A Unified Catalog of Main Earthquakes for Northern Algeria from A.D. 856 to 2008

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INTRODUCTION

The primary goal of this work is to catalog all the main earthquake events above magnitude M_W 4.0 in northern Algeria and its surrounding region, specifically for the area between 32° to 38°N and 3°W to 10°E, as part of a project to reassess the seismic hazard in this zone. The catalog can be downloaded from the University of Jaén Web site at `http://www.ujaen.es/investiga/rnm024/northern_algerian_catalog.dat`.

Until now, there have been only partial (albeit useful) catalogs compiled specifically for this zone (Rothé 1950; Grandjean 1954; Mokrane *et al.* 1994; Yelles Chauche *et al.*, 2002; Yelles Chauche, Deramchi *et al.* 2003), as well as regional earthquake catalogs that included seismicity for this area (*e.g.*, Mezcua and Martínez Solares 1983; Benouar 1994; El Mrabet 2005; Godey *et al.* 2006); however, none of these catalogs focused on seismic hazard studies. The main drawbacks of these catalogs are: no usage of a unified magnitude, coverage of only a short time interval for this type of study, inclusion of non-Poissonian events, and no consideration of known mainshocks in the historical period.

In recent years, several efforts have been made to compile more or less complete, homogeneous, and accurate new catalogs in different regions of the world in order to define and characterize seismicity, forecast long-term seismicity, or perform seismic-hazard analysis (*e.g.*, Kagan *et al.* 2006; Peláez *et al.* 2007; Wang *et al.* 2009; Yadav *et al.* 2009). Along these same lines, we present the most complete and homogeneous unified catalog that we could compile, collecting earthquakes from several individual and international seismological agencies, as well as from research papers reporting seismicity data. To achieve this goal, we performed a declustering analysis and a magnitude unification process in order to provide a unified main earthquake database.

The resulting catalog includes 923 main events above magnitude M_W *4.0* from A.D. 856 to June 2008. Its main characteristics are discussed below.

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TECTONIC FRAMEWORK

Northern Algeria, in the eastern part of the Ibero-Maghrebian region, is one of the most active seismogenic regions in the westernmost Mediterranean area. Its seismicity is determined by the contact between the Eurasian and the African plates. From north to south, northern Algeria is divided into four main structural domains. These domains acquired their present geological configuration during Mesozoic and Cenozoic extensional and compressional stress regimes related to the openings and closings of the Mediterranean Sea (Dewey *et al.* 1989).

These domains, associated to interplate processes, are: the Tell Atlas, the High Plateaus, the Saharan Atlas or Atlas Mountain System, and the Saharan Platform (Figure 1). Some authors, such as Frizon de Lamotte *et al.* (2000), simplify this tectonic sketch by including the High Plateaus within the Atlas Mountains System. The Tell Atlas is part of an Alpine thrust system that extends from the Betic Cordilleras, in southern Spain, to Tunisia. The Tell has been under a compressional regime since the early Cenozoic, with N-S to NW-SE convergence since the late Quaternary (Negredo *et al.* 2002).

The High Plateaus, which lie between the Tell and the Saharan Atlas, belong to the Atlas domain, and can be divided into two parts: 1) a southern section characterized by relatively undeformed thick sequences of Mesozoic epicontinental deposits, and 2) a northern section with thinner, more deformed Mesozoic sediments containing several allochthonous Tellian thrust sheets. The Atlas Mountains developed within the Proterozoic-Paleozoic Saharan Platform, and involved deformation of a continental margin previously weakened during the formation of Triassic-Jurassic rift basins. Due to their position, the mountains can be classed as an intracontinental orogenic belt consisting of Mesozoic rift sediments deformed into a series of large step folds. In the Saharan Atlas, the Mesozoic rift sediments were inverted into a major mountain range by thrust faults and block uplift tectonics.

The southern boundary of the Atlas Mountains is termed the South Atlas front or flexure. It consists of a sequence of discontinuous thrust and strike-slip faults, folds, and simple flexures that are highly variable throughout their length (Outtani *et al.* 1995).

The distribution of epicenters clearly shows that earthquakes occur mostly in the Tell Atlas, with only a few located

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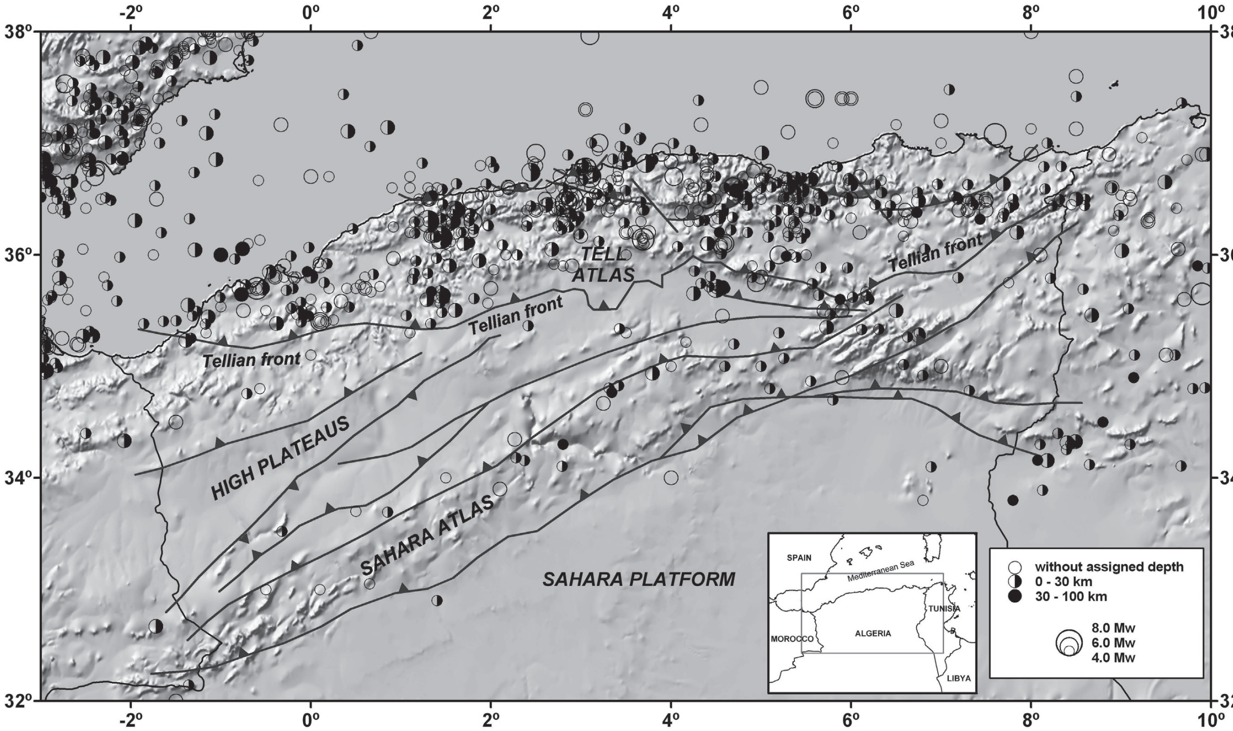


