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Newsletter

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EDITORIAL

The most disastrous earthquake in the past year, occurred in Iran, centred on the town of Bam, on 26 December, with over 40,000 fatalities. This latest reminder of the human impact of our subject underlines the value of our community's work to understand earthquakes, their hazards, causes and effects, and to seek ways of mitigating such disasters. To this end, EMSC is extending its activities in two most relevant ways, at present. Remy Bossu has been pursuing an opportunity to help rebuild and develop seismology in south-eastern Europe, which has been held back through the turmoil of recent years. Its seismicity remains poorly monitored, cross-border data exchange is limited, expertise is low and connections with the engineering community non-existent. There is the potential for countries to be overwhelmed by the next large earthquake. Working with the "Stability Pact" initiative for the region, EMSC in coordination with ORFEUS is helping to create a framework and programme to build a modern capacity over the next few years.

We are also working to achieve funding and development for a rapid damage prediction service both for the Euro-Med region and more globally, which would help in focussing national resources on preparedness and both national and international efforts in the immediate aftermath of a destructive earthquake.

Alongside these initiatives, the core EMSC service is being maintained and gradually improved with our members' support. Most recently, our thanks are especially due to LDG for the provision of a complete upgrade of computer hardware.

Chris Browitt
President

CONTENT

News from EMSC

Group photo of the ***Meeting of South Eastern European Seismologists.***
Ig, near Ljubljana, Slovenia 16-18 November 2003 during which the proposal was finalised

Upgrading Seismological Networks in South-Eastern Europe

Last November, the *Meeting of South Eastern European Seismologists* organised by the EMSC, the Seismological Office of the Environmental Agency of the Republic of Slovenia, and the Disaster Preparedness and Prevention Initiative (DPPI) of the Stability Pact for SE-Europe was held in Ig (Slovenia) with the support of the Ministry of Defence, Administration for Civil Protection and Disaster Relief and the Ministry for Foreign Affairs of the Republic of Slovenia.

First a brief history! This meeting was the result of a long process initiated by the occurrence of the ML5.2 Gnjilane earthquake (Serbia and Montenegro) on April 24th 2002. This event clearly illustrated the difficulty to locate earthquake in this region due to the limited data available. Discussions have started with our colleagues from the region to evaluate how seismological networks could be upgraded and EMSC agreed to look for potential sources of funding. Finally, in July 2003, we heard about the Disaster Preparedness and Prevention Initiative (DPPI) of the Stability Pact for SE-Europe and got in contact with its Executive Secretary, Mrs C. Krajic-Tomin. DPPI offers a framework for 12 countries of SE-Europe (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, FYR of Macedonia, Greece, Hungary, Moldova, Romania, Serbia and Montenegro, Slovenia and Turkey) and as its name states, deals with preparedness and prevention. It was then decided to focus our proposal on real-time seismic monitoring as a contribution for crisis management. Institutes in charge of informing their authorities in case of an earthquake have been contacted and a team of 15 institutes from the 12 countries has been set up with the efficient help of Nicholas Voulgaris (Athens Univ.) who had previously worked on a similar initiative. ORFEUS joined our efforts to accurately define the current status of the different networks and to identify the needs. We then decided to organise a meeting to finalise the proposals. There are many people to be thanked for this meeting. I would like to mention first Mladen Zvicic who has locally organised it and who has been persuasive enough to get strong support in Slovenia and make this meeting very cheap. Mrs C. Krajic-Tomin managed to secure the funds necessary to make it happen. Winfried Hanka (GFZ/GEOFON), Salvatore Mazza and Marco Olivieri (INGV/MedNet) thanks to their large experience, provided very useful expertise and advice during the discussions. Peter Suhadolc (Secretary General of IASPEI) chaired a session to demonstrate IASPEI's support for this initiative. There was an excellent working atmosphere and a strong willingness to collaborate during the meeting and together we defined a proposal based on bi-lateral and multilateral collaborations.

The proposal was finally sent early December to the DPPI. Since then, there has been a large lobbying activity, not only from the project partners but also from a large proportion of EMSC members who lobbied their government for potential financial support. We are still trying to improve the project and notably its training component. We are looking for Institutes to host visiting seismologists from some of the DPPI countries for periods up to a year to build-up expertise in observational seismology (any suggestion is welcome!).

Today, we do not know whether the project will be funded but we strongly

On the use of EMSC services

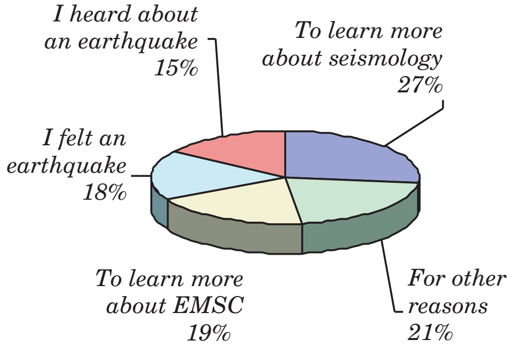

Figure 1: *Why did you fisrt access EMSC web site ?*

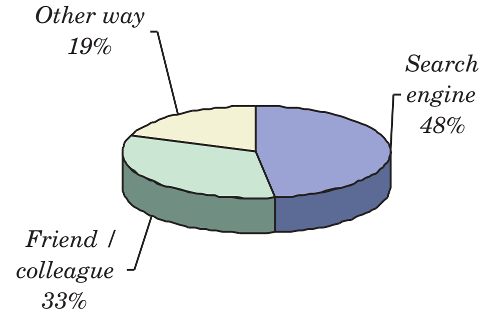

Figure 2: *How EMSC web site was first reached?*

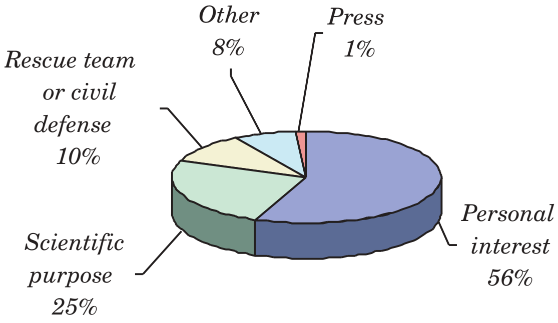

Figure 3: *The use of EMSC alert services*

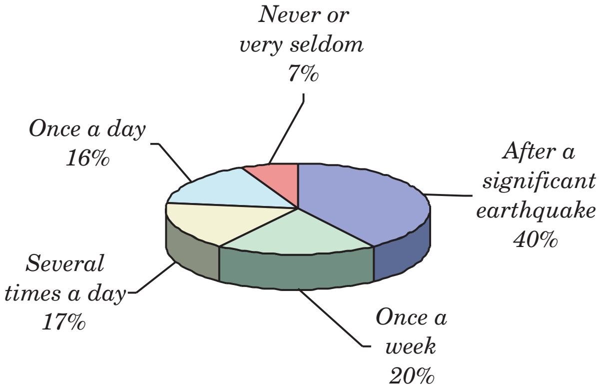

Figure 4: *Periodicity of visits*

believe that this project is important and timely as the integration process of the European seismological community is going on. We will keep you informed on the future developments and the complete proposal and the list of participants can be found on the EMSC web site (www.emsc-csem.org/Html/BALKANS.html)

On the use of EMSC alert service

A survey has been performed to analyse the use of EMSC alert service. Three hundred and ten users completed the questionnaire (among 1,300 recipients). Half of the users first visited EMSC web site to get information on a specific event or on seismology (Figure 1). Forty eight percent find the site using search engines and 33% following get the address by a friend or a colleague (Figure 2). The majority of our users are driven by their personal interest (56%), a quarter of them by scientific purpose and 10% uses the alert for rescue or civil defence purposes (Figure 3). The are two main types of users of EMSC web site: a third are regular visitors with at least one visit a day while half of the visitors visit the site only in rare occasions or only after a damaging earthquake (Figure 4).

When asked about the necessary improvements of the current service, end-users have mentioned many items notably the addition of clickable maps, the description of the site content for non-specialists and information on potential damage. We will do our best to implement these changes/improvements as rapidly as possible and we thanks all the participants for their valuable inputs.

New applications for EMSC membership

Three new Institutes have been discussing with us their possible EMSC membership: the Seismological Observatory of Republic Macedonia (FYROM), the Centre of Experimental Seismology (Moldova), and the Seismological Survey of Serbia (Serbia and Montenegro). So, our membership continues to expand and these new members will be joining the EMSC community during our next General Assembly to be held next September in Potsdam during the ESC meeting.

The database of Earthquake Mechanisms of the Mediterranean Area (EMMA): a call for contributions

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Abstract

We present to CSEM/EMSC community a database on MS-ACCESS platform of revised fault plane solutions, taken from the literature, including earthquakes which occurred in the Mediterranean and in surrounding regions. A PC installable CD-ROM is freely available, for scientific purposes, to all investigators upon e-mail request to the writers' addresses:
vannucci@bo.ingv.it, paolo.gasperini@unibo.it.
We also want to take advantage of this occasion to make a request to the authors of papers not already included, to cooperate to next releases of the database by signaling us missing and/or new data and possibly sending the numerical parameters by e-mail or other computer media. Any correction, recommendation or suggestion is also heartily welcome. A new release of the database is planned for mid summer 2004, the

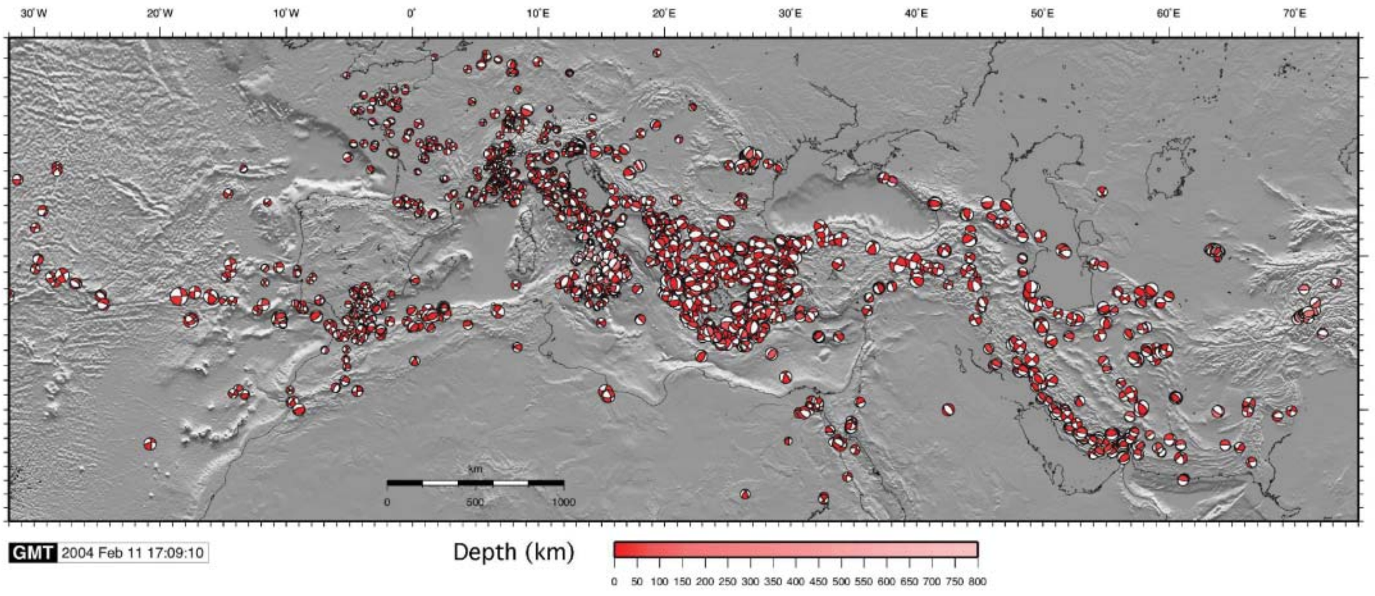


Figure 1: *Spatial distribution of fault plane solutions taken from the literature (on-line CMT catalogs excluded).*

