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Catalogue of focal mechanisms of Moroccan earthquakes for the period 1959-2007; analysis of parameters

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Abstract. We present a brief analysis of the focal mechanisms catalogue of Morocco. Most solutions (129 from 167) were determined for the Central Rif and Alboran earthquakes. The P-axes are mostly sub-horizontal and show mainly a NNW-SSE trend, so as the T-axes but with an ENE-WSW trend. Both axes distribution is in conformity with the general state of stress in Morocco. However, several focal mechanisms determined by different institutions appear to be different or even contradictory and therefore, gives rise to a serious troubles for structural geology studies.

Key words: seismotectonics, focal mechanism, Morocco

Catalogue des mécanismes au foyer des séismes du Maroc pour la période 1959-2007; analyse des paramètres.

Résumé. Une brève analyse du catalogue des mécanismes au foyer des séismes du Maroc pour la période 1959-2007 est présentée. La plupart des solutions (129 d'un total de 167) ont été déterminées pour les séismes du Rif central et la mer d'Alboran. Les axes P sont pour la plupart subhorizontaux et regroupés autour de la direction NNW-SSE, alors que les axes T sont également subhorizontaux et de direction ENE-WSW. La répartition des axes est en conformité avec l'état général des contraintes au Maroc. Cependant, plusieurs mécanismes au foyer déterminés par des institutions différentes sont assez différents ou même contradictoires, ce qui conduit à un problème de choix pour les études de géologie structurale.

Mots clés : sismotectonique, mécanisme au foyer, Maroc

INTRODUCTION

Determination of earthquake fault-plane solutions has become one of the main tools for the evaluation of the displacement along seismic faults and the determination of the state of stress related to plate motions. Therefore, several catalogues have been elaborated for various seismic areas in the world. In the Mediterranean region, we can quote, for instance, those published by Constantinescu *et al*. (1966), McKenzie (1978), Udias *et al*. (1989), and those available from the websites of the National Earthquake Information Center (US Geological Survey; http://neic.usgs.gov), Harvard University (http://www.globalcmt.org), the European Mediterranean Seismological Centre (http://www.emsc-csem.org), Instituto Geografico Nacional (http://www.ign.es) and Instituto Andaluz de Geofisica (http://www.ugr.es/~iag/).

A recent inventory of the focal mechanisms of earthquakes in Morocco (29°–36°N; 1,5°–9°W ; extending to 11°W in the Agadir area) for the 1959-2007 period (Medina 2008), allowed us to elaborate a catalogue using 167 solutions determined by various authors and institutions. To give this document a dynamic character in terms of allowing correction and addition of data, and exporting to other software or GIS mapping tools, parameters of the solutions published in 2008 were inserted in an EXCEL files and then to GMT. In the previous publication (Medina 2008), no seismotectonic interpretation of data was included; therefore, we analyze in the present paper, the distribution of solutions over the structural domains in Morocco and we discuss the veracity of the results by confronting to the solutions determined by various authors and institutions for the same events.

SEISMOTECTONIC SETTING

Seismicity of Morocco is related to the convergent motion that involves the African and the Eurasian plate, occurring along a N320 trend with a velocity of 0.5 cm/y according to models NUVEL-1 and NUVEL-1A (DeMets *et al.* 1994). Recent GPS data indicate that the direction of convergence is rather WNW-ESE (N116) with a rate of 5 mm.y^{-1}. This motion is accommodated within the mobile zone north of the Atlas chain, including a probable SSW verging escape zone in the Al Hoceima area (Fadil *et al.* 2006, Stich *et al.* 2006, Vernant *et al.* 2010).

At the Moroccan scale, seismicity is relatively important but, as shown in figure 1, appears to be diffuse (Cherkaoui 1988, El Alami *et al*. 2004). These earthquakes are of low to moderate magnitude (maximum Mw = 6.2 at Al Hoceima in 2004) and the foci are generally shallow, although some events have focal depths around 100 km, such as those of 1977/08/01 (Z = 125 km) in the High Atlas

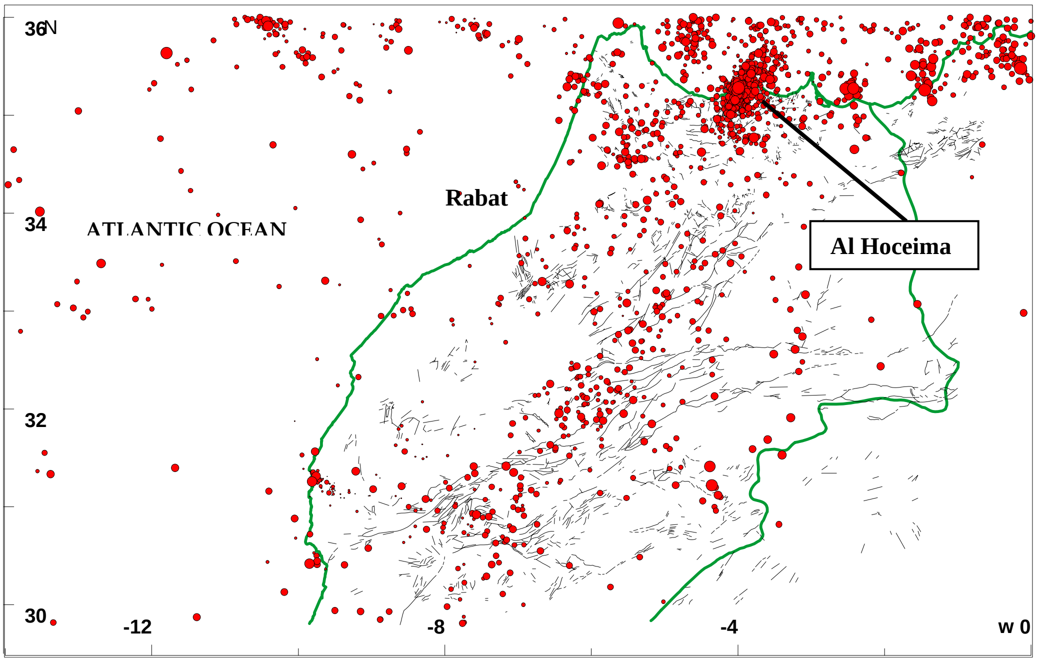


Figure 1. Seismicity of Morocco (northern provinces) and adjacent Atlantic and Mediterranean areas for the period 1987-2000 (file El Alami) and main fault structures (main faults are not clearly mentionned on the figure).

(Hatzfeld & Frogneux 1981, and 1990/04/13 (35.61 N; 4.62 W; M = 3.9; Z = 89) in western Alboran (Buforn *et al.* 2004).

