely known fault planes, although its correct interpretation would help in constraining regional geodynamic models of subducted plates and the involved stress field. It is equally important to identify active crustal blind faults, whose knowledge may improve the earthquake hazard assessment.

The fault plane can be sometimes well ‘mapped’ (constrained) by spatial distribution of numerous early aftershocks. However, this technique has serious limitations. One of them is the fact that in sparsely instrumented regions accurate location of weak aftershocks is impossible. Moreover, some events lack numerous aftershocks at the mainshock fault plane at all (typical for the intermediate-depth earthquakes). The
apparently trivial case, where the earthquake occurs at or close to a geologically well
known fault, needs also an independent check, because the ‘known’ fault may have a
complex tectonic structure at depth.

The most challenging task is the \textit{quick} identification of the earthquake fault plane. If
made in almost real time, it might play a vital role in fast simulation of strong ground
motions (shake maps) for the post-event emergency services. If ‘quick’ means a few
hours, or a few days after the event, it still might greatly contribute to assessing
increased spatial probabilities of aftershocks based on the Coulomb stress loading of
neighboring faults due to the mainshock rupture (McCloskey et al., 2005). Actions
like that cannot be absolutely postponed until the fault plane is mapped by the
aftershocks.

Existing methods to identify the fault plane from seismograms are based mainly on
finite-extent source models: The distributed-slip models are generated for both nodal
planes and that one better fitting the records is considered to be the fault plane.
Using near-fault records, this method is applicable even with very few stations
(Delouis and Legrand, 1999). However, employment of the nearest stations is highly
vulnerable to location errors and complexities of the rupture process. Use of long-
period regional or teleseismic records is also possible, often with relatively simple
fault models. However, as a rule, the two nodal planes provide just a slightly
different waveform match, so the preference of one plane often remains difficult
(e.g., Roumelioti et al., 2004). Conceptually similar are attempts to resolve the
nodal-plane ambiguity by calculating the higher-order moment tensors for both
planes, and comparing the variance reduction; the advantage is in no need of the
slip distribution model and applicability to weak events (McGuire, 2004 and
references therein). A new method to identify the fault by the source scanning has been suggested recently by Kao and Shan (2007). The moment tensor solution is not needed, but the other requirements seem to be quite strong, e.g. the records close to epicenter with well separated P and S arrivals. Additional support of preferred slip directions on pre-existing zones of weakness can be also gained from the seismotectonic setting, in terms of regional stress field and tractions acting on the nodal planes (Gephart, 1985). In case of well-expressed directivity effects, the macroseismic field may indicate the preferred nodal plane, even without any instrumental observation. However, the macroseismic data are collected too late after the earthquake.

The H-C method

As an innovation, this paper suggests a simple method, applicable (under favorable conditions) immediately when a reliable earthquake location and its centroid moment tensor solution (CMT) are available. Location, based on travel times, provides the hypocenter position (H), the place at which the rupture propagation initiated. The CMT solution from relatively long-period waveforms provides the centroid (C), which is the point-source approximation of the dominating slip region(-s) on the fault. Further, the CMT solution gives also two planes passing though C (plane I and II) defined by the strike and dip angles of the moment-tensor solution.¹ Then, assuming a planar fault, the fault plane can be identified as that one among planes I and II

¹For simplicity we may call them nodal planes, but, more often, this term is reserved for two planes passing through the hypocenter.
which encompasses the hypocenter (Fig. 1a,b). Hereafter we speak about the H-C method. Although not yet broadly recognized as a useful tool for the fault plane identification, its great potential is in simple linking of the independent short- and long-period seismic information pieces.

What are the favorable conditions under which the H-C method works? Any successful application needs: (i) a reasonably accurate determination of the H and C position, (ii) a sufficient distance between H and C, larger than the individual errors of the H and C positions, and, (iii) not very complex earthquake geometry (see further). The orientation of the planes I and II plays also a role, but their strike and dip angles are often stable enough during the MT inversion (say within 10° each). In this sense, the usual uncertainty of the fault plane solution is less critical than the H and C positions. For example, for earthquakes whose uncertainty of H and C is of the order of 10 km, the method becomes usable when the H-C distance gets larger than 10 km, i.e., starting at about M6. Under special conditions, e.g., in presence of a dense local network providing better constrained H and C parameters, the method might be applicable already at about M5. These are only rough estimates based on empirical relations between the fault size and magnitude (Somerville et al., 1999). In practice, it is also important whether the data ‘see’ the whole fault (at very long periods), or the individual largest asperities, and whether the rupture nucleates in, close to-, or far from the asperity (Mai et al., 2005).