▲ **Figure 1.** Tectonic sketch of Northern Algeria (simplified from Bracene *et al.* 2003), including cataloged earthquakes.

in the Saharan Atlas. Kinematic models and tectonic studies for the region (Argus *et al.* 1989; Negredo *et al.* 2002; Henares *et al.* 2003; Buforn *et al.* 2004) show that this area absorbs 4 to 6 mm/year of crustal deformation. The seismicity in this part of northern Algeria is characterized by the continuous activity of low to moderate ($5.5 < M_W < 6.5$) shallow earthquakes in the vicinity of Quaternary basins (Bezzeghoud and Buforn 1999). In any case, some destructive events have taken place in the Tell Atlas, to the north of the Tellian front. Examples of these include the 1954 and 1980 Ech-Chlef (previously Orleansville) earthquakes (M_S 6.8 and M_S 7.3, respectively) and the more recent 2003 Zemmouri (M_W 6.8) earthquake (Edwards 2004; Hamdache *et al.* 2004).

CATALOG COMPILATION

To compile this catalog, we used the following published databases:

- National Geographic Institute (Instituto Geográfico Nacional, IGN) (Madrid, Spain) catalog, including data from Mezcua and Martínez Solares (1983) and Martínez Solares and Mezcua (2002). Their Web page (`http://www.ign.es/ign/es/IGN/SisCatalogo.jsp`) contains online access (updated daily) for readers. As in a previous work (Peláez *et al.* 2007) by the authors of this paper, we have used it as our "basic catalog," considering that this is the most reliable catalog for regional use covering the Ibero-Maghrebian area (Mezcua and Martínez Solares 1983). In the latest versions, this catalog includes some moment magnitude appraisals for historical earthquakes (Mezcua *et al.* 2004) from macroseismic data (Bakun and Wentworth 1997), as well as near real-time seismic moment assessments (Rueda and Mezcua 2005). The major contributing magnitude of this agency is the m_{bLg} magnitude.

  Concerning the instrumental period, the catalog includes data from the Spanish seismological network and from different institutions maintaining local seismic networks. Periodically, the IGN reappraises magnitudes and locations, including data from other national (Portugal, France, Morocco, etc.) and local Spanish (Catalonia, Andalusia, etc.) networks.
- Centre de Recherche en Astronomie, Astrophysique et Géophysique (CRAAG) (Algiers, Algeria) catalog, including data from Mokrane *et al.* (1994), Yelles Chauche *et al.* (2002), and Yelles Chauche, Deramchi, *et al.* (2003). This database is updated periodically but is unpublished. The main contributing magnitude of this agency is the M_L magnitude. Considering the non-continuous coverage of the Algerian seismological network (*e.g.*, Bezzeghoud *et al.* 1994; Yelles Chauche, Haned, *et al.* 2003; Yelles Chauche *et al.* 2007), the completeness of this Algerian database is strongly time-dependent.
- International Seismological Centre (ISC) catalog (ISC 2009). As is well known, this agency includes data from national and other local agencies that is not always checked. Their Web page (`http://www.isc.ac.uk/search/bulletin/`) allows online access to this database, regularly updated. This source did not provide new locations, but did give data concerning M_S and M_W magnitudes.
- National Earthquake Information Center (NEIC) Preliminary Determination of Epicenters catalog (USGS 2009). This is a well-known international online data-

base (http://neic.usgs.gov/neis/epic/epic_global.html). It includes magnitudes both determined by the NEIC and contributed by different agencies. The data we drew from this database mainly concerns M_S and M_W magnitudes.

- European-Mediterranean Seismological Centre (EMSC) catalog (Godey *et al.* 2006). This is a regional catalog covering the Euro-Mediterranean region, gathering and merging both automatically and manually revised data since 1998 from several national seismological networks. It provides near real-time seismic data online (http://www.emsc-csem.org/index.php?page=data&sub=catalog&db=emb).