CATALOGUE FEATURES

Database

The database used for this catalogue comprises all the fault-plane solutions published for Morocco in widely-distributed and less known journals, theses, reports and also in available online catalogues (NEIC, IGN, IAG, ZUR, MED…). Composite and microseismicity survey solutions were not included because of their large number and local character (see discussion in Medina 1995). Fault planes determined graphically for mechanisms of earthquakes previous to 1987 were revised and corrected using adequate stereographic software (Medina 2008).

Historically, most events were initially determined in the latest 1970’s to the early 1990’s by the Institut Scientifique researchers using P-wave first motions, until the analogical network decline. Since the early 1990s, widespread use of moment tensor inversion by national and international agencies (IGN, IAG, MED, ZUR) leads to determine a large set of moment tensors for strong and moderate events. All available solutions were included in the catalogue.

Presentation of the files

The catalogue is a simple EXCEL file in which the lines correspond to the events listed by date and the columns to the parameters of the earthquakes and those of the corresponding focal mechanisms (Fig. 2).

The earthquake parameters are the date, origin time, epicentre coordinates, the epicentral area and its structural code, the focal depth (with estimated error), the magnitude, and the institution source or author (Fig. 2, A).

The parameters of the mechanisms comprise the strike, dip and rake of the planes, the trend and plunge of the P- and T-axes, the number of stations used, and in brackets, the number of inconsistent stations for P-wave first motion solutions and also the institution source or author (Fig. 2, B).

RESULTS

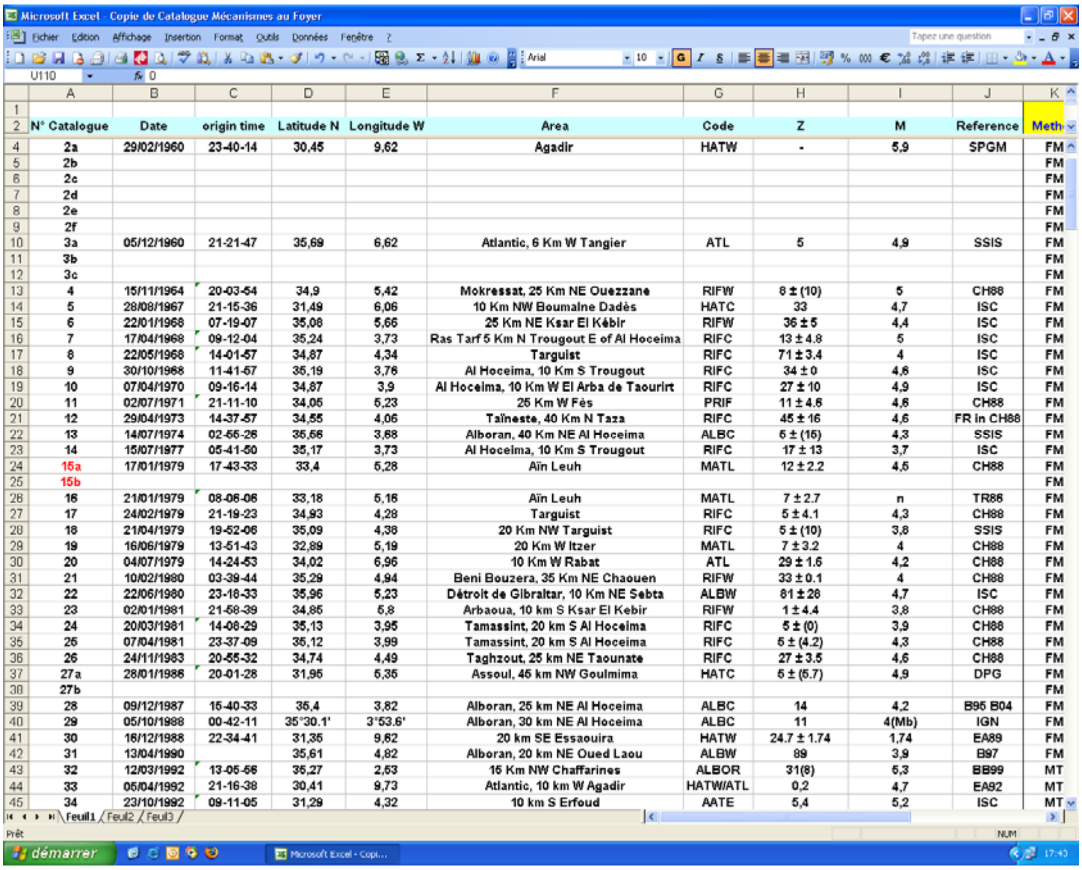
We present the distribution of fault-plane solutions by geological domains, namely: (i) the western Rif, western Alboran and Rif foreland; (ii) central Rif and central Alboran; (iii) eastern Rif and eastern Alboran; and (iv), the Atlas chains and their Atlantic neighboring areas[1].

Western Rif, Western Alboran and Rif foreland

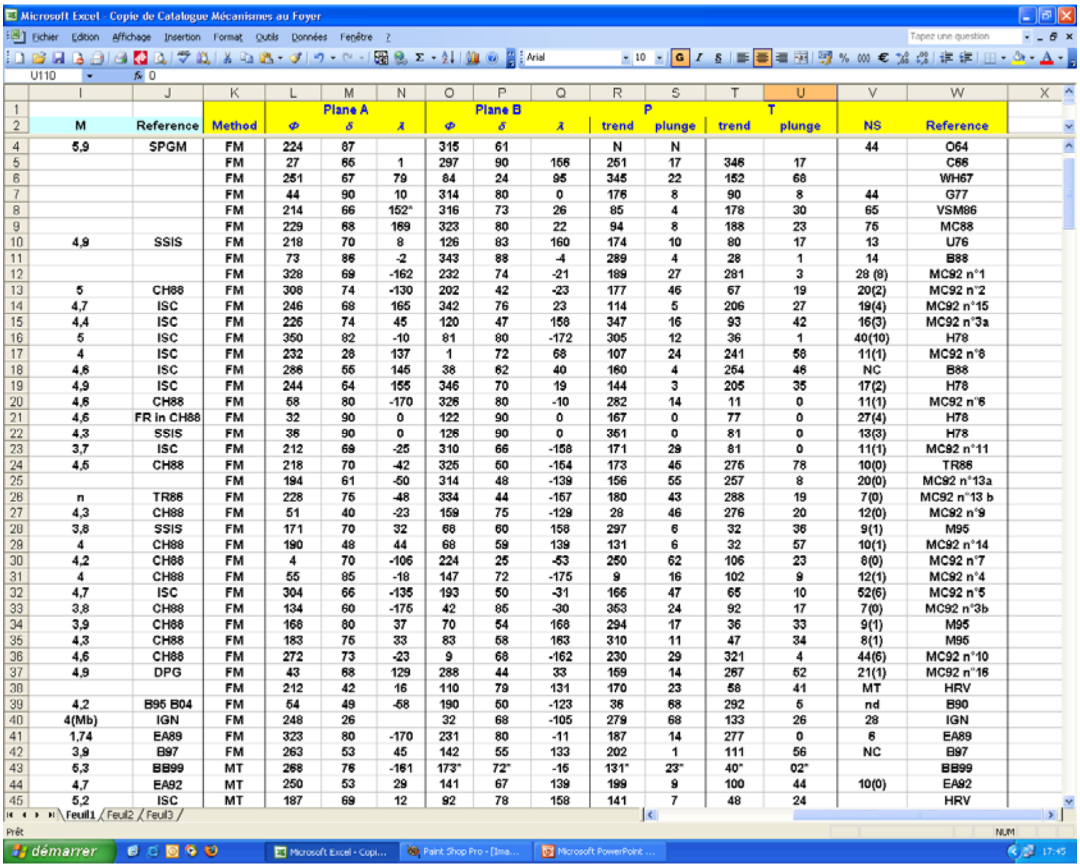
In this area, 19 solutions were determined, among which 7 correspond to reverse faulting, 5 to normal faulting and 7 to strike-slip faulting (Fig. 3).

