No ISSN : 1607-1980

Centre Sismologique Euro-Méditerranéen
European-Mediterranean Seismological Centre
www.emsc-csem.org

Newsletter

N° 20 SEPTEMBER 2003

EDITORIAL

Since the last Newsletter, our region has been devastated by an earthquake which killed over 2000 people in Algeria, rendered 150,000 homeless and caused €100M of damage, including to boats and underwater cables. Our thought and sympathies are with our Algerian neighbours, who have, once again, suffered the effects of awesome tectonic forces which are a characteristic of our European-Mediterranean region. An article in this Newsletter explains in more detail the role of EMSC members in rapidly gathering, and making available, objective information on such events even when communications with the affected area, are, inevitably, difficult. A special session on the earthquake was convened at the most recent RELEMR meeting of eastern and southern Mediterranean countries, in Cyprus, which was coordinated by EMSC in association with UNESCO, USGS, the Geological Survey of Cyprus and ORFEUS. The EMSC's web-page has been of particular value in keeping the community and public updated on this earthquake; web traffic increased dramatically, demonstrating the need for this special service and its further development.

Our joint FP6 infrastructure bid, with ORFEUS, is in the review process. We consider that, regardless of the outcome, the wide-ranging consultation and cooperation in preparing it will provide a platform for further collaboration and bids in the future. The complementary roles of EMSC and ORFEUS in serving our seismological community have been further defined and endorsed in the process.

Finally, news from our sister organisation and EMSC member by right, the International Seismological Centre. Following an indication last year, that Ray Willemann would like to move on at the end of 2003, after six years, his successor as Director of the ISC has been selected. Avi Shapira, presently the director of the Geophysical Institute of Israel, who built up its Seismological Group and who is a long-time supporter of ISC and EMSC, will be continuing the significant developments achieved under Ray Willemann both in Thatcham, and in ISC/EMSC collaboration. The EMSC's monthly bulletin, which should go live in early 2004, will be yet another vehicle for fostering that process. We wish Ray every success in his future career in the US and welcome Avi into his important new role with international seismological infrastructure.

Chris Browitt
President

Foreword to the special section on the May 21st, Algeria earthquake

The magnitude Mw6.8 (ETH, INGV, CPPT) earthquake which struck Algeria on May 21st, 2003 is the largest earthquake to have occurred in the region since the El-Asnam earthquake, Ms7.3 in 1980. The human and economic consequences are disastrous for the country. This earthquake is of particular scientific interest for the Euro.-Med. Region because it shares some characteristics with a large area of the Mediterranean region. It has occurred in a zone characterised by a relatively moderate and diffuse seismic hazard where the vulnerability remains significant. It also illustrates the difficulty of implementing an efficient prevention policy in a region where past damaging events have been long forgotten and where the authorities had to deal with a boom in new buildings.

This special section, as a follow-up to the EMSC special Web page (http://www.emsc-csem.org/Html/ALGER_210503.html), aims at providing a preliminary description of the main characteristics of this event at a time scale located after the initial focus of the main media and before peer-reviewed articles have been published and when limited information is available. We hope that this will contribute to a better understanding of the seismic risk in the Mediterranean region and thus improved prevention policies.

CONTENT

EMSC actions concerning the Boumerdes-Zemmouri event

R. Bossu, S. Godey and G. Mazet-Roux, EMSC

Alert system and Real Time Seismicity

The Zemmouri event has triggered the EMSC alert procedure 8 minutes after the occurrence of the event. The first reviewed alert message was disseminated 41 minutes after the occurrence announcing a mb 6.0; the magnitude was re-evaluated 47 minutes later to Ms6.6 and then completed by a Mw 6.8

The final epicentral location which includes regional arrival data (from Algeria, Tunisia, Egypt and Balearic Island) is 37.02°N, 3.76°E. It is important to note that the initial epicentral location disseminated in the first alert message differs by less than 3 km.

The moment tensor determined by ETHZ (Zurich, Switzerland) was automatically made available on our web site 2 hours after the earthquake occurrence and was followed by the solutions provided by INGV-MedNet (Italy), CPPT (Pamataï, LDG, France), Harvard and USGS solutions (Figure 1).

Following the main shock, 20 aftershocks were located by EMSC and 4 of them have been the subject of an alert and/or information message.

Special web page

A special web page has been opened on May 22nd to provide a more detailed and regularly-updated information on this event, its seismotectonic context, the aftershock activity and the consequences. It includes maps of seismic activity but the majority of the contributions was kindly provided by the seismologist community. This page has induced a significant increase in the number of individual daily visitors to the EMSC Web page, from an average of about 250 before the event to a daily average of 900 over the whole month of June (Figure 2). During this time period 400,000 pages have been viewed (this web page has had a durable impact on our visibility with, in July, an average of 1,300 individual visitors a day). It has also been linked by a number of sites and referenced by several publications. These figures clearly demonstrate the need for such a special page in this particular type of situation.

Conclusion

The alert system has performed well for the Zemmouri event both in terms of rapidity and reliability, thanks to the data contributors. Such information was particularly important for this event as the communication with Algeria had been severely hampered following the breakage of several sub-marine phone cables. Official organisations that EMSC deals with such as the Council of Europe or ECHO have received the source parameter information in a timely manner. New organisations have also shown interest for closer relationship. Notably, the K9 *search and rescue team* (Germany) informed us that our email message has allowed them to contact their task force more rapidly than usual and they arrived on the field the day following the earthquake; from now on, they have requested to receive messages by fax. The special web page has proved to be a very efficient way to disseminate information on this event. We will do our best to systematically open such a page in case of a damaging event in the Euro.-Mediterranean region and improve the service. For example, the regional tectonic, historical and instrumental seismicity and hazard level should be made available more quickly; Joint hypocenter determinations would also help to follow the seismic activity and identify the active structures… Today, we would really appreciate to receive your feedback, comments or ideas to further improve our services.

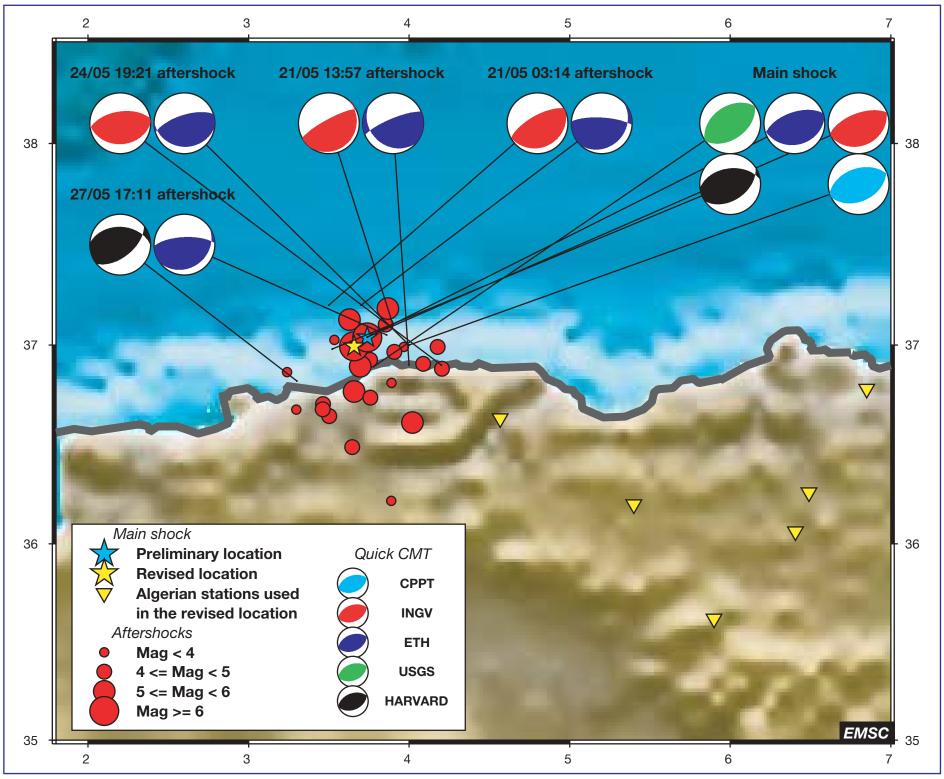

Figure 1: *Map of the seismic activity in the Boumerdes area following the May 21st mainshock.*

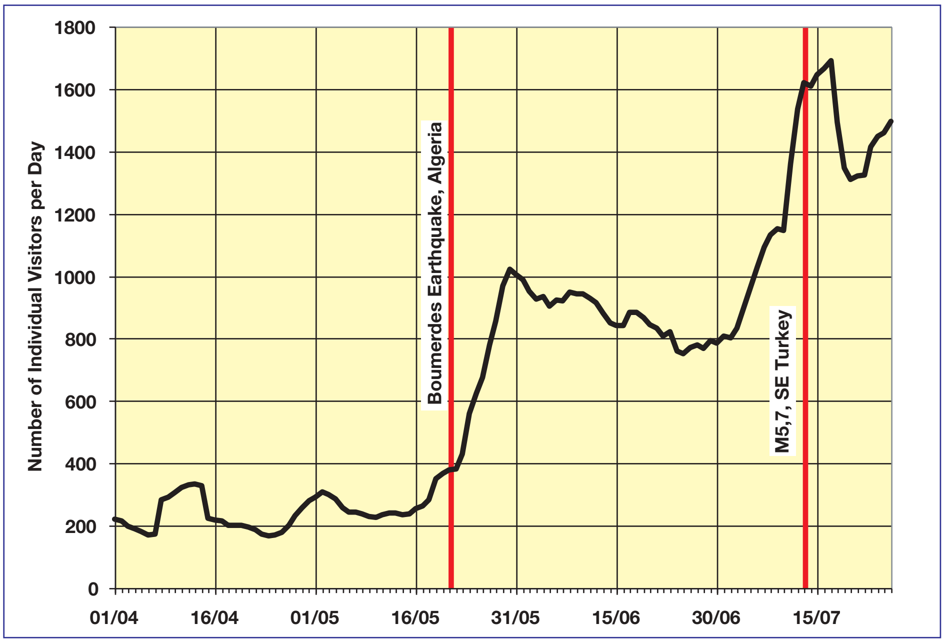

Figure 2: *Evolution with time of the daily individual visitors (individual IP) of EMSC web site. Values are averaged in a centred, seven-day-long moving window.*

The Boumerdes -Algiers (Algeria) Earthquake of May 21st, 2003 (Mw=6.8)

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Abstract

The Boumerdes-Algiers earthquake of magnitude Mw:6.8 is the second major event which seriously affected Algeria in the last twenty years. This seismic event, located 7 km north of the village of Zemmouri (50 Km east of Algiers) happened in a region characterized previously by a low to moderate seismic activity. With a depth of 10 km, the earthquake killed 2300 persons and caused huge damage in the epicentral area located between Dellys and Algiers. In this region, site effects such as liquefaction, minor landslides, rock falls, surface breaks have been observed. The earthquake was generated by an unknown offshore reverse fault, the Zemmouri fault. This NE-SW oriented fault extents over 50 km along the margin, between Dellys and Corso.

Geological investigations revealed in the epicentral area, surface breaks affecting the Quaternary sedimentary cover. These breaks display two main orientations parallel to the coastline: N35° from Corso to Dellys and N120 from Corso to Tamentefoust. Along this coastline, an uplift of the seafloor with a mean value of about 60 cm has been also observed.

Introduction

On May 21st 2003 at 19h 44' 19"GMT, a destructive earthquake of magnitude Mw=6.8 occurred in Boumerdes, a city located 50 km east of Algiers. The epicentre was located 7 Km north of the sailors village of Zemmouri (CRAAG) (Figure 1).

The earthquake, with a maximum intensity of X, caused important damage in Boumerdes and the main villages of the region (Zemmouri, Dellys, Thenia,...). In these urban centres, many recent buildings totally collapsed and many of them have been seriously damaged (figure 2). In Algiers, thousands of buildings have been affected with various intensities. For some of them, torsion of the pillars or deep cracks on the walls were observed. In the epicentral area 2273 persons died and about 200 000 people were made homeless.

Figure 2: *Building damages observed in the city of Boumerdes*

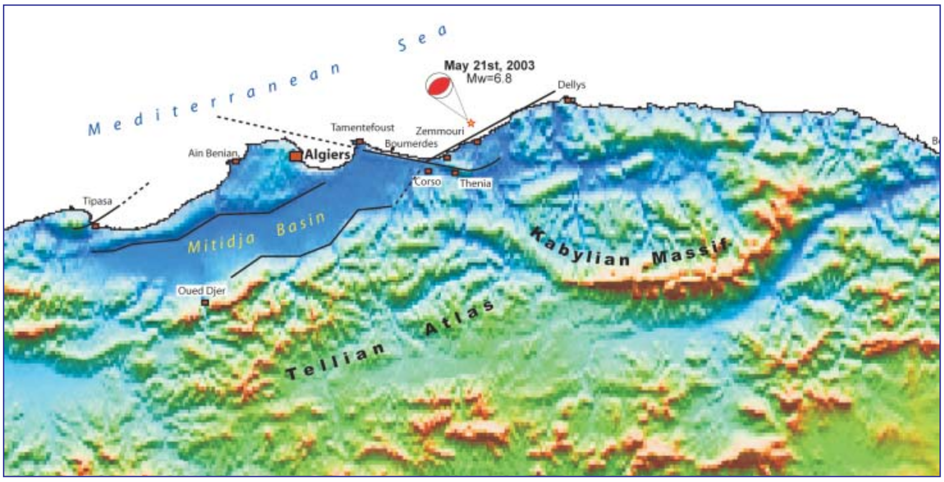

Figure 1: *Boumerdes, Algiers (Algeria) earthquake (May 21st, 2003) location.*

Using records of the Algerian seismological network , the epicentre of the main shock was located precisely in the Algerian margin at 3°58 E, 36° 91N. The magnitude of M_l=6.2 was calculated using time duration of seismic signals recorded at stations of the Algerian Seismic Network operated by the CRAAG. A depth of 10 Km was determined and represents a value close to the depth of the Algerian earthquakes. The CRAAG epicentre characteristics are slightly different from those given by EMSC (3.76 E, 37.02N) and USGS (3.78 E, 36.89N).

The focal mechanisms calculated by the international seismological centres correspond to a NE-SW thrust fault (strike: 54 ; dip: 47 ; rake: 86). The seismic moment is M_0=2.4x 10^{19} N.m. (from Yagi, 2003) .

Following the occurrence of the main shock, an important aftershock activity was recorded by a portable seismic network installed by the CRAAG in the epicentral area. A rapid fruitful cooperation with the UMR Geosciences Azur (France) also allowed installation for three weeks, of four OBS, few miles from the coastline. Processing of the aftershocks is still going on but we can pointed out that the spatial aftershocks distribution is mainly concentrated offshore along an NE-SW axis extending from Dellys to Corso. The aftershock activity was marked by the occurrence of two main events of Ml=5.8 occurring respectively on May 24th and 28th.

The main shock has been followed by a small tsunami, which affected the Spanish coast. During the main shock, the sailors observed a temporary withdraw of the sea of about 100 m. Along the Spanish coast of the Balearic Islands, a sea wave height of about 1.5 m sunk hundred small boats parking in the ports.

Historical seismicity

During history, the region of Algiers-Boumerdes and its surroundings, was repeatedly affected by moderate to large earthquakes (Rothé, 1950, Benhallou,1985; Ambraseys and Vogt,1988). These events were generally located within the Mitidja basin. Nevertheless, some of these earthquakes were related to coastal faults such as the earthquake of January 2nd 1365 or the one, which occurred on February 3rd, 1716.

In the region of Boumerdes, the most important seismic event, which happened during the twentieth century in the region, was on September 16th,1987 (M=5.2). This earthquake had no effects on the region as no huge damage was reported. Other minor earthquakes occurred in the region of Boumerdes-Thenia, sometimes felt by the population.

In the western side, Algiers region was affected more strongly by three moderate earthquakes, the Oued Djer event on October 31st, 1988, Ml=5.0; the Tipaza event on October, 1989 27th, Ml=6.0 and the Ain Benian earthquake on September 4th, 1996, Ml=5.7. These last two earthquakes displayed reverse mechanisms and were generated by ENE - WSW reverse faults.

Historical seismicity of this region is still poorly known because of the lack in the past of geological or geophysical studies. Some evidences of active faulting have been pointed out by previous studies (Meghraoui, 1988; Boudiaf, 1996).

Seismotectonic setting

The Northern region of Algeria is located along the western part of the plate boundary between Eurasia and Africa. This boundary is under compression due to the convergence of the two major plates with a calculated rate of 0.6 cm/yr (Argus et al., 1989). This led to the occurrence, in this region, of repeated moderate to large earthquakes, one of the most important earthquake was the El-Asnam earthquake of October 10th, 1980 (Mw=7.3).

