

FMC  
A program to manage, classify and plot focal  
mechanism data

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## Acknowledgments

I have been using different versions of this program during the last decade. Initially I reworked some of the [Gasperini and Vannucci \(2003\)](#) FORTRAN subroutines on Matlab in order to obtain all the focal mechanism parameters from the Harvard CMT psmeca formatted catalog. During my research on seismotectonics I started to use the [Frohlich and Apperson \(1992\)](#) diagram, but after [Kagan \(2005\)](#) I decided to try the [Kaverina et al. \(1996\)](#) one. From the original Matlab program I jumped to the Free Software world adapting it to Octave. The program only produced the x and y positions of the events and all the plotting where done by means of GMT ([Wessel et al., 2013](#)).

Some colleagues wanted to use the diagram for their work, but they were not familiar with GMT, so I decided to make a big improvement in the program to make it easy to use, distributable and with plotting support. I choose to program it in Python with the following basic ideas:

1. It should be called from the terminal or the command line in order to be incorporated into shell scripts
2. It should behave like any other shell unix tool, compatible with redirection, piping and ASCII format
3. it should be compatible with the GMT psmeca formats to allow the mapping of the focal mechanisms
4. It should has the option to produce a [Kaverina et al. \(1996\)](#) type classification diagram

Part of the programming where done during my happy days as Ph.D. candidate at the UCM; so I have to acknowledge the UCM scholarship that allow me to start my scientific career.

I would like to thank the beta testers Jorge L. Giner-Robles and Alberto Jiménez-Díaz for their comments and suggestions.

If you use FMC, and consider it appropriate, you can acknowledge it by citing the following reference:

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# Part I

## The manual

### 1 Introduction

This is the user manual for the program FMC (from Focal Mechanisms Classification). This program has been developed on Python 2.7.3 and adapts some of the [Gasperini and Vannucci \(2003\)](#) FORTRAN routines to obtain the different parameters of the earthquake focal mechanisms depending on the input format. Several output formats are eligible and a classification diagram for the focal mechanisms is produced. The input and output formats are the same used by the GMT program `psmeca` in order to make the program integration easiest and facilitate the mapping of the data.

The program basically takes the focal mechanisms data, computes the different parameters that can be obtained, classifies each focal mechanism in one of seven possible types, and optionally outputs the parameters in different formats and generates a classification diagram from the input data.

### 2 Installation

FMC has been programmed in Python 2.7.3 and uses several common python libraries: `sys`, `argparse`, `os`, `NumPy` and `matplotlib`. Depending on your operative system and Python installation you could need to install some of the libraries manually.

For **Windows** and **Mac** users a good starting point is the installation of predefined packages. From [www.SciPy.org](http://www.SciPy.org) you can download program packages that includes Python, NumPy and matplotlib, as well as other modules and IDEs. With one of these packages installed FMC should work properly.

For **Linux** users all the required software can be easily installed through your favorite distribution repository (the python modules `sys`, `argparse` and `os` are usually installed with the default python installation).

### 3 Usage

The user interface is as simple as a “command line”, or a “terminal”. I decided to keep the program as simple as possible so it can be integrated into

scripts with other programs such as **GMT**, **AWK** (or **gawk**) or any other tool running from a shell or script (in \*nix) or a command window or batch file (in Windows/DOS). In the following the commands are written assuming that your python installation recognizes automatically the python format. In some systems, depending on your personal configuration, you will need to call first Python (like “python FMC.py ...”) or in a \*nix system with the “./” needed to execute a script (like ./FMC.py ...).

In \*nix you will need to give execution permission to the program:

```
chmod +x FMC.py
```

To run FMC on a file simply type in the terminal:

```
FMC.py input-file.dat
```

By default FMC will read the input file as a psmecha Centroid Moment Tensor (CMT) format (in Harvard convention). This kind of file can be downloaded directly from **Global CMT**. The output will be shown on the screen in psmecha CMT format so it can be directly pipe into psmecha:

```
FMC.py input-file.dat | psmecha -R {...etc}
```

Or stored as an ASCII file:

```
FMC.py input-file.dat > output-file.dat
```

In this case FMC will add a new column at the end of each register with the focal mechanism type.

Alternatively the input file can be a single plane in **Aki and Richards (1980)** convention (Right Hand Rule for the plane orientation, and rakes from 0 to 180 in reverse faults and 0 to -180 in normal faults, 0 for left-lateral and ±180 for right-lateral). This format is also compatible with psmecha.

### 3.1 Input

FMC input can be given as an ASCII file or as standard input, from a pipe (“|”) or a redirection (“<”). The following codes are then equivalent:

```
FMC.py input-file.dat  
cat input-file.dat | FMC.py  
FMC.py < input-file.dat
```

If no input is given, then FMC will show the on-screen help.

The input format is specified with the optional flag “-i”, and the possible values are:

**CMT** Harvard Centroid Moment Tensor (by default):

[longitude, latitude, depth, mrr, mtt, mff, mrt, mrf, mtf,  
Exponent (dyn·cm), X plot, Y plot (for GMT), ID]

**AR** Aki and Richards one plane convention:

[longitude, latitude, depth, strike, dip, rake, magnitude (Mw),  
X plot, Y plot (for GMT), ID]

### 3.2 output

FMC output format can be selected among the following options with the flag “-o”:

**CMT** Harvard Centroid Moment Tensor (psmeca compatible):

[longitude, latitude, depth, mrr, mtt, mff, mrt, mrf, mtf,  
Exponent (dyn·cm), X plot, Y plot (for GMT), ID, TYPE]

**P** Focal mechanism both nodal planes (psmeca compatible):

[longitude, latitude, depth, strike A, dip A, rake A, strike  
B, dip B, rake B, Scalar seismic moment mantissa, Exponent  
(dyn·cm), X plot, Y plot (for GMT), ID, TYPE]