In the Rif foreland, the earthquakes of Rabat-Kénitra area show various solutions; a normal motion with E-W

[1] For detailed references on mechanisms, the reader should refer to the companion catalogue published in 2008 (available online from www.israbat.ac.ma)



	N° Catalogue	Date	origin time	Latitude N	Longitude W	Area	Code	Z	M	Reference	Meth
4	2a	29/02/1960	23-40-14	30,45	9,62	Agadir	HATW	-	5,9	SPGM	FM
5	2b										FM
6	2c										FM
7	2d										FM
8	2e										FM
9	2f										FM
10	3a	05/12/1960	21-21-47	35,69	6,62	Atlantic, 6 Km W Tangier	ATL	5	4,9	SSIS	FM
11	3b										FM
12	3c										FM
13	4	15/11/1964	20-03-54	34,9	5,42	Mokressat, 25 Km NE Ouezzane	RIFW	8 ± (10)	5	CH88	FM
14	5	28/08/1967	21-15-36	31,49	6,06	10 Km NW Boumalne Dadès	HATC	33	4,7	ISC	FM
15	6	22/01/1968	07-19-07	35,08	5,66	25 Km NE Ksar El Kébir	RIFW	36 ± 5	4,4	ISC	FM
16	7	17/04/1968	09-12-04	35,24	3,73	Ras Tarf 5 Km N Trougout E of Al Hoceima	RIFC	13 ± 4.8	5	ISC	FM
17	8	22/05/1968	14-01-57	34,87	4,34	Targuist	RIFC	71 ± 3.4	4	ISC	FM
18	9	30/10/1968	11-41-57	35,19	3,76	Al Hoceima, 10 Km S Trougout	RIFC	34 ± 0	4,6	ISC	FM
19	10	07/04/1970	09-16-14	34,87	3,9	Al Hoceima, 10 Km W El Arba de Taourirt	RIFC	27 ± 10	4,9	ISC	FM
20	11	02/07/1971	21-11-10	34,05	5,23	25 Km W Fès	PRIF	11 ± 4.6	4,6	CH88	FM
21	12	29/04/1973	14-37-57	34,55	4,06	Taïneste, 40 Km N Taza	RIFC	45 ± 16	4,6	FR in CH88	FM
22	13	14/07/1974	02-56-26	35,56	3,68	Alboran, 40 Km NE Al Hoceima	ALBC	5 ± (15)	4,3	SSIS	FM
23	14	15/07/1977	05-41-50	35,17	3,73	Al Hoceima, 10 Km S Trougout	RIFC	17 ± 13	3,7	ISC	FM
24	15a	17/01/1979	17-43-33	33,4	5,28	Aïn Leuh	MATL	12 ± 2.2	4,5	CH88	FM
25	15b										FM
26	16	21/01/1979	08-06-06	33,18	5,16	Aïn Leuh	MATL	7 ± 2.7	n	TR86	FM
27	17	24/02/1979	21-19-23	34,93	4,28	Targuist	RIFC	5 ± 4.1	4,3	CH88	FM
28	18	21/04/1979	19-52-06	35,09	4,38	20 Km NW Targuist	RIFC	5 ± (10)	3,8	SSIS	FM
29	19	16/06/1979	13-51-43	32,89	5,19	20 Km W Itzer	MATL	7 ± 3.2	4	CH88	FM
30	20	04/07/1979	14-24-53	34,02	6,96	10 Km W Rabat	ATL	29 ± 1.6	4,2	CH88	FM
31	21	10/02/1980	03-39-44	35,29	4,94	Beni Bouzera, 35 Km NE Chaouen	RIFW	33 ± 0.1	4	CH88	FM
32	22	22/06/1980	23-16-33	35,96	5,23	Détroit de Gibraltar, 10 Km NE Sebta	ALBW	81 ± 26	4,7	ISC	FM
33	23	02/01/1981	21-58-39	34,85	5,8	Arbaoua, 10 km S Ksar El Kebir	RIFW	1 ± 4.4	3,8	CH88	FM
34	24	20/03/1981	14-08-29	35,13	3,95	Tamassint, 20 km S Al Hoceima	RIFC	5 ± (0)	3,9	CH88	FM
35	25	07/04/1981	23-37-09	35,12	3,99	Tamassint, 20 km S Al Hoceima	RIFC	5 ± (4.2)	4,3	CH88	FM
36	26	24/11/1983	20-55-32	34,74	4,49	Taghzout, 25 km NE Taounate	RIFC	27 ± 3.5	4,6	CH88	FM
37	27a	28/01/1986	20-01-28	31,95	5,35	Assoul, 45 km NW Goulmima	HATC	5 ± (5.7)	4,9	DPG	FM
38	27b										FM
39	28	09/12/1987	15-40-33	35,4	3,82	Alboran, 25 km NE Al Hoceima	ALBC	14	4,2	B95 B04	FM
40	29	05/10/1988	00-42-11	35°30.1'	3°53.6'	Alboran, 30 km NE Al Hoceima	ALBC	11	4(Mb)	IGN	FM
41	30	16/12/1988	22-34-41	31,35	9,62	20 km SE Essaouira	HATW	24.7 ± 1.74	1,74	EA89	FM
42	31	13/04/1990		35,61	4,82	Alboran, 20 km NE Oued Laou	ALBW	89	3,9	B97	FM
43	32	12/03/1992	13-05-56	35,27	2,53	15 Km NW Chaffarines	ALBOR	31(8)	5,3	BB99	MT
44	33	05/04/1992	21-16-38	30,41	9,73	Atlantic, 10 km W Agadir	HATW/ATL	0,2	4,7	EA92	MT
45	34	23/10/1992	09-11-05	31,29	4,32	10 km S Erfoud	AATE	5,4	5,2	ISC	MT