The region of Boumerdes is located, along the coastal region of the central part of Algeria. It is located, more precisely in the eastern tip of the Mitidja basin (figure 1). The latter was formed during the N-S Miocene extension (Guiraud, 1977; Philip, 1983). This extension was followed by a N-S to NNW-SSE compression, which peaked, between Upper Pliocene and Villafranchian (Guiraud,1977). The compression has continued during the Quaternary (Philip and Thomas, Meghraoui, 1988) and is still active as shown by the observed seismic activity and recent deformation. This deformation is represented by active folding oriented NE-SW and by thrusts and strike slip faults trending respectively NE and SE (Meghraoui,1988 ; Boudiaf,1996).

In the Boumerdes region, the quaternary geological formations are marked by two series. The first one related to the sandy Calabrian and Villafranchian formations and the second to the quartzitic Thyrrhenian formations. In these later series, several uplifted marine terraces at different topographic levels are distinguished. These series are deformed and associated with folds with a N120 orientation (from Cap Matifou to Thenia). From previous geological investigations (Boudiaf, 1998), this topographic height corresponding to the eastern flank of the Sahel region is associated to the Thenia fault.

Coseismic surface breaks

Coseismic surface breaks were observed onshore in several areas of the epicentral region as Boudouaou, Zemmouri port and Dellys (figure 3). They affect the Thyrrhenian marine terraces of the eastern littoral of Algiers. Surface breaks correspond to a clear set of cracks with a NE-SW (N35°) orientation along the Zemmouri bay. Along the Tamentefoust-Thenia, axis, breaks with N120 direction affects the marine terraces.

Figure 4: *Uplift of the seafloor observed along the coastline.*

Offshore, an uplift of the seafloor has been observed, marked by the appearance at the sea surface of small rocky blocks (figure 4). In fact, this uplift concerns the whole area around Boumerdes as this phenomenon has been observed along the coast, ranging from 0.4 m at Reghaia beach to 0.8 m at Zemmouri embankment port.

In addition, the earthquake induced some minor landslides as observed along the sandy dunes of the beaches or along the roads (Figure 5). Some liquefaction phenomenon was also observed. It would be responsible of the destruction of several buildings. Some other effects as creation of new water springs has also accompanied the earthquake.

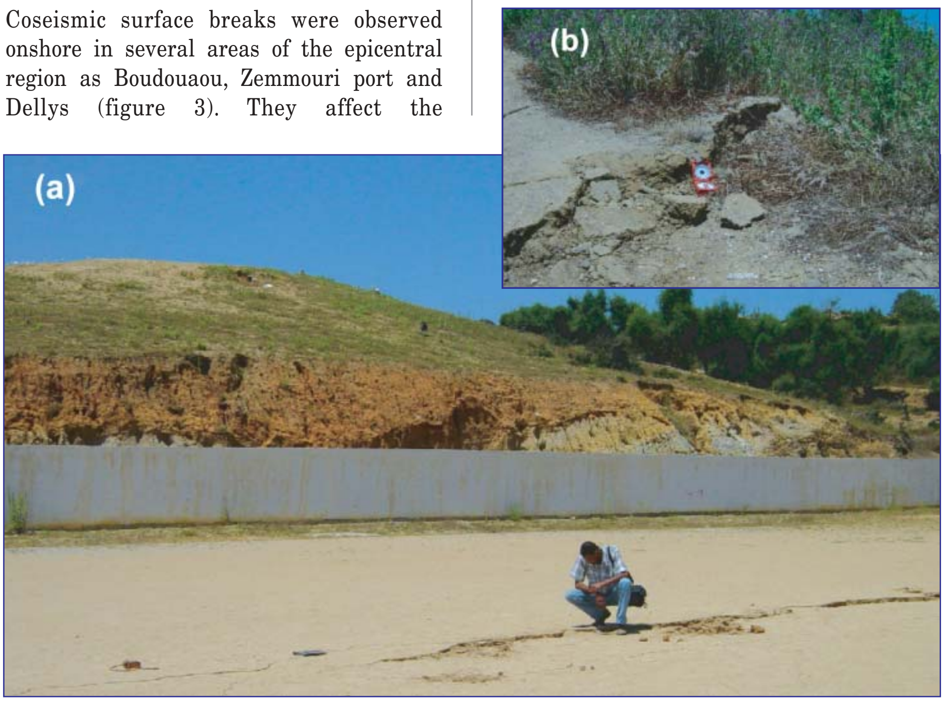

Figure 3: *Surface breaks in the epicentral area. (a) general view near Corso. (b) details of the thrust.*

The Zemmouri fault

From the geophysical and geological investigations, we can assume that the Boumerdes Algiers earthquake has been generated by a new revealed offshore fault crosscutting the margin. It is oriented N 35 and extents from Dellys to Corso (about 40 km) (Figure 1). This fault allowed the uplift of the coastal region. This fault is associated with the Thenia onshore fault that appears as a major active structure in this area (Boudiaf, 1996, 1998). The evidence of folding and faulting in the region of Boumerdes are now well understood by the offshore Zemmouri fault.

Evaluation of the seismic hazard

The occurrence of the Boumerdes earthquake drastically changes the evaluation of the seismic hazard of the Algiers region. Indeed, before the earthquake, the maximum PGA was evaluated 0.15g. This is explained by the poor knowledge of the seismicity of the region.

Using the earthquake design scenario, assuming that the maximum possible magnitude is the magnitude of earthquake at 20 km ± 5 km from Algiers or Boumerdes. The maximum PGA is now:

$$A_{sup}^{G\text{-}K}=0.3172g, A_{sup}^{Pi}=0.2352g, A_{sup}^{K\text{-}S}=0.2367g$$

Discussion and Conclusions

The Boumerdes earthquake demonstrates that northern region of Algeria remains highly active. Indeed, during the last twenty years, this region experienced six moderate events (Constantine, October, 27th, 1985, M_l=6.0; Tipaza, October, 29th, 1989, M_l=6.0 ; Mascara, August, 18th, 1994, M_l=5.7; Ain Benian, (Algiers) September, 4th, 1996, M_l=5.8; Ain Temouchent (Oran region), December, 22th, 1999, M_l=5.8 ; Beni Ouartilane (Bejaïa region), November, 10th, 2000, M_l=5.4) and two important earthquakes (El Asnam of October 10th, 1980, Mw=7.3 and Boumerdes earthquake of May, 21, 2003). All these earthquakes are more precisely located in the Tellian mountains which remains the more active zone of Algeria. This region could be the location of some violent earthquakes of the western part of the

Figure 5: *Landslides along the coastline in the epicentral area.*

Mediterranean region and the Boumerdes earthquake is among these major events.

The Boumerdes earthquake remains the first major seismic event in the Algiers region since the February, 3rd, 1716 earthquake. If we consider the seismic destructive event of the January 2nd, 1316, we can consider that the Algiers region is repeatedly affected by major strong shakings.

The Boumerdes offshore earthquake is the third recent seismic event, which happened along the Algerian margin. Its destructive character indicates the urgent need of investigation on the active structures of the offshore region of Algeria whose recent tectonic is still poorly known.

The next Maradja French Algerian survey which will be carried out in August in this region will be an excellent opportunity to improve the knowledge of this region and to extent the onshore seismotectonic map. On the other hand, results of this survey will allow to better understanding the uplift mechanism of the Algerian margin due to the compressional stress regime of the region.

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Analysis of Strong Ground Motions Recorded during the 21st May, 2003 Boumerdes, Algeria, Earthquake

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Introduction

The regions of Algiers and Boumerdes, North of Algeria, were shock by a destructive earthquake of magnitude M_w=6.8 (EMSC/USGS) on Wednesday 21st, May 2003 at 19:44:40 (GMT+1) which claimed about 2300 human lives and injured about 11000 peoples. It's therefore, the worst seismic event since the El Asnam October 10th, 1980, Ms=7.3.

The main shock caused widespread destructions mainly in the area of the Eastern part of Algiers, the capital, and Boumerdes, about 50 km NE of Algiers. The main shock was felt as far as 250 km from the epicentre which was located offshore.

Many records were made by the national accelerograph network monitored by CGS. The maximum pick ground acceleration recorded at 20 km from the epicenter reached 0.58 g. This earthquake induced liquefaction mainly along the Isser and Sebaou river valleys, tsunamis in the Balearic islands, and site amplification mainly in the quaternary Mitidja basin, as well as uplift of the coastal line. The main shock was followed by several aftershocks among them those of May 27th, 2003 (M_S=5.8) and May 28th, 2003 (M_S=5.8) causing panic among the population which fled their homes, few people left Algiers for other regions of Algeria. The earthquake of May 27th, 2003 injured about 100 people, two of them threw themselves from windows, killed 3 and destroyed the mostly affected constructions, particularly the R+10 building at Reghaia and the minaret of Zemmouri mosque.

Strong ground motion data analysis

In addition to the epicentral and surrounding areas, the earthquake was felt in a radius of more than 250 km where it was recorded accelerations of about 0.02 g. The main shock was recorded by many stations of the national accelerograph network monitored by CGS.

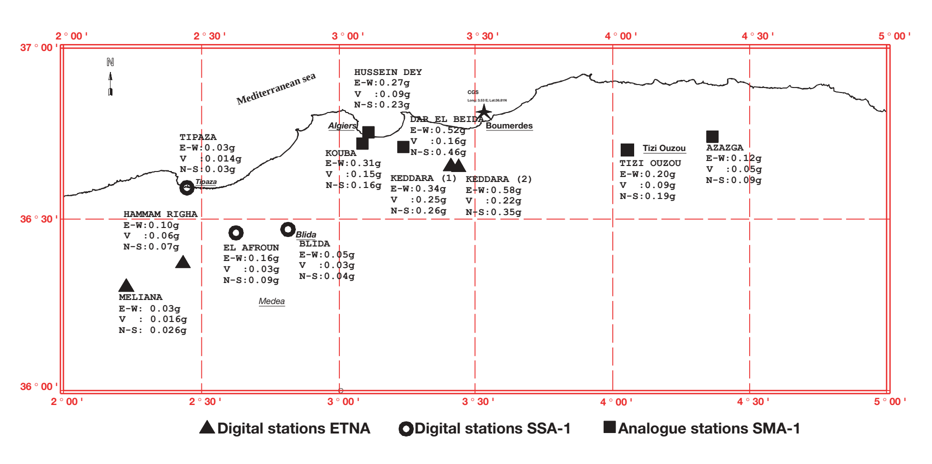

Figure 1: *Location of the recording stations and the corresponding recorded PGA in the E-W, N-S and Vertical directions. The star indicates the epicentre determined by CGS using accelerograms : Long: 3.53 E, Lat: 36.81 N*

A temporal and frequential analysis was performed (Laouami et al., 2003).

Figure 3 show the map of the stations location with the pick ground accelerations recorded during the main shock in the E-W, N-S and Vertical directions.

The closest stations to the epicentre, in free field, which recorded the main shock are those of Keddara at 20 km. From figure 1, one can underline the following observations:

- At Keddara site, the maximum accelerations recorded by two stations distant from each other approximately 150 m are as follows:

  Station 1: E-W: 0.34 g Ver: 0.25 g N-S: 0.26 g
  Station 2 : E-W : 0.58 g Ver : 0.22 g N-S : 0.35 g

  The very significant variation observed between stations 1 and 2 concerning more particularly accelerations in E-W direction suggest the presence of site effect particularly significant at station 2. A current geotechnical study will quantify this local site effects.

- PGA in E-W direction are more significant than those in the N-S direction. This observation is valid almost at the majority of the stations, and is probably related to the directivity effect of the fault.

- Because they are located on the Mitidja quaternary basin classified as soft soils, The Dar El Beida and El Afroun stations records show high acceleration level compared to those located on firm soils.

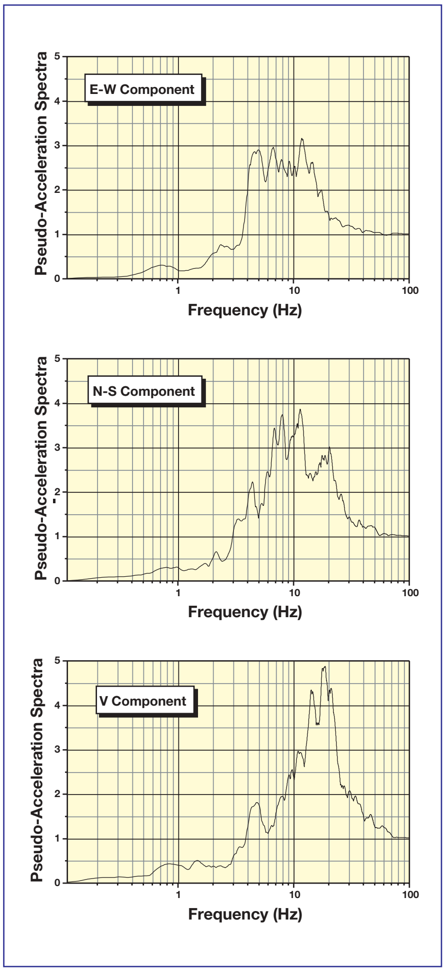

Figure 3: *E-W, N-S and Vertical pseudo accelerations response spectra at Keddara 1 station.*

Figure 2 shows the E-W, N-S and Vertical accelerations recorded at Keddara 1 station. The strong part duration given by the Husid diagram is about 10 s.

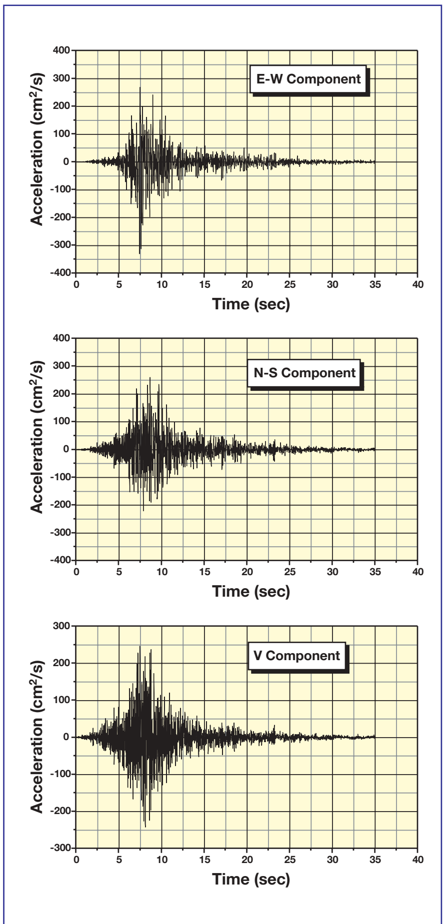

Figure 2: *E-W, N-S and Vertical accelerations recorded at Keddara 1 station.*

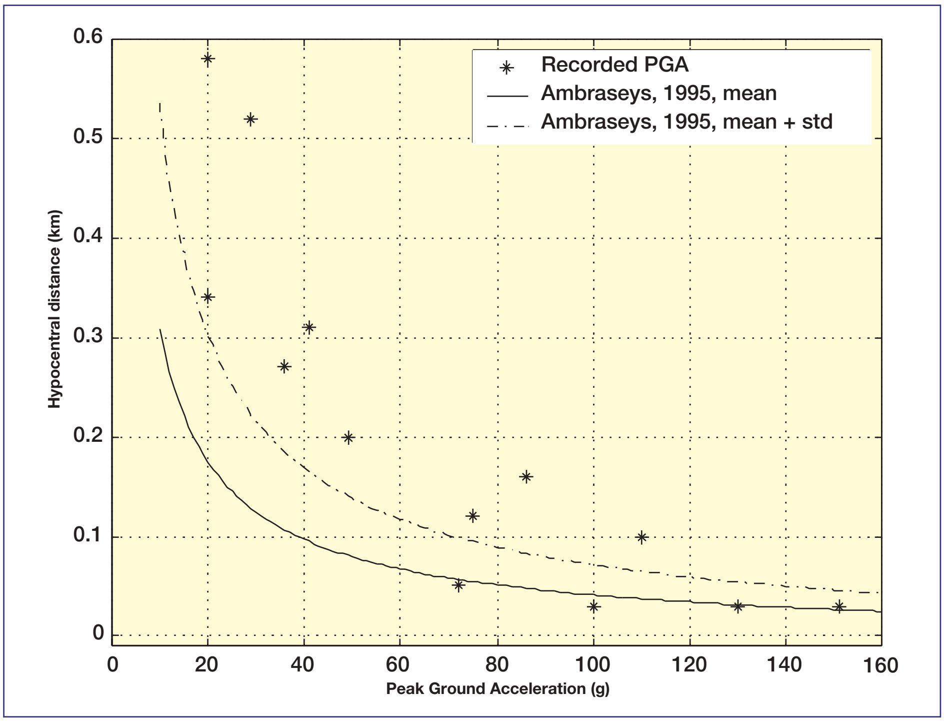

Figure 4: *Comparison between the Recorded PGA attenuation with the mean and the mean plus std empirical Ambraseys attenuation law (1995).*

Response spectra

The other parameter which characterizes the seismic movement is the frequency content. The study performed on the recordings obtained during the main shock may explains the observed damages in the epicentral region.

Figure 3 shows the response spectra of the E-W, NS and Vertical components for the station of Keddara1. The plotted curves show high frequency content for the Keddara station (near field). On the other hand, the most damaged buildings in the epicentral region have a fundamental frequency close to the earthquake frequencies.