Due to inherent uncertainties of the H and C positions, any individual location can hardly be combined with an individual CMT solution; more likely the hypocenter does not fall in any of the planes I and II (the so-called H-C inconsistency is detected). The correct approach is based on the concept of the collective solutions (Fig. 1b,c).
We seek families of acceptable solutions (a ‘cloud’ of the hypocenter locations and a set of planes I or II given by inherent uncertainty, use of different methods, structural models, etc.), and compare them collectively. We arrive at the H-C consistency more often when considering uncertainties in this way.

Routine agency data typically provide the individual (rather than collective) solutions; usually, with H and C often calculated by different teams. Therefore, the H-C method only rarely works with the very preliminary agency data. Or, at least, solutions of several agencies should be employed. Revised solutions may perform better, namely if S waves from near stations are included for a better depth estimate, but a specific H-C study by a single team is always preferable. It can be performed quickly enough, namely if applied to a previously studied geographical regions and using seismic networks of a well-known performance. At such conditions, the operators are best aware of their alternative crustal models, the more and less reliable stations, noise levels, etc., so they can easily construct the families of the collective solutions, adequately reflecting typical model uncertainties due to varying data subsets.

A note regarding the C position. In practice, the MT inversion is often accompanied by a search of the source depth optimizing the waveform match, i.e. assuming C under the epicenter. Although such an approximation may be good enough for retrieving the fault-plane solution, it is not sufficient for H-C method. The C position should be searched in the 3D vicinity of the hypocenter, far enough, accordingly to magnitude of the studied earthquake (hence reflecting the expected fault length). Details are left for the application section of this paper.

Last but not least, success of the H-C method is a matter of a suitable technique to visualize the geometrical configuration of the H, C and planes I, II. We suggest a
plotting tool allowing ‘rotated’ (animated) 3D view (the \texttt{hcplot} script in Matlab, accompanying this paper in the electronic supplement). Note that we don’t need to know the precise extent of the rupture to visualize the planes I and II.

The price we pay for simplicity and speed of the H-C method is in several limitations. First of all, we have to keep in mind that the method is nothing but a quick guess of the likely fault plane. There is no chance to validate the result within the method itself. Only independent detailed (thus not ‘quick’) posterior studies can prove or disprove the fault-plane identification. There are also situations in which the H-C method can fail not only due to inaccuracy in H and C, but for a more fundamental reason. Imagine a segmented, piecewise planar fault (Fig. 1e,f). If the CMT solution is calculated from low-frequency data, ‘seeing’ all segments as a single point source, then C is out of both segments and none of the planes I and II passing through C encompasses the hypocenter. A large non-DC component can alert about the source complexity in cases like this (Frohlich, 1994). Obviously, increasing frequency, to ‘see’ the two asperities separately, can help to recognize at least the segment encompassing H. Even more difficult would be the case analogous to Fig. 1e in which the segment containing H releases much less seismic moment than the other segment, thus apparently putting H out of the fault plane. At the low-frequency range, problems may arise even on a single fault when an almost symmetric bilateral fault is represented by the centroid position C very near to H (Fig 1g); consideration of the centroid time may help, in this case.

Obviously, the H-C method is not equally well suited for all events of the same magnitude. It depends on geometry of the planes I and II with respect to hypocenter, because the hypocenter depth is always more problematic then the
epicenter position (E). Therefore, a strike-slip event with two vertical planes I and II is the easiest case to be successfully resolved (Fig. 1h); the fault identification can be performed by means of the epicenter only, the problematic depth has no effect. The map-view analysis is sufficient, thus no 3D visualization is needed in that special case. A vertical dip-slip event (or low-dip thrust) is also easy (Fig. 1i): the vertical plane, as a fault-plane candidate, can be simply accepted or rejected by means of the epicenter position only. Of course, to confirm the horizontal (or sub-horizontal) plane, we already have to care more about the hypocenter depth. Oblique normal and reverse events are the most difficult ones (Fig. 1j): in case of a highly uncertain location depth, H may fall in both planes I and II. Finally, let us mention that the H-C method always fails where the line connecting H and C coincides with the intersection of the planes I and II (Fig. 1k,l).