				Plane A			Plane B			P		T			
	M	Reference	Method	Φ	δ	λ	Φ	δ	λ	trend	plunge	trend	plunge	NS	Reference
4	5,9	SPGM	FM	224	87		315	61		N	N			44	O64
5			FM	27	65	1	297	90	156	251	17	346	17		C66
6			FM	251	67	79	84	24	95	345	22	152	68		WH67
7			FM	44	90	10	314	80	0	176	8	90	8	44	G77
8			FM	214	66	152*	316	73	26	85	4	178	30	65	VSM86
9			FM	229	68	169	323	80	22	94	8	188	23	75	MC88
10	4,9	SSIS	FM	218	70	8	126	83	160	174	10	80	17	13	U76
11			FM	73	86	-2	343	88	-4	289	4	28	1	14	B88
12			FM	328	69	-162	232	74	-21	189	27	281	3	28 (8)	MC92 n°1
13	5	CH88	FM	308	74	-130	202	42	-23	177	46	67	19	20(2)	MC92 n°2
14	4,7	ISC	FM	246	68	165	342	76	23	114	5	206	27	19(4)	MC92 n°15
15	4,4	ISC	FM	226	74	45	120	47	158	347	16	93	42	16(3)	MC92 n°3a
16	5	ISC	FM	350	82	-10	81	80	-172	305	12	36	1	40(10)	H78
17	4	ISC	FM	232	28	137	1	72	68	107	24	241	58	11(1)	MC92 n°8
18	4,6	ISC	FM	286	55	145	38	62	40	160	4	254	46	NC	B88
19	4,9	ISC	FM	244	64	155	346	70	19	144	3	205	35	17(2)	H78
20	4,6	CH88	FM	58	80	-170	326	80	-10	282	14	11	0	11(1)	MC92 n°6
21	4,6	FR in CH88	FM	32	90	0	122	90	0	167	0	77	0	27(4)	H78
22	4,3	SSIS	FM	36	90	0	126	90	0	361	0	81	0	13(3)	H78
23	3,7	ISC	FM	212	69	-25	310	66	-158	171	29	81	0	11(1)	MC92 n°11
24	4,5	CH88	FM	218	70	-42	325	50	-154	173	45	275	78	10(0)	TR86
25			FM	194	61	-50	314	48	-139	156	55	257	8	20(0)	MC92 n°13a
26	n	TR86	FM	228	75	-48	334	44	-157	180	43	288	19	7(0)	MC92 n°13 b
27	4,3	CH88	FM	51	40	-23	159	75	-129	28	46	276	20	12(0)	MC92 n°9
28	3,8	SSIS	FM	171	70	32	68	60	158	297	6	32	36	9(1)	M95
29	4	CH88	FM	190	48	44	68	59	139	131	6	32	57	10(1)	MC92 n°14
30	4,2	CH88	FM	4	70	-106	224	25	-53	250	62	106	23	8(0)	MC92 n°7
31	4	CH88	FM	55	85	-18	147	72	-175	9	16	102	9	12(1)	MC92 n°4
32	4,7	ISC	FM	304	66	-135	193	50	-31	166	47	65	10	52(6)	MC92 n°5
33	3,8	CH88	FM	134	60	-175	42	85	-30	353	24	92	17	7(0)	MC92 n°3b
34	3,9	CH88	FM	168	80	37	70	54	168	294	17	36	33	9(1)	M95
35	4,3	CH88	FM	183	75	33	83	58	163	310	11	47	34	8(1)	M95
36	4,6	CH88	FM	272	73	-23	9	68	-162	230	29	321	4	44(6)	MC92 n°10
37	4,9	DPG	FM	43	68	129	288	44	33	169	14	267	52	21(1)	MC92 n°16
38			FM	212	42	16	110	79	131	170	23	58	41	MT	HRV
39	4,2	B95 B04	FM	54	49	-58	190	50	-123	36	68	292	5	nd	B90
40	4(Mb)	IGN	FM	248	26		32	68	-105	279	68	133	26	28	IGN
41	1,74	EA89	FM	323	80	-170	231	80	-11	187	14	277	0	6	EA89
42	3,9	B97	FM	263	53	45	142	55	133	202	1	111	56	NC	B97
43	5,3	BB99	MT	268	76	-161	173"	72"	-16	131"	23"	40"	02"		BB99
44	4,7	EA92	MT	250	53	29	141	67	139	199	9	100	44	10(0)	EA92
45	5,2	ISC	MT	187	69	12	92	78	158	141	7	48	24		HRV

Figure 2. Presentation of the Catalogue of focal mechanisms. Upper panel: epicentre parameters; lower panel: mechanism parameters.

