CARTOGRAPHICAL SYNTHESIS OF SEISMIC HAZARD ON THE NORTH-EASTERN OF ALGERIA : CASE OF BEJAIA CITY AND VICINITIES

SYNTHÈSE CARTOGRAPHIQUE DE L'ALÉA SISMIQUE DU NORD-EST DE L'ALGÉRIE : CAS DE LA VILLE DE BÉJAÏA

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LILLOUCH Samir[1*], AIT MEZIANE Yamina[2], BENDADOUCHE Hocine[1]

(*) Corresponding author: samirlillouch@gmail.com,

[1] Université de Bejaia, faculté de technologie, Laboratoire de Génie de la Construction et Architecture, Bejaia 06000, Algérie
[2] Centre National de Recherche Appliquée en Génie Parasismique, Alger 16000, Algérie.

Abstract - In the Mediterranean, the deformation is the expression of tectonics of southern northern average convergence of Africa and Eurasia. The Tellien Atlas is one of the four great fields of Algeria, it is known by active tectonics, owing to the fact that it constitutes a segment of collision of these two plates. This zone is characterized by shallow and strong to moderate seismicity. The Eastern part of the Tellien Atlas is less active compared to the western part; this activity is associated to faults in setback. It was shaken by several violent seism, Kherrata February 17th 1949 of magnitude M_b =4,9 , generating the appearance of fault on the surface, Beni Ourtillane, November 11th 2000withM_s=5,7 and Boumerdès Mai 21th 2003 of magnitude Mw =6,8. The geomorphological complexity of this area suspects a great number of features morpho-tectonics (fault), the direct identification these last is tasks delicate, it requires a complex data, geological, historical and instrumental. The town of Béjaïa belongs to Tellien the Eastern field of Algeria, its population is 176 000 inhabitants in 2008, who does not cease increasing. This article presents a preliminary study of seismic hazard of Béjaïa city and its surroundings; it consists in mapping, using GIS tools, the seismic hazard of this area, while combining data of instrumental seismicity, tectonics and geological data.

Keywords: Earthquake, Hazard, seismicity, tectonic, fault

Résumé - En Méditerranée, la déformation est l'expression de la tectonique de la convergence moyenne sud-nord de l'Afrique et de l'Eurasie. L'Atlas Tellien est l'un des quatre grands domaines de l'Algérie. Il est connu par la tectonique active, du fait qu'il constitue un segment de collision de ces deux plaques. Cette zone est caractérisée par une sismicité superficielle, forte à modérée. La partie orientale de l'Atlas Tellien est moins active par rapport à la partie occidentale ; cette activité est associée à des failles en retrait. Elle a été secouée par plusieurs séismes violents, Kherrata le 17 février 1949 de magnitude M_b = 4,9 générant l'apparition de faille en surface, Béni Ourtillane, le 11 novembre 2000 avec M_s= 5,7 et Boumerdès le 21 mai 2003 de magnitude M_w= 6,8. La complexité géomorphologique de cette zone suspecte un grand nombre de caractéristiques morpho-tectoniques (faille), l'identification directe de ces dernières est une tâche délicate. Elle nécessite un ensemble complexe de données géologiques, historiques et instrumentales. La ville de Béjaïa appartient au domaine tellien oriental de l'Algérie. Sa population est de 176 000 habitants en 2008, qui ne cesse d'augmenter. Cet article présente une étude préliminaire de l'aléa sismique de la ville de Béjaïa et de ses environs. Il consiste à cartographier, à l'aide d'outils SIG, l'aléa sismique de cette zone, tout en combinant des données de sismicité instrumentale, de tectonique et des données géologiques.