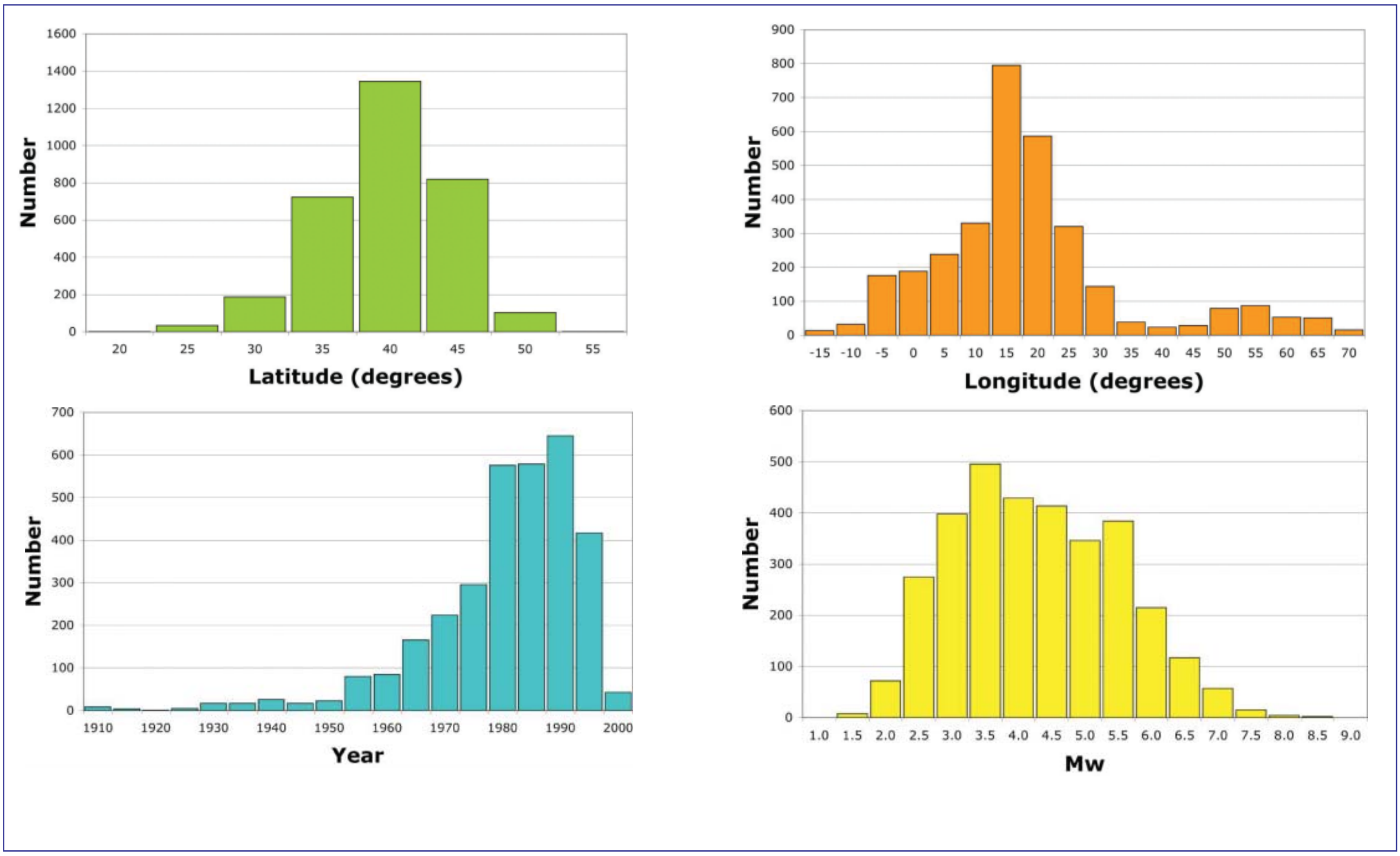


Figure 2: *Distribution in space, time and magnitude of earthquakes included in EMMA database.*

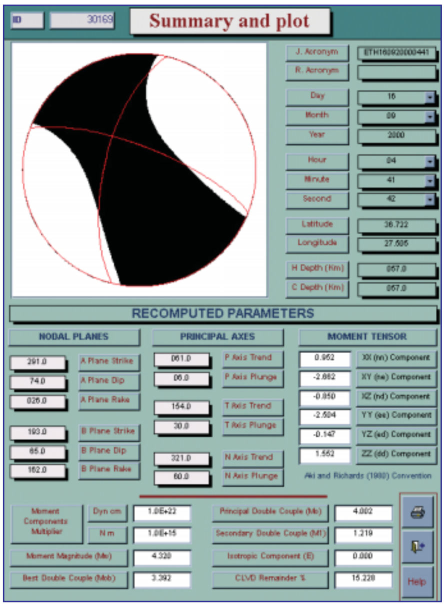
approximate deadline for contributors is at end of May 2004.

Motivations of the work

The analysis of earthquake focal mechanism data is the most common tool to characterize the tectonic style of a seismogenic area and to estimate stress and strain principal directions and rates. The global CMT on-line catalog, continuously updated by the Harvard Seismology team (Dziewonski et al., 1981 and subsequent papers appeared quarterly on *Phys Earth Plan. Int.,* available at address: http://www.seismology.harvard.edu/projects/CMT/), gives a rather detailed and complete description of seismic styles for most areas of the globe where the occurrence rate of earthquakes above the catalog magnitude threshold (about Mw≥5.5) is relatively high. This is the case for example of eastern Mediterranean area, where several hundreds of CMT mechanisms are available since 1976 but it is not true for central and western sectors of this sea. In the last few years (since 1997 and 1999 respectively), two Regional CMT (RCMT) catalogs of the Mediterranean Region were also made available by the *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) of Rome (Pondrelli et al, 2002, available at address: http://www.ingv.it/seismoglo/RCMT/) and by the *Eidgenössische Technische Hochschule* (ETH) of Zürich (Braunmiller et al., 2002, available at address: http://seismo.ethz.ch/info/mt.html) including earthquakes with about Mw≥4.5.

However, for certain areas like Italy and central Europe, where seismic activity is moderate or low, the recourse to solutions published in the literature (mainly first motion) still represents the only way to focus on the fine details of seismotectonic pattern. This is particularly important in probabilistic seismic hazard assessment (PSHA) studies where this information is very useful for example to establish the seismic zonation to be used in computations.

Just in the ambit of Framework Project 2000/2002 of the Italian *Gruppo Nazionale Difesa dai Terremoti* (GNDT), devoted to the revision of seismic hazard assessment in Italy, we have started the collection of fault plane solutions, for the Italian regions, published on national and international journals. The area of interest has been extended later to include the entire Mediterranean Sea and surrounding regions. At present time we have collected in all 5100 mechanisms coming from 141 papers, some of which also report data from other sources that we were not able to examine directly (about 200). We anyhow recorded for each solution both direct bibliographic references



ID 30169

J. Acronym ETH160920000441
R. Acronym
Day 16
Month 09
Year 2000
Hour 04
Minute 41
Second 42
Latitude 36.722
Longitude 27.606
H Depth (Km) 067.0
C Depth (Km) 067.0

291.0 A Plane Strike
74.0 A Plane Dip
026.0 A Plane Rake
193.0 B Plane Strike
65.0 B Plane Dip
162.0 B Plane Rake

061.0 P Axis Trend
06.0 P Axis Plunge
154.0 T Axis Trend
30.0 T Axis Plunge
321.0 N Axis Trend
60.0 N Axis Plunge

0.962 XX (nn) Component
-2.682 XY (ne) Component
-0.850 XZ (nd) Component
-2.504 YY (ee) Component
-0.147 YZ (ed) Component
1.552 ZZ (dd) Component
Aki and Richards (1980) Convention

Moment Components Multiplier Dyn cm 1.0E+22
N m 1.0E+15
Moment Magnitude (Mw) 4.320
Best Double Couple (Mob) 3.392
Principal Double Couple (Mo) 4.002
Secondary Double Couple (M1) 1.219
Isotropic Component (E) 0.000
CLVD Remainder % 15.228

Figure 3: *Summary mask with plot of mechanism (red lines indicate best double couple nodal planes).*

Region	Relations	Reference
Italy and surrounding areas ($34 \leq latitude \leq 45$, $6 \leq longitude \leq 19.5$)	$LogM_0=19.3+0.96Ms$ $LogM_0=17.9+1.21mb$ $LogM_0=17.7+1.22Ml$	Gasperini and Ferrari (2000)
All others	$LogM_0=24.66-1.083Ms+0.192Ms^2$ $LogM_0=18.28+0.679mb+0.077mb^2$ $LogM_0=18.31+1.017Ml$	Johnston, (1996)

Table 1: *LogMo-magnitude regressions used in the database*

(actually examined) as well as indirect ones (only referred by other sources).

During this preliminary stage we verified that a significant fraction of published data (about 1/3) was showing a number of defects, ranging from the misuse of terms and notations (for example the confusion between strike and dip direction) to various kind of misprints and inconsistencies. In other cases the reported data were not sufficient to constrain the solution at all (whenever for example only the orientations of planes were reported, without the indication of slip directions). Moreover, a further source of uncertainty concerns cases where several solutions (often very different from each other) are available for the same earthquake from different authors. This implies an ambiguity that cannot be easily settled but requires an evaluation of the quality of the computations and/or the "authoritativeness" of the source of the data.

The work done

In order to correct some of the defects encountered, we firstly wrote a structured package of Fortran 77 subroutines (Gasperini and Vannucci, 2003) performing the most common computations and checks on focal mechanism data. This package (that is freely available from the ftp server of Computers & Geosciences journal: ftp://ftp.iamg.org/VOL29/v29-07-08.zip) includes, among the others, routines to compute nodal planes from P and T axes and vice versa as well as to compute moment tensor components from planes or axes or best double couple parameters from moment tensor components. Using different criteria we were able to re-compute consistent data for the majority of defective solutions so that the final dataset of "usable" fault plane solutions presently includes about 4600 mechanisms relative to more than 3300 distinct earthquakes.