**Test examples**

To demonstrate both easy and difficult cases, the H-C method is applied in this section to three earthquakes with known fault planes; Fig. 2. For simplicity, only agency solutions are used, although generally they cannot be conclusive due to limited H- and C-position accuracy, as already discussed above.

**Mw6.0 Parkfield, Central California, September 28, 2004**: the strike-slip case. Although based on the agency data (the Harvard CMT and the USGS location), the two individual solutions demonstrated that the hypocenter is closer to the plane II, strike 321°, marked as green in Fig. 2a. This is the San Andreas fault segment,
unambiguously mapped by the aftershock distribution\(^2\) (Thurber et al., 2006) and associated with the secondary surface rupture (Rymer et al., 2006).

**Mw7.1 Andreanof Islands**, Aleutians, December 19, 2007; the low-angle thrust fault case. Even better that in the above example, the Harvard and USGS data are almost H-C consistent, and provide clear identification of the sub-horizontal fault plane in Fig. 2b, typical for large subduction events of that region.

**Mw6.0 Athens**, Greece, September 9, 1999; the normal-fault case. This is an example of a difficult situation. As seen from Fig. 2c, the USGS location seems to prefer plane II (red, strike 284°) of the Harvard CMT solution, while the NOA preliminary location identifies the plane I (green, strike 116°). The NOA relocated hypocenter points out to plane I again, which was indeed clearly mapped by the aftershock distribution, as revealed by a temporary local network (Tselentis and Zahradnik, 2000). In this case, using the individual agency solutions, the H-C method is not indicative enough. The reason is not only in the uncertainty of the solutions, but also in the less favorable geometry, as discussed in the previous section (Fig. 1j).

The message of the test examples is simple: It is useful to try the H-C method even with preliminary agency data. If we get an H-C inconsistent case, it clearly shows that the H and C solutions need more accuracy. If we get an H-C consistent case, it still needs more verification. Adding next agency solutions, as they arrive after the earthquake, may help to obtain a more likely fault-plane candidate. Variability among the agency solutions also brings some uncertainty estimate, without which the H-C

\(^2\) [http://www.cisn.org/special/evt.04.09.28/Parkfield_DD/Park4.html](http://www.cisn.org/special/evt.04.09.28/Parkfield_DD/Park4.html)
method cannot give reasonable results. Nevertheless, the most recommendable procedure is a specifically focused application of the H-C concept, as illustrated in the next section.

**Mw6.2 Leonidio earthquake**

In this section, the H-C method introduced above is applied to the intermediate-depth earthquake of January 6, 2008, Southern Greece. The earthquake produced minor damage to the city of Leonidio and surroundings at the eastern coast of the Peloponnese, 120 km from Athens, but it was felt all over the country, and in several places in southern Italy. No aftershocks that could potentially map the fault plane were located by regional networks, except four ML~3 and just one M4 event as late as January 11.

**Hypocenter location.** The HYPOINVERSE code was applied to invert the manual P and S picks from fifteen stations; those used below for CMT (Fig. 3), plus the PSLNET short period stations and a few stations belonging to Aristotle University of Thessaloniki up to 350 km. The uncertainty was evaluated by repeated calculations with: a) various starting depths, b) various data subsets, e.g. keeping only stations closer than 200km, b) two $V_p/V_s$ ratios, and c) two crustal models (Tselentis et al., 1996 and Novotny et al., 2001). The latter provided the least RMS residuals, in particular for $V_p/V_s=1.75$. The best fitting location is in Table 1. The family of the alternative hypocenter solutions is plotted later in Figs. 4 and 5.

**CMT solution.** Broadband records from the permanent seismological network PSLNET (University of Patras, Seismological Laboratory, UPSL) were studied, complemented
with waveforms provided by other near-regional stations available through ORFEUS and GEOFON. Finally, 3-component un-clipped records from 10 stations were used in the MT inversion, providing a fairly good azimuthal coverage of the event (Fig. 3). Furthermore, the EW horizontal component (clipped) of the nearest station PYL was excluded. The epicentral distances range from 117 to 490 km.