Mots-clés : Séisme, aléa, sismicité, tectonique, faille

1- Introduction

The concept of seismic hazard was released only rather recently, it was confused a long time with the risk i.e. the probabilistic estimation of seismic consequences[1].In these twenty years, Algeria were choked by several earthquakes, violent ones sometimes but often moderated to weak, among of these earthquakes,Kherrata's earthquake February 17th 1949, El Asnam earthquake October 10th 1980, Beni-Ourtillane earthquake November 10th 2000 and the Boumerdès earthquake Mai 21th 2003, with magnitude M_w = 6.8 inducing an important causalities, during this seism, a fault with a significant length was activated [2]. This region was the aim of several works namely: Bennouar, 1994; Mokrane, 1994; A.K. Yelles-Chaouche, 2000; Y. Bouhadad, 2013…etc. This entire works had an objective: to better define the seismicity of Northern Algeria. The mapping and understanding of active structures, in the Algerian tell atlas, which is the most active zone with maximum observed degree of intensity of XI-X [3], has been initiated after the El Asnam earthquake, October 10th 1980. This region is characterized by an active faulting, shallow seismicity and short historical record of earthquake (1365 at our days)[4]. Since the Boumerdès earthquake, Algerian authorities had taken certain decisions about the earthquake-resistant payment, by the actualization of several rules in the Algerian earthquake code RPA 99 Modified 2003.The aim of this work, is to synthetize all available information about the seismicity of the Algerian tell atlas, precisely all data relating to the region of Béjaïa city and vicinities.

2- Géographia situation

The Tellien Atlas is one of four great domains of Algeria; it is limited by the Mediterranean Sea at the north, Tunisia in the East, Morocco in the West and the Saharan Atlas in the South (Figure01). From Moroccan border to Algiers, the western part of Tellien Atlas , it does not constitute a continuous assembly line. It is cut out in the vicinity of the sea by a series of plains of Oran, Sig and Chelif in Oranie, plain of Mitidja around Algiers. The eastern part, from Algiers to Tunisia border, Tellien atlas becomes higher and more solid mass. The plains are rare, the vastest one is that Bone (Annaba actually).[5]

Béjaïa city is one of most important cities of Algeria, it situates on the north eastern part of country, in the Mediterranean edge, precisely on the oriental part of Tellien Atlas (Figure01). It is located between the latitudes 36°15' and 36°55' Northern and longitudes 4°20' and 4°30' east (Figure02), its population was 184 722 inhabitants in 2013.

3- Historical seismicity

Algerian seismicity is known as far as 1365(A.K.Yelles-Chaouche, 2003), this date corresponds to the seism of Algiers. Before this date, the seismicity is unknown, for lack of unavailability of documentation and files relating to the ancient and medieval time of this area. This event was of an intensity of ***X*** (A.K. Yelles-Chaouche, 2003). Since 1365, Algeria was shaken by several earthquakes, among them certain were violent and murders one (Table 01)

Many efforts have been deployed, in aim to obtain a complete Algerian seismicity catalogue, namely : Roussel, 1967; Benhallou, 1985; Mokrane et al., 1994; Bennouar, 1994; Boudiaf, 1996, Yelles et al., 2002 (A.K.Yelles-Chaouche, 2003).

4- Regional geology

The Tellien Atlas of Algeria consists of mountains ranges and valleys parallel to coastline, and showing diverse morphological aspect [4]. Indeed this zone is made of young mountain formed during tertiary time by alpine orogeny, who consist of structural sedimentary units from then north to south [15]. The Tellien Atlas is the nappe domain with mountain basin and sedimentary column ranging from the Jurassic to the Miocene (Figure 03).

North Kabylia belongs to the geological whole of Tellien Atlas; it corresponds to the internal zones of Maghribides. It is represented by two massifs, small Kabylia and large Kabylia (Figure 03). These two massifs regroup the crystalline base, no metamorphic Paleozoic, the kabylian ridge or calcareous range [17]. Northern and Southern kabylian flysch, form a large band between internal and external zones. The southern part of kabylian domain corresponds to external zone of Maghribides range.