**AR** Focal mechanism one plane (psmeca compatible):

[longitude, latitude, depth, strike, dip, rake, magnitude (Mw),  
X plot, Y plot (for GMT), ID, TYPE]

**K** Kaverina diagram position for plotting outside FMC:

[X Kaverina diagram, Y Kaverina diagram, Mw, Depth, ID, TYPE]

**ALL** All the parameters obtained:

[longitude, latitude, depth, mrr, mtt, mff, mrt, mrf, mtf,  
Exponent (dyn·cm), Scalar seismic moment (dyn·cm), Mw, strike  
A, dip A, rake A, strike B, dip B, rake B, P trend, P plunge,  
B trend, B plunge, T trend, T plunge, fclvd, X Kaverina diagram,  
Y Kaverina diagram, ID, TYPE]

### 3.3 Plot

Optionally FMC will produce a classification diagram. FMC uses `matplotlib` libraries and can generate figures in different formats (emf, eps, jpeg, jpg, pdf, png, ps, raw, rgba, svg, svgz, tif, tiff). The format is determined automatically from the plot file name extension.

The diagram uses the [Kaverina et al. \(1996\)](#) projection technique, used also by [Kagan \(2005\)](#); but incorporating a classification similar to the geological conceptual classification of faults. The earthquakes are classified into

seven types according to the values of the P, T and B Centroid Moment Tensor axes following a simple algorithm (Figure 3.1), and are represented conveniently on the Kaverina diagram (Figure 3.2). This classification is very similar to the used by Johnston et al. (1994).

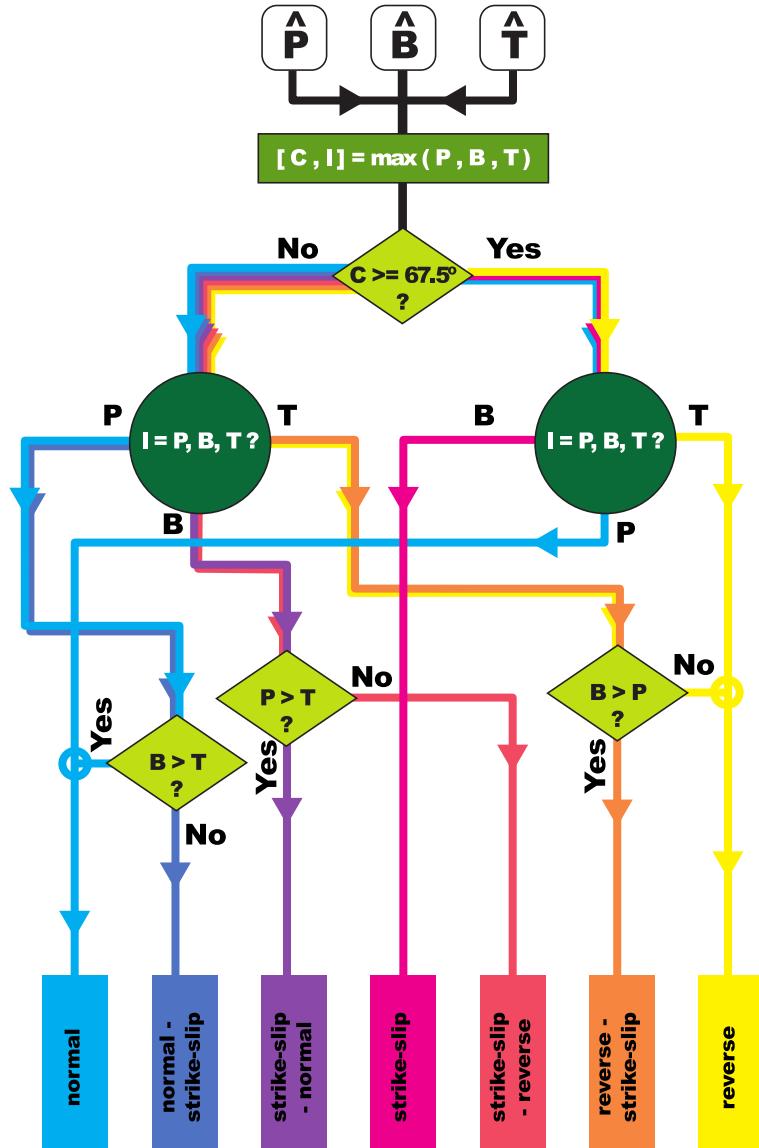


Figure 3.1: Focal mechanism classification algorithm flow chart.

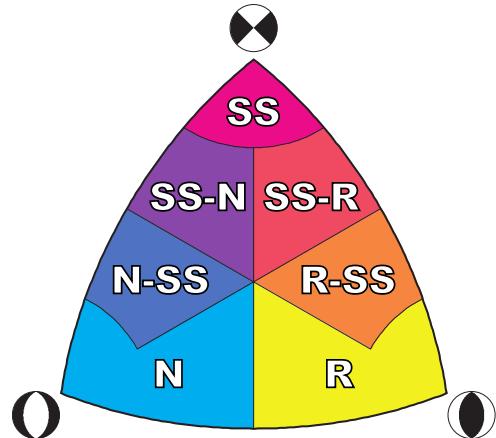


Figure 3.2: Classification diagram. N: Normal; N-SS: Normal - Strike-slip; SS-N: Strike-slip - Normal; SS: Strike-slip; SS-R: Strike-slip - Reverse; R-SS: Reverse - Strike-slip; R: Reverse.