The spatial coverage approximately corresponds to Fig. 1. The distribution of included earthquakes in space, time and magnitude is shown in Fig.2. The origin time year ranges from 1905 to 2001 while the moment magnitude Mw from 1.4 to 8.7.

The final revised database (Vannucci and Gasperini, 2003) has been imported in a MS-ACCESS application allowing the visual comparison between original and recomputed data and the importing (without checking) of the data of the Global CMT Harvard catalog and of the two regional CMT catalogs (INGV and ETH). Each user can easily perform the latter operation, after downloading the data files from corresponding web sites (see above).

The MS-ACCESS application also permits to make selections on the basis of earthquake source parameters (date, location, magnitude, etc.) and of bibliographic data (authors, journal, etc.). The selected mechanisms can be examined singularly as well as they can be exported to ASCII files in order to be plotted by the Graphic Mapping Tool (GMT) (Wessel and Smith, 1991), or processed by external codes. A button of the display mask activates a procedure, making use of GMT and Ghostscript, displaying the "beach-ball" plot of the selected mechanism (Fig. 3). Another feature of the application exports the list of bibliographic references of selected data in a format suitable to be included in manuscripts. This simplifies the correct citation of all of the papers that contributes with mechanism data to investigations making use of the EMMA database.

To make uniform selections on the basis of the earthquake size as well as to compute the seismic moment tensor, we compute the scalar seismic moment, using empirical regressions with available magnitude estimates, for all of the mechanisms for which this parameter is not reported on the original paper. For Italy and surrounding regions, we used the relations estimated by Gasperini and Ferrari (2000) while for all other areas we provisionally adopted the ones computed by Johnston (1996) (see Table 1). This point, however, will be a matter of future revision based on specific analyses of earthquake data included in the database.

To choose, in case of duplications, the most representative mechanism for each earthquake we assigned to each solution a weight based on a series of objective criteria. Listed with decreasing rank, these are:

1. correctness of the solution (presence or absence of errors in the published FPS parameters);
2. originality of the source (original sources are preferred with respect to indirect ones);
3. "authoritativeness" of the source, roughly based on the impact factor of the journal or on the diffusion ambit of the publication (international, national, thesis, etc.) where the solution is published;
4. recentness of the publication (most recent papers override previous ones).

Among all duplicate mechanisms we choose the one having the largest weight.

As this choice is to some extent arbitrary the user is free to override it and to follow different criteria, as the data of all of the alternative solutions are also included in the database.

A call for contributions

Although we made our best, we can easily predict that at least some mistakes are still present in our work. As well we certainly missed some published papers (see below the complete list of contributing papers). So we explicitly request the collaboration of all investigators that are interested in the improvement of this database to indicate us any kind of mistakes and malfunctioning of the procedure they could find or the omission of interesting papers they know had been published.

We want to stress that our contribution represents only an added value to the work done by the authors of original papers and thus the database must not be cited as the source of data but only as a tool to easily access them. We thus strongly recommend the users to insert in their references the complete list of original works that really computed the focal plane solutions they use. As noted above a specific option is available to simplify this task in our MS-ACCESS application.

We are presently updating the database with the addition of new papers since the first release (end of year 2002). We expect to continue this updating in the coming years and to release new versions on an yearly basis. The next issue is planned for mid summer 2004 on a special issue of the INGV journal *Annals of Geophysics* (with an enclosed CD-ROM) together with the new release of the INGV Regional CMT Catalog mentioned above. We thus renew our invitation to signal us missing papers and/or to send numerical data possibly before the end of May 2004.

References

Braunmiller, J., Kradolfer, U., Giardini, D., 2002. Regional moment tensor determination in the European-Mediterranean area – initial results, Tectonophysics, 356, 5-22.

Dziewonski, A.M., Chou, T.A., Woodhouse, J.H., 1981. Determination of earthquake source parameters from waveform data for studies of global and regional seismicity, Journal of Geophysical Research, 86, 2,825-2,852.

Johnston, A.C., 1996. Seismic moment assessment of earthquakes in stable continental regions – I. Instrumental seismicity, Geopys. J. Int., 124, 381-414.

Gasperini, P., Ferrari, G., 2000. Deriving numerical estimates from descriptive information: the computation of earthquake parameters, Annali di Geofisica, 43, 729-746

Gasperini, P., Vannucci, G., 2003. FPSPACK: A package of simple FORTRAN subroutines to manage earthquake focal mechanism data, Computers & Geosciences, 29, 893-901.

Kostrov, V.V., 1974. Seismic moment and energy of earthquakes and seismic flow of rocks. Izvestia Earth Physics, 1, 23-40.

Pondrelli, S., Morelli, A., Ekström, G:, Mazza, S., Boschi, E., Dziewonski, A.M., 2002. European-Mediterranean Regional Centroid Moment Tensors catalog: 1997-2000, Physics of the Earth and Planetary Interior, 130, 71-101.

Vannucci, G., Gasperini, P., 2003. A database of revised fault plane solutions for Italy and surrounding regions, Computers & Geosciences, 29, 903-909.

Wessel, P., Smith, W.H.F., 1991. Free software helps map and display data, Eos Transactions of the AGU, 72, 441.

Contributing papers (directly examined)

Abou Elenean et al., 2000. Annali di Geofisica, 43, 485. **Amorese et al., 2000**. Geophys. J. Int., 143, 837. **Amoruso et al., 1998.** J. Geophys. Res., 103, 29989. **Anderson and Jackson. 1987**. Geophys. J. R. Astr. Soc., 91, 613. **Anderson and Jackson. 1987**. Geophys. J. R. Astr. Soc., 91, 937. **Augliera et al., 1990**. Atti Gngts, 9° Conv., 221. **Augliera et al., 1994.** Boll. Geof. Teor. Appl., 36, 363. **Azzara et al., 1993**. Annali di Geofisica, 36, 237. **Badawy, 2001**. Tectonophysics, 343, 49. **Badawy and Fattah. 2001**. Tectonophysics, 343, 63. **Baker et al., 1993. Geophys**. J. Int., 115, 41. **Baker et al., 1997**. Geophys. J. Int., 131, 559. **Baroux et al., 2001.** Geophys. J. Int., 145, 336. **Basili et al., 1996**. Annali di Geofisica, 39, 1167. **Batini et al., 1993.** Atti Gngts, 12° Conv., 207. **Berberian et al., 2000**. Geophys. J. Int., 142, 283. **Bonasia et al., 1986**. Atti Gngts, 5° Conv., 539. **Bonjer, 1997**. Tectonophysics, 275, 41. **Boore et al., 1981**. Phys. Earth Plan. Inter., 27, 133. **Bottari et al., 1989**. Tectonophysics, 166, 221. **Bowers and Pearce**, 1995. Tectonophysics, 248, 193. **Buforn et al., 1995.** Tectonophysics, 248, 247. **Buforn et al., 1988**. Bull. Seism. Soc. Am., 78, 2008. **Buforn et al., 1988.** Tectonophysics, 152, 89. **Caccamo et al., 1996**. Geophys. J. Int., 125, 857. **Canitez and Uçer, 1967**. Tectonophysics, 4, 235. **Cattaneo et al., 2000**. Journ. of Seismol., 4, 401. **Chandra, 1984**. Phys. Earth Plan. Inter., 34, 9. **Chiodo et al., 1994**. Atti Gngts, 13° Conv., 915. **Ciaccio et al., 2001**. Atti Gngts, 20° Conv., 247. **Cipar, 1980**. Bull. Seism. Soc. Am., 70, 963. **Cisternas et al., 1982**. Bull. Seism. Soc. Am., 72, 2245. **Console, 1976**. Boll. Geof. Teor. Appl., 18, 549. **Console and Favali, 1981**. Bull. Seism. Soc. Am., 71, 1233. **Console et al., 1989.** Tectonophysics, 166, 235. **De Luca et al., 2000**. Journ. of Seismol., 4, 1. **Deichmann et al., 1991**. Atti Gngts, 10° Conv., 317. **Del Ben et al., 1991**. Boll. Geof. Teor. Appl., 33, 155. **Del Pezzo et al., 1985**. Atti Gngts, 4° Conv., 79. **Delibasis et al., 1999**. Tectonophysics, 308, 237. **Deschamps and King, 1984**. Bull. Seism. Soc. Am., 74, 2483. **Ekstrom and England, 1989**. J. Geophys. Res., 94, 10231. **Ekstrom et al., 1998**. Geophys. Res. Lett., 25, 1971. **El-Sayed et al., 1998**. Journ. of Seismol., 2, 293. **Eva et al., 1978**. Boll. Geof. Teor. Appl., 20, 263. **Eva et al., 1988**. Boll. Geof. Teor. Appl., 30, 53. **Eva and Pastore, 1993**. Atti Gngts, 12° Conv., 147. **Eva and Solarino, 1992**. Studi Geol. Camerti, Vol. Spec. 2, Append. Crop 1-1a, 75. **Eva and Solarino, 1998**. Geophys. J. Int., 135, 438. **Eva et al., 1997**. J. Geophys. Res., 102, 8171. **Eyidogan, 1988**. Tectonophysics, 148, 83.**Eyidogan and Jackson, 1985**. Geophys. J. R. Astr. Soc., 81, 569. **Frepoli and Amato, 1997**. Geophys. J. Int., 129, 368. **Frepoli and Amato, 2000**. Annali di Geofisica, 43, 437. **Frepoli et al., 1996**. Geophys. J. Int., 125, 879. **Galindo-Zaldivar et al., 1993**. Tectonophysics, 227, 105. **Gallart et al., 1985**. Annales Geophysicae, 3, 239. **Gasparini et al., 1982**. Tectonophysics, 84, 267. **Gasparini et al., 1985**. Tectonophysics, 117, 59. **Giardini, 1984**. Geophys. J. R. Astr. Soc., 77, 883. **Grimison and Chen, 1986**. J. Geophys. Res., 91, 2029. **Grimison and Chen, 1988**. Geophys. J. Int., 92, 391. **Grunthal and Stromeyer, 1992**. J. Geophys. Res., 97, 11805. **Hatzfeld et al., 1993**. Geophys. J. Int., 115, 799. **Hatzfeld et al., 1993**. Geophys. J. Int., 120, 31. **Horálek et al.,2002**. Tectonophysics, 356, 65. **Huang and Salomon, 1987**. J. Geophys. Res., 92, 1361. **Hussein, 1999.** Annali di Geofisica, 42, 665. **Iannaccone et al., 1985**. Atti Gngts, 4° Conv., Roma, 145. **Jackson and Mckenzie, 1984.** Geophys. J. R. Astr. Soc., 77, 185. **Jackson et al., 1992. J. Geophys**. Res., 97, 17657. **Jackson et al., 1995**. J. Geophys. Res., 100, 15205. **Jost et al., 2002**. Tectonophysics, 356, 87. **Kiratzi and Langston, 1989**. Phys. Earth Plan. Inter., 57, 225. **Kiratzi and Louvari, 2001**. Annali di Geofisica, 44, 33. **Kiratzi et al., 1991**. Pure Appl. Geophys., 135, 515. **Lammali et al., 1997**. Geophys. J. Int., 129, 597. **Louvari et al., 1999**. Tectonophysics, 308, 223. **Lyon-Caen et al., 1988**. J. Geophys. Res., 93, 14967. **Maggi et al., 2000**. Geophys. J. Int., 143, 629. **Main and Burton, 1990**. Tectonophysics, 179, 273. **Mckenzie, 1972**. Geophys. J. R. Astr. Soc., 30, 109. **Mckenzie, 1978**. Geophys. J. R. Astr. Soc., 55, 217. **Medina, 1995**. Journ. Struct. Geol., 17, 1035. **Medina and Cherkaoui, 1992**. Eclogae Geol. Helv., 85/2, 433. **Meghraoui et al., 1996**. Bull. Soc. Géol. Franc., 167, 141. **Melis et al., 1995.** Geophys. J. Int., 122, 815. **Mezcua and Rueda, 1997.** Geophys. J. Int., 129, F1. **Milano et al., 1999**. Tectonophysics, 306, 57. **Morelli et al., 2000**. Journ. of Seismol., 4, 365. **Muço, 1994**. Tectonophysics, 231, 311. **Nicolas et al., 1998**. Pure Appl. Geophys., 152, 707. **Nicolas et al., 1990**. Tectonophysics, 179, 27. **Nowroozi, 1972.** Bull. Seism. Soc. Am., 62, 823. **Oncescu et al., 1990**. Tectonophysics, 172, 121. **Ouyed et al., 1983**. Geophys. J. R. Astr. Soc., 73, 605. **Papadimitriou, 1993**. Boll. Geof. Teor. Appl., 35, 401. **Papazachos and Delibasis, 1969**. Tectonophysics, 7, 231. **Papazachos et al., 1983**. Geophys. J. R. Astr. Soc., 75, 155. **Papazachos et al., 1984**. Boll. Geof. Teor. Appl., 26, 101. **Papazachos et al., 1988**. Pure Appl. Geophys., 126, 55. **Papazachos et al., 1991**. Pure Appl. Geophys., 136, 405. **Patanè et al., 1990**. Atti Gngts, 9° Conv., 57. **Pierri et al., 1993**. Atti Gngts, 12° Conv., 227 **Pino and Mazza, 2000**. Journ. of Seismol., 4, 451. **Polonic, 1985**. Tectonophysics, 117, 109. **Pondrelli et al., 2001**. Journ. of Seismol., 5, 73. **Priestley et al., 1994**. Geophys. J. Int., 118, 111. **Renner and Slejko, 1986**. Atti Gngts, 5° Conv., 577. **Renner and Slejko, 1994**. Boll. Geof. Teor. Appl., 36, 141. **Renner and Slejko, 1994**. Atti Gngts, 13° Conv., 907. **Renner et al., 1991**. Atti Gngts, 10° Conv., 305. **Ribeiro et al., 1996.** Tectonics, 15, 641. **Ricciardi et al., 1986**. Atti Gngts, 5° Conv., 503. **Rigo et al., 1996**. Geophys. J. Int., 126, 663. **Rocca et al., 1985**. Boll. Geof. Teor. Appl., 27, 101. **Rouland et al., 1976**. Boll. Geof. Teor. Appl., 18, 889. **Schick, 1979**. Tectonophysics, 53, 289. **Scordilis et al., 1985**. Pure Appl. Geophys., 123, 389. **Selvaggi, 2001**. Annali di Geofisica, 44, 155. **Sipkin and Needham, 1991**. Phys. Earth Plan. Inter., 67, 221. **Slejko and Rebez, 1988**. Atti Gngts, 7° Conv., 157. **Slejko et al., 1987**. Cnr-Gndt, Rend. 1, Trieste, 82 pp. **Slejko et al., 1989**. Boll. Geof. Teor. Appl., 31, 109. **Slejko et al., 1999**. Bull. Seism. Soc. Am., 89, 1037. **Soufleris and Stewart, 1981**. Geophys. J. R. Astr. Soc., 67, 343. **Stanishkova and Slejko, 1990**. Atti Gngts, 9° Conv., 177. **Sue et al., 1999**. J. Geophys. Res., 104, 25611. **Suleiman and Doser, 1995**. Geophys. J. Int., 120, 312. **Sulstarova et al., 2000.** Journ. of Seismol., 4, 117. **Taymaz, 1993**. Geophys. J. Int., 113, 260. **Taymaz and Price, 1992**. Geophys. J. Int., 108, 589. **Taymaz et al., 1990**. Geophys. J. Int., 102, 695. **Taymaz et al., 1991**. Geophys. J. Int., 106, 537. **Taymaz et al., 1991**. Geophys. J. Int., 106, 433. **Thio et al., 1999**. J. Geophys. Res., 104, 845. **Thouvenot et al., 1998**. Geophys. J. Int., 135, 876**. Udias, 1967**. Tectonophysics, 4, 229. **Udias et al., 1976**. Tectonophysics, 31, 259. **Udias et al., 1989**. Dept. of Geophysics, Univ. Complutense, Madrid. **Ward and Valensise, 1989**. Bull. Seism. Soc. Am., 79, 690.