Attenuation law

A comparative study is carried out between the recorded data during the main shock of the May 21st, 2003 Boumerdes earthquake with the attenuation law of Ambraseys (1995), developed on the basis of a sample of 1260 seismic records generated by 619 shallow earthquakes including Algerian data. Figure 4 shows the recorded maximum ground accelerations (E-W component) and the Ambraseys (1995) empirical curves. From the plotted curves, one can deduce the followings :

- The mean curve of the Ambraseys law underestimate largely the recorded accelerations for all distances.
- The envelop curve of Ambraseys law underestimate the recorded acceleration up to 70 km, while it captures the trend of the recorded accelerations from 70 km.

It is clear that for certain accelerations (stations of Keddara, Dar El Beida, El Afroun), the amplification effect explains the significant variation with the empirical curves of Ambraseys, 1995.

Conclusion

The earthquake which shook the areas of Algiers and Boumerdes (Mw = 6.8, EMSC) on May 21st, 2003, is seen as the major earthquake which has occurred in this area of Algeria for at least two centuries, and the second of this importance after El Asnam October 10th, 1980 (Ms = 7.3) earthquake. The main shock was felt 250 km far from the epicentre, and was recorded by several accelerograph stations of the national network monitored by the CGS.

Analysis of the recordings of the strong movements allows to conclude what follows :

I A significant variation observed between two stations distant from each other approximately 150 m. A current geotechnical study will quantify this local site effects.

II Pick Ground Acceleration in E-W direction are more significant than those in the N-S direction. This observation is probably related to the directivity effect of the fault.

III Stations located on the Mitidja quaternary basin classified as soft soils such as the Dar El Beida and El Afroun stations records show high acceleration level compared to those located on firm soils.

IV A comparative study shows that the attenuation law of Ambraseys (1995) underestimates largely the recorded data during the main shock of the May 21st, 2003 Boumerdes earthquake.

On the other hand, this earthquake induced liquefaction mainly along the Isser and Sebaou river valleys and tsunamis in the Balearic islands as well as uplift of the coastal line.

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A Short Note on Building Damage

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The last official report concerning the consequences of the May 21st 2003 earthquake in Algeria indicates 2 278 deaths, more than 10 000 injured and about 180 000 homeless.

Concerning the buildings, about 7 400 of them have been destroyed and about 7 000 others have been heavily damaged in the wilaya (administrative region) of Boumerdes; in the wilaya of Algiers 8500 apartments were lost and more of 20 000 others were heavily damaged.

CONSTRUCTION USE	GREEN		ORANGE		RED	TOTAL
	NIV. 1	NIV. 2	NIV. 3	NIV. 4	NIV. 5	
Residential buildings	18130	32352	19343	11727	10183	91735
Administrative buildings	213	300	184	76	52	825
Schools	420	814	467	286	103	2090
Hospitals	94	114	44	23	10	285
Sportive and cultural buildings	106	97	90	87	32	412
Commercial buildings	189	193	140	82	137	741
Industrial facilities and hangars	85	153	98	73	66	475
Other (water tanks, etc...)	54	112	110	74	61	411
TOTAL	19291	34135	20476	12428	10644	96974
%	19.90	35.20	21.11	12.82	10.97	100
	55.10		33.93		10.97	100

Table 1: *Level of damage in wilayas of Algiers and Boumerdes*

Damage assessment and analysis

More than 500 experts from CGS, C.T.C, OPGI, local technical administrations, engineering offices, etc. have been mobilised following a request by the Ministry of Housing to rapidly assess the damage. This is the first step to rapidly provide a shelter to the homeless and to ensure the new school year next September in adequate conditions of security

Damage assessment form

A form containing approximately 60 different data has been used by the teams on the field to classify the damaged buildings. The same form has been in use since 1980 and it ensures homogeneous damage evaluations. It includes information on the type of building (e.g., building identification, building occupancy, number of levels, etc....), soil conditions, an assessment of the structural and non structural elements damage, commentaries on the damage causes, global building damage level and the recommendations of emergency measures if necessary. Five levels of damage are identified and buildings are classified in 3 categories:

Green category (Damage levels 1 and 2): No damage or slight damage. The building can be reoccupied immediately.

Orange category (Damage levels 3 and 4): Significant damage requiring an extensive expertise.

Red category (Damage level 5): Constructions partially or totally collapsed.

Damage distribution

Until the end of June, 96974 buildings have undergone damage assessment; among them 91735 (94.6%) are residential buildings. Table 1 gives an overview of the level of damage.

Causes of damage

The three main causes of the damage are the magnitude of the event (Mw6.8, EMSC), the important urbanisation close to the epicentre but also to insufficiencies in design and construction of the buildings. Concerning these insufficiencies, one can mention the following points:

- ***Poor conceptual design*** (building configuration and structural layout) for seismic resistant buildings.

Figure 1: *Short column*

Figure 2: *Soft (first) storey*

Figure 3: *Non tied stone masonry*

For example, the presence of short columns in "vides sanitaires" (crawl spaces) and between upper windows of classrooms (Figure 1); the presence of soft storeys, generally at the ground zero (first storey) used as car parks or stores, with lack of infill and/or height greater than for upper storeys (Figure 2); the use of many heavy ornamental elements at building facades; insufficient dimension of the seismic joint (between two blocks of the same building, or between two buildings), Use of important and heavy cantilevers; Use of irregular building configurations with severe discontinuities in mass, stiffness, strength, and ductility resulting in torsional effects and stress concentration; Use of "heavy girders / weak columns"; Use of very heavy roofs; Non tied (or non reinforced) masonry (in rural or old urban buildings) (Figure 3)

- ***Lack of structural design or under-dimensioning*** (non seismic resistant design)

This is the case of all the buildings aged before 1981 and the great majority of individual or private houses built after 1980.

- ***Poor quality of execution and poor quality of structural material***

One can note the low strength of concrete (average of 14-17 MPA instead of 25 MPA required by the standards for current buildings) and the inadequate restarts of concrete pouring in columns (Figure 4).

- ***Inadequate proportioning and detailing of structural elements*** (Figure 5).

Figure 4: *Bad quality of materials*

- ***Poor inspection and construction techniques***
- ***Inadequate building maintenance***

Concluding remarks

This short notes only intends to present preliminary analysis of damage following the Boumerdes earthquake. More detailed studies will be made available to the community as soon as possible.

Figure 5: *Non adequate detailing*

The 2003 Boumerdes (Algeria) earthquake: Source process from teleseismic data

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The aim of this article is to present and discuss the source process of May 21st, 2003 Boumerdes earthquake (Mw=6.9) obtained by modelling broadband seismograms recorded at teleseismic distance by the global seismic network. In the absence of near source measurements, remote seismological data can provide the information needed to retrieve the main characteristics of the rupture process, provided that some care is dedicated to the exploration of the model space. Robustness can be gained by combining body waves together with surface waves.

After we determined the focal mechanism of the event (strike 57°, dip 39°, rake 83°), we investigated the slip distribution for the southeast dipping nodal plane which corresponds most likely to the fault plane according to the tectonic data. We performed several waveform inversions to evaluate the stability of the slip pattern. The most stable features of the rupture process are the following: *1*) the essential part of the rupture occurred at shallow depth (< 10 km), *2*) the

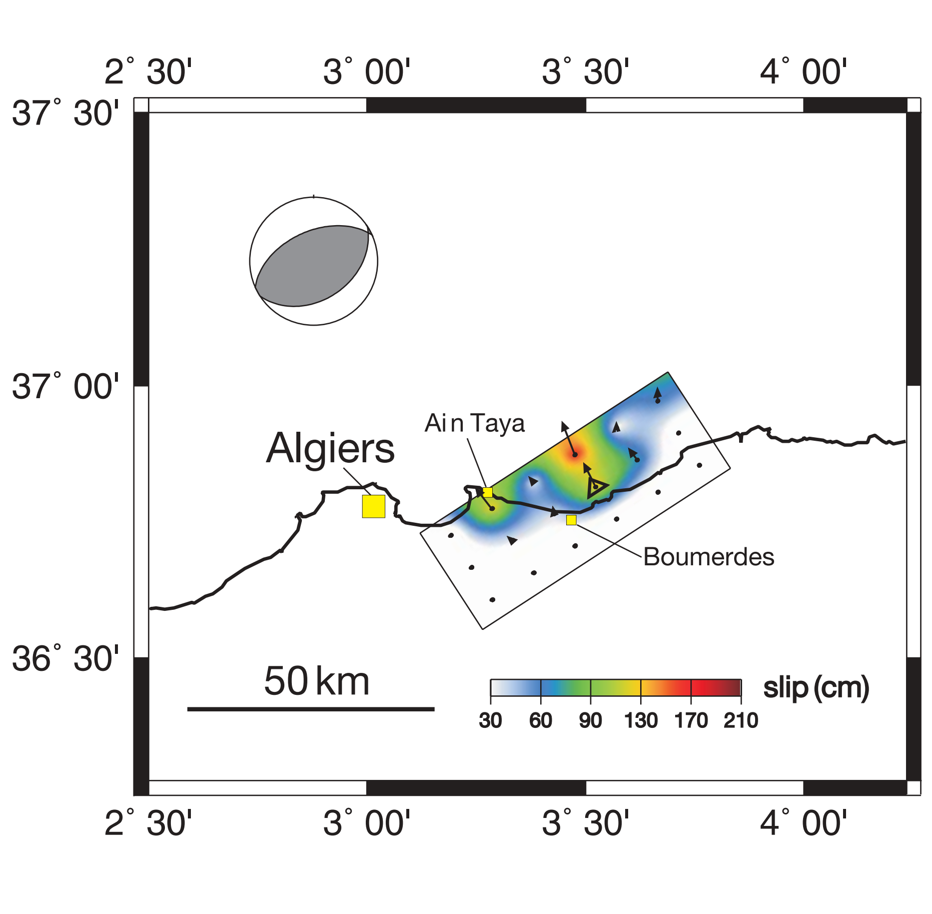

Figure 1: *Slip map projected onto the surface. Black arrows indicate the slip direction. The focal mechanism is from this study. Rupture initiate at the hypocenter indicated by the open triangle. Absolute positioning of the fault is not constrained by the teleseismic data used in this study, but is chosen according to independent observations (see text).*

hypocenter itself was relatively shallow, best located around 10 km depth, and *3)* consequent slip occurred southwest of the hypocenter, as indicated by a marked directivity effect. A second order feature, required nonetheless by the data, is that some slip propagated toward the northeast.

The model shown in Figures 1 and 2 represents a median solution for the slip distribution and displays the most stable features. This model fits optimally the P, SH, and apparent source time functions derived from the surface waves (see web page of the ESMC-CSEM, http://www.emsc-csem.org/). Maximum slip in the model is 170 cm and is located updip of the hypocenter. At the hypocenter itself, slip amounts to 130 cm. The main directivity effect toward the southwest is accounted for by a shallow asperity located 25-30 km southwest of the hypocenter. There, slip reaches 130 cm also. Propagation towards the northeast is related to the existence of a shallow slipping area 25-30 km away of the hypocenter, where slip reaches about 60 cm. The total seismic moment (2.38 10^{26} dyne.cm) indicates a moment magnitude (M_w) of 6.9. The total rupture length and duration are 50 km and 15 s respectively. Details concerning the methodology that we used can be found in Delouis et al. (2002) and Vallée (2003).

Yagi (2003), modelled the teleseismic P waves alone and obtained similar results but with higher maximum values of slip (~ 230 cm) (http://iisee.kenken.go.jp/staff/yagi/eq/algeria20030521/algeria2003521.html). Using a grid search approach, we explored the model space and found that the optimal values (from the data fit point of view) for maximum slip may vary between 100 and 250 cm.

An important issue is the absolute location of the fault plane activated during the earthquake. It cannot be constrained by teleseismic data alone. Geodetic data (levelling, GPS, SAR) and strong motion records, when available, will help to locate the rupture plane and to constrain further some details of the rupture process. The absolute location of the hypocenter may be used, but in the absence of seismic stations very close to the event, the uncertainty may be relatively large. Observations of coastal uplift exceeding several tens of cm near Boumerdes and on the Peninsula of Ain Taya (Meghraoui, pers. comm.) indicate that the rupture should be located very close to the coast. On Figure 1, we have chosen a location of the rupture which would be compatible with those observations and with the location of a major thrust fault imaged on deep seismic profiles (Mauffret, pers. comm.). We conclude that the main characteristics of the rupture process of the Boumerdes earthquake are well established, although some uncertainties remain regarding the maximum slip amplitude and the absolute location of the activated fault. Near source data (geodetic, strong motion) will help to further resolve these issues in the very near future.

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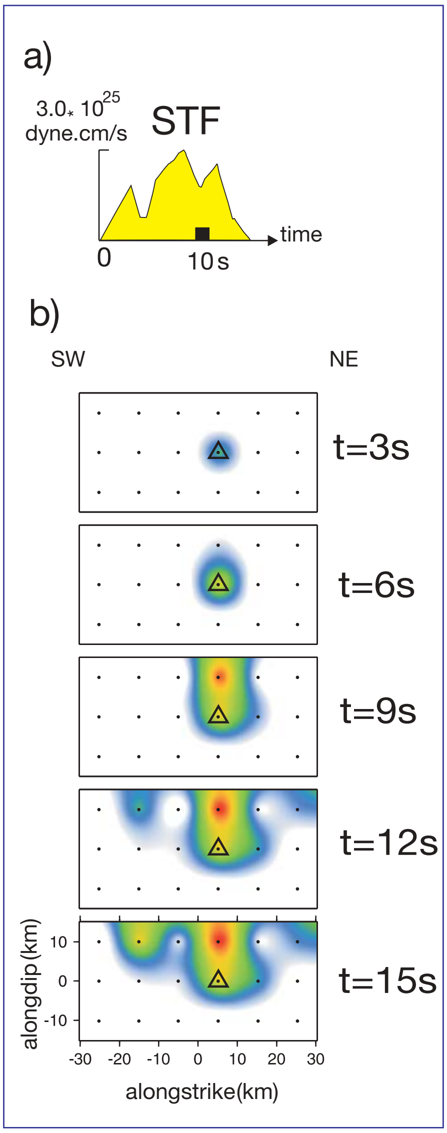

Figure 2:
a) Moment rate Source Time Function (STF).
b) space-time evolution of the rupture represented by the cumulative slip at different times after rupture initiation (hypocenter indicated by the open triangle).

The tsunami triggered by the 21 May 2003 Algiers earthquake

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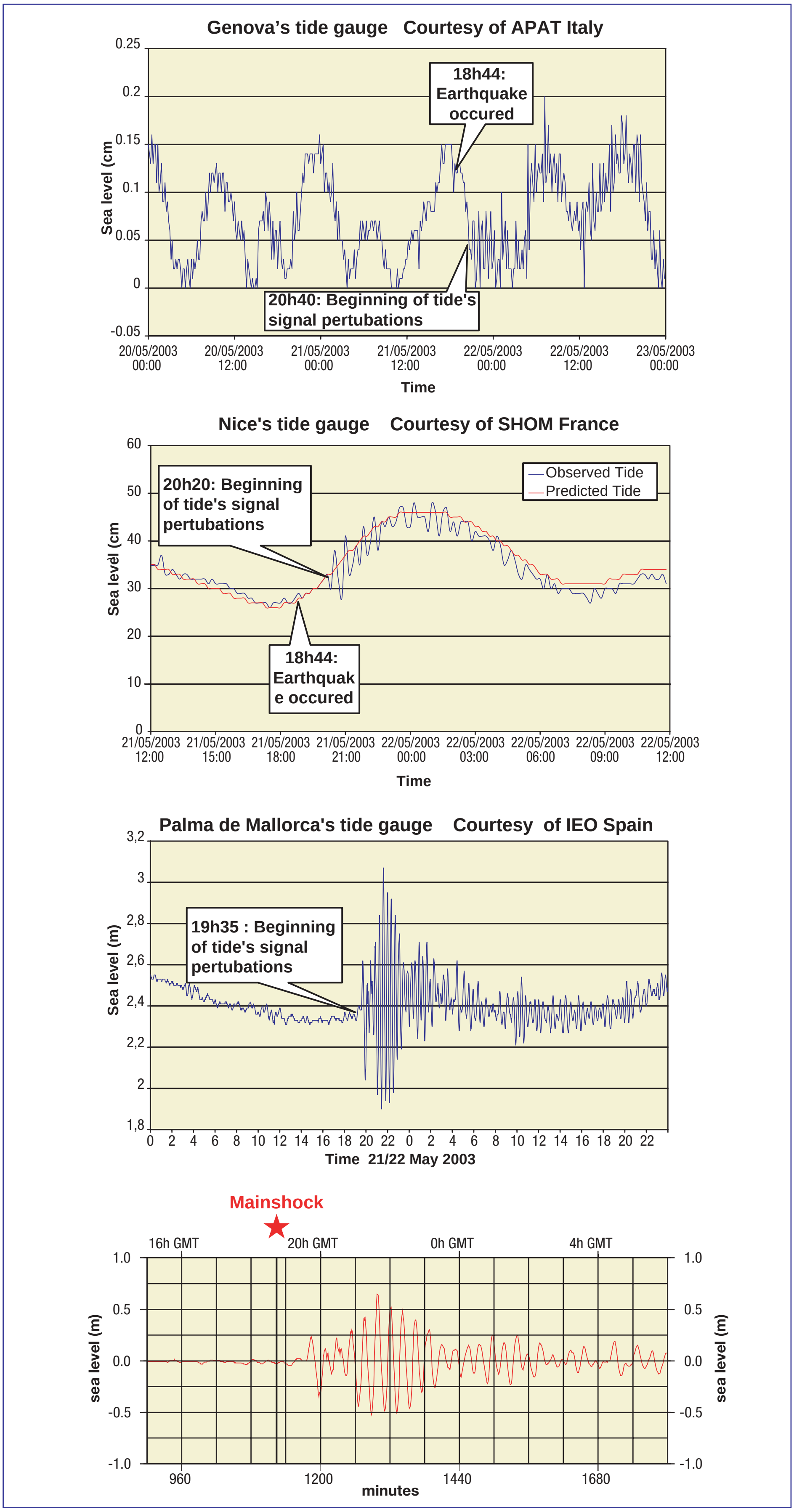

Figure 1: Sea level variations recorded in A) Genoa (Italy, courtesy of APAT, Italian Agency for the protection of environment and the technical services), B) Nice (France, courtesy of SHOM, French Hydrographic Service), and C) Palma (Majorca, Balearic Islands, courtesy of IEO, Spanish Oceanographic Institute). For the latter, data have been filtered from the tide signal using a high-pass filter. The resulting data show that the first arrival in Palma occurs about 50 min after the mainshock, and 20-min periods are observed.