From these five catalogs, we compiled a new catalog including all events located in the previously defined region. Our preferences, whenever an event was included in more than one catalog, were, in this order: IGN, CRAAG, ISC, EMSC, and NEIC. Apart from these databases, we also employed data, mainly M_S and M_W magnitudes, from the agencies/databases below:

- National Geographic Institute (IGN) online seismic moment tensor catalog (Rueda and Mezcua 2005). Available from http://www.ign.es/ign/es/IGN/SisCalculo.jsp.
- Andalusian Institute of Geophysics (Instituto Andaluz de Geofísica, IAG) online regional seismic moment tensor catalog (Stich, Ammon, *et al.* 2003). Available from http://www.ugr.es/~iag/tensor/mtc.html.
- Harvard Centroid Moment Tensor (CMT) catalog (*e.g.*, Dziewonski *et al.* 1987). Available from http://www.globalcmt.org/CMTsearch.html (now the Global Centroid Moment Tensor catalog.
- National Earthquake Information Center (NEIC) Centroid Moment Tensor catalog. Available from http://neic.usgs.gov/neis/sopar/.
- European-Mediterranean Regional Centroid Moment Tensors catalog (*e.g.*, Pondrelli *et al.* 2007). Available from http://www.bo.ingv.it/RCMT/searchRCMT.html.

Single-intensity or magnitude values used in our work were also obtained from papers by Ambraseys (1982), Tadili and Ramdani (1983), Aoudia and Meghraoui (1995), Samardjieva *et al.* (1998), Badal *et al.* (2000), Ayadi *et al.* (2002), Braunmiller *et al.* (2002), Harbi, Benouar, *et al.* (2003), Harbi, Maouche, *et al.* (2003), Stich, Battló, *et al.* (2003), Mezcua *et al.* (2004), El Mrabet (2005), Rueda and Mezcua (2005), and Camassi *et al.* (2008).

After database compilation, our next step was to unify magnitudes using the moment magnitude. For earthquakes with reported moment magnitudes or moment magnitudes computed from intensity values using the Bakun and Wentworth (1997, 1999) approach, these values were simply used as the equivalent moment magnitudes. For earthquakes with reported M_S or m_b magnitudes, we used the relationships by Johnston (1996) to assign a moment magnitude from these values. For earthquakes with a reported m_{bLg} magnitude, such as the majority of those in the IGN catalog, the Rueda and Mezcua (2002) relationship was used to obtain the equivalent moment magnitude. For most of the CRAAG catalog earthquakes, with reported M_L magnitudes computed from the duration of the record, we have considered (in the absence of empirical ad hoc relationships) that the equivalent moment magnitude is just this value, following the criterion by Bakun (1984) and Heaton *et al.* (1986). To date, CRAAG does not establish any relationship between its reported duration magnitude and other types of magnitudes used by other agencies in the region. Finally, when the reported size of the event was the maximum intensity, the equivalent magnitude was computed from the Mezcua (2002) relationship. In this last case and for offshore locations, epicentral intensity was computed from the maximum intensity onshore and the intensity attenuation relationship by López Casado *et al.* (2000). The Appendix gives these empirical relationships.

The final step was to remove all non-Poissonian (dependent) events. These earthquakes were identified using the classic routine, and essentially using the same parameters, proposed by Gardner and Knopoff (1974). Following this routine, the largest earthquake within a certain window in distance and time, with distance and time being magnitude-dependent, is considered to be the mainshock. For example, window sizes of 900 days and 100 km were used for a given M_W 8.0 event.

RESULTS AND CONCLUSIONS

The main earthquake catalog presented in this work spans the years A.D. 856 to 2008, including shocks with a magnitude above or equal to M_W 4.0 within the region bounded by 32°–38°N and 3°W–10°E. Tabulated data contain origin time, coordinates, depth, reported magnitude and/or maximum intensity, and unified moment magnitude. The reported size is included in the database in deference to those researchers who might prefer to use relationships other than those employed herein to obtain the unified magnitude.

The seismicity spatial distribution is depicted in Figure 1. Clearly, this is a region with very shallow seismicity. Most earthquakes are located in the crust, and only a few scattered events in the area have depths between 30 and 120 km.