5- Local geology

Small Kabylia belongs to the geological whole of Tellian Atlas, which is characterized by a lithological and structural complexity, which made this zone the object of several work in particular : L. DUPLAN and M. GRAVELLE 1960, M. ROUBAULT (1974), M. DURAND DELGA (1996), H. HASSISSENE (1989) [18]. Indeed, it is one of the old solid masses of the internal zones of Maghrebides, with a Mesozoic and Tertiary cover. The sector of study corresponds to the oriental party of Babors, located at the West of Béjaïa's golf axis. In Béjaïa's area, several formations are distinguished (Figure 4), the quaternary one results in falls of slopes unconsolidated, solifluctions, dunes and beaches sands, recent alluvia, muddy deposits of Soummam wadi and torrential alluvial cones, marshy alluvia, old alluvia, low terraces, muddy deposits, sandy and stony. Miocene superior-Pliocene, at the base, breaches of re-cemented slopes passing under grey-bluish clays of Srir wadi. Lower Miocene, with Facies Sea which are not very deep, limestones, sandy marl and conglomerates. Nummulitic represented in Bouhattem by conglomerates. Two series of flysch are distinguished: missylien flysch and the Mauritanian one, and an intermediate series. Moreover, the cretaceous is composed of two sedimentary cycles, one cenomanien-turonien and second senonien higher. The Jurassic one is presented by red and green schists and limestones. The Lias represented by calcareous marl and marl on cap Carbon and Djebel Oufarnou. Inter alia, several authors announced the presence of Trias in Gouraya-Aghbalou link. [18]

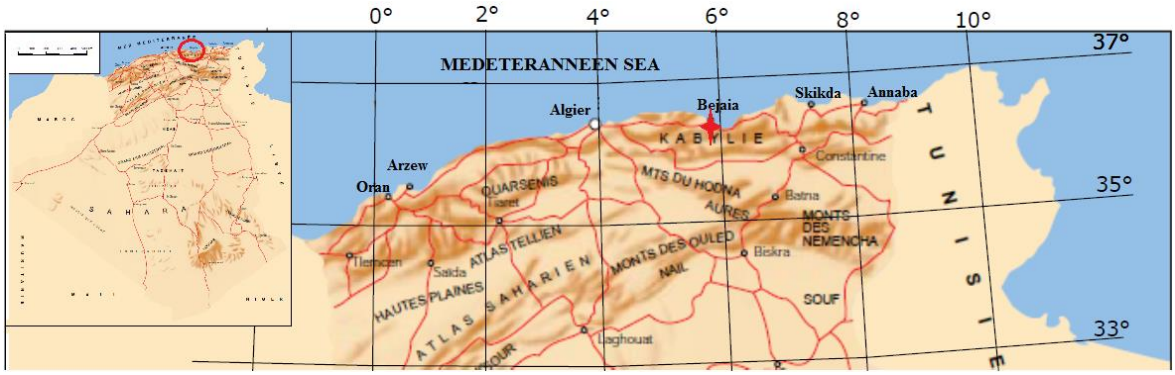

Figure 01: Geographical situation of Tellien Atlas. (Creation map LR/GÉOGRAPH, 1994)

Figure 01 : Situation géographique de l'Atlas Tellien. (Carte création LR/GÉOGRAPH, 1994)