## 4 Examples of use

### Obtaining nodal planes from moment tensor

Command:

```
echo -2.54 37.09 12 -3.4669 -2.0652 5.5321 6.2368 -1.8004
-5.1775 22 X Y ID | FMC.py -o P
```

Result:

```
#Lon Lat Depth Strike_A Dip_A Rake_A Strike_B Dip_B Rake_B
Seismic_moment_mantissa Exponent_(dyn-cm) X_position
Y_position ID Mechanism_type
-2.54 37.09 12 190.925 42.4899 -20.9735 296.709 76.0089
-130.541 9.604500 22 X Y ID N-SS
```

### Obtaining moment tensor from one nodal plane

Command:

```
echo -2.54 37.09 12 190.925 42.4899 -20.9735 4.6 X Y ID |
FMC.py -i AR -o CMT
```

Result:

```
#Lon Lat Depth mrr mtt mff mrt mrf mtf Exponent_(dyn-cm)
X_position Y_position ID Mechanism_type
-2.54 37.09 12 -3.17787 -1.97794 4.62601 4.62601 -5.15581
-4.62601 22 X Y ID N-SS
```

### Obtaining all the parameters from the moment tensor

Command:

```
echo -2.54 37.09 12 -3.4669 -2.0652 5.5321 6.2368 -1.8004
-5.1775 22 X Y ID | FMC.py -o ALL
```

Result:

```
#Lon Lat Depth mrr mtt mff mrt mrf mtf Exponent_(dyn-cm)
Scalar_seismic_moment (dyn-cm) Mw Strike_A Dip_A Rake_A
Strike_B Dip_B Rake_B P_Trend P_plunge B_trend B_plunge
T_trend T_plunge fclvd X_Kaverina_diagram Y_Kaverina_diagram
ID Mechanism_type
-2.54 37.09 12 -3.4669 -2.0652 5.5321 6.2368 -1.8004 -5.1775
22 9.6045e+22 4.62165 190.925 42.4899 -20.9735 296.709 76.0089
-130.541 167.141 43.8185 308.393 39.1024 56.0979 20.5155
0.0445259 -0.243839 0.0899979 ID N-SS
```

### Obtaining all the parameters from CMT input file and storing to an ASCII file

Command:

```
FMC.py -o ALL japan_CMT.dat > Japan_parameters.dat
```

### Plotting data from standard input

Command:

```
echo -2.54 37.09 12 -3.4669 -2.0652 5.5321 6.2368 -1.8004
-5.1775 22 X Y ID | FMC.py -p CMT_data.pdf
```

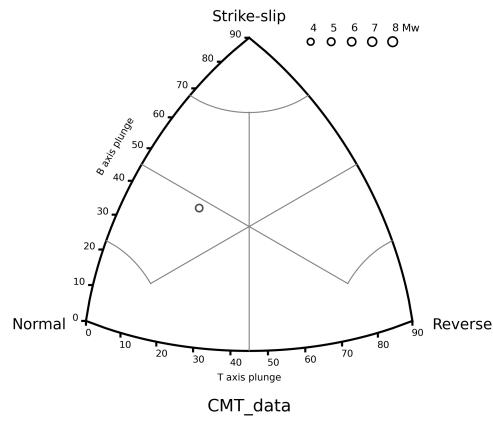


Figure 4.1: Plot result from the command "echo -2.54 37.09 12 -3.4669 -2.0652 5.5321 6.2368 -1.8004 -5.1775 22 X Y ID | FMC.py -p CMT\_data.pdf"

### Plotting data from input file

Command:

```
FMC.py -p 'Japan data.pdf' japan_CMT.dat
```

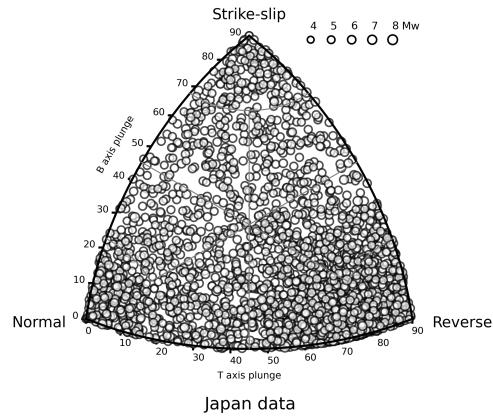


Figure 4.2: Plot result from the command "FMC.py -p 'Japan data.pdf' japan\_CMT.dat"

### Plotting data from input file and piping to psmeca

Command:

```
FMC.py -p 'Japan data.pdf' japan_CMT.dat | psmeca  
-R125/170/30/60 -JM8c -Ba10f2WESN -Sm5p/-1 > CMT_map.ps
```

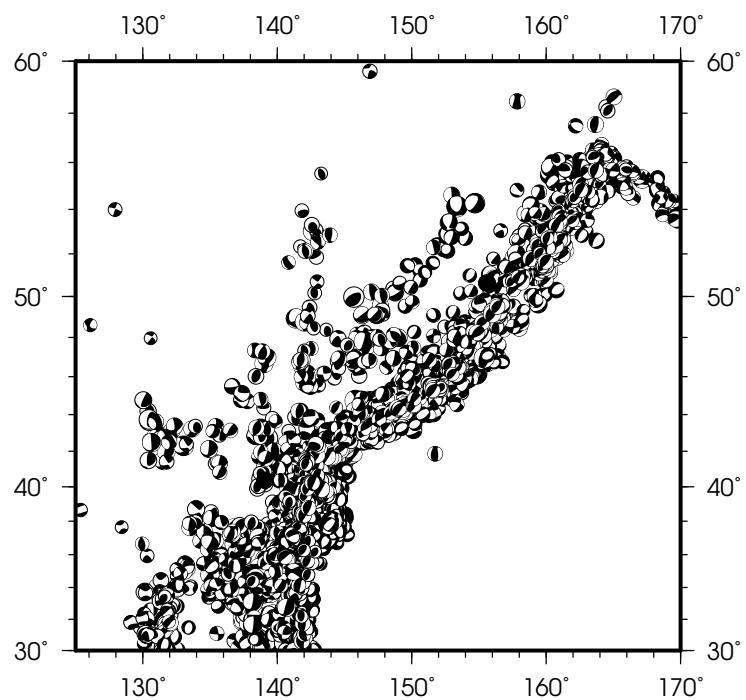


Figure 4.3: Map generated with psmeca (GMT) from the FMC output.