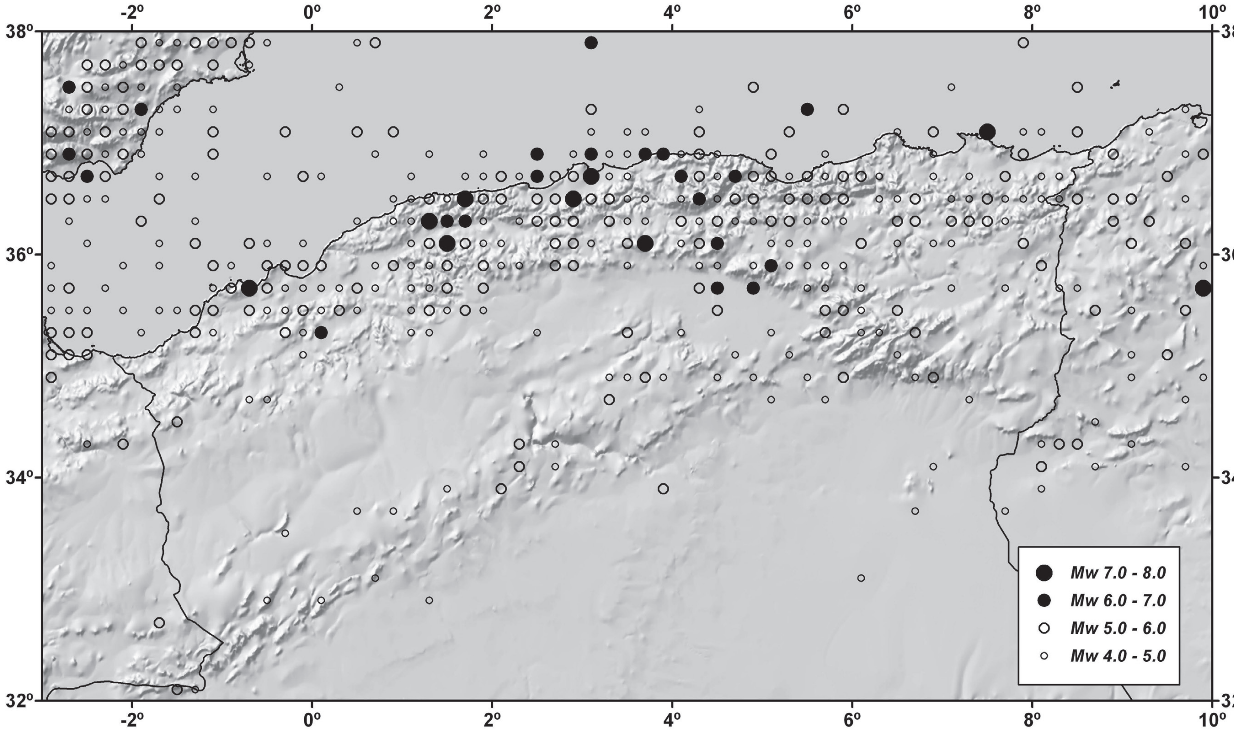
Table 1 presents earthquakes above a unified magnitude of M_W 6.0, that is, the most energetic ones. The two most significant earthquakes were the M_W 7.3 1867 Blida and 1980 Ech-Chlef (El Asnam) earthquakes. The first one, the 2 January 1867 Blida earthquake, had a felt intensity of X–XI. There were approximately 100 fatalities, and the town of Mouzaïa was entirely destroyed (Cochard 1867; Mokrane *et al.* 1994). Effects were felt over a widespread area. The 10 October 1980 Ech-Chlef earthquake, at an intensity of IX, is the strongest one recorded in northern Algeria to date (Ouyed *et al.* 1981; Leeds 1983; Philip and Meghraoui 1983). It caused about 5,000 fatalities victims out of a population of 120,000 and destroyed almost half the buildings in Ech-Chlef.

Figure 2 shows the total amount of released radiated energy in terms of magnitude. Energy released for earthquakes in cells of dimension 0.2° by 0.2° has been computed adding the energy released for each earthquake included in the cell and then converting the total amount into the equivalent magnitude. To do so, we used Kanamori's (1977) relation between

TABLE 1
Cataloged Earthquakes with a Magnitude Equal to or Above M_W 6.0.

Date mm/dd/year	Hour GMT	Longitude	Latitude	Depth (km)	Reported Magnitude	Maximum Intensity	Location	Unified M_W
12/03/ 856	—	9.900	35.650	—	—	X	Tunis. Tunisia	7.0[b]
01/03/1365	18:00:00	3.050	36.770	—	—	X	Algiers. Algeria	7.0[b]
04/05/1504	—	5.600	37.400	—	—	IX	N Jijel. Algeria	6.4[b]
11/09/1518	23:30:00	–1.866	37.233	—	—	VIII–IX	W Almería. Spain	6.1[b]
09/22/1522	10:00:00	–2.667	36.967	—	M_W 6.5[a]	VIII–IX	Almería. Spain	6.5
09/22/1522	—	2.500	36.910	—	—	IX	N Tipaza. Algeria	6.4[b]
09/30/1531	04:00:00	–2.733	37.533	—	—	VIII–IX	Baza. Spain	6.1[b]
05/11/1624	—	3.891	36.920	—	—	IX–X	Dellys. Algeria	6.7[b]
10/09/1680	—	4.400	36.500	—	—	IX	Tizi Ouzou. Algeria	6.4[b]
02/03/1716	02:00:00	3.100	36.700	—	—	X	Algiers. Algeria	7.0[b]
11/27/1722	—	7.600	37.080	—	—	X	NW Annaba. Algeria	7.0[b]
10/09/1790	01:15:00	–0.600	35.700	—	—	X	Oran. Algeria	7.0[b]
03/01/1819	—	0.100	35.400	—	—	IX	Mascara. Algeria	6.4[b]
03/02/1825	07:00:00	2.900	36.500	—	—	X	Blida. Algeria	7.0[b]
03/09/1856	—	1.800	36.300	—	—	IX	Kherba. Algeria	6.4[b]
03/09/1858	04:30:00	1.800	36.300	—	—	IX	Kherba. Algeria	6.4[b]
01/02/1867	07:13:56	2.833	36.467	—	—	X–XI	Blida. Algeria	7.3[b]
12/03/1885	20:00:00	4.600	36.100	—	—	IX	M'sila. Algeria	6.4[b]
01/15/1891	04:00:00	1.800	36.500	—	—	X	Gouraya. Algeria	7.0[b]
01/13/1901	—	4.690	36.610	—	—	IX	Sidi Aich. Algeria	6.4[b]
06/24/1910	—	3.690	36.140	—	—	X	S El Ghozlane. Algeria	7.0[b]
12/24/1920	13:06:06	3.100	36.967	—	—	V	N Algiers. Algeria	6.2[c]
08/22/1922	11:47:00	1.300	36.300	4	—	X	Cavaignac. Algeria	7.0[b]
02/06/1946	05:17:58	–2.400	36.700	—	M_S 6.0	—	Gulf of Almería	6.0[d]
02/12/1946	02:43:24	4.950	35.750	—	M_S 6.0	VIII–IX	M'Sila. Algeria.	6.0[d]
10/25/1949	08:32:00	3.200	37.000	—	—	VI	N Ain Taya. Algeria	6.3
07/08/1954	03:51:50	4.033	36.700	—	M_S 6.8	III	Tizi Ouzou. Algeria	6.8[d]
09/09/1954	01:04:37	1.467	36.283	—	M_S 6.7	X–XI	NW Beni R. Algeria	6.7[d]
09/04/1963	05:06:42	5.200	36.000	—	m_{bLg} 6.3	—	SW Setif. Algeria	6.8[e]
01/01/1965	17:32:21	4.500	35.700	—	M_S 6.5	VIII	M'Sila. Algeria	6.5[d]
05/29/1965	20:40:56	1.600	36.400	—	M_W 6.2	VI	Djebel Frina. Algeria	6.2
10/10/1980	12:25:23	1.447	36.153	5	M_S 7.3	IX	Chlef. Algeria	7.3[d]
10/29/1989	19:21:52	2.444	36.740	10	M_W 6.0	—	N Tipaza. Algeria	6.0
05/21/2003	18:44:19	3.720	36.819	15	M_W 6.9	IX–X	Boumerdes. Algeria	6.9