The February 24th, 2004 AL Hoceima earthquake

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Abstract

A strong earthquake, with a magnitude, Mw=6.5, struck at 2h 27m on February 24th 2004 the region of Al Hoceima situated some 200 km to the east of the Strait of Gibraltar on the Mediterranean coast of Morocco. The epicentre was located on the continent some 10 km to the south of Al Hoceima city.

The number of casualties surpassed 600 people and an equal number was reported to be injured. Forty-thousand people were made homeless. Rescue teams from different countries joined, since the first day, their Moroccan colleagues in the rescue efforts. The earthquake was felt within a 300km radius from the epicentre, either in Moroccan provinces or in the Spanish coastal zones. The maximum intensity was IX degrees on MSK scale in the epicentral area, namely the village of Ait Kamra and the small town of Imzourene. High intensities, observed in these two areas, are probably due to site effects as soft soil is dominant in both areas. Also, minor landslides and rock falls were reported from the coast line and nearby hills. The topographic effect might have contributed significantly in these cases. A strong motion instrument, situated some 10 km to the south-east of the epicentre, recorded a peak horizontal acceleration of 0.24g. This high acceleration is due in part to the high amplification of seismic waves in this site which is characterized by a soft soil.

This earthquake caused the destruction of practically all the traditional houses of the villages surrounding the city of Al Hoceima. Traditional houses are made essentially of stones and adobe, other types of constructions with unchained masonry did not resist to ground shakings. The centre of the city, composed of more recent buildings, experienced less damage. According to macroseismic reports, cracks on walls are the common effect; few structural damages were observed mainly in weak and non engineered constructions.

Hundredths of aftershocks followed the main shock, three strong aftershocks occurred on February 26th, March 2nd and March 7th with a magnitude of Mw=5.0. They caused the collapse of many houses already affected by the main shock.

Introduction

The Al Hoceima earthquake of February 24th is the largest seismic event which affected the Northern part of Morocco in the past two centuries. This earthquake took place in an area delimited by the Nekor basin to the east and the Al Hoceima horst to the west. Miocene strike-slip movement on the Jebha and Nekor faults bounding the Al Hoceima region has resulted in the formation of distributed synthetic strike-slip faults (Figure 1), along which seismic deformation has occurred.

Two stations of the national seismic network are located in the region of Al Hoceima, especially PAL station which

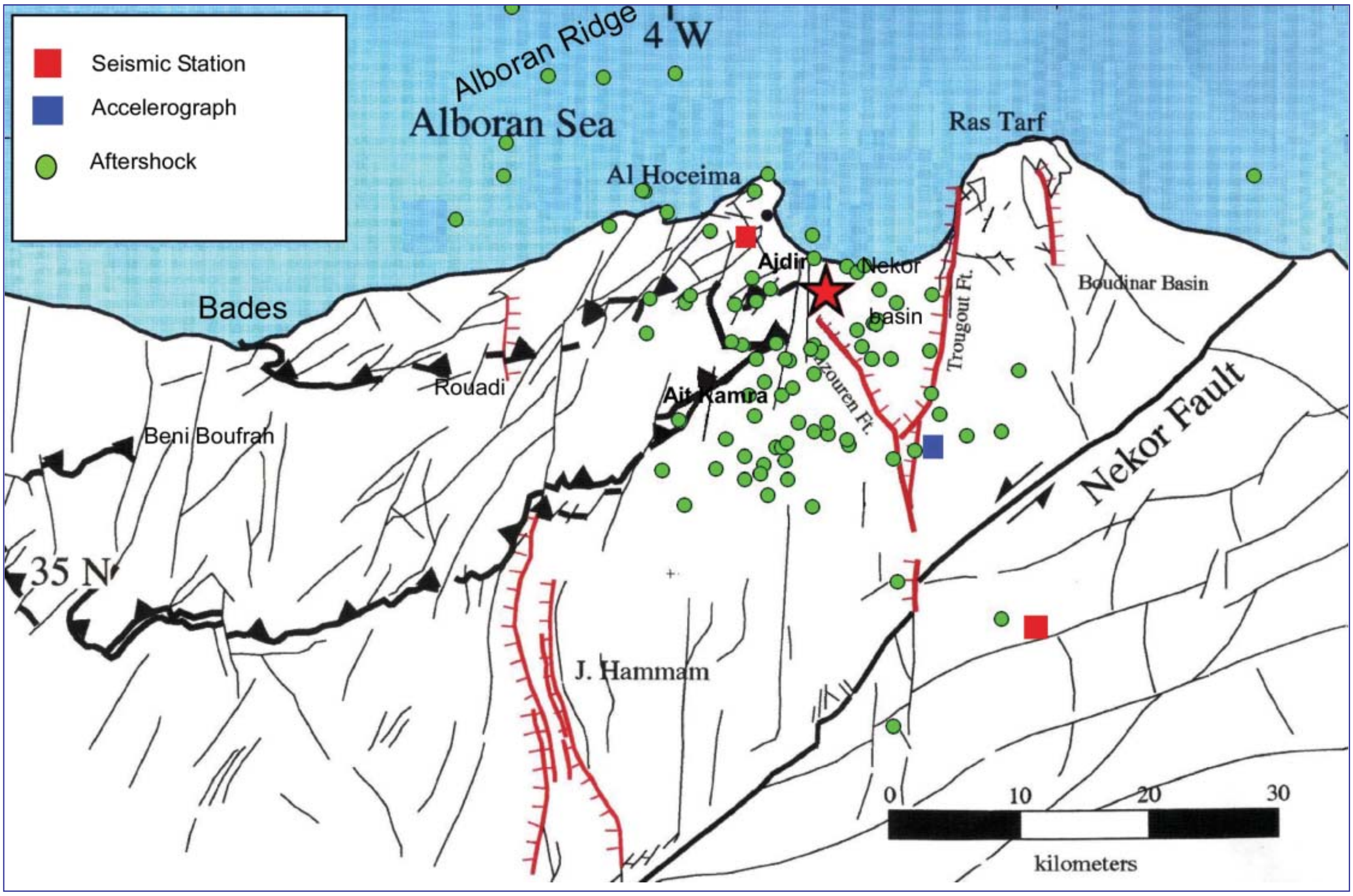

Figure 1: *Tectonic setting of Al Hoceima region, mainshock (February 24th 2004) location and 13 days of aftershocks activity, (M>3).*