Context

A strong Mw 6.9 earthquake occurred on 21 May 2003 on the Algerian coast, near the city of Boumerdes, about 60 km east of Algiers. The epicenter has been rapidly located offshore, and has been subsequently confirmed by the lack of direct observations of ground deformation on the coast, and by the offshore location of the following aftershocks. The shallow depth (10 km at most) could partly be responsible for the important damage due to the earthquake on the buildings and the high death toll (about 2500 casualties). This earthquake belongs to a series of several thrusting events that have frequently struck the Northern Algerian coast, in response to the convergence between the African and Eurasian plates.

Observations of the tsunami

For this kind of submarine shallow thrusting earthquake a tsunami is to be expected, however the level of magnitude was not prone to trigger a high-energy tsunami. Indeed, reports of sea disturbances along the Algerian coasts have been rather poor so far, and the coseismic uplift of the coast has been more frequently evoked by the eyewitnesses. The mainshock together with highly probable submarine slides seem to have cut several underwater telephonic cables, causing significant trouble to establish communications with Algeria in the days following the earthquake.

A few tide gauges have recorded sea level variations around the Mediterranean Sea, as in Genoa (Italy) (Figure 1 A) where amplitudes hardly exceed 5 to 8 cm, and in Nice (France) (Figure 1 B) where 10 cm amplitudes are observed. Arrival times can be roughly estimated to GMT 8 h 40 p.m. in Genoa (corresponding to an about 2 h propagation duration) and GMT 8 h 20 p.m. in Nice (a roughly 1 h 40 min propagation).

Sea disturbances have been clearly observed on the southeastern coast of the Balearic Islands, located about 250 km to the north, in Majorca and Minorca Islands, as well as in

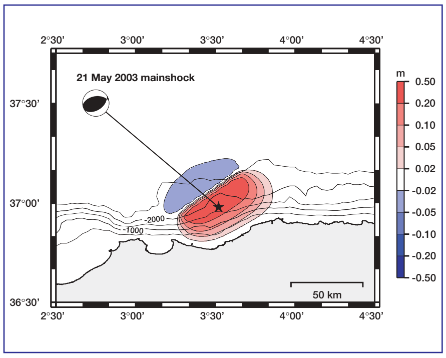

Figure 2: *Initial seafloor deformation computed from the Harvard CMT parameters modified as explained in the text.*

Ibiza. Witnesses have reported waves up to 2 m high, and a mean observed period of 10-12 min in Majorca. The consequences were quite important in Minorca (especially in Mao harbour, located SE of the island) where all in all about 10 boats sunk and several other tens were seriously damaged.

While the previous tide gauges in Genoa and Nice do not record sea level variations at a better rate than 1 point every 10 min, the tide gauge in Palma (Majorca, Balearic Islands) provides a very valuable data set sampled at a 1-min rate (Figure 1 C), that agrees well with the testimonies reported above. A maximum water height of about 70 cm (or 1.2 m peak-to-trough amplitude) has been recorded, with periods of about 20 min. The first arrival is observed about 50 to 60 minutes after the mainshock in the epicentral area, at about GMT 7 h 30 pm.

These data together with the reports gathered in the other harbour communities confirm that a tsunami was generated by the 21 May 2003 Algiers earthquake, and that the sea waves have propagated across the western Mediterranean Sea. They have caused moderate material damage in the Balearic Islands. For this magnitude level, the significant tsunami was quite a surprise. The possibility for one or several submarine landslides should not be discarded because of the reported submarine cable breakings, however these slides may have been unable to produce a tsunami.

Preliminary modeling of the tsunami

In a first attempt we test here a source due to a coseismic seafloor deformation that we derived from preliminary seismological studies of the source. The initial seafloor deformation has been first computed from the parameters of the rupture taken from the Harvard CMT solution (Table 1). Using the analytical formula describing a simple elastic dislocation model (Okada, 1985), we obtain a mean deformation on the fault plane of 0.85 m, and the initial positive deformation computed on the seafloor amounts to 0.3 m at most.

This is undoubtly lower than the values obtained from a recent seismological inversion performed using body and surface waves (Vallée, personal communication; Delouis et al., 2002; Vallée, 2003), that leads to a deformation reaching 1.7 m locally on the fault plane, while the maximum seafloor deformation reaches 0.9 m locally. The depth particularly is much shallower than the one we tried here first.

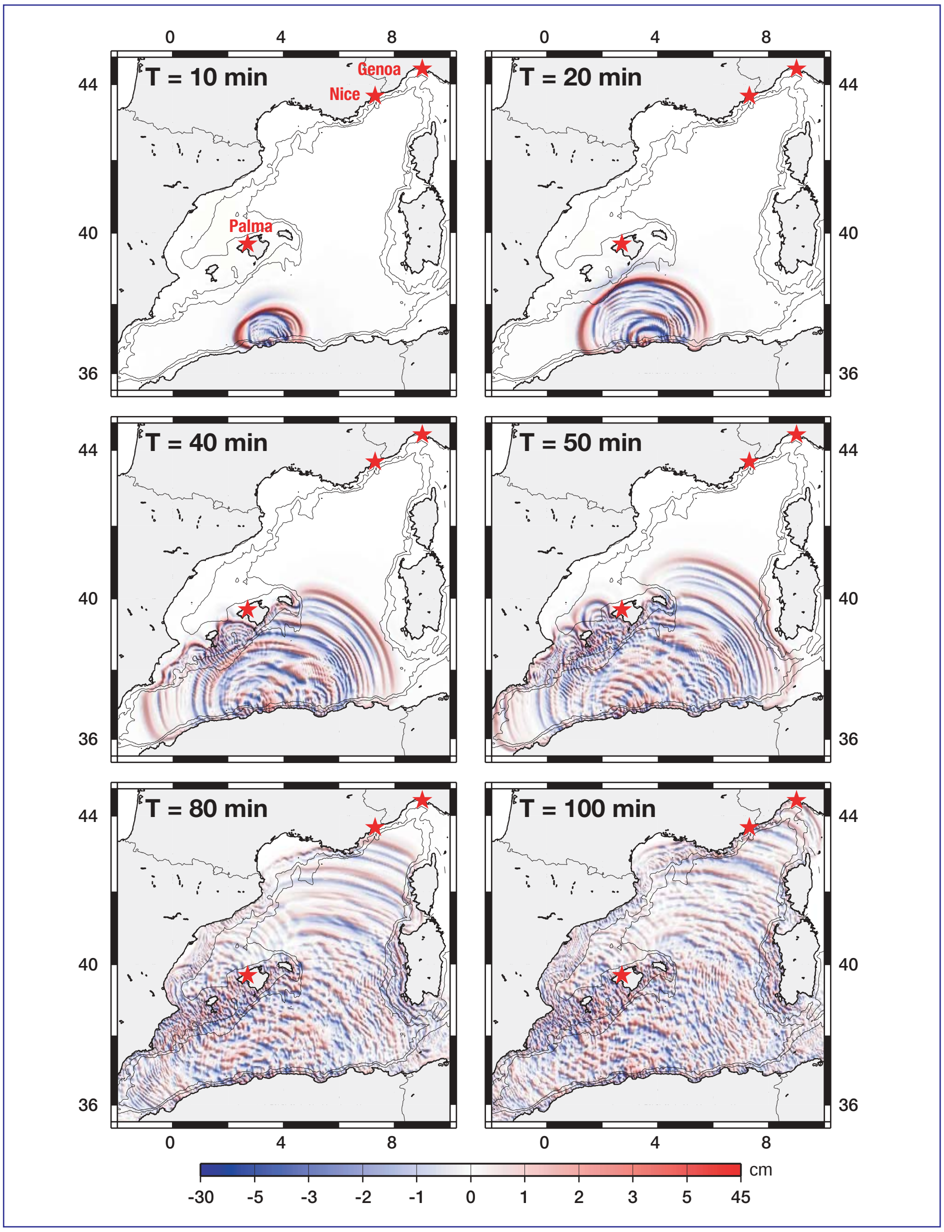

Figure 3: *Snapshots of the propagation of the tsunami, with bathymetric contours plotted at 1000 m intervals. The first leading wave approaches the Balearic Islands after about 20 min, where the shallower water depth slows down the propagation. Consequently the first wave reaching Palma does not arrive before 45 min, in rough agreement with the tide gauge record. In Nice and Genoa, the simulation shows leading waves arriving after 80 to 100 minutes, and then provides minimum values for the actual arrival times that could be refined through detailed modeling.*

	Harvard CMT solution	**modified model**
Fault dimensions (km x km)	40 x 20	40 x 20
Strike, dip, rake	56°, 46°, 71°	56°, 46°, 71°
Seismic moment (Nm) - Mw	0.201 10^{20} – 6.8	0.239 10^{20} – 6.9
Rigidity (Nm^2)	30 109	30 109
Epicenter	3.52°E - 36.98°N	3.52°E - 36.98°N
Depth (km)	17	10

Table 1: *Parameters used for the tsunami modeling, taken and then modified from the Harvard CMT solution.*

To deal with these first seismological studies of the Algiers earthquake, we slightly modified the fault parameters and used a shallower depth (10 km) as well as a seismic moment corresponding to a moment magnitude Mw 6.9. With these values, the initial deformation is slightly higher than 0.4 m on the seafloor. This model does not account for the local

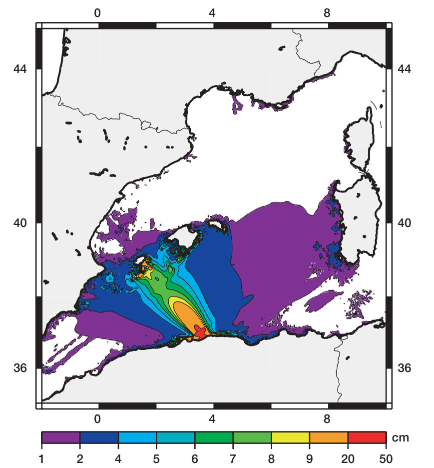

Figure 4: *Maximum water heights obtained after a 1 h 40 min of tsunami propagation in the Mediterranean. Given the fault strike, the maximum values are found towards the westernmost island of the Balearic islands (Ibiza).*

heterogeneities of the slip pattern, an improvement that should be considered in further modeling.

Then we assume that the initial seafloor deformation is fully and instantaneously transmitted to the sea surface, where, through restoring gravity forces, tsunami waves begin to propagate across the sea. Since tsunami wavelengths are much larger than the mean water depth, we assume that the long wave theory is valid. The simulation of the propagation is performed using a finite difference method that solves the hydrodynamic equations of continuity and motion, including non-linear terms.

Bathymetric data are required to solve these equations. Under the shallow-water assumption, and since the amplitude is much smaller than the water depth, the wave velocity can be given by $c = (gh)^{1/2}$. To account for the wave amplification near the coasts, we need to refine the bathymetric data used to compute the propagation of the tsunami waves. We used data taken from the global bathymetry data deduced from altimetry (compiled by Smith and Wessel, 1997), to build a 2' grid describing the western Mediterranean Sea, and a 30" grid for the Balearic Islands. We did not refine here our modelings in the bays of the Balearic Islands, for the compilation of detailed bathymetric data (in the Balearic Islands as well as in Algeria) is now in progress and deserves a more comprehensive study.

Figure 3 shows several snapshots of the tsunami propagation. The tsunami waves slow down towards the eastern Spanish margin where the water depth decreases, and in the Balearic Islands where the first arrival in Palma does not occur before 45 to 50 min. We did not try to match the tide gauge data from Palma since the bathymetric grid used here is not detailed enough to deal with the shoaling effect. In Nice and Genoa, the modeling shows arrival times of 80 to 100 minutes, yielding minimum values that could better agree with the observations through an another refined modeling. Figure 3 also shows that, after the Balearic Islands, the Sardinia Island may have been struck by the tsunami as well, especially along its southwestern coasts. No observations have been however reported on these poorly inhabited coastal areas.

Finally the maximum water heights recorded during the propagation at each grid point reveal how the tsunami energy was radiated in the Mediterranean (Figure 4). The maximum energy is perpendicular to the fault strike, in agreement with the analysis or radiation pattern (e.g. Okal, 1988) and tsunami modelings (Hébert et al., 2001). For the Algiers tsunami, our results show that the westernmost island in the Balearic archipelago (Ibiza) was more exposed to the tsunami, with respect to Minorca, the easternmost one. Several bays in the Balearic (and especially Mao harbour in Minorca) are however known to be extremely sensitive to storm sturges and other meteorological sea level perturbations (e.g. Campos, 1991), and a specific configuration of the bay may also account for the disturbances observed.

Concluding remarks

This preliminary modeling shows that a coseismic source can explain a focusing of the tsunami energy toward the Balearic Islands, especially along their SE coasts, as well as tsunami waves observed further to the North, in Nice and Genoa. Our first results do not provide new significant facts to describe the behavior of the waves along the Algerian coasts. We observe that the slopes offshore Algeria are extremely steep, probably favoring a reflexion rather than an amplification of the waves. Nevertheless it is worth noting that these steep slopes could also be at the origin of submarine slope failures that are known to provoke tsunamis prone to be locally devastating (e.g. Heinrich et al., 2001).

Historical tsunamis observed on Spanish coasts have been compiled into a catalogue (Campos Romero, 1992; Carreño et al., 1998) that shows frequent inundations on the southern coasts of the Iberian peninsula, occasionally in the Balearic. Among these tsunamis having reached southern Spain, hardly one event originating from Algeria is clearly identified. However sea disturbances reported on the southern Spanish coasts after the 1954 Orleansville and the 1980 El Asnam earthquakes (Campos, 1991), and observations gathered after the late 2003 earthquake indicate that earthquakes occurring on the Algerian margin can create tsunamis able to propagate across the western Mediterranean Sea and generate moderate damage up to 200 km away from the source.

Regarding local tsunami hazard in Algeria, a preliminary investigation has stressed the occurrence of historical tsunamis apparently linked to earthquakes, in 1365, 1856 and 1891 (Yelles Chaouche, 1991). The 1856 tsunami, following the Djidelli strong earthquake, was particularly noticeable and several flooding of low lands were reported. But the source of these tsunamis, although they followed earthquakes, could be related to the coseismic deformation as well as to turbidity currents, an origin frequently proposed. The same combined sources can be suggested for the 2003 earthquake, but fine modelings of the tsunami constrained by observations as detailed as possible could help, first, to refine the source mechanism, then to improve the tsunami hazard assessment along the Algerian coasts. Indeed, even though tsunami hazard is apparently rather moderate in Algeria, the combination of thrusting events, occurring on steep slopes, off densely inhabited coastal areas, makes the study worth an effort.

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Monitoring of Seismicity in Albania

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The observation and monitoring of the seismicity in Albania is carried out by the Department of the Seismological Network, which is part of the Seismological Institute of Albania, Albania Academy of Sciences. The Seismological Network of Albania was established in 1968 with the setting up of the first seismological station at Tirana which became the Seismological Center, after setting up of the other seismological stations all over the country in 1976. In 1994, the Seismological Center has been renamed the Seismological Institute, by decision of Academy of Sciences of Albania. This Institute incorporates: Department of Seismological Network; Department of Seismicity and Seismotectonics; Department of Engineering Seismology and Department of Earthquake Engineering. The Seismological Network constituted by 10 seismological stations is the main department of this Institute and is responsible for the seismic activity monitoring and the relevant data collection in and nearby Albania, also ensuring the maintenance of the Albanian Seismological Network.