a. Martínez Solares and Mezcua (2002), from intensity data, using the Bakun and Wentworth (1997, 1999) approach
b. From *Imax*, using the Mezcua (2002) relationship between *Imax* and *MW*
c. From reappraised epicentral intensity for offshore epicenters using the López Casado *et al.* (2000) attenuation relationships and the Mezcua (2002) relationship among *Imax* and *MW*
d. From *MS*, using the Johnston (1996) relationship between *MS* and *MW*
e. From *mbLg*, using the Rueda and Mezcua (2002) relationship between *mbLg* and *MW*



▲ **Figure 2.** Released energy for the events included in the catalog in terms of equivalent moment magnitude (see text).

radiated energy and moment magnitude (see the Appendix). Solid circles represent the equivalent moment magnitudes above 6.0 and open circles indicate the range of M_W 4.0 to 6.0.

This figure shows different interesting areas according to their released energy: southeasternmost Spain, and the Tell and the Saharan Atlas in northern Algeria. In northern Algeria, the Tell Atlas seems to be the most efficient and, accordingly, the most dangerous area in this part of the contact between the Eurasian and African plates. Equivalent magnitudes above 6.0 mainly cluster in the central part of the Tell Atlas. This section covers the Ech-Chlef region (very close events in space, including three cells with equivalent magnitudes above 7.0), the Algiers-Blida region (also an equivalent magnitude above 7.0 in certain areas), and the Bouira-Batna region (prevailing equivalent magnitudes in the range of 6.0–7.0). The Oran-Mascara region lies in the westernmost part of the Tell, and the Skikda-Annaba area in the easternmost part, both of which include isolated events. The released energy in the Saharan Atlas, far from the plate contact, is clearly less than that in the Tell Atlas, although it is slightly higher in its central-eastern part.

The catalog completeness can be inferred from Figure 3. This figure depicts the cumulative number of earthquakes above magnitudes of M_W 4.0, 5.0, and 6.0. It appears that magnitudes M_W 4.0 and 5.0 are likely complete since 1920 for the whole catalog, with rates of 7.0 and 1.8 events/year, respectively, and that magnitude M_W 6.0 is likely complete since 1850 with a rate of 0.13 earthquakes/year. In any case, in the last nine years an increase can be seen in the rate of events above magnitude M_W 4.0 (up to 21.2 events/year) not observed for other magnitude values. This could be related to the improvement of the CRAAG network (Yelles Chauche *et al.* 2007) and consequently to the improvement of its data quality, enabling the location of minor earthquakes ($4.0 < M_W < 4.5$) not monitored by other networks.

Finally, Figure 4 displays the recurrence (magnitude-frequency) relationship for earthquakes in the catalog in the time period likely complete for magnitudes above M_W 4.0 (*i.e.*, 1920–2000). There is a very good fit in the magnitude interval M_W 4.5–7.2, with a typical *b*-value equal to 0.96. This result emphasizes the fact that in this time interval the catalog is likely complete and Poissonian for magnitudes of this order or higher.

As a corollary, we are confident that the main result of this work has been to obtain a uniform magnitude catalog, covering some gaps and lack of homogeneity in the existing catalogs. Despite this achievement, this new catalog certainly has some deficiencies and is not as complete and homogeneous as could be wished.