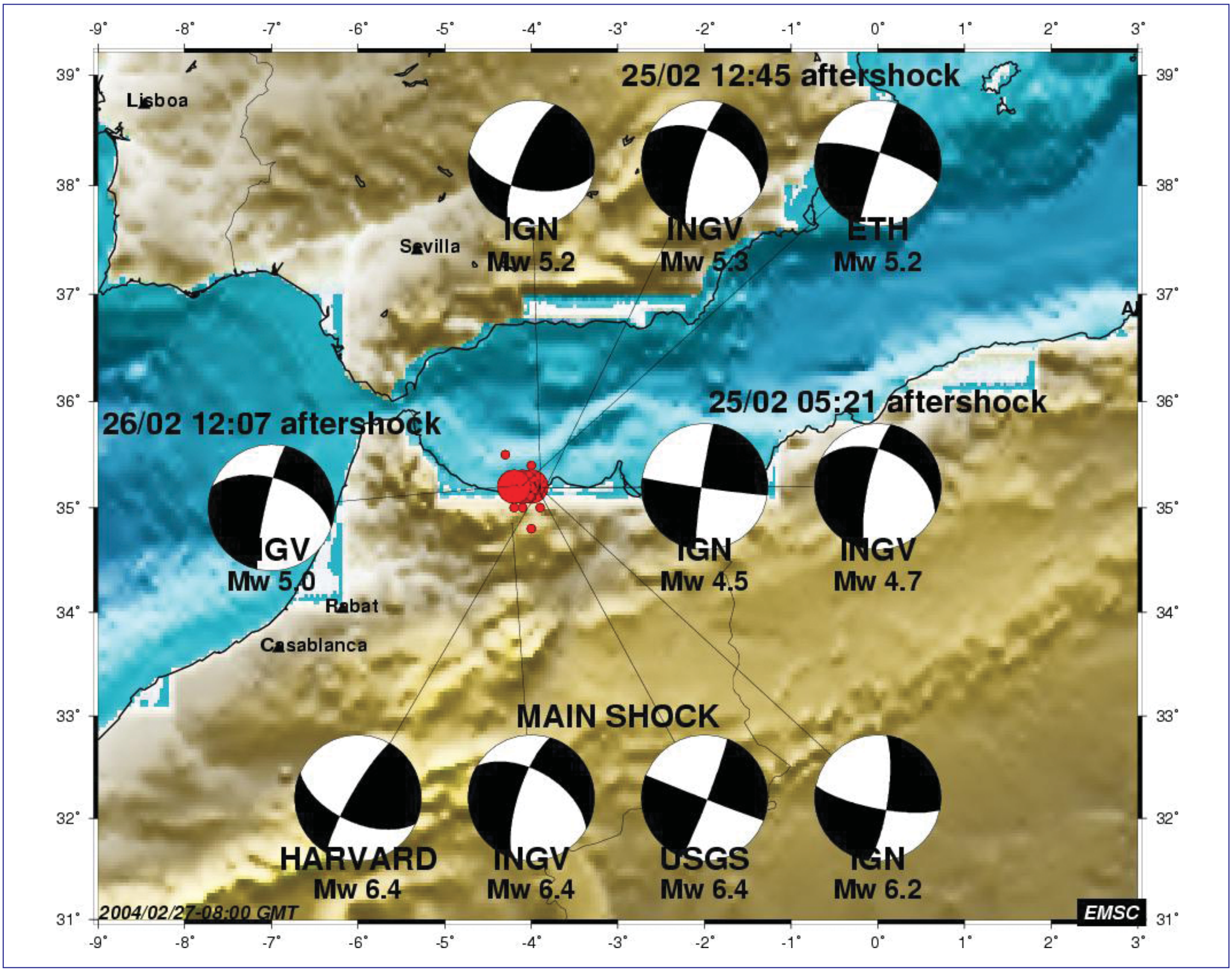

Figure 2: *Moment tensors determined for the mainshock and 3 aftershocks (epicentral locations are from EMSC)*

is very close to the active areas. The azimuthal coverage allows the determination of stable solutions for the main shock and aftershocks with magnitudes greater than 3.0. Portable stations were deployed in the region after the main shock to better constrain the aftershocks distribution.

The region of Al Hoceima is considered as the most seismically active region in Morocco (e.g. Cherkaoui, 1991). The magnitude Mw=6.0 earthquake of May 26th 1994 is an example from recent seismicity (e.g.,Calvert et al 1997). The survey of the seismic activity revealed a notable decrease in the rate of seismicity several months before the occurrence of the February earthquake. We observed even a total quiescence of this activity during the week preceding the February 24th event over all the Moroccan territory. This seismic event came as to interrupt a seismic quiescence.

A preliminary study of the aftershocks activity is carried out using the national network in order to investigate the geologic structure or the fault involved in this major seismic event. We will try to emphasize the seismic behaviour of the Al Hoceima region according to recent seismicity too.

Seismotectonic Setting

The region of Al Hoceima is a complex part of the westernmost limit of the Alpine orogenic belt (Morel and Meghraoui 1996). The seismicity is governed by the relative motion of the African and Eurasian lithospheric plates. Being within a compressive tectonic context, the seismicity depends probably on previous tectonic phases. Structures visible in the Al Hoceima region are interpreted to result from changes in the principal stress direction from NE-SW in the Tortinian, to N-S at the Tortonian-Messinian boundary, to Plio-quaternary orientation of NNW-SSE (Ait Brahim, 1991; Medina, 1995).

The neotectonic and present evolution of the region of Al Hoceima is guided by three main trends of faults: NE-SW, N-S, NW-SE (Figure 1). Some are superposed on kilometric mapped faults that have guided the eastern Rif evolution during the lower and mid-Miocene, others are more recent (Ait Brahim et al, 1990). The N-S to NNW-SSE direction of compression is compatible with the right lateral strike slip of the NW-SE trend of faults and left lateral strike slip of the NE-SW trend of faults. Normal faulting is observed on the N-S trending faults as they are parallel to the compression axis.

The comparison of the seismicity with the mapped main faults that have guided the evolution of the region of Al Hoceima and the Alboran Ridge presents a good correlation in particular with the NE-SW; ENE-WSW






Figure 3: *Photos of damage in modern constructions; total and partial collapse of buildings*

and N-S faults. Three seismotectonic zones are identified:

- A seismotectonic zone of NE-SW direction. It connects the region of Al Hoceima to the region of Targuist. This zone is staked out by a network of faults of N30° to N50° direction (Boussekkour fault, Taoussert fault).
- A seismotectonic zone of ENE-WSW direction. It covers the Alboran Ridge, where reverse faults, with N70° direction, have been active during the plio-quaternary and folds with N70° direction.
- A seismotectonic zone of N-S direction. A first zone situated along the Ras Tarf horst. N-S faults separate this horst from the Boudinar basin to the east (Ras Tarf fault) and Al Hoceima basin to the west (Trougout fault that continues off-shore). A second zone corresponds to the Al Hoceima basin (Lower Nekor); quaternary faults of N-S direction border the basin (northern part of the fault corridor of Al Hoceima-Aknoul) and inside the basin itself. A third zone is outlined near Arbaa de Taourirt, the central part of the fault corridor of Al Hoceima-Aknoul is characterised by the junction with the Nekor fault. A fourth zone is observed to the SW of Imzouren, faults network of N0° to N20° direction are observed. The last zone is outlined around the horst of Jbel Hamam, where faults of N20° direction are observed.

Historical Seismicity

The seismic crisis currently affecting the region of Al Hoceima is not a new element, as several strong earthquakes have taken place in the region in the past, in particular the earthquakes of 1522, 1624, 1791, 1801 (El Mrabet, 1990). These historical earthquakes caused some damage in the region of Al Hoceima and were also felt in the regions of Mellila to the east and Bades to the west.

For the 1801 earthquake, the seismic activity started even before the main shock and finished in 1802, indicating an aftershock activity of approximately two years; this shock is believed to have a magnitude greater than 6.0. The comparison was done with the 1994 event of magnitude 6.0, whose associated aftershock activity had duration of 6 months to suggest the possible occurrence of large size earthquakes in the region.

Seismological Observations

The determination of this main shock using the records of the Moroccan seismic network gave the following focal parameters: Lat=35.20°N, Long=3.89°W, at a depth of 7 km, (Figure 1). Other international observatories gave determinations close to those given by the Geophysics Laboratory (CNRM), EMSC (35.23°N, 4.02°W), depth=2, and USGS (35.19°N, 3.90°W), depth=13. The magnitude was underestimated using the signal duration technique, Md=5.5. The saturation of the magnitude scale with this technique compelled us to give the average of the highest values, Md=6.0. The moment magnitude, Mw=6.4 is given by many international observatories.

The location of aftershocks with magnitudes greater than 3 forms a cluster around the epicentre of the main shock. Some of these events are located off-shore near the Alboran ridge, whereas, others are isolated few kilometres to the south-east of the epicentre. This distribution over kilometric distances indicates clearly the reactivation of many faults in the region. Nevertheless, a general trend with a NNE-SSW direction can be observed from the distribution of events in the immediate vicinity of the epicentre. Off-fault aftershocks are grouped to the west of the main shock in the Bokkoya structures and to the east in the Nekor basin. Some aftershocks follow the Imzourene fault.

This event seems to be the continuation of the 1994 event (Calvert et al, 1997). The rupture that swept the NNE-SSW fault in 1994 was certainly stopped by a structural barrier, then it took ten years of stress accumulation for the rupture to break the barrier and to continue northward.

Several focal mechanism solutions were calculated from Harvard, USGS, ETHZ, IGN, INGV, (Figure 2) that are all in agreement with the seismotectonic context of the epicentral area (Hatzfeld et al, 1993). The NNW-SSE compression axis is approaching the relative vector of motion between the African and the Eurasian plates (Rebai et al, 1992). The NNE-SSW nodal plane (NP1 in the USGS Moment Tensor Solution) is the preferred fault plane as it corresponds to the general trend of the faults in the area and to the aftershocks distribution near the main shock epicentre. The mechanism is then a left lateral strike- slip movement.

The earthquake did not clearly break the surface. Different surface traces directions were revealed by geological investigations striking from N10° to N120° in the same active area. Some surface breaks may correspond to segments that contributed to the main shock. For large discrepancies with the main direction, the traces can be regarded as conjugate faults that have undergone movement later and to which we can attribute some shallow aftershocks. Another possibility is to consider all the traces as soil openings and then we suggest that the main rupture started at a depth of 7 km and swept the fault downward.