Albanian seismicity in the frame of the geodynamics of the surrounding zone

Albania is located in the western part of the Balkan Peninsula where earthquakes are the most significant hazard on the list of natural hazards of the country. On the worldwide seismic zonation, Albania is situated on the Alpin-Mediterranean seismic belt. This belt comprises the wide zone of contact between lithospheric plates of Africa and Eurasia, from Azores Islands up to the eastern border of Mediterranean basin. The concept of plate tectonics in this zone is especially complicated by the presence of numerous blocks and the release of stress through plastic deformation on a large part of it. The region that surrounds Albania comprises a wide tectonic belt with relatively rigid blocks as Adriatic, some sectors of Alpine belt, Alps, Carpathians, Balkan Mountains, Dinarides, Helenides, the Hellenic Arc and Anatolian belts as well as internal basins as Terrene, Aegenian, Panonia and Black Sea. In the above-mentioned belt, the seismically most active region is the Aegenian and the surrounding zones, including Greece, Albania, Montenegro, Macedonia, South Bulgaria and Western Turkey. Leaving apart the Helenic Arc where the African plate sinks under the Eurasian plate in the subduction form, the other contact between these two plates and especially the part where the western wing of Helenic Arc already meets the western coasts of the Balkan peninsula, is realized through the Adria microplate. This unit acts as a wedge between the Apenines, Alps and Dinarides-Albanides-Helenides mountain range. The origin of orogenic systems of western Balkan as well as those systems surrounding on the north and west of the Adriatic Sea, is strongly connected with the convergence between Eurasian and African plates.

From the focal mechanism and paleomagnetism studies, it is revealed that the Adria microplate participates on a clockwise rotation with pole in the northern Italy. The conclusions of many studies on the geodynamics and seismicity of Aegenian and generally of eastern Mediterranean zones where Albania takes place are converged on the point that mostly the seismicity of Albania is strongly connected with the contact between Adria and Albanides orogen which is part of a wider collision between Eurasian and African plates (Sulstarova et al, 2003). This contact which possibly takes effect through a continental type of collision unceasingly accumulates deformations and propels along the longitudinal tectonic faults bordering it. This also creates transversal tectonic faults cutting it and penetrating to the interior of the peninsula (Figure 1).

The strongest seismic events in Albania

The seismicity of a certain region is determined as a function of earthquake size (magnitude, intensity, seismic moment etc.) as well as the frequency of their occurrences. On this basis, keeping in mind the well known classification of earthquakes according to their magnitudes (Hagiwara, 1964, Lee et.al., 1981), the seismicity of Albania is characterized by an intensive seismic microactivity ($1.0<M\leq3.0$), many small earthquakes ($3.0<M\leq5.0$), rare medium-sized earthquakes ($5.0<M\leq7$) and very seldom by strong earthquakes ($M>7.0$) (Sulstarova *et al*, 2003).

Usually the seismicity of a country is separated in two periods: the historical seismicity and the instrumental one. Historical seismicity is based on the information collected from different sources and has to do with the period of history when the earthquakes were not yet recorded by special instruments. Instrumental seismicity is associated with the 20th century when the implementation of seismological stations started in Europe and worldwide and earthquake records began to be collected and analyzed systematically.

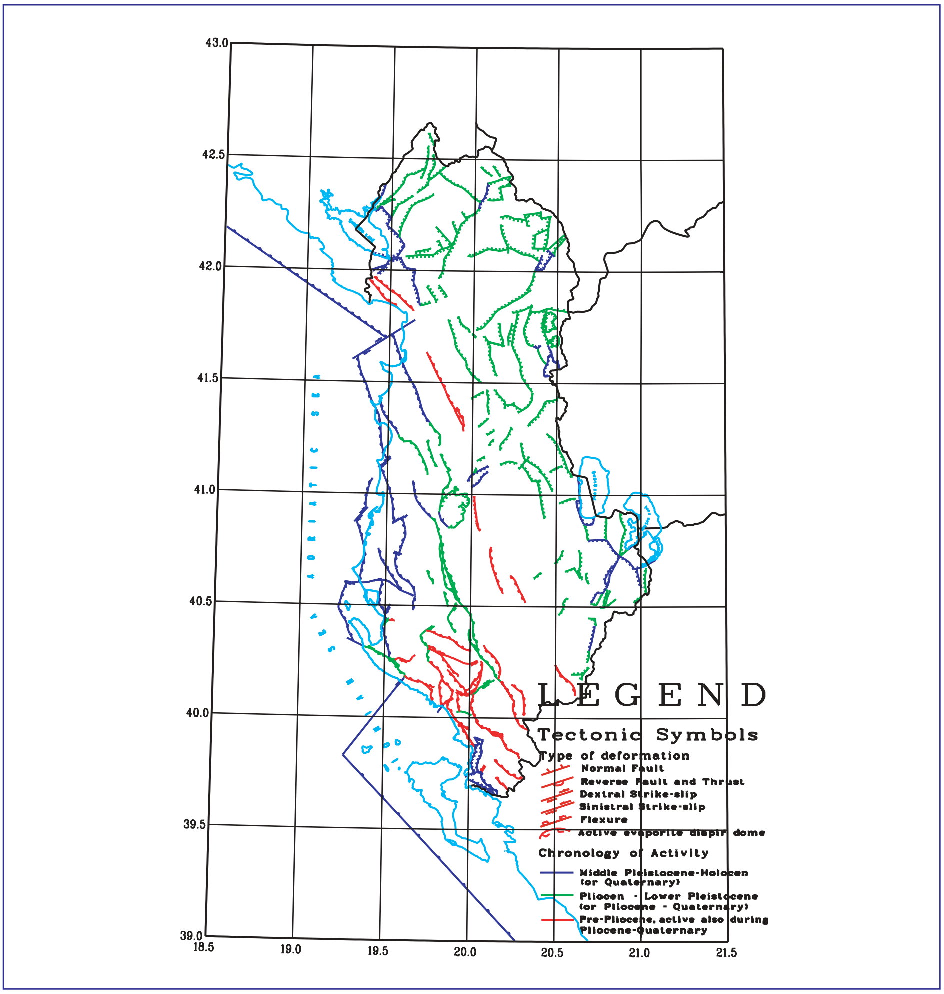

Figure 1: *Map of active faults*

The historical seismicity

The historical seismicity of Albania is described in some various catalogues such as: Mihajlovic 1951; Shebalin *et al.*, 1974, Sulstarova *et. al.*, 1975, Makropoulos *et. al.*, 1981, Papazachos et. al., 1989.

From the evidence we possess today it results that from the period of III–II centuries B.C to our days, Albania has been stricken by 55 strong earthquakes with intensities I_o_VIII degree (MSK-64), for which 15 have had an intensity I_o_IX degree (MSK-64). From these 55 earthquakes, for a period longer than 2000 years, 36 of them belong to the 19^{th} century, which make us believe that the number of disastrous earthquakes we report is underestimated and other disastrous earthquakes are hidden on the depth of historical time.

There are reliable evidences that old town of Durres (Dyrrahum) has been stricken several times by strong earthquakes, which caused serious human and economic losses. Old chronicles report that this town has been almost totally destroyed on the year 177 B.C, 334 or 345 A.C., 506, 1273, 1279, 1869 and 1870. Documents for the earthquake of March 1273 say that the town of 25 thousand inhabitants at the time has been totally destroyed. There were many casualties and the people who survived left the town seeking for other living places. After this earthquake the importance of the town of Durresi as a harbor in the Adriatic Sea was diminished.

On the centuries III-II B.C. there are evidences that Apolonia, another ancient town, has been stricken by strong earthquakes which caused large casualties and damages.

On the year 1153, the town of Butrinti (old Buthrot) on the south of Albania, has been destroyed from a strong earthquake. Its traces could be found even today on the remnants of this old town. Some descriptions of the strongest historical earthquakes are given here:

The earthquake of October 12th, 1851

On October 12th, 1851, around 07 o'clock a strong earthquake hits the gulf of Vlora. In Vlora town a part of the buildings was destroyed and the other part was heavily damaged. According to the news of that time the number of casualties was about 200. Kanina village was heavily damaged as well. The sea level in Vlora bay rose of 66 cm and floods were observed. Before the main shock at 02 h 40 min a weak foreshock was felt in Vlora town. The strong main shock (07 h) was followed by a great number of aftershocks.

The earthquake of October 12th, 1851 was strongly felt in Italy, causing panic among the population of Taranto, Bari, Barleta, Canosa and Cerignola. It was felt V degree at Ioannina (Greece) and III-IV degree at Naples (Italy). According to other data serious damage was observed at Berat. Previous authors did not mention Berat, but Himara. According to our opinion this earthquake caused damages in both these towns (Vlora and Berat). The highest intensity of this earthquake had to be IX degrees and its epicenter at coordinates 40o.5 N, 19o.5E.

The earthquake of October 17th, 1851

On October 17th, 1851 a very strong shock caused lots of destructions in town of Berati. The fortress of the town was damaged and under its ruins 400 soldiers were buried. This fact showed that other victims had to be observed in the town of Berati. Cracks on the ground were observed together with fountains of sands and water mixed together, and a kind of a sulfur dust, which made the breathing difficult, was observed. Big landslides were observed as well. The highest intensity for this earthquake had to be IX degree (based mainly on the degree of destructions of the city fortress).

The earthquake of June 14th, 1893

On June 14th, 1893 a destructive earthquake hits the region of Himara and especially the village Kudhes was totally destroyed. Rock-falls and cracks on the ground were observed over a considerable area. The majority of the dwelling houses was destroyed in Kuç village (Vlora) as well. The highest observed intensity of this quake had to be IX degree with the epicenter nearby the village of Kudhes and Çorraj. This earthquake was felt in Puglia, and in Italy.

The Instrumental seismicity

The establishment of seismological stations in Europe at the end of the 19^{th} century and especially at the beginning of 20^{th} century made possible even the evidence of earthquakes occurred in Albania and nearby. Depending on the density and modernization of seismological stations in Europe and worldwide one can say that the earthquakes of Albania and nearby with magnitudes $M_S \geq 6.0$ are recorded from the seismological stations since the beginning of 20th century; those with magnitude $M_S \geq 5.5$ since 1911; those with $M_S > 5.0$ since 1940; those with $M_L \geq 4.0$ since 1968 and those with magnitude $M_L \geq 2.5$, since 1976.

From the data collected and elaborated it is evidenced that during 20^{th} Albania has been stricken by many damaging earthquakes (Figure 2). The most disastrous earthquakes, also displaying the highest magnitudes occurred in Albania during 20^{th} century are:

The Shkodra earthquakes of 1905

It represents one of the biggest series of strong earthquakes of Shkodra valley: the highest intensity, large number of aftershocks and large consequences of the main shock and strongest aftershocks. This serie had been the subject of many seismological studies (Koçiaj *et. al.*, 1980).

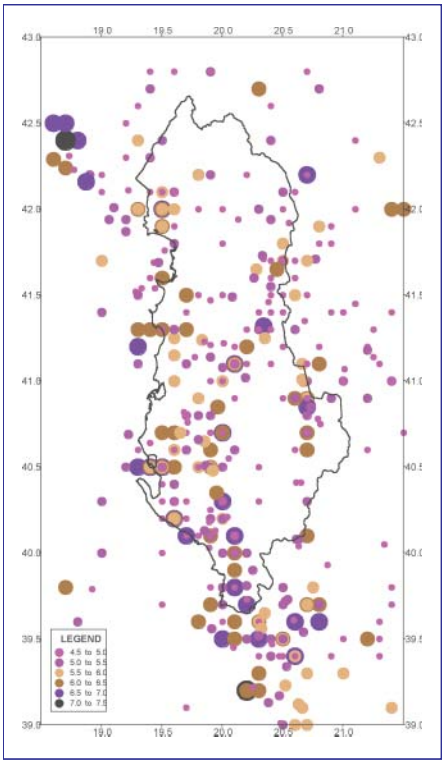

Figure 2: *Map of earthquake epicenters; Time span 1958-2000, Ms≥4.5.*

The strongest shock occurred on June 1st, 1905 at 4 hour 42 min 43 sec. This shock was recorded by a large number of seismological stations despite their lower sensibility. The magnitude of this earthquake was determined as M_S=6.6. The duration of the earthquake on June 1st, 1905 was 10-12 sec and caused big damages among the population and properties in the town of Shkodra and the surrounding villages (especially in the villages SE to Shkodra). This shock caused about 200 dead and about 500 injured.

The highest intensity of this shock had to be IX degree (MSK-64). This earthquake was felt in the Yugoslavian territory, in the southern part of Hungary, in Bulgaria, Greece and Italy.

The earthquake of June 1st, 1905 is famous for its large number of aftershocks, some of them very strong. These aftershocks continued up to July 1906.

The earthquake of November 30th, 1967

This earthquake occurred at $07^h 23^m$ and had M_S=6.6. It caused heavy damages in the districts of Librazhdi and Dibra in Albania and in Western Macedonia. The intensity was IX degree. In the districts of Dibër and Librazhdi, this earthquake caused damages in 13 localities and 177 villages implied the death of 12 people and 174 people were injured. Were damaged: 6336 buildings; 5664 dwelling houses, 156 social-cultural objects (133 schools), 534 houses collapsed, 1623 suffered heavy (of 3-4 degree) damages and 4179 suffered medium (second degree) damages. Damages of first degree were observed over a wide zone, including districts of Elbasan, Tirana, Rreshen, Burrel and

Pogradec. Casualties were observed in the Yugoslav territory as well.

The largest damages were observed during the contact between limestone and flysch sediments and along the fault created by this earthquake on free surface. This fault had a zigzag form of general strike of NE 40 degrees. This earthquake was accompanied by many rock-falls especially in the epicentral area. The number of aftershocks arrived up to 1200. The strongest one was that of December 2nd, 1967 at 12h.

The earthquake of April 15th, 1979

The earthquake of April 15th, 1979 (so-called the Montenegro earthquake), is one of the strongest earthquakes, which occurred in the Balkan Peninsula during the 20th century. Its magnitude has been evaluated between 6.6 and 7.2. In our catalogue we assigned the value of M_S=6.9 (Karnik, 1996). The epicenter of this earthquake is in the coastal area, near Petrovac, Montenegro. It happened at 06h 19m of April 15th, 1979. Many foreshocks occurred about two weeks before the main shock of April 15th, and the aftershocks continued for more than 9 months. The strongest aftershock is that of May 14th, 1979, with magnitude M=6.3. The intensity of this earthquake in epicenter is IX-X degree (MSK-64). The main shock of April 15th, 1979 earthquake caused 35 casualties in Albania and 382 injuries. More than 100.000 inhabitants (mostly in the districts of Shkodra and Lezha) were left homeless. There were destroyed almost completely 17.122 dwelling houses and social-cultural facilities. The most casualties and economic losses were observed on the coastal part of Montenegro. The earthquake of April 15th, 1979 has been felt strongly in all the territory of Albania. It has been felt IV degree (MSK-64) in Northwestern Greece, Croatia, Slovenia and Eastern Italy.

This earthquake has been accompanied by a lot of physical-geological phenomena on the ground. In Shkodra and Lezha districts many soil cracks, liquefaction phenomena, riverbanks subsidence and rock falls were observed.

The earthquake of Tirana, January 9th, 1988

On January 9th, 1988, 01h 02m (GMT), an earthquake with M_S=5.4 hits Tirana city and the villages nearby causing relatively slight damages. The epicenter of this earthquake was situated ten kilometers on the southwestern part of Tirana city. The highest intensity reached VII degree (MSK-64). The most damaged villages were Petrela, Arbana on the south of Tirana. Slight damages were evidenced in Tirana city, especially on the northwestern and western part.

It is worth mentioning that for this earthquake, the strong motion instrument installed in Tirana seismological station recorded a very high and unusual value for maximum acceleration in E-W component: 404.8 cm/s^2. It can be explained by the fact that the strong motion instrument was very near to the fault, which generated this earthquake.

The history of instrumental observations in Albania

As previously mentioned, the instrumental seismological observations in Albania begun with the setting up of the first seismological station at Tirana, on 1968 as part of the Geophysical Department of the Tirana University. This station was first equipped with an intermediate-period instrument, three-component SS-1, Sprengnether type seismograph with light paper recording. Later on, the station of Tirana has been equipped with one short period instrument, DDJ-1 (1973), one Kinemetrics short period, three-component instrument SS-1 and a three-component, long period LP-S-5100 (1975). Since 1973 this station was named The Seismological Center and became an integral part of the Academy of Sciences of Albania. The main task was to perform studies on seismicity and seismic zoning of Albania, monitor the seismic activity of the country, compile the bulletins of earthquakes and to inform the government on earthquake emergence situations. As result of the studies performed by this center, based on the information of instrumental data, some important works were carried out, such as: The Seismic Map of Albania on scale 1:1.250.000 (Sulstarova et al., 1972); The Catalog of Earthquakes of Albania (Sulstarova & Koçiaj, 1975); The Seismotectonic Map of Albania on the scale 1: 1.000.000 (Aliaj *et al.*, 1973).