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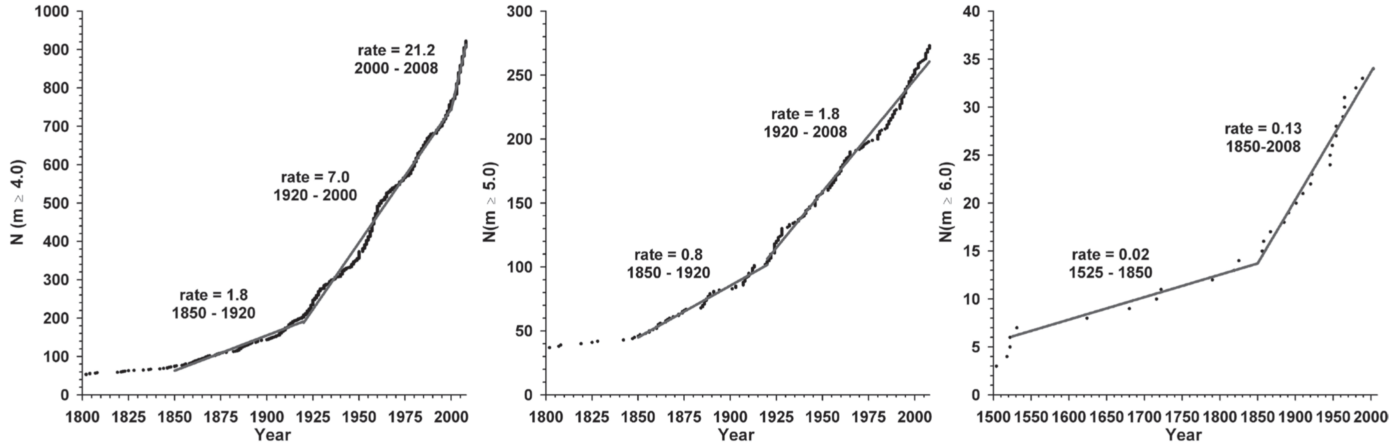
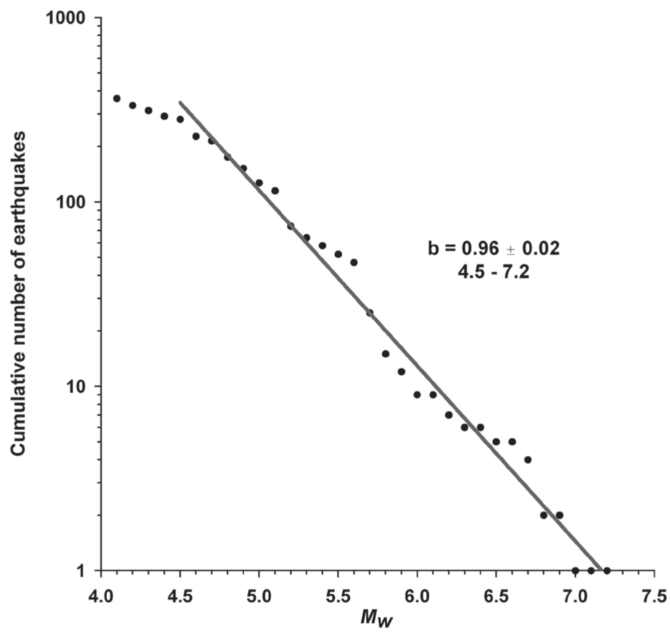
REFERENCES

Ambraseys, N. N. (1982). The seismicity of North Africa: The earthquake of 1856 at Jijeli, Algeria. *Bollettino di Geofisica Teorica ed Applicata* **24**, 31–37.

Aoudia, A., and M. Meghraoui (1995). Seismotectonics in the Tell Atlas of Algeria: The Cavaignac (Abou El Hassan) earthquake of 25.08.1922 ($M_S = 5.9$). *Tectonophysics* **248**, 263–276.



▲ **Figure 3.** Number of earthquakes above magnitudes M_W 4.0, 5.0, and 6.0 vs. time showing different completeness periods.



▲ **Figure 4.** Cumulative number of earthquakes vs. magnitude in the time interval of 1920–2000. The *b*-value obtained is equal to 0.96 ± 0.02.

Argus, D. F., R. G. Gordon, C. de Mets, and S. Stein (1989). Closure of the Africa–Eurasia–North America plate motions circuit and tectonics of the Gloria fault. *Journal of Geophysical Research* **94**, 5,585–5,602.

Ayadi, A., F. Ousadou-Ayadi, S. Bourouis, and H. Benhallou (2002). Seismotectonics and seismic quietness of the Oranie region (western Algeria): The Mascara earthquake of August 18th 1994, M_W = 5.7, M_S = 6.0. *Journal of Seismology* **6**, 13–23.

Badal, J., E. Samardjieva, and G. Payo (2000). Moment magnitudes for early (1923–1961) instrumental Iberian earthquakes. *Bulletin of the Seismological Society of America* **90**, 1,161–1,173.

Bakun, W. H. (1984). Seismic moments, local magnitudes, and coda-duration magnitudes for earthquakes in central California. *Bulletin of the Seismological Society of America* **74**, 439–458.

Bakun, W. H., and C. M. Wentworth (1997). Estimating earthquake location and magnitude from seismic intensity data. *Bulletin of the Seismological Society of America* **87**, 1,502–1,521.

Bakun, W. H., and C. M. Wentworth (1999). Erratum to "Estimating earthquake location and magnitude from seismic intensity data." *Bulletin of the Seismological Society of America* **89**, 557.

Benouar, D. (1994). An earthquake catalogue for the Maghreb region 20°-38°N, 10°W-12°E for the period 1900–1990. *Annali di Geofisica* **37**, 511–528.

Bezzeghoud, M., A. Ayadi, A. Sebai, and H. Benhallou (1994). Seismogenic zone survey by Algerian Telemetered Seismological Network; case-study of Rouina earthquake, 19 January 1992. *Physics of the Earth and Planetary Interiors* **84**, 235–246.

Bezzeghoud, M., and E. Buforn (1999). Source parameters of the 1992 Melilla (Spain, *Mw* = 4.8), 1994 Alhoceima (Morocco, *Mw* = 5.8), and 1994 Mascara (Algeria, *Mw* = 5.7) earthquakes and seismotectonic implications. *Bulletin of the Seismological Society of America* **89**, 359–372.

Bracene, R., M. Patriat, N. Ellouz, and J. M. Gaulier (2003). Subsidence history in basins of northern Algeria. *Sedimentary Geology* **156**, 213–239.

Braunmiller, J., U. Kradolfer, M. Baer, and D. Giardini (2002). Regional moment tensor determination in the European-Mediterranean area—initial results. *Tectonophysics* **356**, 5–22.

Buforn, E., M. Bezzeghoud, A. Udías, and C. Pro (2004). Seismic sources on the Ibero-African plate boundary and their tectonic implications. *Pure and Applied Geophysics* **161**, 623–646.

Camassi, R., C. H. Caracciolo, and V. Castelli (2008). Strong earthquakes in north-western Africa in the second half of the 17th century, A.D.: A critical reappraisal of the historical evidence. In *Historical Seismology: Interdisciplinary Studies of Past and Recent Earthquakes*, ed. J. Fréchet, M. Meghraoui, and M. Stucchi, 163–184. New York: Springer.