Conclusion

The 24 February 2004 Al Hoceima earthquake is a major seismic event. The earthquake took place in a seismically active region that had already experienced a moderate earthquake ten years before. The Al Hoceima earthquake reminds us the vulnerability of our cities and villages. The seismic hazard assessment must be considered as a fundamental step in the land use planning in general and for the reconstruction of the damaged districts of the Al Hoceima region in particular.

The Al Hoceima earthquake can be regarded as the continuation of the 1994 event, this previous event might have loaded the faults at its termination, the stress developed during ten years was sufficient to nucleate another seismic event. This seismological aspect is related to the heterogeneity of the geological structure in Al Hoceima region and to the high degree of fracturation. Beside scientific results, this event is a call for the implementation of a more effective disaster management.

References

Ait Brahim, L. (1991). Tectoniques cassantes et états des contraintes récents au Nord du Maroc, Ph.D. Thesis, Université Mohammed V, Rabat, 244 pp.

Ait Brahim, L., Chotin, P., Tadili, B. A., Ramdani, M., (1990). Failles actives dans le Rif central et oriental (Maroc), C. R. Acad. Sci. (Paris), 310, 1123-1129.

Calvert A., Gomez F, Seber D, Barazangi M., Jabour N., Iben Brahim A., and Demnati A. ; (1997) : An Integrated Geophysical Investigation of Recent Seismicity in the Al-Hoceima Region of North Morocco., Bullletin of the Seismological Soceity of America, vol.87, N°3, pp.637-651, June 1997.

Cherkaoui,T.E., Hatzfeld, D., Jebli, H., Fida, M. & Véronique, C. 1990, Etude microsismique de la région d'Al hoceima, Bull. Inct. Sci. Rabat.

El Mrabet, T. (1991). Historical Seismicity of Morocco. Thèse de $3^{\text{ème}}$ cycle, in Arabic, Université Mohamed V, Rabat. Morocco.

Hatzfeld, D., Caillot, V., Cherkaoui, T-E., Jebli, H., and Medina, F., (1993). Microearthquake seismicity and fault plane solutions around the Nekor strike-slip fault, Morocco, Earth Planet. Sci. Lett. 120, 31-41.

Morel, J. L. & Meghraoui, M.(1996). Goringe – Alboran – Tell tectonic zone : A transpression system along the Africa – Eurasia plate boundary ? Geology ; August 1996 ; V. 24 ; no. 8 ; p. 755-758.

Rebaï, S., Philip, H. & Taboada, A. (1992). Modern tectonic stress field in the Mediterranean region: evidence for variation in stress directions at different scales. Geophys. J. Int. 110, 106-140.

Structural analysis and interpretation of the surface deformations of the February 24th, 2004 Al Hoceima earthquake

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Introduction

Al Hoceima region has been shaken by a M6 earthquake on Tuesday February 24th 2004 at 02:27 AM. The epicentral area was located 10 kilometers south of Al Hoceima in the district of Ait Kamra. This earthquake caused the death of 628 people, 926 injured, 2539 collapsed houses and 15,230 homeless people. The damage were considerable especially in the rural area (Ait Daoud, Ait Messaoud, Izemouren, Bni Abdellah, Imrabten, Ait Aziz, Idderdouchen, etc.), where almost all constructions have been destroyed. In the urban area, Imzouren town suffered the worst damage with a number of totally collapsed buildings. In the North of Imzouren (Ajdir and Al Hoceima) and in the South (Beni Bouayache), damages were recorded especially in masonry, but only few walls of old houses broke.

Surface observations

The surface deformations which appeared within 20 km from the epicenter span over centimetric, metric, decametric and kilometric fissures (Figure 1). The NE-SW to NNE- SSW oriented fissures are the most dominant along a 20 km-wide corridor between Ajdir to the NE and Beni Abdellah to the SW. They are organized along three major branches: the first one is located at the North of Ait Zekri and Ait Daoud, the second one crosses Bouheme, Ait Kamra (Figure 2) and Ait Messaoud and the third one at the South skirts the Rhis River from Iderdouchene, Ait Ammar to Tigart and Ait hicham (Figure 3). This last is the most visible

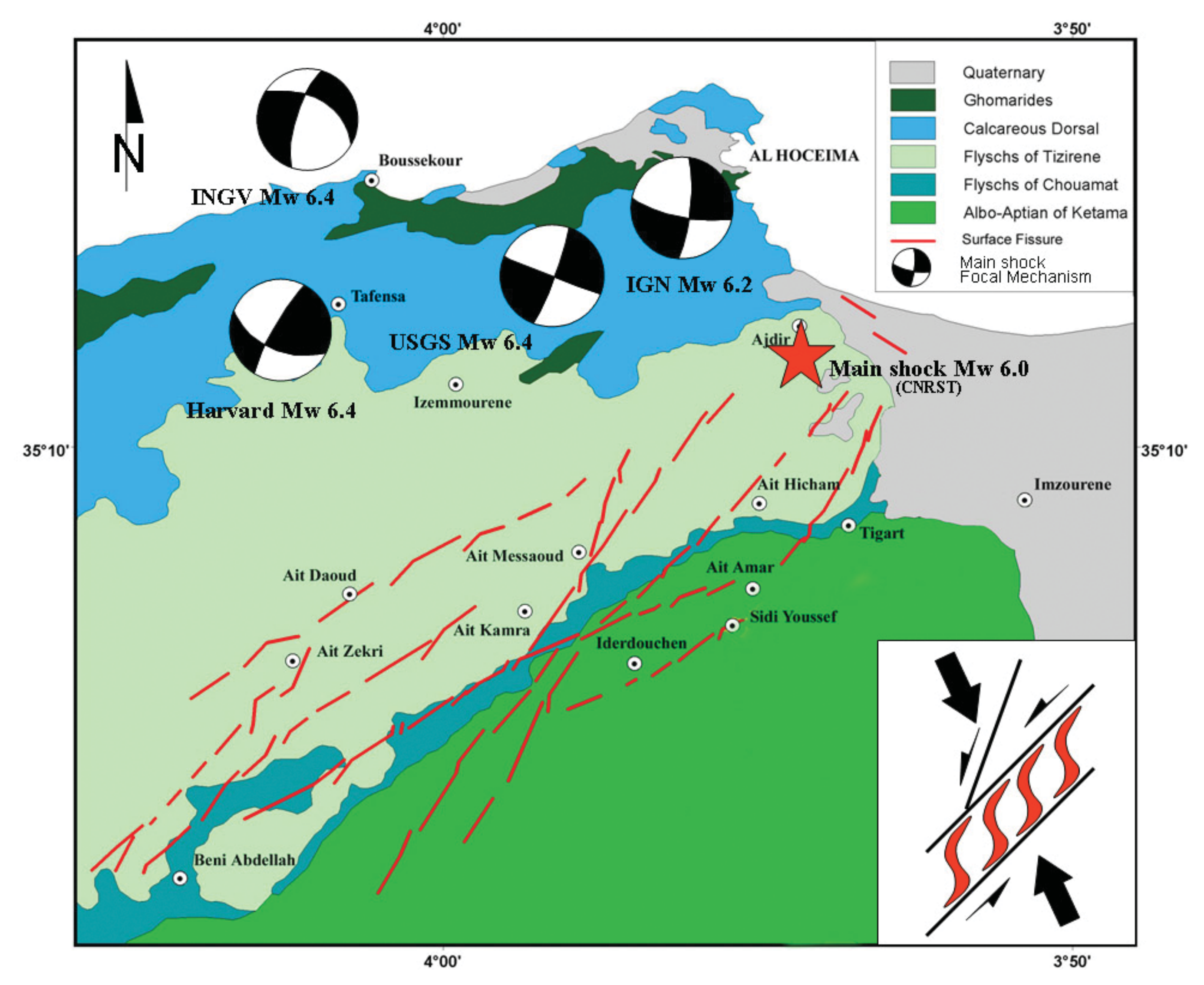

***Figure 1:** Mapped earthquake fissures induced by the main shock of the Feb 24th 2004 and deformation model.*

and continuous; it develops as well in the bed of the Rhis River as on its two banks. Although it follows the principal direction of the Rhis River (NNE-SSW with NE-SW), it does not take the form of the meanders, but it passes across them on the Tisirène sandstone, the Chouamat schists and the Kétama schisto-quartzitic series, marls and limestones. Locally these fissures are organized in slits “en echelon” of simple shape or sigmoïdal (S shaped) compatible with a sinistral strike-slip movement (Figure 4). Although no fault plan (with or without scratches) was observed until now, these secondary deformations correspond to a surface response of a deep sinistral strike-slip fault oriented NNE-SSW to NE-SW.

Metric to decametric landslides (Figure 5) were also caused by the principal shock. The macroseismic investigation carried out helped us to map a provisional chart of the isoseismals by using the MSK scale. It shows a maximum intensity of IX within an area including Ajdir and Imzouren (Figure 6). The general feature of the isoseismals shows a NE-SW direction.

Focal mechanism

The analysis of the focal mechanisms provided by international observatories (IGN, INGV, Harvard, USGS, etc.) on Figure 1, shows an average mechanism which represents a sinistral strike-slip fault oriented N018° to N021° with a sub vertical dip (73° to 86°). The subhorizontal P-axis, has a NNW-SSE direction (N151° to N156°). The depth computed by the CNRST indicates 7 km. Thus, according to surface observations (deformations and shape of the isoseismals) and focal mechanism computations, the causative fault of this major earthquake is a sinistral strike-slip fault oriented NNE-SSW to NE-SW.

***Figure 2:** N050° oriented fissures in the Ait Kamra area.*

Figure 3: *Kilometric open fissures oriented N010-020° along Rhis River.*

The rupture start in the South of Al Hoceima between Ajdir and Imzouren and ends towards the SW along the localities of Ait Hicham, Ait Messaoud, Ait Kamra, Bouheme, Ait Daoud, Ait Zekri. The maximal P-axis oriented NNW-SSE is compatible within the convergence between the European and African plates.

Distribution of aftershocks

The Moroccan seismic network (CNRST) has recorded a large series of aftershocks in the Al Hoceima region, about 30 of them with magnitude between 3.5 and 5.0. The spatial distribution of these aftershocks has a direction NW-SE to NNW-SSE, from the Mediterranean Sea to the North and continues towards the SW through Al Hoceima, Ajdir, Imzouren and Beni Bouayach. This direction is almost perpendicular to that indicated by the focal mechanism, the surface deformations and the spatial distribution of the damage. This shows the complexity of the seismicity in the Al Hoceima area and the possibility of having 2 fault plane direction activated, one along the NNE-SSW direction and the other along the NNW-SSE direction. These results are preliminary and the mapping of the surface deformation and seismic monitoring still continues.