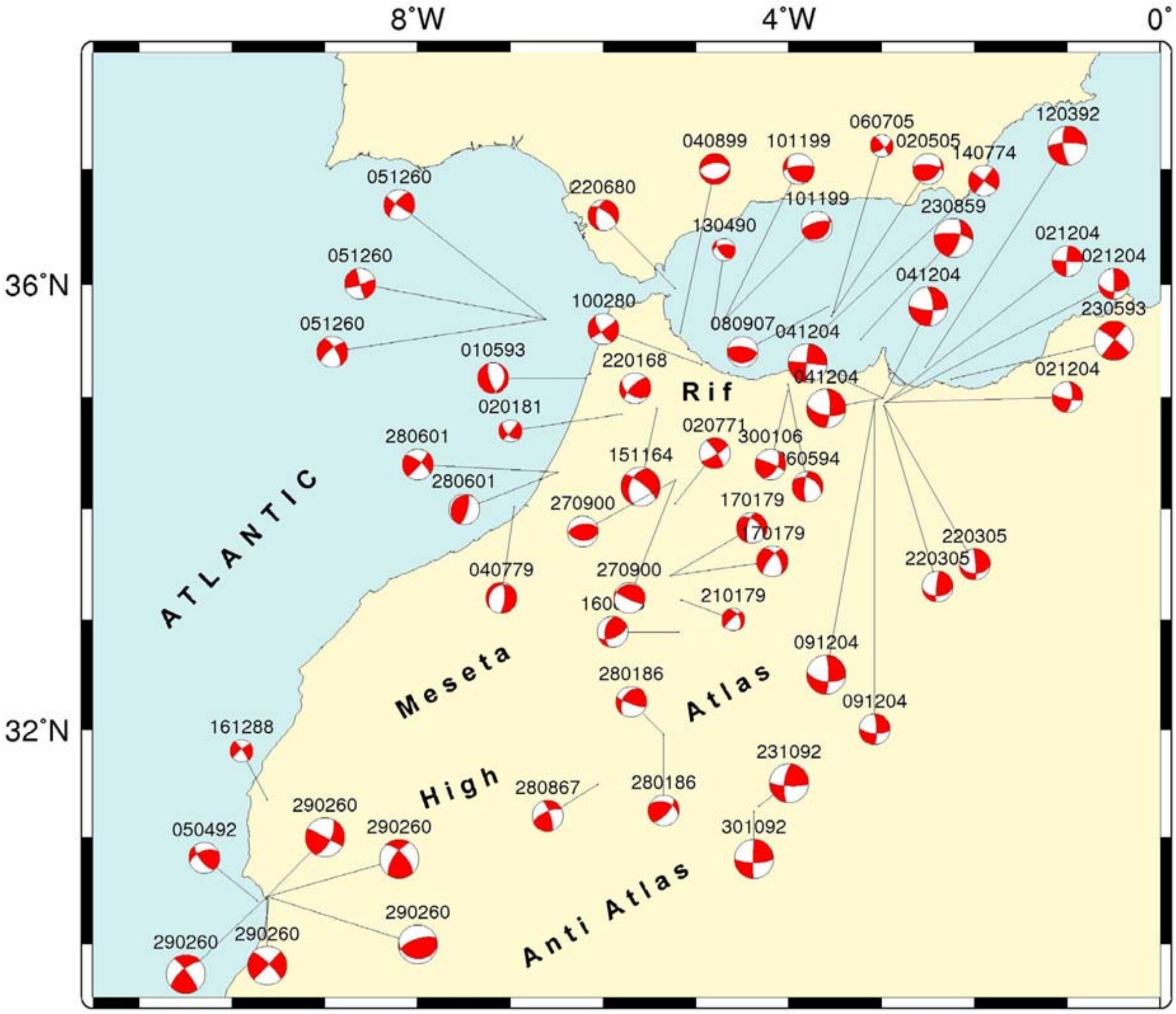


Figure 3. Geographical distribution of focal mechanisms in Morocco (Western and Eastern Rif and Alboran areas, Atlantic and High Atlas chains).

trending T-axis has been determined for the 04/07/1979 Rabat event (Medina & Cherkaoui 1992). Concerning Kenitra earthquake of 28/06/2001, two contradictory MT solutions were published, one is reverse (MED) with E-W trending P-axis, the other (ZUR) as strike-slip, with N-S trending P-axis. Northwest of Fès, the two solutions determined by ZUR and MED for the event of 27/09/2000 are similar, corresponding to reverse faulting with N-S trending P-axis. The strike-slip mechanism located west of Fès is much less reliable (see original data in Medina & Cherkaoui 1992).

Further to the north, 4 solutions located within the Western Rif correspond to strike slip faulting with normal or reverse components. The P-axes are roughly N-S.

In the western Alboran area, the solutions determined for 2 intermediate events are homogeneous and correspond to reverse faulting with roughly N-S trending P-axes. The intermediate event near Sebta in the Gibraltar straits, shows normal faulting with NE-SW trending P-axis. The mechanism of the shallow earthquake of Tetouan (04/08/1999) shows pure normal faulting with N-S trending T-axis.

Finally, 4 solutions were determined for the events of the Atlantic area west of the Gibraltar Straits. They correspond to strike-slip faulting with NW-SE to NNE-SSW trending P-axis in the case of the 05/12/1960 event, and to normal faulting with E-W trending T-axis in the other.

Central Rif and Central Alboran

The Central Rif and Central Alboran areas are the most seismic regions of Morocco (Fig. 1). Most of the mechanisms determined onshore (Fig. 4) correspond to the Al Hoceima earthquake aftershocks of 2004. Mechanisms are mainly strike-slip, with the P- and T-axes trending respectively NNW-SSE and ENE-WSW (Figs 4). These strike-slip solutions have mainly a small to moderate normal component. A fewer number of mechanisms show either normal faulting with ENE-trending T-axes, or reverse faulting with NW-SE (Al Hoceima) and NNE-SSW (Alboran) trending P-axes.

Eastern Rif and Eastern Alboran

In the Nador area (Eastern Rif) and Eastern Alboran, the 10 available mechanisms are quite homogeneous,