The year 1976 is the beginning of the Albanian Seismological Network (ASN). The first four seismological stations were installed around the Fierza Reservoir in northen Albania. The purpose of this sub-network was the monitoring of the possible induced seismicity from the reservoir impoundment. The swarm of Nikaj–Merkuri in North Albania, near the high dam of Fierza HPS Reservoir and Reservoir of Komani HPS was a special event observed and monitored by ASN. It started abruptly on November 10th, 1985, reached its peak by the end of November-beginning of December 1985 and then continued at a much lower level of activity for some months. A total of more 17.000 micro earthquakes with local magnitude M_L>1.0 were recorded by Bajram Curri Seismological Station–the nearest station to the swarm zone; 1800 of which were used to determine the hypocentral coordinates. About 300 of them were felt and caused slight damages in the epicentral zone; the maximum intensity was VI–VII degree of MSK-64 scale. The maximum magnitude of earthquakes in this swarm was M_L=4.6; the depth of micro earthquakes in this swarm was shallow, up to 10–15 km.

All the stations were equipped with Chinese type analog drum record three-component short-period seismographs DDJ-1. The practice of work in these stations and homogenization of magnitude formulas and other routine procedures were the object of a long and continuous work from the responsible staff. By the end of the 80's, ASN was composed of 13 seismological stations.

The Seismological Center of Albania enlarged the scope of its research and seismic monitoring of the natural and induced earthquake activity. In this period the seismological and seismotectonic studies were completed on higher basis, begun the studies of seismic hazard on regional and national scale, the monitoring of strong motion shaking and earthquake engineering studies.

The strong motion network has been established for the first time in 1983. During a two years period, thirteen seismological stations of the albanian seismological network were equipped with SMA-1 analog accelerographs. The second phase begun in 1985 with the equipment of the major dams of the country with accelerographs and seismoscops of WM-II type. At the end of 1986, thirty SMA-1 accelerographs and fifty seismoscops were distributed around the country and intended to constitute the base for future seismic hazard assessment studies, studies concerning the soil amplification, microzonation of major towns, soil-structure interaction etc. This network recorded the Tirana earthquake of January 9th, 1988 (M_L=5.4) with acceleration as high as 404.8 cm/sec^2 on E-W component on sandstones of the Tirana seismological station. The peak values of the corrected acceleration computed velocity and displacement are given in Table 1 (Muço et al., 2001).

The duration of the strong motion, with acceleration above 0.05g is about 6 sec. This value of peak ground acceleration is much higher than the value of seismicity coefficient k_E=0.1 proposed by the KTP-N2-89 (Albanian aseismic design code) for this seismic zone, with an expected seismic intensity of VII degree according to MSK-64 scale, to which the area of Tirana belongs. It should nevertheless be mentioned that in spite of the

Comp.	Max. acc.	Max. vel.	Max. displ.
	(cm/sec^2)	(cm/sec)	(cm)
Z	69.3	4.7	1.6
E-W	404.8	14.3	1.6
N-S	106.3	5.9	1.3

Table 1: *Ground motion parameters of January 9th, 1988 earthquake.*

large recorded peak acceleration, the damage was not as severe as one might have expected.

The strong earthquake of April 1979 with M_S=6.9, hitting the border region between Montenegro and Albania leaded to an increasing attention by Albanian Government toward the seismological studies. The first Seismic Zonation of Albania in the scale 1:500.000 was followed by the Technical Design and Construction Code, replacing the old Code compiled on 1952 and updated on 1963. Important studies were carried out on the characteristics of Albanian earthquakes, focal mechanism, macroseismic field, energetic estimations, seismotectonics, active faults systems, etc. The engineering seismological studies on the period 1982-1991 were concentrated mainly on the seismic hazard assessment at local level at relatively large scale of 1:10.000 for the most important inhabited centers situated in seismic hazardous zones of the country. The most important works produced during this period are: Seismic Zonation of Albania in the scale 1:500.000 (Sulstarova et al., 1980); The Earthquake of April 15th, 1979 (Proceedings of the symposium on this earthquake on Shkodra, 1980); Microzonations Studies of different cities of Albania (Group of authors, 1984-1991). Some periodical publications on seismological studies are issued during this period.

Latest improvements of the seismological network

With the beginning of the 90's, progress were made for a modest upgrading of ASN, through a fund granted by the Academy of Sciences of Albania for buying some spare parts such as pen-motors, amplifiers, digital timing systems, etc. In the framework of the ASPELEA project, the upgrading of the network continued, and a new seismographic station, a Teledyne Portacorder has been set up in Saranda seismological station. Nevertheless, it was clear that this kind of instrumentation at the ASN was not in the contemporaneous level with many seismological stations technologically and physically exhausted. An attempt has been made in the framework of PLATO-1 Project (Implementation of telemetered net-works in the countries of Mediterranean area) by World Laboratory, Switzerland, to set up a telemetered network constituted by 8 stations, short-period one component system. 5 stations were implemented, but the political events of 1997 did not allow the continuation of the project.

At present time the Seismological Network Department has substituted the analog instruments with digital ones. Now, all the stations are equipped with short-period, three component instruments of GBV-316 type, GeoSig production. Their control and data downloading is carried out remotely by the dial-up communication. When, any event with magnitude $M_L \geq 2.5$ is triggered within the country, the new network provides the necessary information for rapid hypocenter determination, using the HYPO71 software, and magnitude estimation. The information is sent to the Civil Protection Department of the Decentralization and Local Government Ministry as rapidly as possible. The information is disseminated to news media only for earthquakes with magnitude M>4. The monitoring of the seismic activity is provided continuously twenty-four hours and one technician is always present, assuring the correct data processing and information distribution. We are taking the necessary measures for the information to be sent to the interested international seismological agencies. The web page of the Institute that will be available shortly will help for a rapid dissemination of the data, including waveforms for important events. Periodically, the Department issues a bulletin, composed by the preliminary readings. This Bulletin is sent to the neighboring Institutes, like Montenegro, Macedonia and also to the EMSC.

The challenging effort for the staff of the Seismological Institute is the implementation of a new fully integrated digital seismograph system using the satellite telemetry (VSAT). The Institute is under a contractual agreement with Nanometrics (Canada) for the implementation of this new system. The central hub data acquisition system and two remote stations have just been commissioned. There will be four remote sites by the end of this year and this number will increase by one or two each next year. This system offers enormous possibilities that data collected to be shared and exchanged on-line by the Internet technologies with the homologues neighbour institutions abroad, especially in Balkan region. Also, the data collected will be complementary with those

Figure 3: *The seismographic and strong motion networks of Albania*

collected by other systems (dial-up and RF telemetry networks, etc.). The new VSAT system will provide support for additional services such as continuous or triggered strong motion, dual frequency GPS reference data, meteorological sensing, auxiliary data communications and LAN or WAN extension to remote sites. With no doubt, it comes apparent that this system will improve seismic activity and in general geophysical monitoring capabilities in Albania improving greatly the detectability and the earthquake parameter (location, magnitude, etc) estimation of the existing seismological network (Figure 3).

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The CRAAG, Algeria

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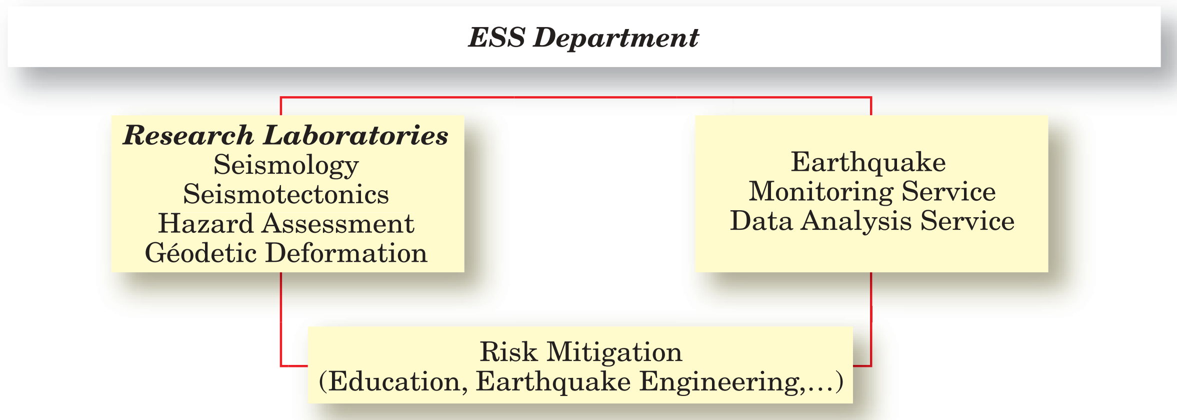
Centre de Recherche en Astronomie Astrophysique et en Géophysique

Organisation

The CRAAG was founded in 1985 after the major El Asnam earthquake of October 10th, 1980. The occurrence of this big event demonstrated the urgent need to promote the research activities in the earth and universe sciences.
The CRAAG inherited from both activities of the Algiers Astronomical Observatory created in 1890 and the IMPGA (Institut de Météorologie et de Physique de Globe d'Alger) established in 1931.

The CRAAG located at Algiers has three main departments: the Astrophysics Department where universe studies are made, the Geophysics Department which is formed by Geomagnetism, Paleomagnetism Gravimetry and Electromagnetic laboratories and the Seismological Monitoring and studies Department. This later is divided in two main services: the first one is responsible for the maintenance and regular operations of the Algerian Seismic Network, the second is devoted to the research activities with four laboratories: seismology, seismotectonic, geodetic deformations and the seismic hazard assessment.

The Seismological Department



In parallel of its research activities, the ESS department is involved in the national programme of seismic hazard reduction launched in 1985 after the El Asnam earthquake. For instance, the CRAAG plays an important role for schools and to inform the population. Some cooperations are established with the Earthquake Engineering Institute for the elaboration of the zoning map of Algeria.

The Algerian Seismic Network (REALSAS)

Seismic activity in Algeria

Algeria is affected by a moderate to high seismicity. From history, the first known earthquake occurred in Algiers in 1365. It caused huge damages to the town and many people died. Since that time, several moderate to strong seismic events happened in Algeria (Algiers, 1716, Blida, 1825, El Asnam, 1980, Boumerdes, 2003).

The Algerian seismicity is mainly located in the northern part of Algeria, more precisely in the Tellian chain (Figure 1).

Some offshore epicentres have been recorded demonstrating that the margin is also active. The High Plateau is marked by a low seismic activity. In the Saharian Atlas, some epicentres have been recorded and might be generated by the south Atlasic flexure.

The Algerian earthquakes are superficial, no deeper than 20 kilometres, explaining their destructive character. This is in agreement with the lack of subduction zone along the margin.
The seismicity of northern Algeria is characterised by a compressional NNW-SSE stress regime (Groupe de Recherche de Néotectonique, Phillip, 1977). The focal mechanisms of the recent important earthquakes indicates that the compressional movements are due to reverse or thrust faults related to folding, trending generally NE-SW (the El Asnam, Tipaza, Ain Temouchent, Boumerdes faults).

History of the network

In Algeria, the instrumental seismology started in 1910 when the first Algerian seismological station was installed at Algiers, more precisely at the Observatory (ABZ). This station was equipped with a mechanical Bosch-

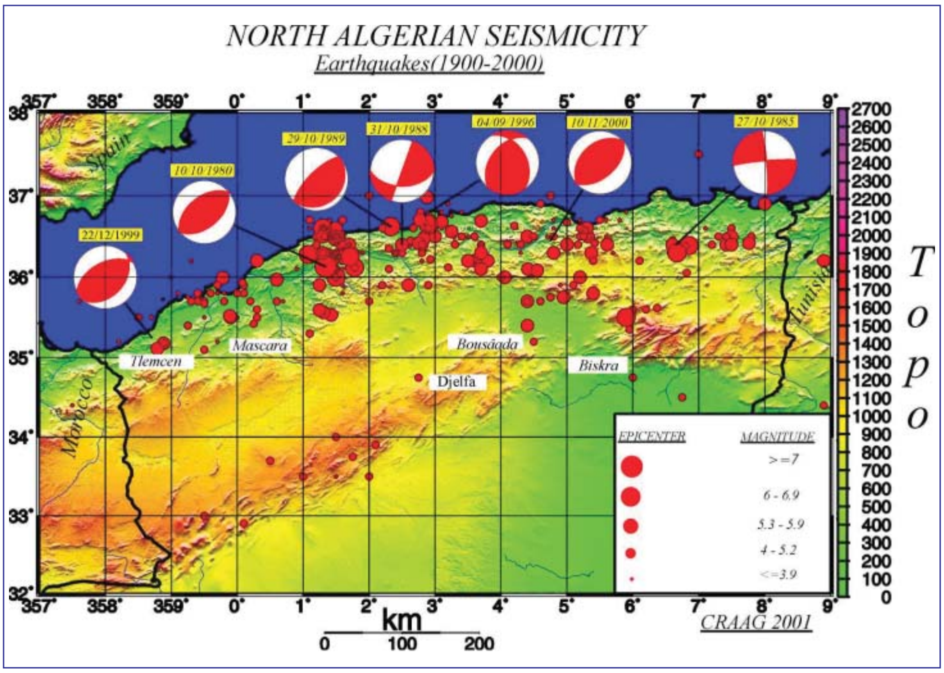


Figure 1: *Seismicity of northern Algeria*

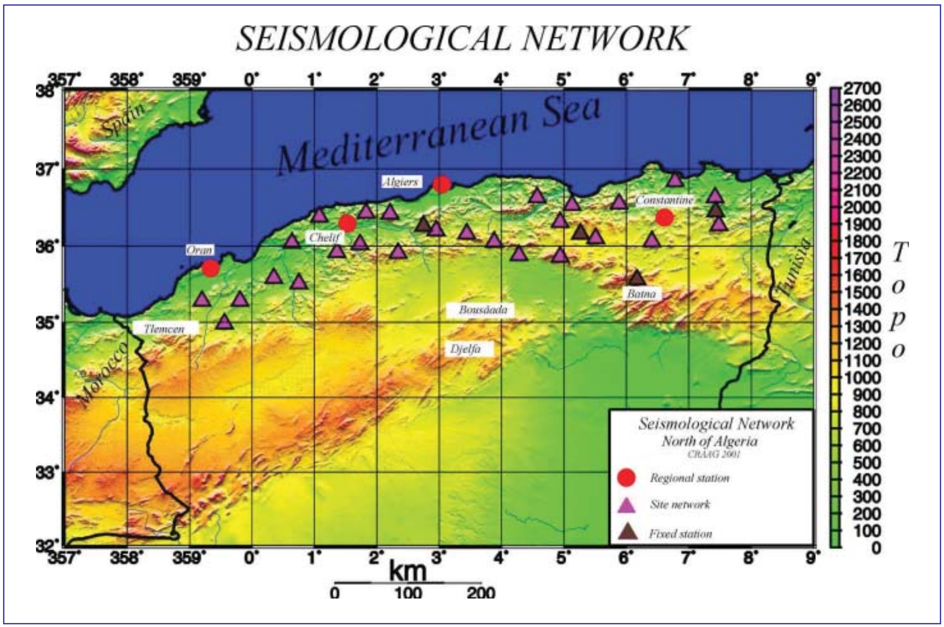


Figure 2: *The Algerian Seismic Network*

Mainka seismograph. Later, other seismic stations with a short- period Grenet-Coulomb seismographs were installed in several localities as Tlemcen, Setif or Relizane; some of them in the dams. The Oued Fodda (El Asnam) station was installed in 1935, the Benaouda (Relizane) station in 1955. The Setif station started to be in operation from 1958. Although these stations recorded the main Orleansville earthquake of September 1954 (M: 6.7), only few studies relative to this important seismic event were carried out.

In that period, the first Algerian seismic catalogues were edited by Grandjean in 1950 and Rothé in 1955. These catalogues reported main seismic events with some information on their effects.

The autonomous stations operated more or less continuously until 1980 when the El Asnam earthquake occurred. This major event demonstrated the urgent need to install a real-time seismic network. In 1985, the CRAAG obtained a financial support, which allowed it to be equipped in 1988 with a telemetric (radio-link stations) seismic network of 32 stations. The Kinemetric Telemetric seismic network (REALSAS **R**éseau **A**lgérien de **S**urveillance et d'**A**lerte **S**ismique) was installed in 1990. Unfortunately, at that time the internal situation of Algeria was marked by political events and the network underwent with force this bad environment.

Since 1998, as the situation improved, the Algerian network has been progressively reinstalled. Today, the network is composed by four subnetwork arrays (Algiers, Oran, Constantine, Chleff) located in the four major seismic regions of Algeria.

The Algerian Seismic Network

Each subnetwork is composed by a three component regional station and seven one-component satellite stations. These later are installed in the mountains of the Tellian chain because of the quality of the signal and the capacity of a good transmission. Each station is equipped with a SS1 short period seismometer of 1s frequency. The signal is transmitted continuously from the remote sites to the regional station by radio-link and then to the central station located at Algiers (figure 3). There, the real time data are recorded in analogue forms on drums and digital forms.