## 5 License

FMC has been developed with Free Software and/or Open Source tools. FMC uses NumPy and matplotlib which are distributed under BSD license.

FMC is distributed under [GNU Generic Public License](#).

## Part II

# The background

## 6 Introduction

Seismicity is frequently used to deduce the tectonics of a region. The study of earthquakes as a tectonic component, the seismotectonics (Scholz, 2002), has grown as one of the key research areas on active tectonics, specially from the analysis of earthquake focal mechanisms.

The first focal mechanism determination methods, based on P wave's first motion polarities, were developed on the first half of the 20th century, specially in Japan where a dense seismic network were available (Byerly, 1928, 1938; Koning, 1941; Honda and Masatuke, 1952; Scheidegger, 1957). Since 1960 the development of the digital computer allow the numerical determination of fault-plane solutions with different methods (e.g. Knopoff, 1961; Langston and Helberger, 1975; Dziewonski et al., 1981).

In parallel with the development of the modern seismology, the theory of Plate Tectonics changed the way geologists understand the Earth. Since the end of the 16th century naturalists made observations on the potential continental drifting; but it was in the early 20th century when the theory started to be formally proposed (Taylor, 1910; Wegener, 1912; Schwinne, 1919; Holmes, 1931). The relevant information acquired on the magnetic stripes on the ocean floor in the 60's (e.g. Hess, 1962; Vine, 1966; Le Pichon, 1968; Morgan, 1968), in addition to an increasing number of geological and geophysical observations, established the Plate Tectonics as the global geodynamical paradigm on Earth Sciences. The study of earthquakes related to Plate Tectonics was developed at the same time establishing the basic concepts of seismotectonics and the lithospheric deformation (e.g. Benioff, 1954; Sykes, 1967; Isacks et al., 1968; Isacks and Molnar, 1969).

Since the 70's focal mechanisms are computed in a systematic way and global catalogs of focal mechanisms are available since then. As the amount of data increases, our knowledge on the active tectonics improves. As a consequence of the continuous increase of data available we need new tools to analyze it systematically.

In order to represent focal mechanism populations Frohlich and Apperson (1992) proposed a diagram to visualize focal mechanism data as a function of the rupture type. This kind of representation is popular and widely used on seismotectonics to represent the focal mechanism types of the study areas (e.g. Frohlich et al., 1997; Borges et al., 2001; Igarashi et al., 2001; Ratchkovski and Hansen, 2002; Kita et al., 2006; Serpelloni et al., 2007). This

representation is not accurate, presenting distortion problems (Frohlich, 2001), and Kagan (2005) used the Kaverina et al. (1996) projection to avoid them. The latter projection is used in FMC by default.

## 7 The focal mechanism

The term “focal mechanism” is used to refer to the parameters that characterize an earthquake rupture. A focal mechanism usually presents the characteristics of the two orthogonal possible rupture planes: strike, dip and rake of the slip vector over the plane. The energy released by the event, its hypocentral location and the exact time of occurrence are also given. The focal mechanism can, instead of describe the geometry of the possible rupture planes (6 variables), describe the characteristics of the rupture by means of the seismic moment tensor (SMT) or centroid moment tensor (CMT) (6 variables).

The SMT is based in the representation of the equivalent forces on a point seismic source. In this tensor the sum of angular moments should be null, in other words, the SMT is a symmetric tensor on a three dimensional space (9 components) with 6 independent components:

$$\mathbf{M} = \begin{pmatrix} M_{XX} & M_{XY} & M_{XZ} \\ M_{YX} & M_{YY} & M_{YZ} \\ M_{ZX} & M_{ZY} & M_{ZZ} \end{pmatrix} \quad (7.1)$$

where

$$\begin{aligned} M_{XY} &= M_{YX} \\ M_{XZ} &= M_{ZX} \\ M_{YZ} &= M_{ZY} \end{aligned} \quad (7.2)$$

Similarly to the strain tensor where we can define the orientation of the principal axes (eigenvectors) and its magnitudes (eigenvalues), the SMT can be defined by the orientation of its principal axes P, B and T (eigenvectors) and its magnitudes (eigenvalues). The T axis describes the greatest of the eigenvalues, the P describes the lowest and the B the intermediate.

If the seismic event is generated by the slip in a fault rupture, its characteristics should be well described as a double couple moment tensor (Figure 7.1):

$$\mathbf{M} = \begin{bmatrix} M_0 & 0 & 0 \\ 0 & -M_0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (7.3)$$

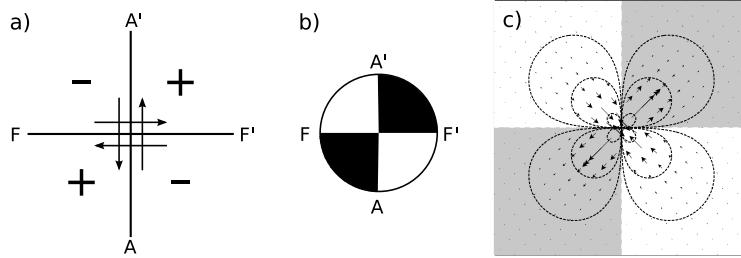


Figure 7.1: Double couple deformation mechanism. a) Plan view of horizontal displacement on an idealized point vertical fault A-A' or F-F' and resulting distribution of compressions (+) and dilatations (-). b) Focal mechanism representation on a stereographic projection. Compression quadrants are filled. c) Horizontal displacement produced by a point size vertical dislocation computed with the [Okada \(1992\)](#) equations; compressional quadrants are filled while dilatational are kept empty following the focal mechanism representation. a) and b) modified from [Bullen and Bolt \(1985\)](#).

where  $M_0$  is the scalar seismic moment.