Cochard, M. (1867). Lettre sur le tremblement de terre d'Alger, adressée par M. Cochard et M. Wolf, et communiquée par M. Le Verrier. *Comptes Rendus de l'Académie des Sciences* **XLIV**, 34.

Dewey, J. F., M. L. Helman, E. Turco, D. Huston, and S. D. Knott (1989). Kinematics of the western Mediterranean. In *Alpine Tectonics*, ed. M. P. Conward, D. Dietrich, and R. G. Park, 265–283. Special Publication of the Geological Society of London 45.

Dziewonski, A. M., G. Ekström, J. E. Franzen, and J. H. Woodhouse (1987). Global seismicity of 1977: Centroid-moment tensor solutions for 471 earthquakes. *Physics of the Earth and Planetary Interiors* **45**, 11–36.

Edwards, C. L., ed. (2004). *Zemmouri, Algeria, M_W 6.8 Earthquake of May 21, 2003*. American Society of Civil Engineers (ASCE) Report (Monograph No. 27), Reston Virginia: ASCE.

El Mrabet, T. (2005). *The Great Earthquakes in the Maghreb Region and Their Consequences on Man and Environment*. Centre National de la Recherche Scientifique, Laboratoire de Géophysique. In Arabic.

Frizon de Lamotte, D., B. Saint Bezar, R. Bracène, and E. Mercier (2000). The two main steps of the Atlas building and geodynamics of the western Mediterranean. *Tectonics* **19**, 740–761.

Gardner, J. K., and L. Knopoff (1974). Is the sequence of earthquakes in Southern California, with aftershocks removed, Poissonian? *Bulletin of the Seismological Society of America* **64**, 1,363–1,367.

Godey, S., R. Bossu, J. Guilbert, and G. Mazet-Roux (2006). The Euro-Mediterranean Bulletin: A comprehensive seismological bulletin at regional scale. *Seismological Research Letters* 77, 460–474.

Grandjean, A. (1954). Séismes d'Algérie de 1940 á 1950 inclus. *Geophysique* VII, 83 pp. Strasbourg: *Annales de l'Institut de Physique du Globe.*

Hamdache, M., J. A. Peláez, and A. K. Yelles Chauche (2004). The Algiers, Algeria earthquake (M_W 6.8) of 21 May 2003: Preliminary report. *Seismological Research Letters* **75**, 360–367.

Hanks, T. C., and H. Kanamori (1979). A moment magnitude scale. *Journal of Geophysical Research* **84**, 2,348–2,350.

Harbi, A., D. Benouar, and H. Benhallou (2003). Re-appraisal of seismicity and seismotectonics in the north-eastern Algeria. Part I: Review of historical seismicity. *Journal of Seismology* 7, 115–136.

Harbi, A., S. Maouche, and H. Benhallou (2003b). Re-appraisal of seismicity and seismotectonics in the north-eastern Algeria. Part II: 20th century seismicity and seismotectonics analysis. *Journal of Seismology* 7, 221–234.

Heaton, T. H., F. Tajima, and A. W. Mori (1986). Estimating ground motions using recorded accelerograms. *Surveys in Geophysics* **8**, 25–83.

Henares, J., C. López Casado, C. Sanz de Galdeano, J. Delgado, and J. A. Peláez (2003). Stress fields in the Iberian-Maghrebi region. *Journal of Seismology* 7, 65–78.

ISC (2009). International Seismological Centre, online bulletin; http://www.isc.ac.uk/Bull.

Johnston, A. C. (1996). Seismic moment assessment of earthquakes in stable continental regions—I. Instrumental seismicity. *Geophysical Journal International* **124**, 381–414.

Kagan, Y. Y., D. D. Jackson, and Y. Rong (2006). A new catalog of southern California earthquakes, 1800–2005. *Seismological Research Letters* 77, 30–38.

Kanamori, H. (1977). The energy release in great earthquakes. *Journal of Geophysical Research* **82**, 2,981–2,987.

Leeds, A., ed. (1983). *El-Asnam, Algeria Earthquake of October 10, 1980. A Reconnaissance and Engineering Report*. Oakland, CA: Earthquake Engineering Research Institute Report CETS CND-022.

López Casado, C., S. Molina, J. Delgado, and J. A. Peláez (2000). Attenuation of intensity with epicentral distance in the Iberian Peninsula. *Bulletin of the Seismological Society of America* **90**, 34–47.

Martínez Solares, J. M., and J. Mezcua J. (2002). *Seismic Catalog of the Iberian Peninsula (880 B.C.–1900)*. Madrid: Ed. IGN (in Spanish).

Mezcua, J. (2002). Seismic Engineering Course (in Spanish). Madrid: Universidad Politécnica de Madrid.

Mezcua, J., and J. M. Martínez Solares (1983). *Seismicity of the Ibero-Maghrebian region*. Madrid: IGN Report (in Spanish).

Mezcua, J., J. Rueda, and R. M. García Blanco (2004). Reevaluation of historic earthquakes in Spain. *Seismological Research Letters* **75**, 75–81.

Mokrane, A., A. Aït Messaoud, A. Sebaï, N. Menia, A. Ayadi, and M. Bezzeghoud (1994). *Earthquakes in Algeria from 1365 to 1992.* Algiers: CRAAG Report (in French).

Negredo, A., P. Bird, C. Sanz de Galdeano, and E. Buforn (2002). Neotectonic modeling of the Ibero-Maghrebian region. *Journal of Geophysical Research* **107**; doi:10.1029/2001JB000743.

Outtani, F., B. Abdoun, E. Mercier, D. Frizon de Lamotte, and J. Andrieux (1995). Kinematics of the South Atlas front, Algeria and Tunisia. *Tectonophysics* **249**, 233–248.