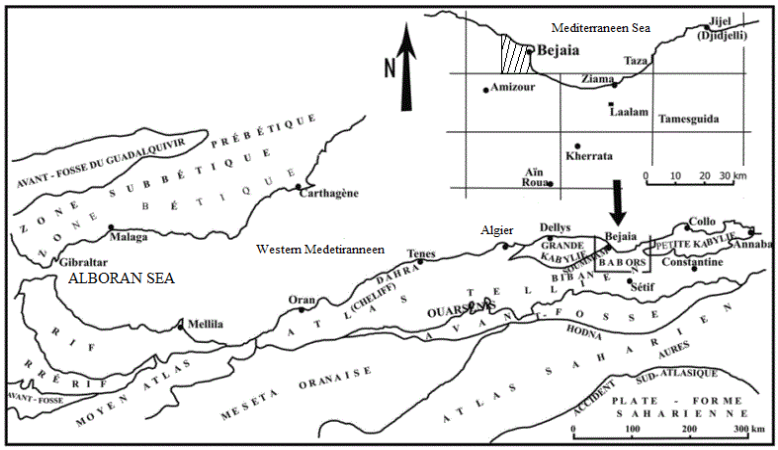

Figure 02: Geographical situation of Béjaïa city and vicinities

Figure 02 : Situation géographique de la ville de Béjaïa et de ses environs

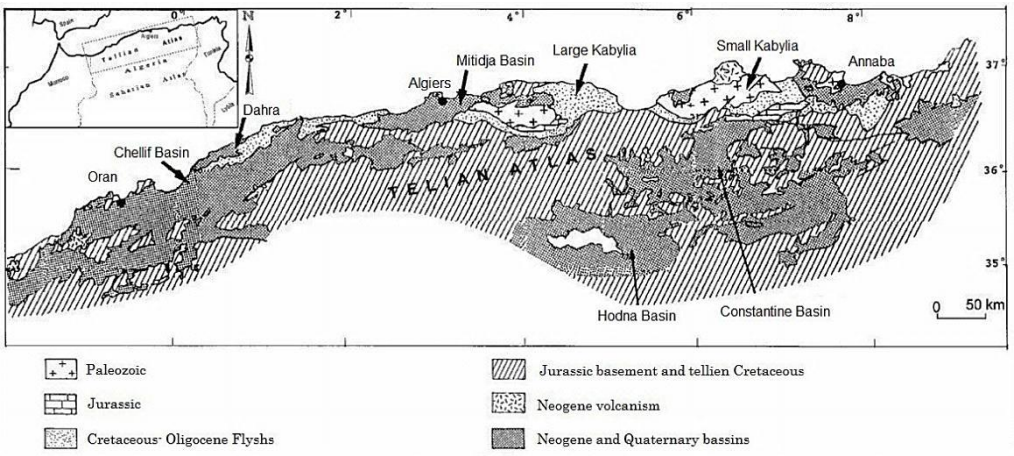

Figure 03: General geological setting of Algerian Tell Atlas (After Meghraoui.1988) [16]

Figure 03 : Cadre géologique général de l'Atlas algérien du Tell (d'après Meghraoui.1988) [16]

Table 01: Main historical earthquake in Algeria (1365-2010)

Tableau 01 : Principaux séismes historiques en Algérie (1365-2010)

Localité	Date	Intensité	Magnitude	Perte humaine	Référence
Alger	03.01.1365	X	-	Plusieurs	(A.K. Yelles-Chaouche, 2003)
Alger	03.02.1716	IX	-	-	[3]
Oran	09.10.1790	X	-	2 000	[8]
Blida	02.03.1825	X	-	7 000	(A.K. Yelles-Chaouche, 2003)
Djidjelli	22.08.1856	X	-	-	[9]
Mouzaïa	02/01/1867	X-XI	-	100	[3]
Aures	16.11.1869	IX	-	30	(A.K.Yelles-Chaouche, 2003)
Mascara	29/11/1887	IX-X	-	80	[3]
Gouraya	15.01.1891	X	-	38	(A.K.Yelles-Chaouche, 2003)
Sidi Aich	01.01.1901	IX	-	-	[10]
Constantine	16.09.1907	VIII	-	-	

Sour El Ghozlane	24/06/1910	X	-	81	[3]
Bejaia	12/02/1946	IX	-	264	[3]
Orléans Ville	09.09.1954	X	6.7	1243	(A.K.Yelles-Chaouche, 2003)
Sétif	13.11.1957	VIII	-	-	[10]
El Asnam	10.10.1980	X	7.3	2633	(A.K.Yelles-Chaouche, 2003)
Constantine	27.10.1985	VIII	5.9	10	(A.K.Yelles-Chaouche, 2003)
Tipaza	29.10.1989	VIII	6.0	22	[11]
Mascara	18.08.1994	VII	5.7	175	[12]
Alger	04.09.1994	VII	5.7	-	(A.K.Yelles-Chaouche, 2003)
Timouchent	22.12.1999	VII	5.7	25	[13]
Béni Ourtillane	10.11.2000	VII	5.4	04	[14]
Boumerdès	21.05.2003	X	6.8	2300	(A.K.Yelles-Chaouche, 2003)
Lâalam	20/03/2006	VII	5.2	04	[3]
Béni Ilmane	14/05/2010	VII	5.2	04	[3]