Various preliminary tests were carried out to find the appropriate crustal model and frequency band to achieve an acceptable waveform match. In particular, the crustal models proposed by Endrun et al. (2004) and Novotny et al. (2001) were tested at frequencies below 0.1 Hz. Finally, all the runs were performed in the model of Novotny et al. (2001), which provided a slightly better match\(^3\), using displacement waveforms from 0.02 to 0.07 Hz. The MT calculations were made with ISOLA software\(^4\) (Sokos and Zahradnik, 2008). Final runs included the centroid grid search in a 7x7 horizontal stencil (step 7 km), at 3 depths (step 5 km). The whole procedure was performed several times, with or without Z and NS component of the PYL station. Stability of the MT solution (the C position and the corresponding strike, dip, rake) was proved by jackknifing, i.e. by repeatedly removing one station. The inversions indicate the NS position of C to be the most stable, the EW position plus/minus one 7-km grid step, and the C depth the least resolved, between 60 and 80 km. The preferred solution, considering the waveform match and the H-C consistency, is in Table 2 (the solution with PYL-Z component). Three samples of the family of the alternative solutions are plotted in Fig. 4.

\(^3\)In this paper, occasionally, the model of Novotny et al. (2001) proved to be good for location as well as the MT inversion. However, in general, use of a single crustal model for both tasks is not necessary; the existing crustal models are rarely equally suitable in both the short- and long-period range.
The nodal planes of the Leonidio earthquake differ considerably in their dip: plane I almost vertical (strike of about 120°), and plane II of low dip ~35° (strike of about 210°). Accordingly to the methodic section, this is a favorable situation. Fig. 4 compares the position of the nodal planes and the hypocenter solutions, separately for the high- and low-dip planes. With no doubt, the hypocenter matches much better with the low-dip nodal plane. The preferred H-C solution is presented in Fig. 5; the hypocenter of Table 2 is at 2 km from the low-dip plane and 13 km from the high-dip one. The animated 3D version of the plot (leonidio.avi) is in the Electronic Supplement. Fig. 6 gives the map view of the solution, together with spatial correlation between the observed and synthetic waveforms. Finally, in Fig. 7 a fairly reasonable waveform match between synthetic and observed waveforms is documented; the overall variance reduction is 0.51.

A few remarks to complement the analysis:

1. All tests provided an almost double-couple event, with a surprisingly stable and high DC percentage (around 90%). In contrast to complex events, accompanied by low DC% (Zahradnik et al., 2008a), the Leonidio earthquake seems to represent a relatively simple rupture. The independent preliminary analysis of teleseismic data are in agreement with this observation (Kiratzi and Benetatos, 2008).

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5 A quick preliminary result (Zahradnik et al., 2008b) was posted on the web page of the European Seismological Mediterranean Center already in one week after the earthquake.
2. As regards the MT solutions of the other agencies, this paper is closer to the USGS CMT solution.

3. The significant difference between the centroid and origin time (of about 4 seconds), reported also by USGS, Harvard, and INGV, is another very stable feature of this event.

Tectonics and stress field. Finally we discuss the preferred solution in the frame of the seismo-tectonic environment. Since the Leonidio earthquake was not preceded by any earthquake that could be considered as an obviously triggering event, it had to be invoked predominantly by the regional stress. The regional stress tensor in the studied region was investigated by Kiratzi and Papazachos (1995). The authors used five MT solutions of earthquakes Ms>5 in the western part of the Hellenic arc (their region 1A). The strain rate orientations associated with their stress tensor implied that the tectonic setting is characterized by shortening of the subducting plate in a direction parallel to the trend of the Hellenic arc, basically in agreement with independent GPS data and geodynamic models. The regional stress is characterized by the dominant tension (azimuth 65°, plunge 55°), roughly perpendicular to the strike of the Hellenic arc in the studied region, and the sub-horizontal pressure (azimuth 163°, plunge 6°) pointing along the arc; Fig. 8. Furthermore, we found that principal directions of this regional stress correspond to the smallest mean rotation angles (Kagan, 1991) with respect to the P and T axes of the earthquake moment tensors involved in the stress inversion.