Ouyed, M., M. Meghraoui, A. Cisternas, A. Deschamps, J. L. Dorel, L. J. Frechét, R. Gaulon, D. Hatzfeld, and H. Philip (1981). Seismotectonics of the El Asnam earthquake. *Nature* **292**, 26–31.

Peláez, J. A., M. Chourak, B. A. Tadili, L. Aït Brahim, M. Hamdache, C. López Casado, and J. M. Martínez Solares (2007). A catalog of main Moroccan earthquakes from 1045 to 2005. *Seismological Research Letters* **78**, 614–621.

Philip, H., and M. Meghraoui (1983). Structural analysis and interpretation of the surface deformations of the El Asnam earthquake of October 10, 1980. *Tectonics* **2**, 17–49.

Pondrelli, S., S. Salimbeni, A. Morelli, G. Ekström, and E. Boschi (2007). European-Mediterranean Regional Centroid Moment Tensor catalog: Solutions for years 2003 and 2004. *Physics of the Earth and Planetary Interiors* **164**, 90–112.

Rothé, J. P. (1950). Les seismes de Kherrata et la seismicité de l'Algerie. *Bulletin du Service de la Carte Géologique de l'Algérie, 4ème série. Géophysique*, no. 3, 40 pp.

Rueda, J., and J. Mezcua (2002). Study of the 23 September 2003, Pego (Alicante) earthquake. Obtaining a m_{bLg}-M_W relationship for the Iberian Peninsula. *Revista de la Sociedad Geológica de España* **15**, 159–173. (In Spanish).

Rueda, J., and J. Mezcua (2005). Near-real-time seismic moment-tensor determination in Spain. *Seismological Research Letters* **76**, 455–465.

Samardjieva, E., G. Payo, J. Badal, and C. López (1998). Creation of a digital database for XXth century historical earthquakes occurred in the Iberian area. *Pure and Applied Geophysics* **152**, 139–163.

Stich, D., C. J. Ammon, and J. Morales (2003). Moment tensor solutions for small and moderate earthquakes in the Ibero-Maghreb region. *Journal of Geophysical Research* **108**, 2002JB002057.

Stich, D., J. Batlló, J. Morales, R. Macià, and S. Dineva (2003). Source parameters of the $Mw = 6.1$ 1910 Adra earthquake (southern Spain). *Geophysical Journal International* **155**, 539–546.

Tadili, B. A., and M. Ramdani (1983). Computer file of Moroccan earthquakes. *Bulletin of the Seismological Society of America* **73**, 653–654.

USGS (2009). U.S. Geological Survey online catalog; http://neic.usgs.gov/neis/epic/epic_global.html.

Wang, Q., D. D. Jackson, and Y. Y. Kagan (2009). California earthquakes, 1800–2007: A unified catalog with moment magnitudes, uncertainties, and focal mechanisms. *Seismological Research Letters* **80**, 446–457.

Yadav, R. B. S., P. Bormann, B. K. Rastogi, M. C. Das, and S. Chopra (2009). A homogeneous and complete earthquake catalog for Northeast India and the adjoining region. *Seismological Research Letters* **80**, 609–627.

Yelles Chaouche, A. K., A. Deramchi, A. Ferkoul, and K. Aoulaiche (2002). *Earthquakes in Algeria from 1992 to 2001.* Algiers: CRAAG Report (in French).

Yelles Chaouche, A. K., A. Deramchi, A. Ferkoul, K. Aoulaiche, K. Meghnine, S. Haned, F. Chaoui, D. Aini, and K. Talbi (2003). *Seismic Catalog 2002*. Algiers: CRAAG Report (in French).

Yelles Chauche, A. K., H. Djellit, S. Haned, A. Deramchi, T. Allili, A. Kherroubi, H. Beldjoudi, F. Semmane, A. Amrani, Z. Haddana, F. Chaoui, A. Aidi, and A. Allili (2007). The Algerian digital network. *European-Mediterranean Seismological Centre Newsletter* **22**, 7–8.

Yelles Chauche, A. K., S. Haned, and A. Deramchi (2003). The CRAAG, Algeria. *European-Mediterranean Seismological Centre Newsletter* **20**, 17–18.

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APPENDIX

Relationships by Johnston (1996):

$$\log M_0 = 24.66 - 1.883 \cdot M_S + 0.192 \cdot M_S^2 \qquad (3.5 < M_S < 7.5)$$

$$\log M_0 = 18.28 - 0.679 \cdot m_b + 0.077 \cdot m_b^2 \qquad (3.5 < M_S < 6.5)$$

where M_o is the seismic moment. Then, the moment magnitude is computed from the well-known relationship between seismic moments and moment magnitudes by Hanks and Kanamori (1979).

Relationship by Rueda and Mezcua (2002):

$$M_W = 0.311 + 0.637 \cdot m_{bLg} + 0.061 \cdot m_{bLg}^2 \quad (1.7 < m_{bLg} < 5.7)$$

Relationship by Mezcua (2002):

$$M_W = 0.96 + 0.6 \cdot I_{\max}$$

Attenuation relationship (medium model) by López Casado *et al.* (2000):

$$I = f(I_0) - a_2 \cdot \ln \Delta - a_3 \cdot \Delta$$

$$f(I_0) = 4.927 + 0.571 \cdot I_0 + 0.037 \cdot I_0^2$$

$$\Delta = \sqrt{R^2 + R_0^2}$$

$$a_2 = 1.445 \quad a_3 = 0.00609 \quad R_0 = 6\ km$$

Relationship by Kanamori (1977):

$$\log E_S = 11.75 + 3/2 \cdot M_W$$