Figure 4: *Tensile "en echelon" cracks attesting the sinistral strike-slip fault oriented N050° in Ait Said area.*

Figure 5: *Landslide with cracks in Ait Daoud area*

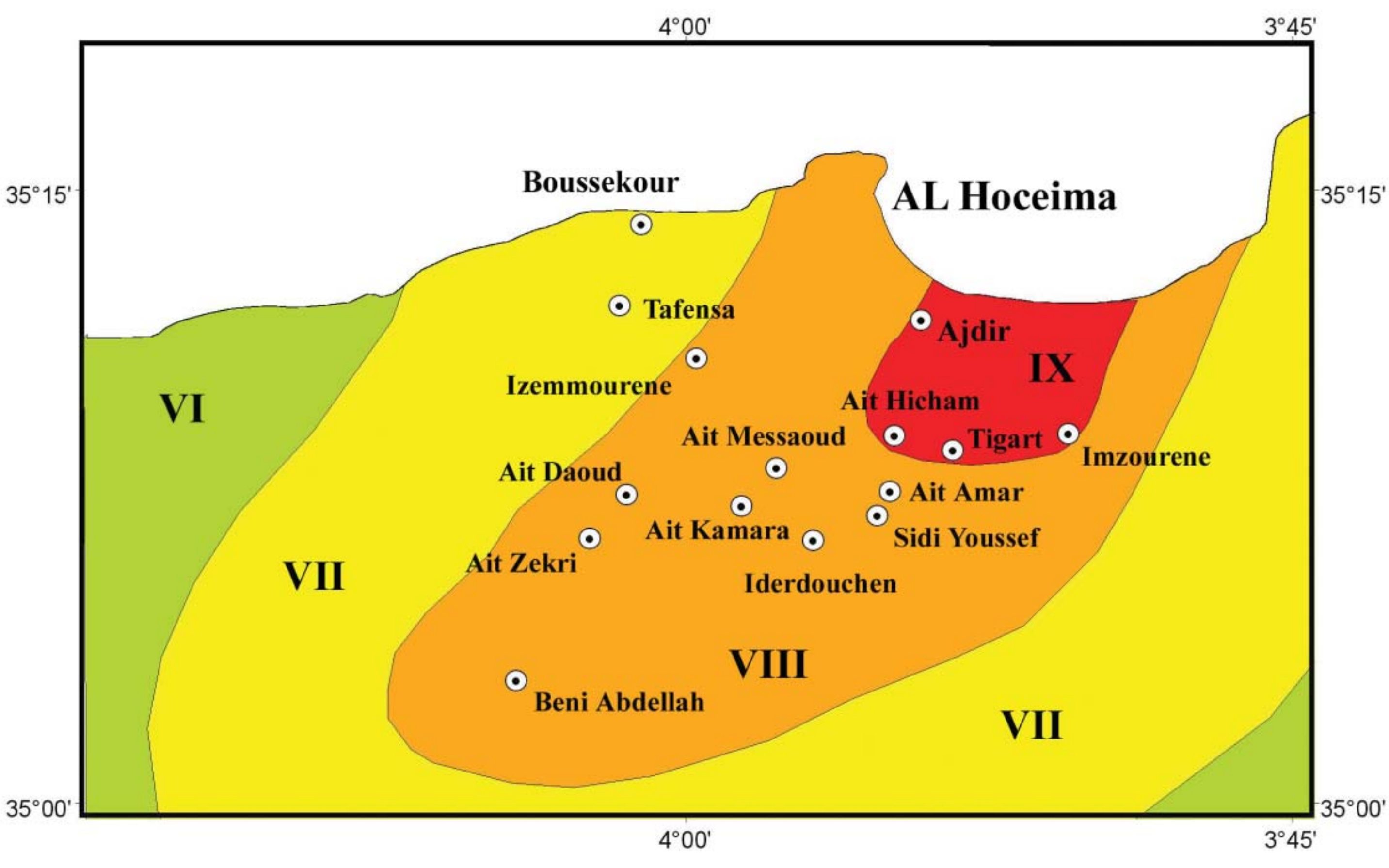

Figure 6: *Provisional macrosismicity map of the Feb 24th 2004 Al Hoceima earthquake.*

Superconducting gravimeters in seismology

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A Global network of more than 20 Superconducting Gravimeters (SGs) (Figure 1) has been collecting data since July 1997 under the auspices of the Global Geodynamics Project, (GGP) (http://www.eas.slu.edu/GGP/ggphome). The GGP was organized to establish a common data archive with standardized data formatting and raw data processing protocols to provide scientists, including those without expertise in superconducting gravity data collection and processing, access to this unique global data set. These data have contributed to numerous and diversified disciplines in the Earth science, such as investigations involving tidal gravity, ocean tidal and atmospheric loading, inner and outer core oscillations, polar motion, continental water mass observations, and volcanology (For a complete review of the scientific applications of superconducting gravimeter data and the GGP, the reader is referred to *Crossley et al*., 1999).

The unique feature of a superconducting gravimeter is the broad spectrum of gravity changes (Figure 2) that can be observed. Periods ranging from seismic free oscillations, including the translational modes of the inner core (Slichter triplet whose detection is still controversial), to periods larger than a year, for example the Chandler wobble.

The Chandler Wobble is the name given to the movement of the Earth's pole by 0.7 arc-seconds over a period of about 435 days. For more information, visit the web site of the International Earth Rotation and Reference Systems Service (IERS) at www.iers.org. The Chandler Wobble can be modelled by 'simply' fitting a harmonic series of sines or cosines to the past record of deflections, and then using this empirical model to make limited forecasts into the future. The cause of this wobble is believed to reside in the natural resonances in the body of the

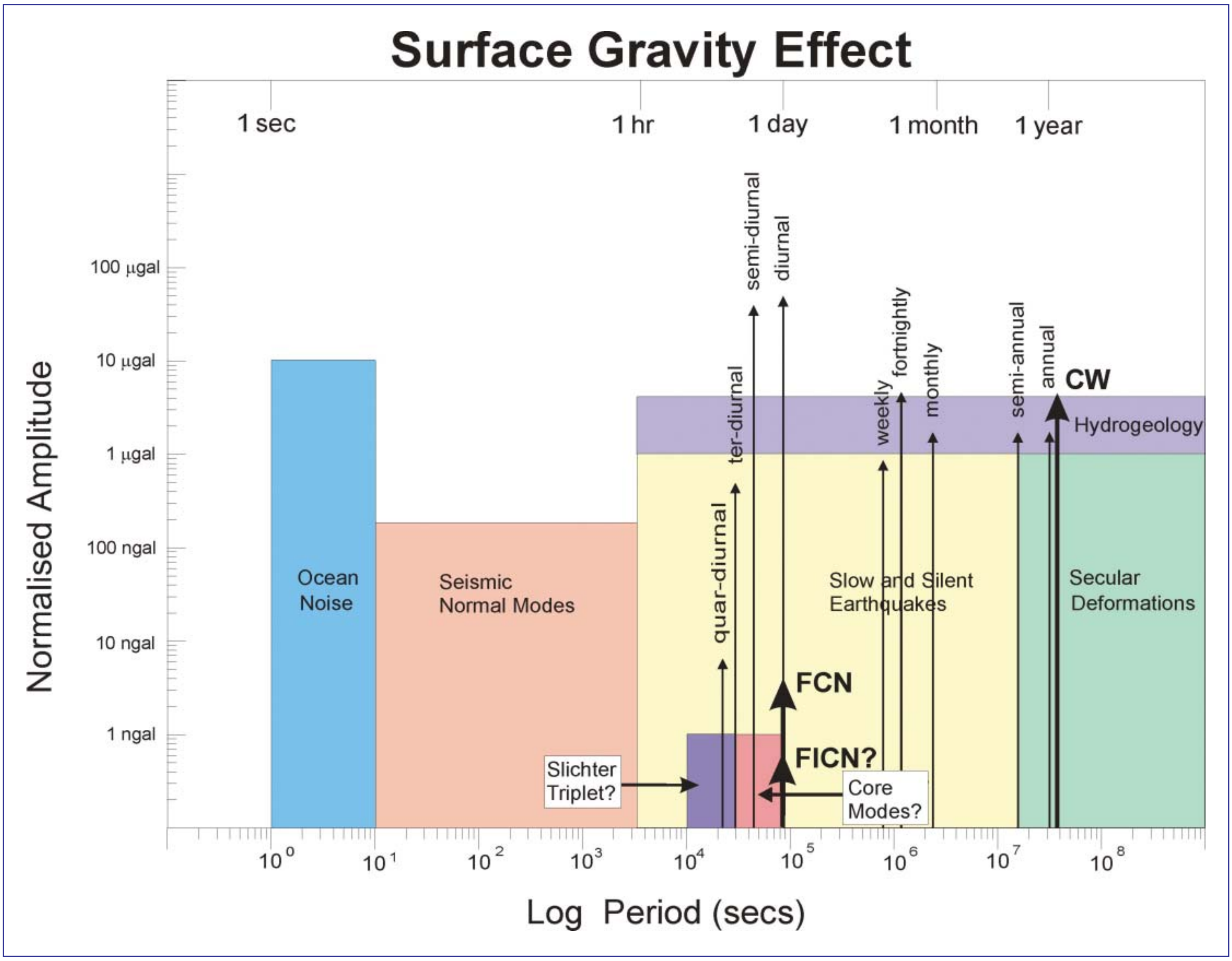

Figure 1: *Surface gravity spectrum showing the wide spectral range (from 1 second to several year periods) observable with superconducting gravimeters (from Crossley and Hinderer, 1995)*

spinning earth due to the detailed distribution of mass in its surface, interior, oceans and atmosphere. This system has a '14-month' harmonic which can be excited through a complex pattern of forcings by the moon, sun and sudden crustal rearrangements (earthquakes). There are many distinct periodic excitations by the sun and moon and their changing distances and tidal forcings, and these result in distinct monthly, yearly and multi-year periodicities in the polar wander. The Chandler Wobble may be a natural harmonic resonance that is also stimulated by these other constant lunar-solar forcings at the natural resonance frequency of the solid earth. A workshop «Forcing of polar motion in the Chandler frequency band: A contribution to understanding interannual climate variations» organized by the European Center for Geodynamics and Seismology will be held on April 21-23, 2004 in Luxembourg (more information at www.ecgs.lu)

In the field of seismology, the recent generation of the superconducting gravimeters promises to achieve even lower instrumental noise as compared to sensors currently deployed in the Global Seismographic Network (GSN) and used in studies of the Earth's free oscillations (*Widmer-Shnidrig*, 2003)

The fundamental component of a SG (*Warburton and Brinton*, 1995, Goodkind, 1999) consists of a hollow superconducting sphere that levitates in a persistent magnetic field. In a way, the SG is a spring gravimeter in which the mechanical spring is replaced by the magnetic levitation of a superconducting sphere above superconducting coils. An incremental change in gravity induces a vertical displacement of the sphere. A feedback voltage is applied to keep the sphere at a 'zero' position. This feedback voltage is proportional to the gravity change. Thus, the SG provides *relative* gravity measurements.

Due to the size of the SG, its power requirements, and the need to refill the instrument at least annually with helium, the most common mode of operation is continuously at a fixed location (Figure 3). While these requirements make remote observations difficult, successful sites such as Syowa, Antarctica and Ny Alesund, Norway (on Spitsbergen Island almost 80 degrees north of the equator) are testament to the fact that many of the requirements can be overcome.