The most used representation of the double couple is based on the stereographic projection. In this projection both nodal planes of the focal mechanism are plotted, and the quadrants containing the T axis, the compression quadrants, are filled (Figure 7.1). This kind of representation - commonly called “beach-ball” - located on a map on the earthquake epicenter is useful to interpret the seismic data from a tectonic point of view, allowing the study of the earthquake and its rupture fault plane on its tectonic context, being one of the basis of the seismotectonics. The compressional and dilatational quadrants are separated by two orthogonal planes, the nodal planes, being one of them the plane of rupture that generated the earthquake (Figure 7.2).

As we increase the number of focal mechanisms to study, we increase the difficulty to interpret the data, obscuring frequently the details of a tectonic environment if we just project them over a map. In order to facilitate the study of groups of focal mechanisms several plots can be proposed, great part of them based on classical structural geology plots.

The plots inherited from the structural geology are based in the geometrical characteristics of the nodal planes of the SMT, equivalent to the characteristics of the fault planes: strike ( $\varphi$ ), dip ( $\delta$ ) and rake ( $\lambda$ ) (Figure 7.2). The main problem of these representations is the duplication of data. Each focal mechanism presents two equivalent and orthogonal nodal planes. The selection of one of them as the fault plane is not straightforward and although from a mechanical point of view they can be discriminated ([McKenzie, 1969](#), [Michael, 1987](#); [Gephart, 1990](#)), when both nodal planes are me-

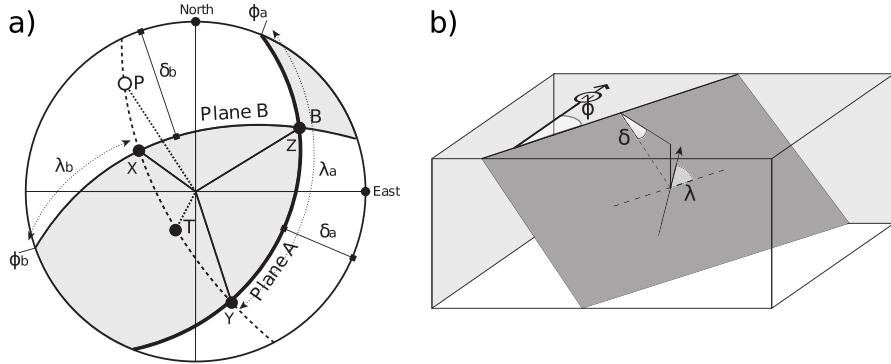


Figure 7.2: a) Focal sphere diagram on stereographic projection on the lower hemisphere. Nodal planes A and B, A representing the fault plane and B the auxiliary plane, with its orientation characteristics:  $\varphi$ , strike;  $\delta$ , dip and  $\lambda$ , rake. The orientation of the SMT principal axes are also shown: T, B and P. Modified from [Udías \(1989\)](#). b) Block diagram showing the parameters that define the orientation of a fault plane in the space:  $\varphi$ , strike;  $\delta$ , dip and  $\lambda$ , rake.

chanically compatible or reactivated structures can be present, additional geological and/or geophysical information is required. There are as many representations of this kind as possible combinations between these parameters and its derivatives (usually trigonometrical functions). These relations can be represented in biaxial plots or stereographic projections (e.g. [Davis and Reynolds, 1996](#); [Ramsay and Huber, 1997](#); [Pollard and Fletcher, 2005](#)).

The focal mechanisms can also be plotted as function of the principal axes T, B and P. These axes form an orthogonal system. The orientation of each axis can be defined in the space as any line, by its direction and plunge. The main advantages of these representations are: the univocality, each focal mechanism is represented by one point; its simplicity of interpretation, the kind of deformation (normal, reverse, strike-slip) is function of the plunge of the axes; and the reduction of errors compared with the planes, as they are derived from the principal axes of the SMT ([Vannucci and Gasperini, 2003](#)).

## 8 Diagram

[Frohlich and Apperson \(1992\)](#) developed a ternary diagram to represent focal mechanisms based in the trigonometrical relation:

$$\sin^2 \iota_T + \sin^2 \iota_B + \sin^2 \iota_P = 1, \quad (8.1)$$

where  $\iota_T$ ,  $\iota_B$  and  $\iota_P$  are the plunges of the axis T, B and P of the SMT. This relation is true for three orthogonal axes.

As the equation of a sphere with radius unity is

$$x^2 + y^2 + z^2 = 1 \quad (8.2)$$

and all the plunge angles are positive between  $0^\circ$  and  $90^\circ$ , then the representation of a focal mechanism defined by these axes is equivalent to the projection of a point in an spherical octant over a planar surface. As a sphere is not a developable surface can not be projected onto a plane without distortion.

The projection used by [Frohlich and Apperson \(1992\)](#) represents this spherical octant as a triangle, which is equivalent to the gnomonic geographical projection. In this projection we define the angles

$$\psi = \arctan \left( \frac{\sin \iota_T}{\sin \iota_P} \right) - 45^\circ, \quad (8.3)$$

and

$$\iota_s = \arcsin \frac{1}{\sqrt{3}} = \arctan \frac{1}{\sqrt{2}} \approx 35.26^\circ, \quad (8.4)$$

which is the angle of the ternary symmetry axis with the orthogonal axes of the octant.