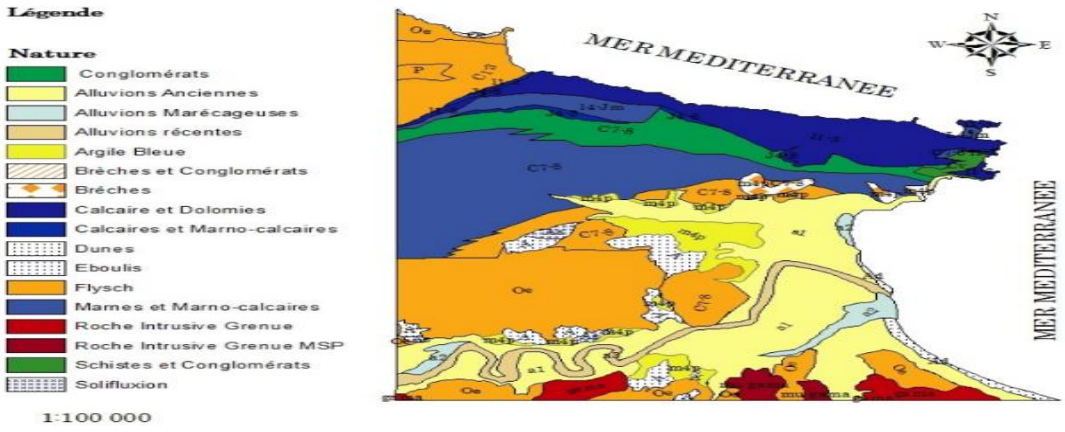

Figure 4 : Geological map of Béjaïa city.

Figure 4 : Carte géologique de la ville de Béjaïa.

6- Instrumental seismicity

In this last two decades, Béjaïa city and vicinities record several earthquakes, with a low to moderate magnitude and sometimes strong. The majority of recorded seism occurred recently on the Béjaïa's golf (Figure5).

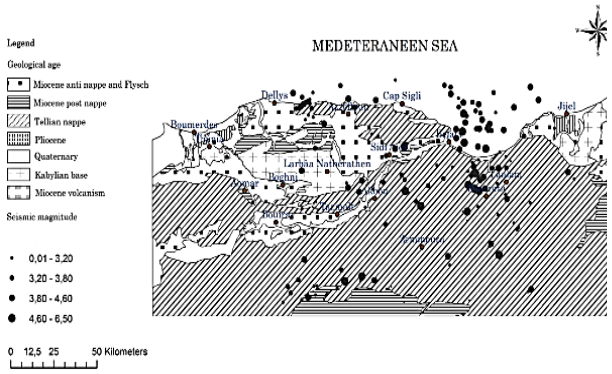

Figure 5: Seismic magnitude and geological setting of Béjaïa city and vicinities.

Figure 5 : Magnitude sismique et cadre géologique de la ville de Bejaia et de ses environs.

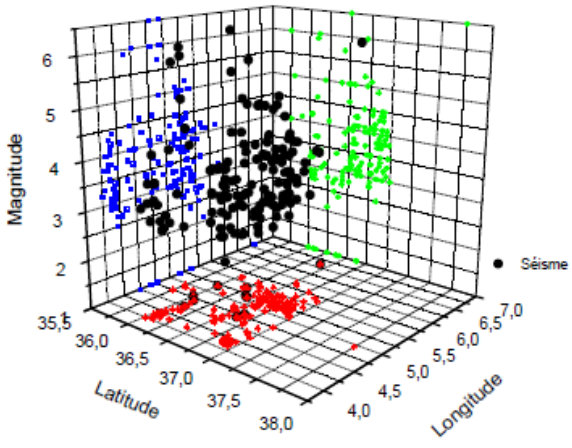

Figure 6 : Map of recorded seismic magnitude.

Figure 6 : Carte de la magnitude sismique enregistrée.

As signaled by A. Aoudia et al, 2000, this region is characterized by a shallow seismicity. Recorded earthquakes (instrumental seismicity) show that earthquake's depth is between 2 km and 40 km, which are shallow (Figure7, Figure8). The raster generated by Natural Neighbor command of GIS tool, shows that in this region earthquakes magnitude are weak to moderate (Figure6), varying between 1 to 5. Among of recorded seism, little of them are violent, namely: Laâlam's earthquake occurred November 10th, 2000. (Figure9)

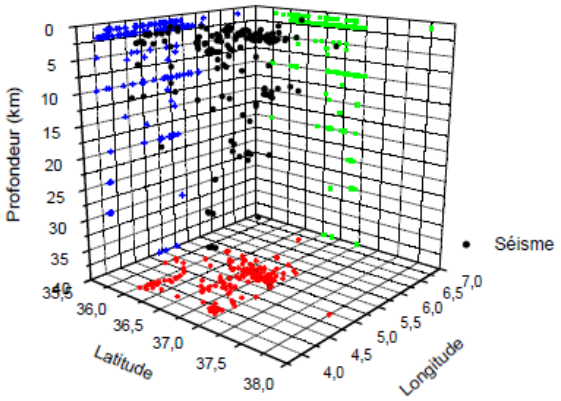

Figure 7 : Seism depth

Figure 7 : Profondeur du séisme.