Being a relative meter, the SG needs to be calibrated in order to convert observed variations in voltage into actual gravity changes. This is achieved by operating an *absolute* gravimeter side-by-side with the SG. This method of calibration allows for a precision in the calibration factor better than 0.1%.

Seismic Normal Modes

The spectral range observable with an SG is broad, ranging from the seismic frequency band (free oscillations) to periods longer than one year (Chandler wobble). In this short note, we discuss an example of an application in the seismic frequency band (periods shorter than one hour), in particular on the observation of seismic normal modes.

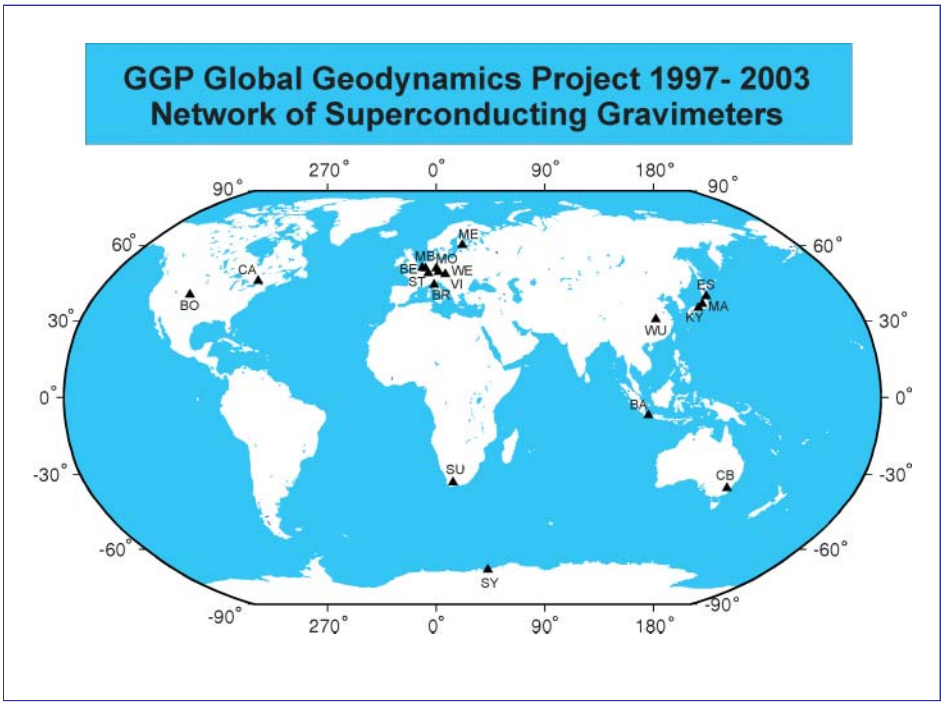

Figure 2: *The GGP network showing currently recording stations.*

Figure 3: *The last Compact Tidal SGs, manufactured by GWR Instruments (San Diego) during its set-up by the manufacturer (R. Warburton) in Walferdange (Luxembourg). The sensor uses a Nb superconducting test mass which is levitated in a magnetic field created by superconducting coils. The extremely low noise and low drift are primarily due to the operation of the components at liquid He temperatures regulated to a few micro-Kelvin inside a vacuum can. A special refrigeration unit allows the instrument to be run indefinitely with only one filling of liquid He.*

Usually this seismic band is investigated using broadband seismometers such as the STS-1. Relative gravimeters, such as the LaCoste-Romberg spring gravimeters, are also able to retrieve these modes as shown by *Zürn et al*. (1991). Numerous studies indicate that a SG can also be an excellent long-period seismograph (see, *Van camp*, 1999 and *Widmer-Shnidrig*, 2003).

It has been shown that the seismic and relative gravity instruments operating at the same quiet site have similar performance. The signal to noise ratio of the seismic modes is almost identical.

To detect the Earth's normal modes as discrete peaks in the spectra of earthquakes recordings, the earthquake generating the signals should have a magnitude which exceeds a minimum moment magnitude of $M_W \approx 6.5$ and the minimum length of the time series required for the subsequent Fourier analysis should be longer than 3 hours. A tradeoff has to be found between the frequencies resolution and the length of the time series. As the modes attenuate, at some point increasing the length of the time series will only add noise to the analysis.

To illustrate this point, the spectrum of the data from the Peru earthquake of 23-June, 2001 (M_W=8.3) observed by SG-C021 operating in Membach Belgium is displayed in Figure 4. The eigenfrequencies are well retrieved and can be easily identified after correcting the data for the atmospheric pressure effect. The OT2 and OT3 modes are not always present as in the example. The absence of the modes is due to the fact that the coupling generating them, is not always induced by earthquakes. A remarkable feature of the example is the splitting of the 0S3 mode and the emergence of the 0S2 mode which itself is also splitted.

In conclusion, superconducting gravimeters and especially the most recent generation of instruments are becoming competitive with the best spring gravimeters and seismometers. SGs have produced data with the highest signal to noise for the modes below 0.6 mHz. They also provide excellent data in the band where splitting modes are very sensitive to the 3-D density structure of the Earth's mantle and core. The final word is taken from *Widmer-Shnidrig* (2003): "To observe this splitting and constrain lateral density structure is one avenue for which SGs are uniquely suited."

References

Crossley D. and J. Hinderer, Global Geodynamics Project – GGP: Status Report, 1994, in Proc. Second IAG Workshopn on "Non-tidal gravity changes: Intercomparison between absolute and superconducting gravimeters, Cahiers du Centre Européen de Géodynamique et de Séismologie, Luxembourg, 11, 244-274, 1995.

Crossley D., Hinderer J., Casula G., Francis O.,. Hsu H.-T, Imanishi Y., Jentzsch G., Kaarianen J., Merriam J., Meurers B., Neumeyer J., Richter B., Shibuya K., Sato T., and van Dam T., Network of Superconducting Gravimeters Benefits a Number of Disciplines, EOS, Transactions, American Geophysical Union, Vol. 80, Number 11, 121-125-126, 1999.

Goodkind J., The superconducting gravilmeter, Review of Scientific Instruments, Volume 71, Number 11, 4131-4152, 1999.

Van Camp M., Measuring seismic normal modes with the GWR C021 superconducting gravimeter, Physics of the Earth and Planetary Interiors, 116, 81-92, 1999.

Widmer-Schnidrig R., What Can Superconducting Gravimeters contribute to Normal-Mose Seismology?, Bulletin of the Seismological Society of America, Vol. 93, No. 3, 1370-1380, 2003.

Zürn W., Wenzel H.G., Laske G., High quality data from LaCoste-Romberg gravimeters with electrostatic feedback: a challenge for superconducting gravimeters, Bulletin d'Information des Marées Terrestres, 110, 7940-7952, 1991.

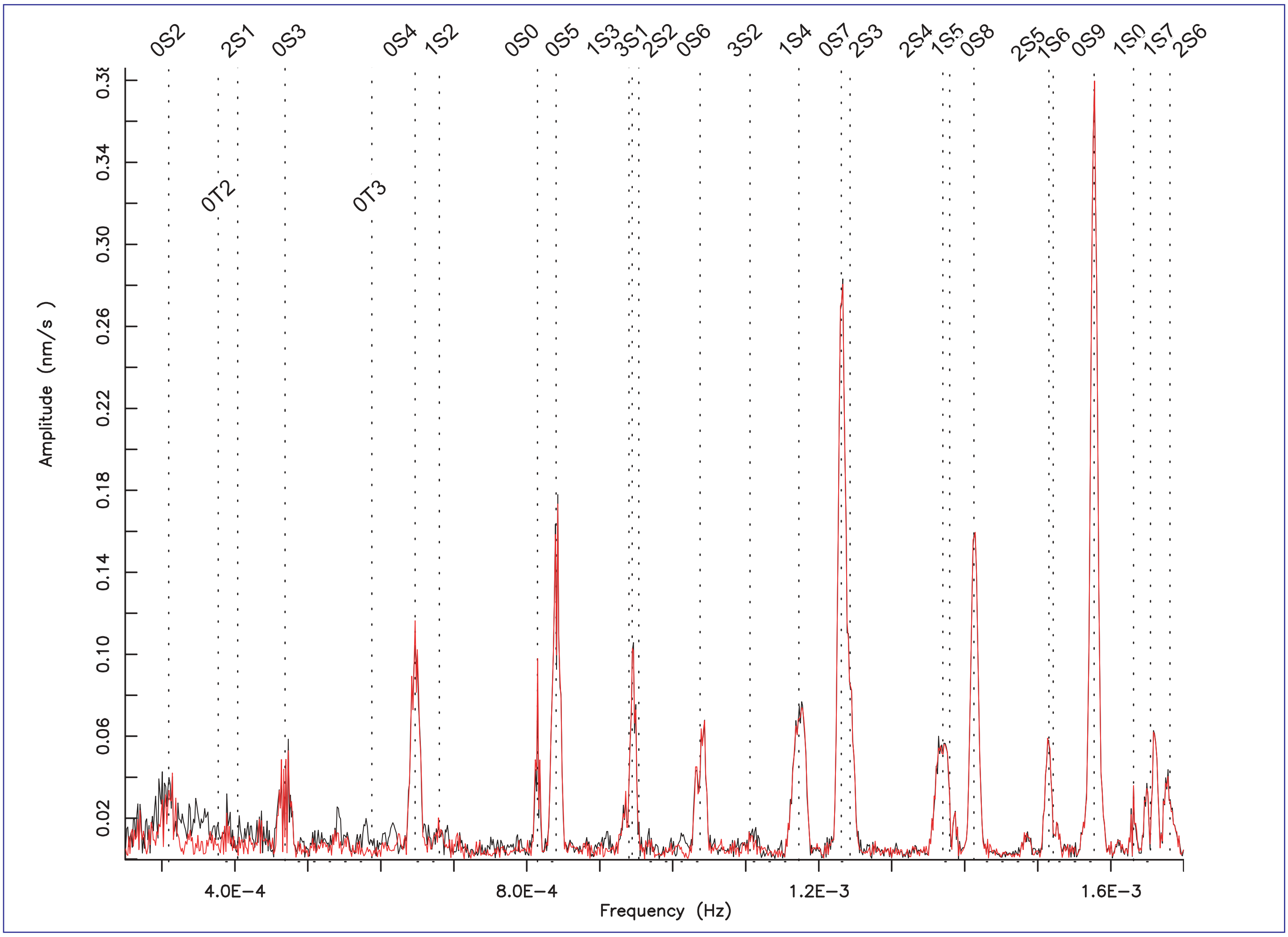

Figure 4: *Amplitude spectrum of the Peru earthquake (16.14S, 73.31W) of the 23th of June 2001 Mw=8.3 . Data from 23th of June 22h15 till 30th of June 2001 04h00 UT. Vertical dashed lines indicate theoretical eigenfrequencies (Courtesy Dr. M. Van Camp, Royal Observatory of Belgium, Seismology Section).*

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