From these angles the  $x$  and  $y$  coordinates over the plane are given by:

$$x = \frac{\cos \iota_B \cdot \sin \psi}{\sin \iota_s \cdot \sin \iota_B + \cos \iota_s \cdot \sin \iota_B \cdot \cos \psi} \quad (8.5)$$

$$y = \frac{\cos \iota_s \cdot \sin \iota_B - \sin \iota_s \cdot \cos \iota_B \cdot \cos \psi}{\sin \iota_s \cdot \sin \iota_B + \cos \iota_s \cdot \sin \iota_B \cdot \cos \psi} \quad (8.6)$$

The angle  $\iota_s$  in the projection is the angle of the plunges of the axes T, B and P for the focal mechanism that occupies the barycentre of the ternary diagram where  $x = y = 0$ .

As can be seen in Figure 8.1a this projection introduces remarkable distortions towards the extremes of the diagram. This distortions could difficult the study of some groups of focal mechanisms as the author pointed out ([Frohlich, 2001](#)). In order to avoid these distortions [Kaverina et al. \(1996\)](#) proposed the use of a projection capable of maintain the proportion of the areas equal, equivalent to the Lambert azimuthal equal-area projection (Figure 8.1b), which is the used in structural geology to generate the stereographic equal-area Schmidt stereonet. In this case the limits of the diagram are formed by great circles instead of straight lines forming a triangle (Figure 8.1).

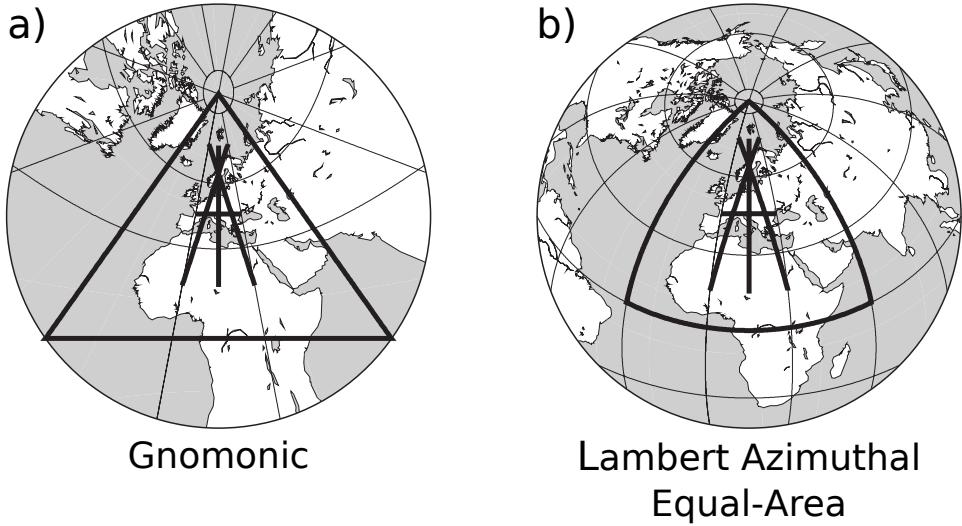


Figure 8.1: Representation of an hemisphere of the globe centred on Europe ( $45^{\circ}\text{N}$ ,  $15^{\circ}\text{E}$ ) in the two different projections referenced in the text: a) Gnomonic projection; b) Lambert azimuthal equal-area. In thick lines are marked the spheric octant and some reference lines in order to compare both projections.

If we take the sines of the plunges of the main axes  $\iota_T$ ,  $\iota_B$  and  $\iota_P$ :

$$\begin{aligned} z_T &= \sin \iota_T \\ z_P &= \sin \iota_P \\ z_B &= \sin \iota_B \end{aligned} \tag{8.7}$$

the length of the vector that connects the center of the diagram with the projected point is defined by

$$L = 2 \sin \left[ \frac{1}{2} \cdot \arccos \left( \frac{z_T + z_P + z_B}{\sqrt{3}} \right) \right] \tag{8.8}$$

and the normalization factor is:

$$N = \sqrt{2 \cdot [(z_B - z_P)^2 + (z_B - z_T)^2 + (z_T - z_P)^2]} \tag{8.9}$$

The coordinates of the projected focal mechanisms in the plane are defined as follows (these equations corrects the wrong equations showed in [Kagan \(2005\)](#)):

$$\begin{aligned} x &= \sqrt{3} \cdot \frac{L}{N} \cdot (z_P - z_T) \\ y &= \frac{L}{N} \cdot (2z_B - z_P - z_T) \end{aligned} \quad (8.10)$$

## 9 Focal Mechanism Classification

In order to classify the focal mechanisms Kagan (2005) divided the octant in three areas (Figure 9.1b) corresponding to the three basic Andersonian regimes: normal, reverse and strike-slip. The dividing lines start at the diagram center and run through the middle of each great circle (dashed lines in Figure 9.1b). This classification, although simple and straightforward, is too basic sometimes for a detailed seismotectonic study.