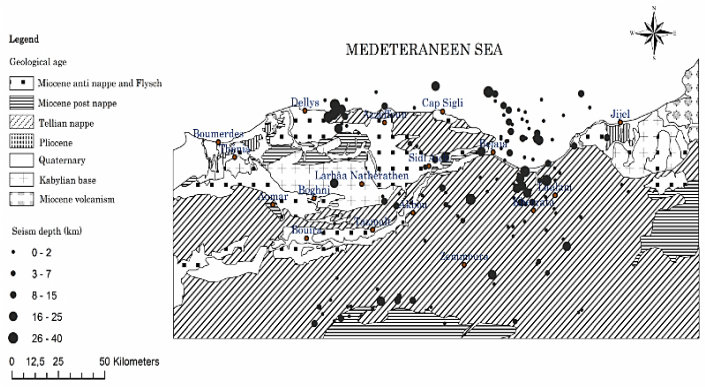

Figure 8 : Seismic depth map's.

Figure 8 : Carte de profondeur sismique.

7- Tectonic and actives faults

One of the principal requirement on seismic hazard evaluation is delineate of an active geological structure [4]. North of Algeria corresponds to Africa and Eurasia boundary, which are moving permanently from 5 to 6 mm/year [14], this zone is characterized by converging tectonic plates, which generate a compressive stress in the Tellian Atlas, consequently a high seismic activity produced by NE-SW[9].

In the literature, significant lineaments are described as being large alpine accidents, among which : Isser–Bouira's accident, Chellata's accident, Tizi Ouzou and Azazga's accident and Aghbalou's accident [19]. The main morpho-tectonic lines (lineament show a high probability to be an active fault) in the

Eastern part of Tellian Atlas are (Figure10, tab.2):

- Kherrata's fault of direction NE-SW, it is aligned in the same direction than babor i.e. in setback, which passes near the Lâalam's village [20], Bouhadad et al., 2001, said that Tachouaft fault, which generating Beni Ourtillane's earthquake November 10 th 2000, it is probably a segment of Kherrata's fault.

- Kabylia south overlap, which corresponds to tectonic escarpment overlooking Soummam valley. It would correspond to a reverse fault in North dipping affecting recent deposits separating the North and South-Kabylia areas over a distance of 100 Km[17].

- Thenia's fault on Boumerdès region of WNW-ESE direction, which corresponds to an active strike-slip. It represents the western limit between kabylian domain and Metidja's basin.

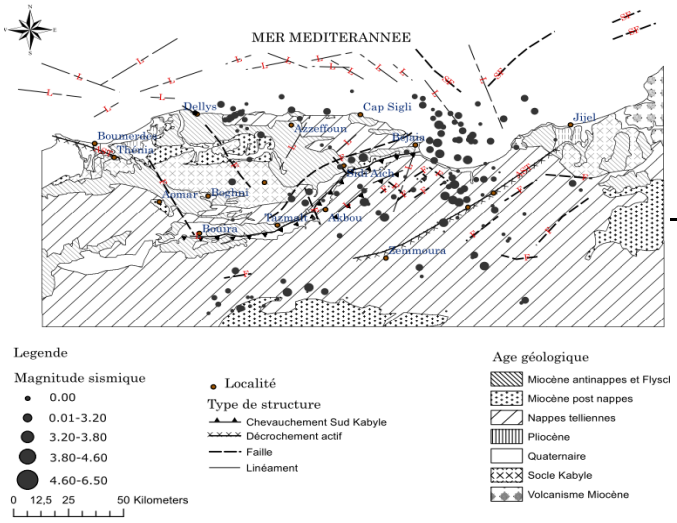

Figure 9: Map of main active structure in the Tellien atlas.

Figure 9 : Carte de principales structures actives dans l'atlas Tellien.