Using the regional stress tensor (of unknown absolute value, thus normalized to unity), we evaluate the dimensionless traction for both nodal planes I and II of the
Leonidio earthquake. Further, let TVN be the normal component of the traction vector with respect to the nodal plane, and TVS the tangential components of the traction parallel to the slip vector, all calculated separately for both nodal planes (Fig. 9, Table 3). The normal components differ substantially for the plane I and II. While the TVN is negative for plane I, it is positive for the plane II. Therefore, the Coulomb failure function $CFF = TVS + \mu TVN$ also differs for the two slip vectors: $CFF=0.70$ for the slip vector in the high-dip plane I, and $CFF=1.07$ for the low-dip plane II. Here the effective friction coefficient $\mu=0.5$ is used. Generally, for deeper earthquakes, a higher value is also possible (Tibi et al., 2003), say $\mu=0.8$, thus further increasing the difference between planes I and II. If assuming a pre-existing zone of weakness, the larger value of the stress criterion is an independent indication supporting that the plane II is the fault plane. Considering it together with the results of the H-C method discussed above, we conclude that the Leonidio earthquake ruptured along the low-dip plane II.

**Conclusion**

It is important to develop new methods for quick identification of the earthquake fault plane, without need to wait for aftershocks (if any, and if located satisfactorily), applicable before more complex and time-demanding studies, such as slip inversions, source-scanning algorithms, etc. The H-C method introduced in the first part of this paper allows identification of the fault plane by analyzing geometrical configuration of the hypocenter (H), centroid (C) and the moment-tensor solution (nodal planes I and II). Note that such a successful though simple approach has not been recognized yet.
Taking into account uncertainties of the location and the waveform inversion, the near-regional waveform data from 117 to 490 km, at frequencies 0.02 to 0.07 Hz, suggested that the Mw6.2 Leonidio earthquake of January 6, 2008, eastern coast of the Peloponnese, represented **strike-slip motion along the low-dip fault plane** (strike 213°, dip 34°, rake 5°). Based on the regional stress field (Kiratzi and Papazachos, 1995), characterized by shortening of the subducting plate in a direction parallel to the trend of the Hellenic arc, the preference of the low-dip plane was also supported by a quantitative estimate of the Coulomb failure function. As there were not enough aftershocks after Leonidio earthquake, enabling identification of the fault plane, the H-C method might be valuable for studies of the subduction process. Generally, equally useful might be the H-C method in the early warning systems and emergency operation after catastrophic events.

To encourage a broader use of the H-C method, a visualization tool (the `hcplot` Matlab script) accompanies this paper.

**Note added shortly before submission:** During writing of this paper, the H-C method was applied to two more earthquakes in southern Greece, M6.9 and M6.2, on Feb. 14 and Feb. 20, respectively, and the preliminary identification of the fault plane was in both cases quickly (within 1 day) reported to EMSC: [http://www.emsc-csem.org/index.php?page=current&sub=recent](http://www.emsc-csem.org/index.php?page=current&sub=recent)

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Electronic Supplement

To encourage a broader use of the H-C method, this supplement provides a simple script (hcplot) in Matlab to quickly produce the 3D animated plot of the hypocenter, centroid and nodal planes. The code is self-explanatory, easy to use on an intuitive basis. It is possible to produce also a movie for presentation purposes, independently of the Matlab environment. The attached example of the movie (leonidio.avi) is related to the investigated earthquake.

References:


**Figure captions:**

**Figure 1.** Schematic explanation of the H-C method. H (and star)=hypocenter, C=centroid, plane I and II are nodal planes, E=epicenter, ovals denote the dominant slip region. For details, see text. Panel a) shows a view perpendicular to the fault plane I and b) a cross-section with H identifying the fault. Panel c) shows typical situation when H does not coincide exactly with any of the planes. Panel d) suggests the use of several H’s and C’s representing the uncertainty in their locations, which can help to identify the fault plane. Panels e) and f) schematically show a possible failure of the H-C method for a segmented fault: C is out of both planar segments of
the fault, including the segment encompassing \( H \); there is no reason to seek \( H \) coinciding with any of the planes I, II. Panel g) demonstrates problems with an almost symmetric bilateral rupture, where \( C \) gets too close to \( H \) at very low frequency. Next panels show situations for different faulting mechanisms: h) the simplest situation for vertical strike slip when even a top view is helpful, without any 3D visualization, and epicenter \( E \) identifies the fault plane, i) a relatively easy fault plane identification for mechanisms when one of the nodal planes is vertical (or near to vertical), and, j) the most difficult case of oblique fault planes. Panels k) and l) show failure of the H-C method when the H-C line coincides with the intersection of plane I and II.