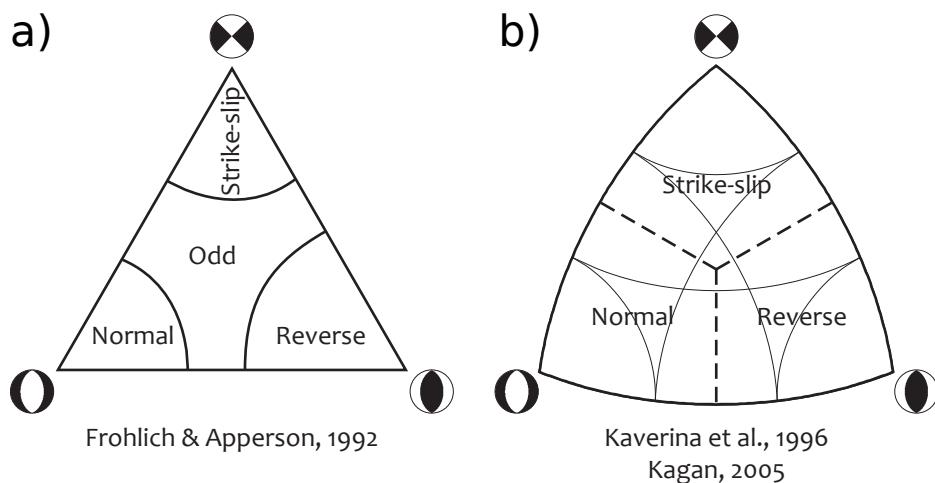


Figure 9.1: Focal mechanisms classification diagrams based on SMT axes plunges proposed by a) Frohlich and Apperson (1992) and b) Kagan (2005).

From the seismotectonic point of view an earthquake reflects the brittle lithospheric strain produced by tectonic processes. The vast majority of earthquakes are produced by displacements on faults (some other processes as deep volume changes or cave collapses can produce seismic signals too), and they are interpreted usually as fault ruptures. Following this reasoning the most appropriate classification for the focal mechanism should be done by means of the slip vector on the fault, given by the rake angle. This classification can be done following one of the proposed conventions (Rickard, 1972; Aki and Richards, 1980; Angelier, 1994). As has been mentioned before, the problem is the duplicity of data due to the two nodal planes solution of the focal mechanism.

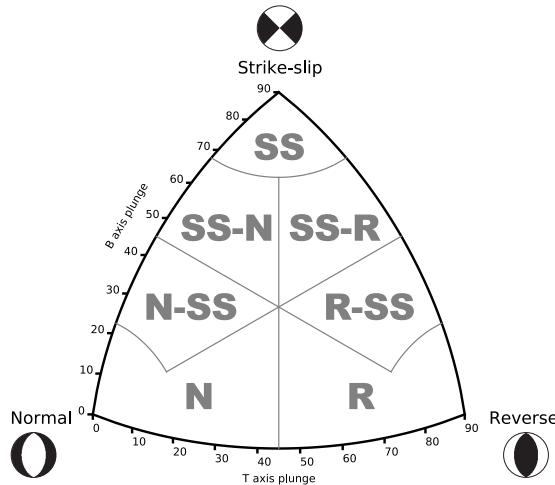


Figure 9.2: Focal mechanism classification diagram. N) Normal; N-SS) Normal - Strike-slip; SS-N) Strike-slip - Normal; SS) Strike-slip; SS-R) Strike-slip - Reverse; R-SS) Reverse - strike-slip and R) Reverse.

An extended discussion on the relation among the different focal mechanism parameters can be found on [Célérier \(2010\)](#); the author also points out the difficulty on interpreting the stress state from the focal mechanisms, specially where oblique faulting takes place and reactivation of inherited structures is possible ([Wyss et al., 1992](#)).

However the SMT can be interpreted as a seismic strain tensor ([Kostrov, 1974](#)) where the main axes are equivalent to the SMT main axes ([Wyss et al., 1992](#)). With this relation in mind we can interpret the populations of focal mechanisms as representations of strains in different tectonic settings. Oblique slip focal mechanisms with normal component can be interpreted as transtensional strain, while oblique slip focal mechanisms with reverse component can be interpreted as transpressional.

In order to count with a classification more detailed than the one of [Kagan \(2005\)](#) I decided to classify the focal mechanism in a series of fields that include the oblique slip regimes ([Álvarez Gómez, 2009](#)). This approximation is similar to the [Johnston et al. \(1994\)](#) classification; with 7 classes of earthquakes: 1) Normal; 2) Normal - Strike-slip; 3) Strike-slip - Normal; 4) Strike-slip; 5) Strike-slip - Reverse; 6) Reverse - Strike-slip and 7) Reverse. The resulting diagram incorporating this 7 fields classification to the Kavirina projection is shown in Figure 9.2.

The algorithm to classify the focal mechanisms based on the SMT main axes plunges is the shown in Figure 3.1.

When one of the three main SMT axes is greater or equal than  $67.5^\circ$  (resulted from  $3 * \frac{\pi/2}{4}$ ) we obtain a "pure" Andersonian tectonic regime. From

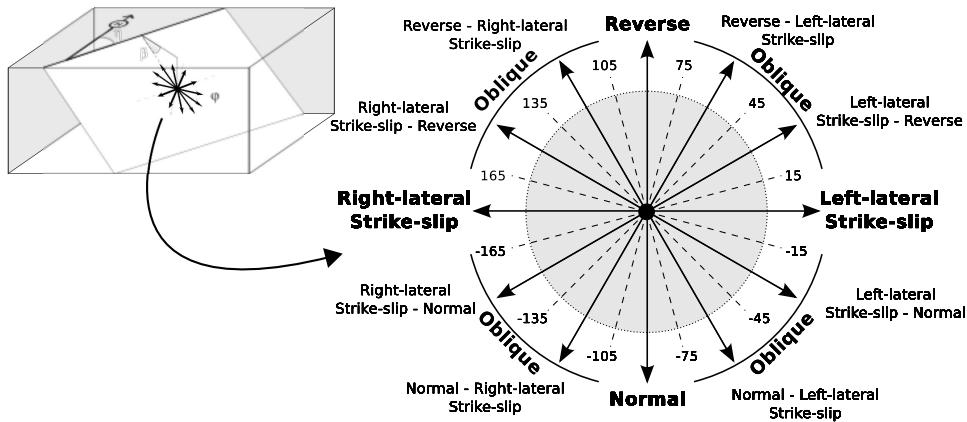


Figure 9.3: Diagram showing the convention used in this work for the rake classification of faults or focal mechanism nodal planes. Inside the grey circle the equivalent SMT axes-based classification is shown (Figure 8.1).

the pure normal or reverse faulting to the strike-slip faulting there is a range of oblique faulting types with more or less relevance of the horizontal component. On the other hand between the pure normal and pure reverse faulting there is a permutation of the T and P axes in the vertical position, while the B axis remains horizontal. The transition takes place when the P and T axes plunge equally and a vertical nodal plane is present.