The Algerian network has been recently expanded by five new stations installed in areas (Guelman Batna, Medea, Tlemcen, Tipaza) not yet covered by the initial configuration of the net. These stations are connected to the central station of Algiers by telephone link.

In the Central station, seismological data are interpreted (P and S arrivals identification, first onsets, signal duration) and processed by computer. For the focal parameters determination, the widespread HYPO71 software is used.

At the Central Station of the REALSAS, two persons are on duty 24 hours per day. These two scientists belongs to a team which is in charge of:

-Permanent high-quality recording and analysis of the seismic signals

-Determination of the earthquake parameters

-A daily service to government agencies (Civil Protection, Wilaya…) and to media.

In the Data Bank Service, data are collected from the monitoring service and International Centres. All data contribute in edition of the monthly bulletin which is transmitted towards the national and International data Centres such as CSEM, ISC, NEIC by mailing and now Internet facilities.

The data bank service has also in charge the publication of the catalogues. A new one (Yelles et al., 2002) for the seismic events between 1992-2002 has been published recently. This catalogue is an extension of the previous one published in 1994 by Mokrane et al.

The earthquake monitoring operated by the REALSAS promotes several scientific projects such as:
-Earthquake source mechanisms
-Seismotectonic studies
-Seismic hazard assessment
-Seismic zonation
-Seismic prediction (precursors, electro-magnetic ,…)
-Geodetic deformation
-Seismic waves propagation
-Sites effects
-International Project (Geoscope, Midsea…)

For the field investigations, 30 short period portable stations are available allowing microseismic investigations in the interested areas.

Future developments for the Algerian Seismic network

After the occurrence of the Boumerdes earthquake of May 21 , 2003 (Mw: 6.8), an opportunity to develop the Algerian Seismic Network is given by all the new investments proposed by the government and the cooperation channel. Near future strategy will include several actions. Among them, densification of the network by installation of five new stations obtained after the Ain Temouchent earthquake, installation of several new stations in the northern region of Algeria and installation as a complementary system to the REALSAS network, a new Broad-Band stations Network (10) with its high dynamic range and stable transfer characteristics. Because of a poor quality of the telephonic network, the use of a satellite technology (VSAT) in the data transmission is also expected. This improvement of the seismic monitoring system will permit a better acquisition of the seismic data, a good data analysis and a better knowledge of the Algerian seismicity. Very relevant seismic studies should be expected, allowing a better contribution of our Institute in the cooperation with the International data Centre and in the seismic risk mitigation in Algeria.

Figure 3: *A view of the Central Station of the seismic network (Algiers station)*

Seismicity of Egypt

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Introduction

Egypt is located close to one of the continental fracture system (Hellenic arc) at the convergence boundary of two big lithospheric plates (Eurasia and Africa). Also, Egypt is affected by the opening of the Red Sea (Mid Oceanic System) and its two branches (the Gulf of Suez and the Gulf of Aqaba-Dead Sea transform system). Thus the seismicity is due to the interaction between the three plates of Eurasia, Africa and Arabia. Within the last decade, Egypt has been shaken by several distant and near damaging earthquakes. Such events were interpreted as the result of the interaction of the African, Arabian, Eurasian plates and Sinai subplate. Some large earthquakes are located near the plate boundaries as far as Cyprus and were felt in Egypt. Damaging earthquakes effects in Egypt are mostly concentrated on the highly populated areas of the Nile Valley and Nile Delta. Earthquake losses from such events started to diminish after the establishment of the Egyptian National Seismic Network (ENSN) from 1997 on. Also, Egypt is affected by the opening of the Red Sea (Mid Oceanic System) and its two branches (the Gulf of Suez and the Gulf of Aqaba-Dead Sea transform system). The relative motion along these plates creates areas of high seismicity in Egypt. Some areas have been stricken by immense earthquakes, causing considerable damage (Sieberg, 1932; Maamoun et al., 1984; Ambraseys et al., 1994; and El-Sayed and Wahlström, 1996). Therefore, it could be concluded that although the damaging earthquakes occurred infrequently, its risky consequences could not be ignored (Osman and Ghobarah, 1996).

In the last century, Egypt has been shaken by many large earthquakes (Ms= 5.8-7.3). These earthquakes caused considerable damage in both historical and recent constructions. The most recent damaging earthquakes were caused by the 1955 (Alexandria) and 1992 (Cairo) earthquakes (see Woodward-Clyde Consultants 1985, Ambraseys et al., 1994, El-Sayed, A. and Wahlstrom, R., 1996, El-Sayed et al., 1999 and 2000, and El-Hadidy, 2000). Reports for such earthquakes reveal that the death caused by seismic activity exceeds the sum of victims caused by other natural hazards. Moreover, Faro, Romanic and Islamic constructions suffered damage. Damages were concentrated mainly in Cairo as well as in cities located within Nile Delta and Nile Valley. Historically, many similar cases were reported. El-Sayed (1996) and Moustafa (2002) investigated the factors that contributed to the damage caused by earthquakes in Egypt. The result of this investigation shows that building quality, site effect and local geological condition are the main contributing factors to damage.

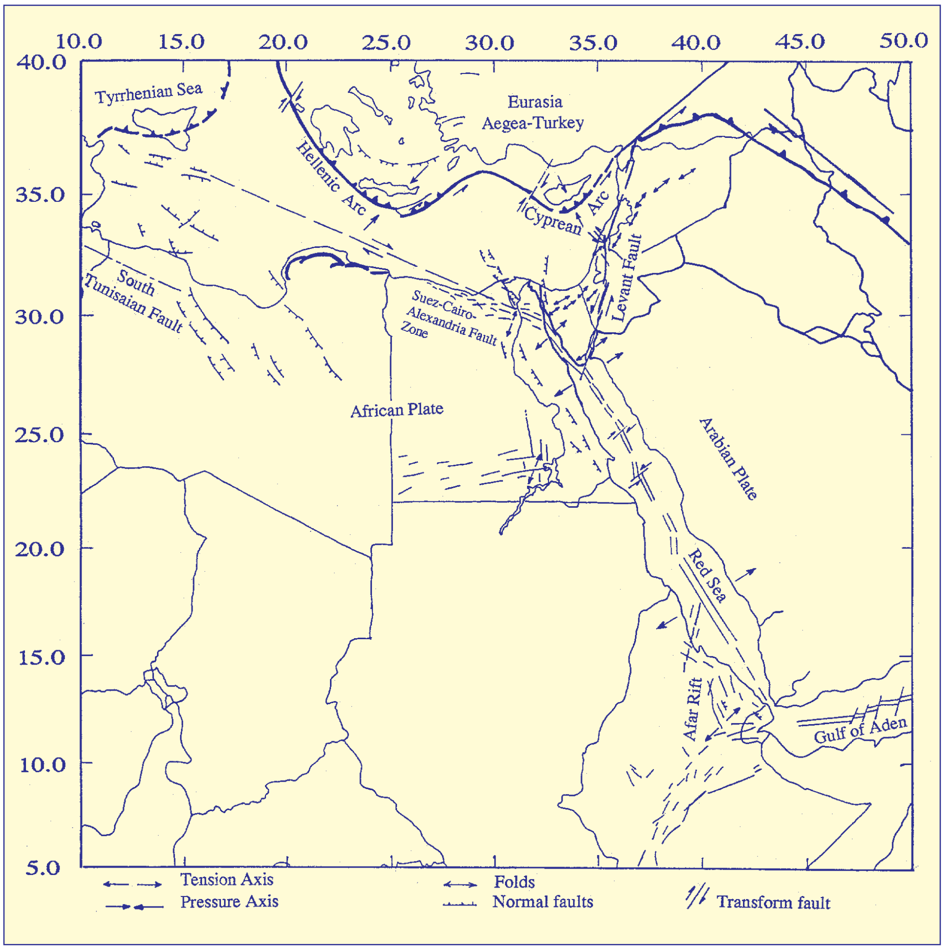

***Figure 1:** General Tectonic Setting of Egypt (Abu Elenean, 1998)*

Tectonic settings

The primary features of active plate tectonics in the vicinity of Egypt are discussed in the literature and are reported on Figure 1. Three major plate boundaries are recognized: the African-Eurasian plate margin, the Levant transform fault, and the Red Sea plate margin. A piece of the African plate, called Sinai block or subplate, is partially separated from the African plate by the spread –apart or rifting along the Gulf of Suez. In addition to these plate boundaries, there are two megashear zones running from southern Turkey to Egypt.

African-Eurasian Plate Margin

The African and Eurasian plates are converging across a wide zone in the Northern Mediterranean Sea. The zone is characterized by folding within the Mediterranean Sea floor and subduction of the northeastern African plate to the north beneath Cyprus and Crete (Mckenzie et al., 1970). To the north of the margin, there is a complex zone of convergence (folding and reverse faulting) and strike-slip faulting (Mckenzie et al., 1970). The effects of the plate interaction are mainly north of and remote from the Egyptian coastal margin. Some secondary deformation appears to occur along the northern Egyptian coast, as shown by earthquake activity (Woodward, 1985).

Levant Transform

The Sinai block and Arabian plate are separated by the Levant transform fault zone, along which left-slip faulting has been observed (Mckenzie et al., 1970). North of the head of the Red Sea, the Levant transform fault extends along the lineament marked by the Gulf of Aqaba and the Dead Sea. Prominent left-slip faulting has been observed on this zone (Garfunkel et al., 1981). The total amount of left-slip was proposed by Freund et al., (1970) to be 110 km. Recently, Mart and Hall (1984) suggested that much of the Levant motion can be explained as geologically recent opening along the Dead Sea Rift and its extension to the north-northeast. According to

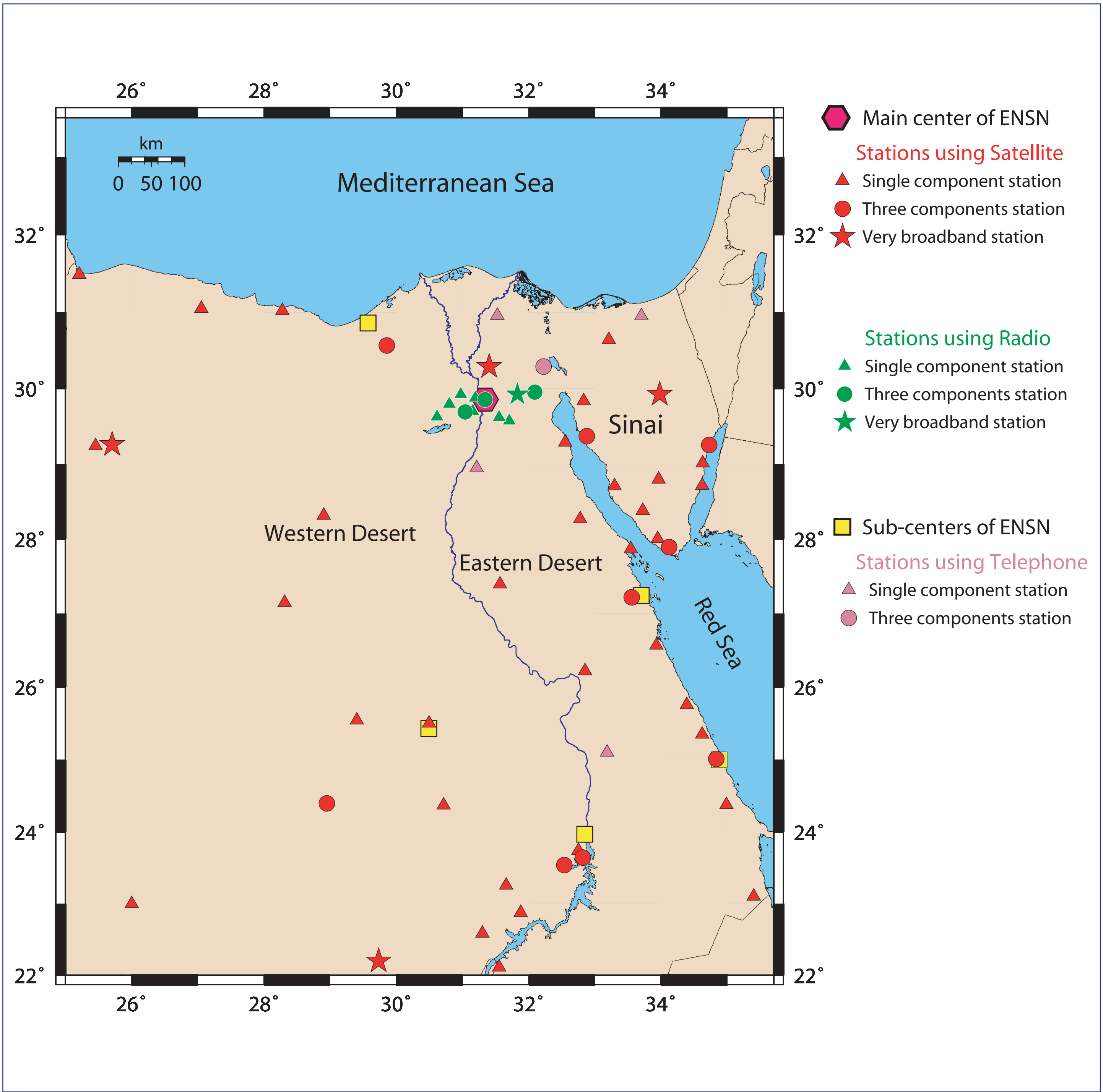

Figure 2: *Geographic Distributions of Egyptian National Seismic Network (ENSN)*

this model, the present-day movement of the Levant zone is both left lateral and extensional. The geomorphologic expressions show a small component of spreading as well as left lateral motion. In general, the boundary is seismically active. The activity along this zone may materialize as swarms, e.g., the swarms of 1983 and 1993, or as foreshock-main-shock-aftershock events e.g., the event of November 22nd, 1995.

Red Sea Plate Margin

The Arabian plate is continuing to rotate away from the African plate along the Red Sea spreading centre. Current sea-floor spreading has been identified as far north as 20° to 22° north, from the continuous presence of basaltic crust in the axial rift of the Red Sea, and the geophysical signatures of newly emplaced oceanic crust (Cochran, 1983). This axial rift represents the boundaries between the Arabian and African plates. In the northern most Red Sea, north of 25°, Cochran (1983) notes the presence of rifted continental crust that has been introduced by discontinuous volcanic rocks. The seismic activity in the northern part of the Red Sea is concentrated at the entrance of the Gulf of Suez and Gulf of Aqaba. Earthquakes of magnitudes up to 6.9 were reported, e.g., the event of March 31st, 1969. Daggetta et al. (1986) conducted a microseismic survey in eastern Egypt in early 1980 and showed that there is a large number of earthquakes in the most northern part of the Red Sea, averaging 25 events per day, with swarms as many as 200 events in one day occurring about once every seven days. These earthquakes occurred at depths varying from 5 to 22 km and had a local magnitude varying from 1 to 3.1.

Suez Rift

The Gulf of Suez is controlled by a rift that extends north west into the African plate from the junction of the Red Sea Rift and the Levant transform fault. It separates the

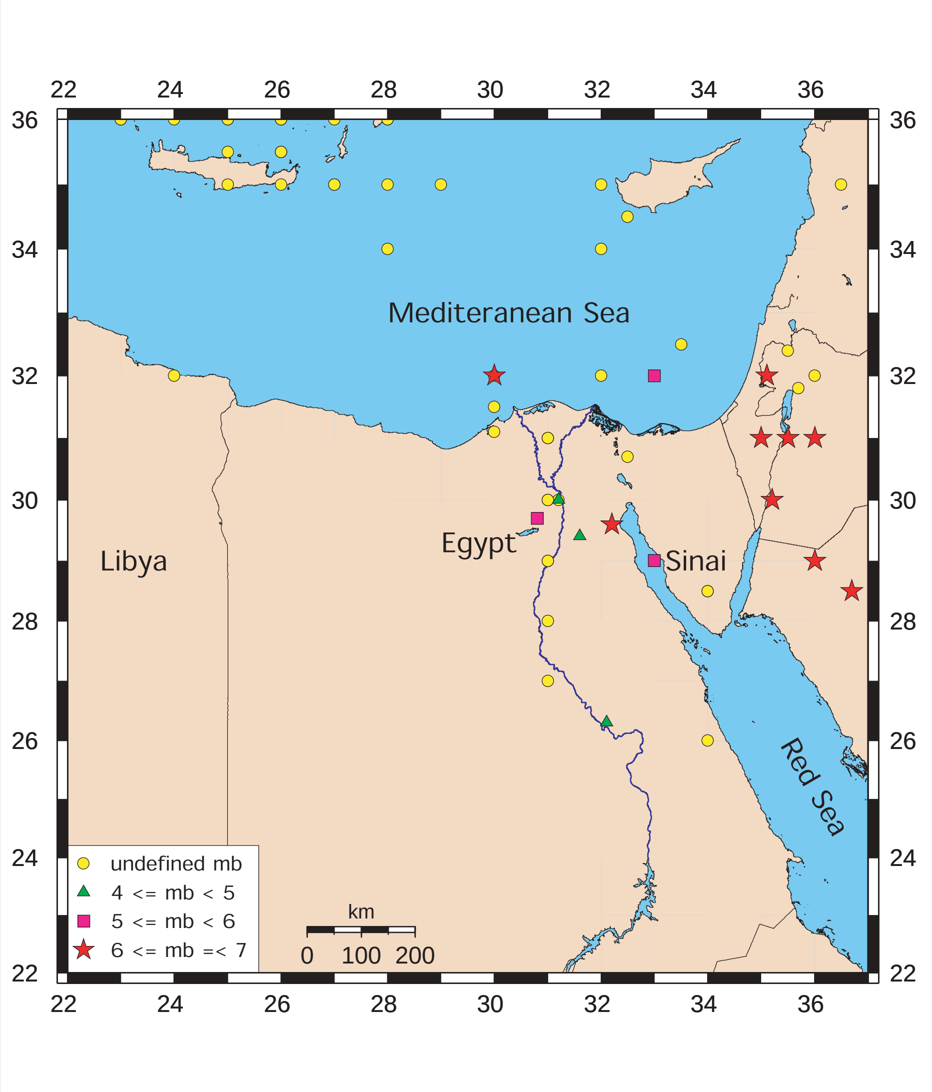

Figure 3: *Location of Historical Earthquakes from 2200 BC to 1900 AD*

northeastern part of Egypt from the Sinai Peninsula. The Suez Rift may have become active as early as Late Mesozoic or late Eocene and established its depression by Early Miocene. The Suez Rift is a tectonically active structure that is considered to be a sub-plate boundary that formed as relict of the early opening of the Red Sea. According to Sfratome (1984), a large part of the deformation due to plate interaction is concentrated along the Suez Rift and its continuation toward the north in the Cairo Alexandria fault zone.