At sea, many tectonic structures are highlighted by Harbi (1996) who have identified a submarine faults, precisely six submarine faults, but only four faults are inscribed on our sector of interest (Figure 9). It's difficult to recognize an active submarine fault. As such, Harbi (1996) has taken account the recognizing of an active submarine fault criteria (Figure 10, Figure 11). Meanwhile, the faults (A) and (B) (Figure 9) are active following the first criterion (Figure 10). (C) and (D) faults of direction NE-SW (Figure 9) are active following the second criterion (Figure 11) [16].

Table 02 : Main morpho-tectonics lineaments

Tableau 02 : Principaux linéaments morpho-tectoniques

N°	Nature	Observation	Direction	Reference
01	Thenia's strike-slip	Active fault	WNW-ESE	S. Aourari, projet de Recherche, DAS/CGS, 2007
02	Iser's fault-Bouira	Active fault	NW-SE	
03	Larbâa Nath Irathen's fault	Active fault	NW-SE	
04	Aghbalou's fault	Probably active	NE-SW	
05	Kabylia south overlap	Active fault	NE-SW	
06	Kherrata's fault	Active fault	NE-SW	
07	Chellata'sfault- Akbou	Probably active	NW-SE	
08	Tifra's fault- Sidi Aich	Probably active	NW-SE	
	Several lineaments	Probably active	NE-SW	
A,B	Faille sous-marine	Active following	NE-SW	Harbi, a, Maouche, S., & Ayadi, a. (1999).
C,D	Faille sous-marine	the first criterion	NW-SE	

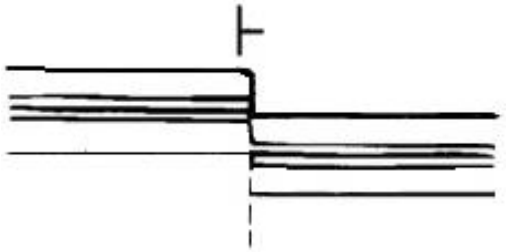

Figure 10: Sea-bottom and younger (plio-quaternary) sedimentary layers are clearly offset (Criterion1)[16]

Figure 10 : Les fonds marins et les couches sédimentaires plus jeunes (plio-quaternaires) sont clairement décalés (Critère 1) [16].

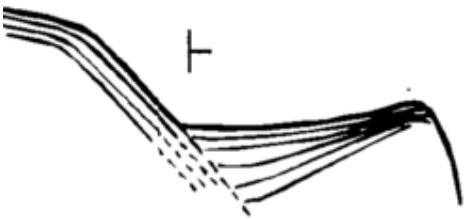

Figure 11: Sedimentary layers on the sea-bottom are in contact with a shelf slope and with sedimentary layers parallel to it; the lower layers on the sea-bottom dip toward the shelf slope (Criterion2)[16].

Figure 11 : les couches sédimentaires au fond marin sont en contact avec un plateau en pente et avec des couches sédimentaires parallèle à elle ; les couches inférieures sur le fond marin tremper la pente du plateau (Critère 2) [16].

8- Conclusion and discussion

The present study presents an attempt tomap the seismic hazard of Béjaïa city and vicinities, using GIS tool, which is based on the combination of seismic data, tectonic and geologic existing data.

Tectonic map shows that the region of interest contains several geologic structures, among of these structures are active. Two major tectonic accidents are active in kabylian region: Soummam fault's, which is an overlap of quaternary land (from Bouira until to Béjaïa's golf), Kherrata's fault which represents an active setback of direction NE-SW. In the Boumerdès region, a fault of direction NW-SE, which is an active setback.

Instrumental seismicity of Béjaïa city and vicinities show that this region faces moderate and shallow earthquakes, which are concentrating on the Béjaïa's golf. The large event in this region was the Beni Ourtillane's earthquake, November 10th 2000, with magnitude of 5, 7.

In Algeria, the seismic hazard notion has recently appeared, since the EL Asnam's earthquake, from which resulting several research studies. It appears clearly that the region of interest is an active zone, other studies must be continued in order to work out more precise maps taking account of a more significant number of observations, and in addition the use of a geographical information system would facilitate the update of these maps

9- Bibliographie

[1] Jacques Betbeder-Matibet, *risques et aléas sismiques, volume2*, Hermès sci. 2003.

[2] IRSN, "Séisme en Algérie," vol. 45, pp. 21–23, 2003.