In the following section I compare the results of both classifications, the one based in the main axes plunges of the moment tensor and the one based on the fault rakes.

## 9.1 Comparison between rake-based and SMT axes-based classifications

In order to classify the nodal planes according to its rakes I adopted a convention hybrid between the [Rickard \(1972\)](#) and [Aki and Richards \(1980\)](#) conventions. The focal mechanism rakes are usually given with the [Aki and Richards \(1980\)](#) convention, while from a geological point of view the [Rickard \(1972\)](#) convention is more used. I define 7 equivalent classes to those used in the SMT axes-based classifications (Figure 9.3).

Each one of the nodal planes of the focal mechanisms from the Global CMT catalog ([Ekström et al., 2012](#)) is classified according to the rake classification shown in Figure 9.3. From the analysis of the focal mechanism alone we cannot choose unequivocally the fault plane responsible of the earthquake. To analyze the degree of uncertainty I show in Figure 9.4a the relative frequency of relations between nodal planes rupture types. For example, it

can be seen that when one nodal plane is classified as normal, the other can be normal as well, or can present some strike-slip component, but it can not present reverse component; the same can be said for the reverse nodal planes. When one nodal plane is pure strike-slip, the other can present dip-slip component too, ranging from normal with strike-slip component (N-SS) to reverse with strike-slip component (R-SS), but being more frequent the relations between nodal planes of mainly strike-slip type.

Comparing the focal mechanism classified with the SMT axes and the nodal planes classified with the rakes (Figure 9.4b) a similar picture as the described above can be seen. The percentages of relations change sensibly, but the common picture is the same. When the focal mechanism is classified as normal type we can expect that both nodal planes are of normal type or normal with some strike-slip component. Similarly when the focal mechanism is classified as reverse, both nodal planes are mainly of the reverse type too. For the case of the strike-slip focal mechanism almost all the nodal planes are of strike-slip type too.

We can conclude that there is not much difference between the results obtained from the rake classification of the nodal planes and the classification of the focal mechanism attending to the SMT axes plunges. The focal mechanism classification based on the SMT axes has the advantage of the univocality of its classification, in contrast with the duplicity of data and uncertainty related to the nodal planes rake classification.

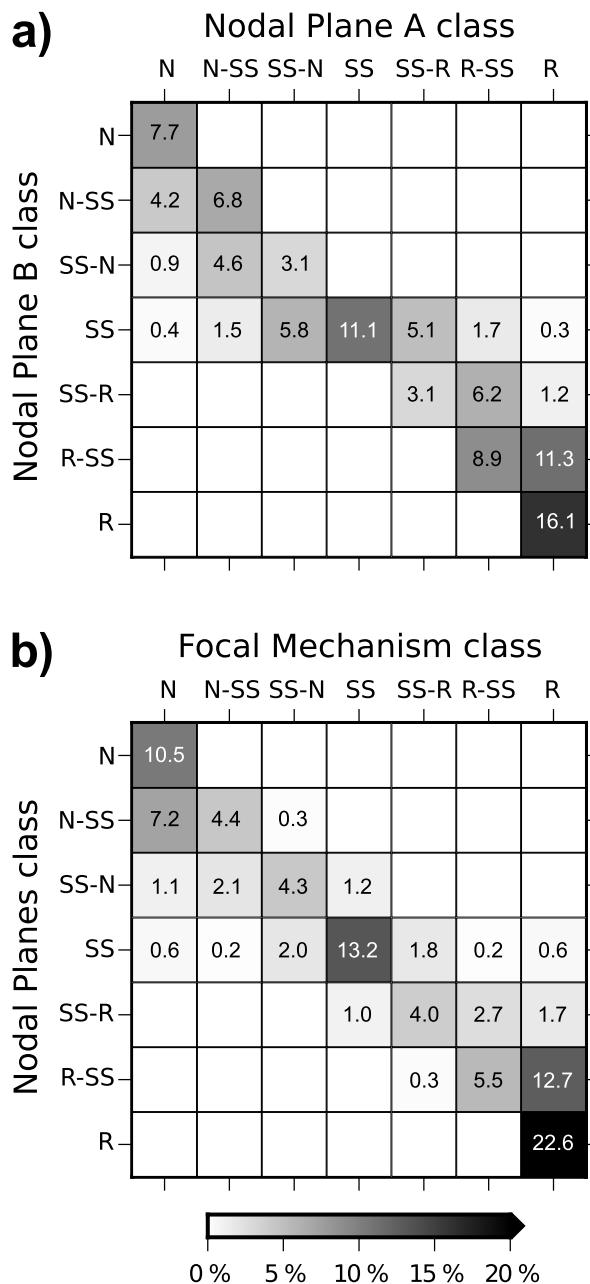


Figure 9.4: Heatmaps of the proportion of relations between a) both nodal planes rupture type based on the rake classification, and b) between the focal mechanism classification and the nodal planes rupture types rake classification. The data used is the entire Global CMT catalog ([Ekström et al., 2012](#)). Numbers show percentages over the entire catalogue.

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