Megashear Zone

A magnetic and gravity trend statistical analysis using the results of all areomagnetic flown and gravity surveys in Egypt was carried out. One of the results is a confirmation of major transcurrent shear zones that belong to the Pelusiem Megashear system across Africa. It extends from Turkey to the south Atlantic running subparallel to the eastern margin of the Mediterranean Sea then curving southwest across Africa from the Nile Delta to the Delta of Nigar. These two zones may correspond to the eastern Mediterranean-Cairo-Fayum zone in Northern Egypt.

Brief History of Seismographs in Egypt

Helwan Standard Station

Instrumental earthquakes recording in Egypt started as early as 1899 with a single station installed at Helwan. In 1962, the Helwan seismic station has been selected as one of the American World Wide of Standard Seismograph Network (WWSSN). It was equipped with long period Springnether and short period Benioff system of seismographs. Seismic data are exchanged regularly with World Data Centres and similar stations in many countries around the world.

Helwan Visual Recording Station

In 1971 a visual recording seismic station was erected at Helwan with a short period frequency analyzer. The equipment was denoted to the institute from Japan International cooperation Agency (JICA).

Aswan Station

It has been erected in 1975 and it is equipped with long period and short period seismographs of Kemos type. The equipment has been denoted from UNESCO.

Matrouh and Abu Simble stations

These stations are equipped with short period seismographs of Kemos type. The first was erected at Matrouh at the northwest coast of the Mediterranean Sea and the second at Abu Simble furthermost south of the country. UNESCO has also donated these stations in 1975.

Aswan Telemetred Seismograph Network

After the occurrence of the 1981 Kalabsha earthquake in Southern Egypt, a seismic network has been established around the Kalabsha fault and Naser Lake to monitor continuously the earthquake activity around the northern part of Naser Lake. It consists of a 13 radio-telemetry vertical seismograph stations network with a frequency analyzer of 0.2 to 30 Hz within the area. Two of the 13 stations have 3-component sensors.

Kottamia Broad Band Station (KEG)

As a result of the cooperation between (NRIAG) and Italian scientists, a broad band seismic has been erected in 1990. This station belongs to MEDNET.

Hurghada seismograph network

As a result of fruitful cooperation between Egypt (NRIAG) and Japan International Cooperation Agency (JICA), in August 1994, telemetric seismological network at the both sides of the Gulf of Suez was installed. It consists of eight stations, four of them in the southern Sinai and four others in the Western Side of the Gulf of Suez. The main center was located in Hurghada City.

The Egyptian National Seismic Network (ENSN)

After the occurrence of the Dahshour earthquake in Oct. 1992, it was decided to establish the Egyptian Seismic Network (ENSN). This network had to be a technologically sophisticated system in order to meet the important needs for public safety and emergency management, quantification of hazard and risk associated with both natural and man-made earthquakes, and engineering applications related to this, as well as basic research. ENSN is a multiphase program. It consists of a centralized recording and analyses system based at the DC at Helwan and 6 sub-networks that consist of different types of seismic stations (e.g. Broad-Band, short period, Bore Hole, Strong Motion) represented on Figure 2. The ENSN is a digital network with a duplex communication network which relies primarily on three major elements: - a high resolution digitizer (HRD series) that provides a resolution of 24 bits (132-DB dynamic range) and GPS timing, - a NAQS32-P acquisition and monitoring software with

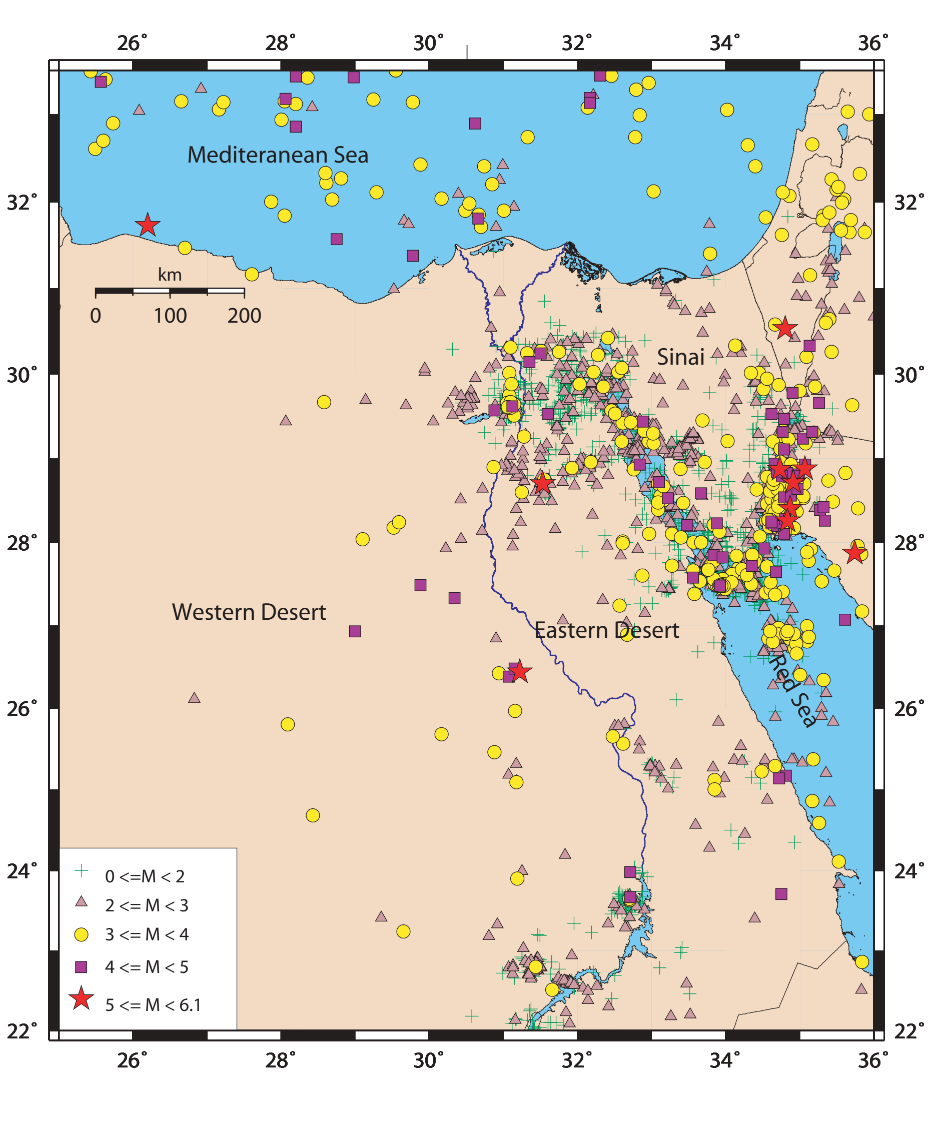

Figure 4: *Location of Local Earthquakes Recorded by ENSN in the period 1997-2002*

reliable error detection and correction mechanism and - the monitoring of the vital technical parameters of the remote and repeater stations, eliminating the unnecessary visits to remote sites.

Objectives

- Monitoring local and regional activity including artificial events.
- Data analysis and interpretation and researches in the field of seismology and geophysics.
- Studying the microearthquake activities of certain areas in Egypt, especially, the areas of dense population.
- Site effect studies
- Strong motion studies.
- Assessment of seismic hazard.
- Estimating the expected future earthquake effects.
- Protecting strategic buildings, high dam and archaeological sites.

Configuration

The network consists of 62 remote sites transmitting the data to the main centre at Helwan and five sub-centres at Hurghada, Burg El-Arab, Mersa Alam, Aswan and Kharga (Figure 2). The main centre receives the seismic data from the near distance stations through a telemetry communication and from the remote stations and the sub-centres via the telephone lines and the satellite communications. The distribution of the seismic stations and the strong motion units are chosen to cover the known seismic sources as much as possible. Also this distribution covers some regions with known historical earthquakes without any evidence of instrumental activity (e.g. Siwa seismic stations).

Brief History of the Egyptian Historical Earthquakes

Although the occurrence of 2200 BC earthquake is not confirmed (Ambraseys et al., 1994), no historic information on the effect of earthquakes are available before that period. The ideas of the causes of earthquakes had a mythological character. Until the beginning of the 20th century, information on earthquakes is coming from macroseismic effects of large shocks. According to Badawy (1999) the total number of historical earthquakes till 1900 is 83 including the non-confirmed ones (Figure 3). Some of these earthquakes are initiated by seismic sources outside the Egyptian territory. He attributed the lack of reported earthquakes in some areas to the political situations at these times and the disappearance of the documents. Despite this, observations can be classified into four time intervals in terms of studied earthquakes: 2200 BC to 1300 AD, 1300 to 1800, 1800 to 1900 and from 1900 on.

The **first time interval** covers the period from the beginning of the 22nd century BC to the beginning of the 14th century. For this period, information for a total of 34 strong earthquakes is available, while the real number of felt earthquakes per century is much larger. The small number of shocks may be due to the fact that people of such period paid their attention toward the important earthquakes and therefore towards the rare events, which caused extensive damage, destroyed important cultural centres. The beginning of **the second time interval** coincides with the beginning of the Mamluk period. This time interval includes the European scientific revolution and the industrial revolution. The total number of strong earthquakes of this period is 36 and thus the frequency of occurrence per century is 6. It is obvious that this rate is much larger than the corresponding rate of the previous period. This is due to the fact that the observational research started to dominate and to become the base for the new science. The beginning of the **third time interval** coincides with the end of the Ottoman Empire period. This time interval includes the actual beginning of the instrumental recording. The total number of strong earthquakes for this period is 17; i.e. the frequency of occurrence per century is 17. This rate is much larger than the corresponding rate in the previous two periods. This may be due to the contribution of Cairo newspaper (Badawy, 1999). The historical earthquakes are strongly related to the population distribution, thus we believe that the real number of the relatively strong earthquakes is much larger than the previously recorded ones. Many earthquakes were not felt due to its generation in the desert or in the sea away from the concentrated population. Figure 3 shows the map of historical events till 1900 AD. The **fourth time interval** covers the period 1900-2002. There are observations for almost all strong shocks. Although many earthquakes with magnitude about 4 are felt by many in the last decades, only earthquakes with magnitude 5.0 which occurred in Egypt are considered to represent the felt earthquakes in the fourth time interval. The total number of earthquakes with magnitude greater than 5.0 in this period is 53. It means that the mean rate of strong earthquake in this area is about 51.96 per century.

Recent Instrumental Seismicity

Generally, the seismic activity of Egypt was discussed and studied by many authors, e.g., Sieberg (1932); Ismail (1960); Gergawi and El-Khashab (1968); Maamoun and Ibrahim (1978); Maamoun et al., (1980); Poirier and Taher (1980), Maamoun et al., (1984); Kebeasy (1984 & 1990), Abu El-Enean (1997), Deif (1998) Badawy (1999) and El-Hadidy (1995 & 2000) to delineate the seismotectonic sources and zones.

The temporal distribution of the last decade reported seismicity shows three periods of observation. These periods are represented by the early instrumental (1900-1960), intermediate instrumental (1961-1997) and recent instrumental period (1997-now). The instrumentally observed seismicity in Egypt has the following characteristics:

- Concentration of earthquakes in four major zones. These zones are known as Northern Red Sea-Gulf of Suez-Cairo-Alexandria trending NW-SE, Gulf of Aqaba-Levant Fault, NNE-SSW, Eastern Mediterranean-Cairo-Faiyum, NE-SW and Egypt-Mediterranean Coast, E-W.
- Noticeable clusters or spots of activities at the north end of the Gulf of Aqaba, the entrance of the Gulf of Suez into the Red Sea and the eastern Nile Delta.
- Occurrence of both mainshock-aftershocks (e.g. the earthquake activity in the Gulf of Suez starting on March 31, 1969) and swarm (e.g. the sequences in the Gulf of Aqaba in 1983 and 1993) types of activity.
- A number of small, scattered earthquakes outside the main seismic zones. Many of these events were located using a single station (Maamoun et al., 1984), making plotted epicentres uncertain.

Damaging earthquakes and development of seismic networks in Egypt

There are many damaging historical and recent earthquakes that have been reported in Egypt. The total reported damage depends mainly on the size of the earthquake, local geology and location with respect to populated areas. Comparing the earthquake size with the associated damage shows that small local or large distant earthquakes could cause large damage in different areas in Egypt, e.g., Cairo, the Nile Delta and the Nile Valley.

Egypt has a historical record of earthquakes activity extending over the past 4,800 years. In addition to the magnitude 5.9 Dahshour earthquake of 12 October 1992, which damaged over 1,000 schools and killed or injured over 7,000 people, the three most significant earthquakes of this century include: 1) the magnitude 6.7 earthquake offshore of Alexandria on 12 September 1955, which destroyed over 300 buildings, 2) the magnitude 6.8 Shadwan Island earthquake on 31 March 1969, and 3) the magnitude 5.2 Aswan earthquake of 14 November 1981, which called attention to the importance of earthquake monitoring in the High Dam area and of hazard and risk studies in the country. More recent is the Aqaba earthquake of 22nd November 1995, magnitude 7.2, which killed at least 8 people and injured 30 in the epicentral area. Damage occurred in many parts of northeastern Egypt as far away as Cairo. Few injuries and some damage were reported in Saudi Arabia. Substantial damage with power outages and liquefaction occurred at Eilat, Israel. Some damage also occurred in Jerusalem and Aqaba. It was felt from Sudan to Lebanon.

Local Seismic activity

The local seismic activity recorded by ENSN from Aug. 1997 (start time of ENSN recording) to Dec., 2002 is located at specific seismic zones that reflect their tectonic activity (Figure 4). These zones are:

- Suez–Cairo shear zone, which extends from the apec of the Suez Gulf toward Cairo City and is characterized by moderate activity.
- Northern Part of Eastern Desert, which reflects a tendency of WSW-ENE active, faults (these faults transverse the Gulf of Suez main faults). A cluster of seismic activity from the Suez gulf to Beni Suef City corresponds to one of these faults.
- South–West Cairo zone (Dahshour area), which is characterized by moderate seismic activity.
- High seismic activity is also related to the Gulf of Aqaba and its extension towards the north.
- A cluster of seismic activity comes clearly from the central part of the Suez Gulf, which indicates that the entire Gulf is active. - Another cluster of seismic activity is shown at the northern part of the Red Sea at the triple junction area. This activity tends to lie at the Aqaba fault extension to the south. - A cluster of seismic activity is as well clearly shown along the central part of the Red Sea after the operation of the ENSN seismic stations, which were located along the western Red Sea Coast. This activity may be related to the active rifting of the Northern Red Sea. - A new cluster of seismic activity is recorded along the southern part of Naser's Lake. This cluster tends to align with the E-W direction in agreement with the major fault trends in this area.
- Moderate seismic activity occurs along the northern part of Naser's Lake to the southwest of Aswan High Dam.
- Another seismic zone was identified thanks to the increasing detectability of ENSN through the installation of some stations in the central part of Egypt (ADB, EDF, DK2 and SFG). This zone extends from Abu Dabab area along the Red Sea coast to the western Direction until the Nile River.
- The Network recorded a scattered activity from the Western Desert to the west of El-Minya and Sohag cities. Scattered events also lie along the Mediterranean coast but this does not reflect any specific trends.

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