**Figure 2.** Tests of the H-C method. Panel a) – Parkfield, panel b) – Andreanof Islands, panel c) – Athens earthquake. Centroid is in the middle of the intersection of nodal planes I and II. Hypocenter is shown by the blue star symbol. Only agency solutions are used: hypocenter of USGS and CMT of Harvard, except for the Athens earthquake. In the latter case two more hypocenter solutions are included (NOA preliminary and NOA revised). In all three tests the true fault plane is the green one, so the hypocenter should fall in that plane.

**Figure 3.** Stations [and networks] used in the MT inversion: PYL, EFP, DDN [PSLNET, HP], ARG and RDO [GI-NOA, HL network], APE, LAST, ZKR, KARN, SIVA [GEOFON, GE].

**Figure 4.** Application of the H-C method to the Leonidio earthquake. Panel a) - three high-dip nodal planes illustrating uncertainty of the centroid determination. Centroid is in the middle of each plane. The blue stars show the family of hypocenter solutions of this paper. With such a distance between the hypocenters and the planes it is
unlikely that the high-dip nodal plane was the fault plane. Panel b) - as in panel a), but for the corresponding low-dip nodal planes. Proximity of the hypocenters (stars) to the planes indicates that the earthquake ruptured along such a low-dip fault. The three CMT solutions are as follows: a) without station PYL, b) with PYL-Z; c) with PYL-Z and PYL-N.

**Figure 5.** The H-C plot of the preferred solution (Tables 1 and 2). Nodal planes I and II are shown in red and green, respectively. Centroid is in the middle of the intersection of the nodal planes. The alternative hypocenter solutions of the mainshock are shown in blue. It is the green plane which encompasses the hypocenters, thus this low-dip nodal plane (strike 213°, dip 34°) is identified as the likely fault plane.

**Figure 6.** Map-view of correlation between the observed and synthetic waveforms at the depth of 65 km for the preferred solution. The preferred hypocenter solution of this paper (Tab. 1) is shown by blue circle. Small black crosses mark the trial source positions at which the MT solution was performed, at various depths. The preferred centroid position, (Tab. 3), the black dot, is connected with the corresponding ‘beach ball’. The maximum correlation value 0.72 corresponds to the overall variance reduction of 0.51 at 10 stations. For comparison, the centroid positions of several agencies are shown by green triangles.

**Figure 7.** Waveform match between the observed (black) and synthetic (red) waveforms for the preferred CMT solution. Maximum amplitudes are shown at the top of each panel in the same color, too.
**Figure 8.** Tectonics and stress field in the studied region. Panel a) Hellenic trench, Greece, where the Africa plate is subducting below the Aegean plate. CTF is the Cefallonia Transform Fault. Isolines in the Aegean Sea are mean depths of earthquakes (after Papazachos et al., 2000). Panel b) the increasing gray shade is a schematic illustration of the increasing depth of slab in the region (after Gudmundsson and Sambridge, 1998). The P and T axes of the regional stress field (Kiratzi and Papazachos, 1995), projected onto horizontal plane, are shown by the arrows (the true T/P eigenvalue ratio is 1.25). The “beach ball” for the Leonidio earthquake, connected with the centroid, shows the P and T axes of the earthquake by circles, while those of the regional field are marked by squares. The main result of this paper, i.e. the identification of the fault plane, is represented by the slip vector of the studied event (strike 209°, dip 3°). It shows the almost strike-slip motion of the top (hanging) block, as it moves along the low-dipping fault plane inferred in this paper.

**Figure 9.** Computed tractions corresponding to the regional stress field acting on the two nodal planes (I and II) of the Leonidio earthquake. TVS = the tangential component of the traction parallel to the slip vector, TVN = the normal component of the traction vector (Table 3). Note that the normal components TVN differ for the plane I and II: while for plane II it is positive, for plane I it is negative. In this sense the Coulomb failure model supports the indication coming from the H-C method that Leonidio earthquake ruptured the low-dip nodal plane II.
**Table 1.** Leonidio earthquake; the preferred hypocenter solution of this paper.

Crustal model of Novotny et al. (2001), Vp/Vs=1.75.

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**Table 2.** Leonidio earthquake; the preferred CMT solution of this paper.

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**Table 3.** Leonidio earthquake and its interaction with the regional (unit) stress tensor: TVS the tangential component of the traction parallel to the slip vector, TVN the normal component of the traction with respect to nodal plane, CFF the Coulomb failure function; all values dimensionless.

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