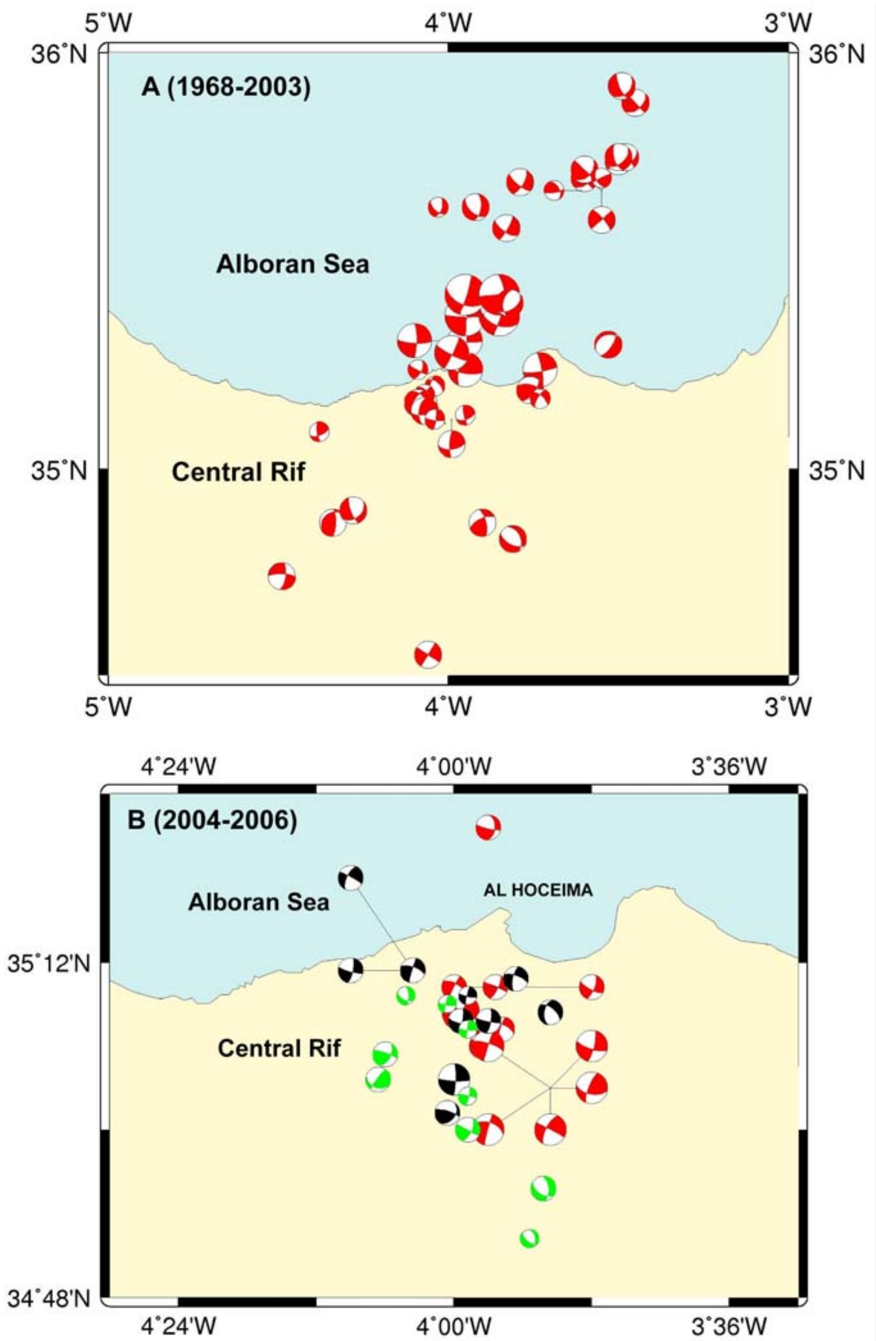


Figure 4. Geographical distribution of focal mechanisms in the Al Hoceima area. A, from 1968 to 2003; B, From 2004 to 2006.

corresponding to strike slip faulting with normal (6 cases) or reverse faulting, with all P-axes oriented NW-SE, except for the event of 23/05/1993 which shows a E-W oriented P-axis (Fig. 3).

Atlas chains and Atlantic area of Agadir

No new mechanisms are available for the Atlas chains since those studied by Medina & Cherkaoui (1991, 1992) and El Alami *et al*. (1992) (Fig. 3), except for Harvard's solutions applied to Assoul earthquake of 28/01/1986 and to Rissani earthquakes of 23/10/1992 and 30/10/1992.

In the Middle Atlas, there are only four mechanisms determined for the Aïn Leuh (17/01/1979) and Aït Oufella (16/06/1979) earthquakes. The three solutions for Aïn Leuh correspond to normal faulting with WSW-ENE to WNW-ESE trending T-axes, while the Aït Oufella solution shows reverse faulting with NW-SE trending P-axis.

The focal mechanism solutions of the Central High Atlas earthquakes were mainly determined for the Assoul 28/08/1967 and 28/01/1986 events. All correspond to reverse faulting with a more or less large strike-slip component. The trends of the P-axes are NW-SE in the three cases.

In the western High Atlas, the mechanism of the Agadir earthquake of 29/02/1960 is still being debated because of the contradictory solutions (Fig. 3). The more recent solution of the 05/04/1992 earthquake indicates reverse faulting.

Finally, the focal mechanisms of the Erfoud-Rissani earthquakes of 23/10/1992 and 30/10/1992 are similar to each other, corresponding to strike-slip faulting with P-axes trending NW-SE. New solutions based on P wave first motions (Bensaid *et al*. 2009) are similar to those provided by Harvard.

INTERPRETATION AND DISCUSSION

Distribution of P- and T-axes vs. state of stress

Distribution of all the P- and T-axes of the solutions (Fig. 5) shows that strike-slip faulting dominates. The latter regime is characterized by nearly horizontal P-axes clusters trending NNW-SSE (N300-350; N140-180), and also nearly horizontal T-axes trending ENE-WSW (N40-80; N220-270). Normal and reverse fault-plane solutions are reflected by steeply plunging P- and T-axes respectively.

A few directionally discrepant P- and T-axes (E-W and N-S), correspond to solutions suggested by various authors for the 1960 Agadir earthquake.

Several studies have attempted to determine the state of stress in the Ibero-Maghrebian area from focal mechanism solutions involving kinematic methods (Medina 1995, Fernandez-Ibañez *et al.* 2007) or dynamic approaches (El Alami *et al*. 1998, Henares *et al*. 2003, Medina & El Alami 2006, Stich *et al*. 2006, de Vicente *et al*. 2008). As discussed in previous papers (Medina 1995, Medina & El Alami 2006), the main problem that hampers the determination of the stress state is the heterogeneous character of the mechanisms' populations due to the occurrence of all possible tectonic regimes reflected by simultaneous compression and extension stress in Alboran and Rif areas. Therefore, the best determinations appear to be those that only take into account the main shock and its largest aftershocks.

Anyway, the P-axis distribution shows a good fit with the trend of the maximum compressional stress determined by most authors, as well as with the plate displacement vector showing N320°E trend in the Al Hoceima area (models NUVEL-1 et NUVEL-1A). This trend matches the NW-SE compressional stress determined for Plio-Quaternary times, and is slightly oblique to the plate displacement vector determined from GPS measurements (McClusky *et al.* 2003), which is oriented N116E (N296).

However, it should be noted that in the Rif chain tectonic complex regime is involving extension and especially lateral escape of fault-delimited blocks (Chalouan *et al.* 2006).

Remarks on the discrepancies observed between Centres

For moment tensor solutions, some discrepancy was observed between different centres (Fig. 6). In order to find out how discrepant are the solutions, the focal mechanisms determined by IGN, IAG and MED for the same events of the Al Hoceima seismic crises, were compared in Frohlisch & Apperson triangles (Fig. 7). These plots readily show that IGN solutions follow a path parallel to the B–T side (P-axis plunge close to 0°), whereas those of IAG are offset towards the P-axis pole. The dashed lines in figure 7 are traced to show the differences between two solutions of the same event and may be regarded as a "discrepancy index". MED solutions plotted against IAG ones are further offset towards the P-axis. The tectonic implications of such discrepancies are dramatic, since the use of different data sources may lead to different interpretations: transpression using IGN data, transtension using IAG or MED data.