[3] M. Bezzeghoud, "Seismicity of Algeria from 1365 to 2013: Maximum Observed Intensity Map (MOI 2014)," vol. 86, no. 1, pp. 1–9, 2015.

[4] A. Aoudia, F. Vaccari, P. Suhadolc, and M. Meghraoui, "Seismogenic potential and earthquake hazard assessment in the Tell Atlas of Algeria," pp. 79–98, 2000.

[5] H. Askri *et al.*, "Géologie de l'Algérie," *Geol. Alger.*, 1995, [Online]. Available: http://www.mem-algeria.org/francais/index.php?page=principales-communications.

[6] A.K.Yelles-Chaouche, "Recent Seismic Activity in Northern ALGERIA," in *Fourth International Conference of Earthquake Engineering and Seismology 12-14 May 2003 Tehran, Islamic Republic of Iran Recent*, 2003, no. May.

[7] A.K.Yelles-Chaouche, "Les Séismes en Algérie du Nord," in *CRAAG*, no. tableau 1, CRAAG, Ed. CRAAG, 2003.

[8] Y. Bouhadad, "The Murdjadjo, Western Algeria, fault-related fold: Implications for seismic hazard," *J. Seismol.*, vol. 5, no. 4, pp. 541–558, 2001.

[9] A. Benhamouche, A. Nedjari, Y. Bouhadad, D. Machane, E. Oubaiche, and N. Sidi Said, "Field evidence of seismites in Quaternary deposits of the Jijel (Eastern Algeria) coastal region," *J. Seismol.*, vol. 18, no. 2, pp. 289–299, 2014.

[10] A. Harbi, S. Maouche, and H. Benhallou, "Re-appraisal of seismicity and seismotectonics in the north-eastern Algeria part II: 20th century seismicity and seismotectonics analysis," *J. Seismol.*, vol. 7, no. 2, pp. 221–234, 2003.

[11] A. Harbi, S. Maouche, A.Ayadi, D.Benouar, G. F. Panza, and H. Benhallou, "Seismicity and Tectonic Structures in the Site of Algiers and its Surroundings : A Step Towards Microzonation," *Pure Appl. Geophys.*, vol. 161, pp. 949–967, 2004.

[12] A. Ayadi, S. Bourouis, and H. Benhallou, "Seismotectonics and seismic quietness of the Oranie region (Western Algeria): The Mascara earthquake of August 18 th 1994 , M w = 5 . 7 , M s = 6 . 0," *J. sei*, no. 16, pp. 13–23, 2002.

[13] A. K. Y. E. Haouche, H. D. Jellit, and H. B. Eldjoudi, "Pure and Applied Geophysics The Ain Temouchent (Algeria) Earthquake of December 22 nd , 1999," vol. 161, pp. 607–621, 2004.

[14] Y. Bouhadad, A. Nour, N. Laouami, and D. Belhai, "The Beni-Ourtilane-Tachouaft fault and seismotectonic aspects of the Babors region (NE of Algeria)," *J. Seismol.*, vol. 7, no. 1, pp. 79–88, 2003.

[15] H. Askri *et al.*, "Geology of Algeria," *Schlumberger WEC Sonatrach*, pp. 1–93, 2000.

[16] A. Harbi, S. Maouche, and A. Ayadi, "Neotectonics and associate seismicity in the Eastern Tellian Atlas of Algeria," *J. Seismol.*, pp. 95–104, 1999.

[17] D. Machane and S. Ourari, "Identification, caracterisation et hierarchisation des failles actives dans la Kabylie, étape 3: Cartographie des failles actives dans la région de la Kabylie Décembre" ,2008.

[18] Y. Hammadi, *cartographie géotechnique des risques de glissements (CRG) et de risques d'inondations (CRI) de la ville de Bejaia*, Univerité. 2011.

[19] D. A. B. S. Aourari, S. Talmat Bouzeguella, "Synthese sismotectonique de la moyenne Soummam", 2003.

[20] S. Ourari, D. Machane, E.-H. Oubaiche, and R. Bensalem, "Identification, caracterisation et hierarchisation des failles actives dans la kabylie, etape2: prospection geologiques et geophysiques en Kabylie méthodologie d'etude des failles actives," pp. 1–13, 2008.