The parameters used for MT calculations are not clearly exposed by the institutions in their catalogues (Earth model, Green's function…). However, the problem can be addressed by preferring the solutions with the following features: (i) hand-determined MT (vs. automatic rapid-MT which are not revised); (ii) the largest number of stations used and the quality of station coverage, which allow a better solution; (iii) the smallest non-double-couple component (CLVD) of the moment tensor (although faults may have a large one, depending on the mechanics of faulting, as stated by Julian *et al*. 1998). These constraints favour the IAG catalogue (de Vicente *et al*. 2008), which has been elaborated on the base of a research project, while IGN and MED fast MT solutions are calculated automatically a short time after the event and are not revised.

Relationship with faults

At a regional scale, the seismicity maps of Morocco show that several epicentres of earthquakes and their aftershocks appear to be aligned along specific trends, especially in the Al Hoceima area as well as in western Alboran (Cherkaoui *et al*. 1990, Calvert *et al.* 1997, El Alami *et al.* 1998, Buforn *et al.* 2004, Dorbath *et al.* 2005). However, the field relationship of seismicity to inferred active faults is generally still not well established, because of several factors which may be of different origin:

(i) Seismological origin, such as the distributed character of seismicity (Fig. 1), the low magnitude of earthquakes (Cherkaoui 1988), the relatively deep foci with respect to the surface traces of the faults (Cherkaoui 1988), and errors in hypocentral determination (depth, location)…

(ii) Geological origin, such as the decoupling of fault planes or "mechanical stratification" (Galindo-Zaldívar *et al*. 2009), and relatively deep blind faults (e.g. Tahayt *et al.* 2008, Mridekh *et al*. 2009).

(iii) Research and technical issues, such as an inadequate geometry of the seismic network (in particular with respect to the south Atlas Front), the absence of field aftershock studies, and the absence of maps of active faults, with the exception of that of Faure-Muret *et al*. (1994), which needs be updated.

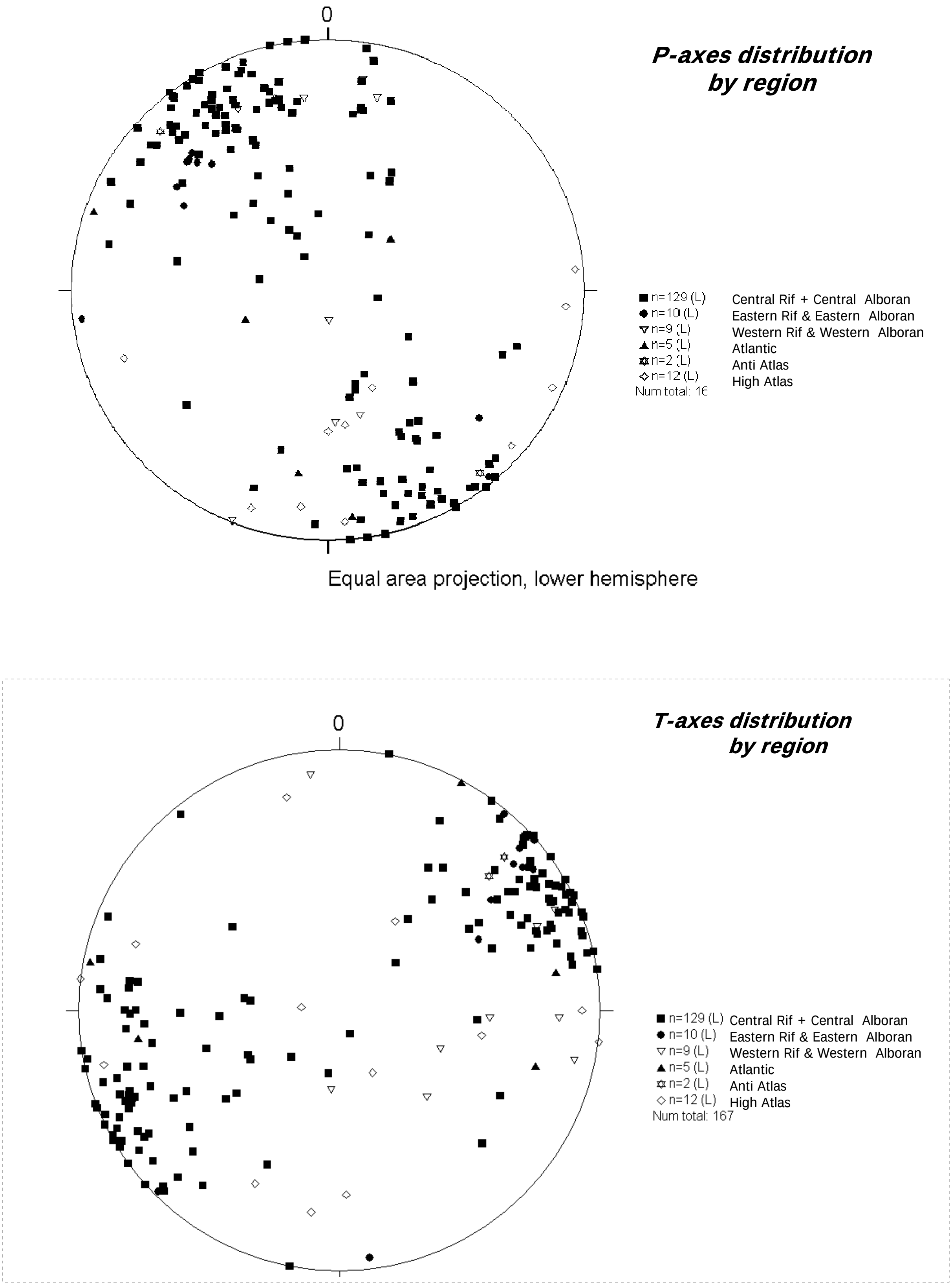


Figure 5. Stereograms of P- (upper panel) and T (lower panel) axes distribution by regions (equal area, lower hemisphere, stereonet software).

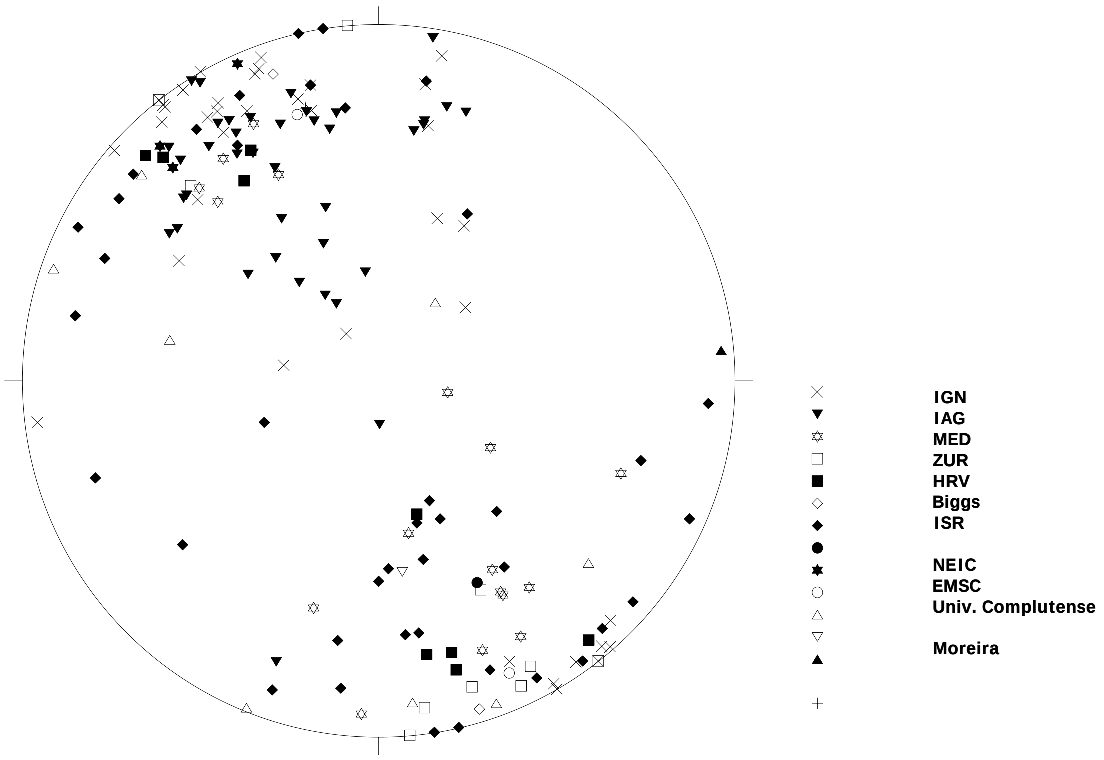


Figure 6. Stereogram of distribution of the P-axes of solutions determined by various institutions and researchers

Therefore, the focal depths are seldom consistent with those of the supposed active faults planes, so it becomes difficult to relate the observed faults and the epicentres.

These problems can be overcome by more field studies of neotectonic structures, and using new techniques; for instance, in the Agadir area, renewed study of the deformations around the city has led to constrain the fault zone related to the 1960 earthquake (Meghraoui *et al.* 1998); other recent studies following the Al Hoceima earthquakes of 1994 and 2004 have visualized, with the help of InSAR radar data, the main faults that generated the earthquakes, which, however, were not so evident in the field (El Alami *et al.* 1998, Biggs *et al.* 2006, Tahayt *et al.* 2008).

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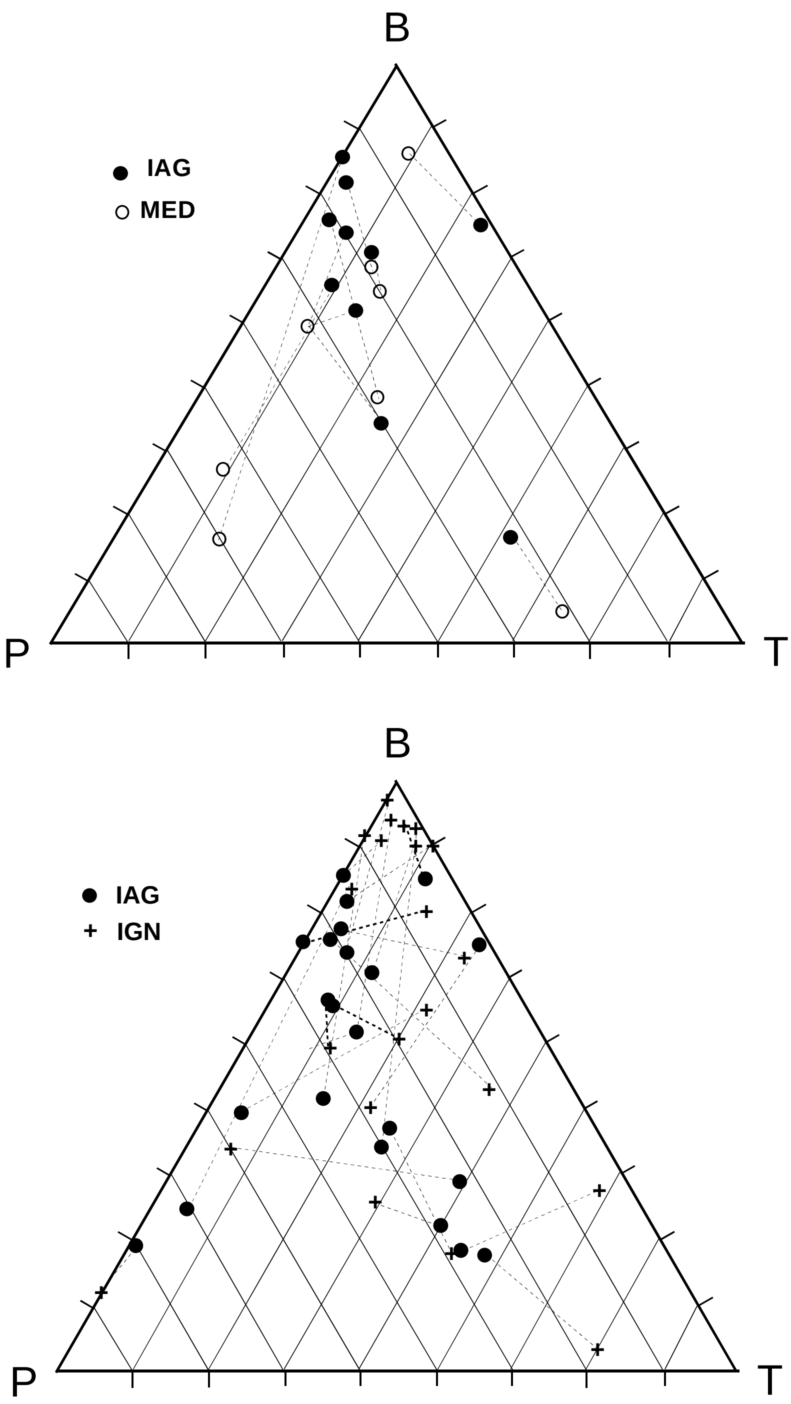

Figure 7. Frohlich & Apperson diagrams for focal mechanisms determined by IGN, IAG and MED. The dashed lines connect points corresponding to the same events (after Medina 2008).

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