Velocity field along the northern Algeria from seismic moment summation of earthquakes

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Abstract:

The Africa-Eurasia slow oblique plate convergence induced a regional NW-SE compressive stress field mainly characterized by reverse faulting. We used seismic moment summation to study the present-day kinematics along the Tellian Atlas (Northern Algeria). A seismic catalogue used for the purpose of this study is distributed by Centre de Recherche en Astronomie Astrophysique et Géophysique (CRAAG) and covers the period from 1365 to 2003 with 2190 historical and instrumental events. In this study, we present the velocity field analysis along the Tell Atlas (northern Algeria), which have been divided into four zones according to geological and seismological aspects. We considered the available seismic database to calculate the seismic slip rate using Brune (1968) method.

Seismicity and tectonic setting:

The seismic activity in northern Algeria is characterized by continuity in time and space with moderate to strong seismicity. This part of the Mediterranean basin have experienced during the last half century, three large events: Orléansville, 1954, MS = 6.7; El-Asnam, 1980, MS = 7.3 and recently Zemmouri, 2003, Mw = 6.8. The epicenter distribution and analysis along the northern Algeria shows a concentration of seismic events within the tellian Atlas. From tectonic point of view, the northern Algeria is characterized by compressive structures which results from Africa-Eurasia plate convergence with a shortening of about 6 to 10mm/yr. Along this domain, we observe a large intramounts post nape basins, elongated in E-W direction. These plio-quaternary structures are affected by the NS to NW-SE compressive stress regime. Along the Tell Alas, several seismogenic zones with E-W and NE-SW striking fold and reverse faults affecting the recent Pleistocene deposits. The tellian Atlas domain can be divided into four zones:

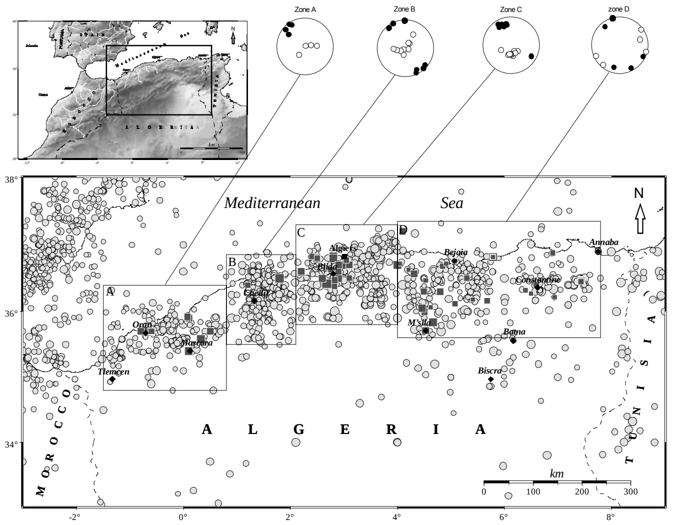
Zone (A): The intense tectonic activity in the western part is responsible of the development and the evolution of sedimentary basins, during the early-Pleistocene. These Quaternary subsiding basins are elongated in the NE-SW direction. The Quaternary compressive phase is associated with the reactivation of the existing faults. The last compressive phase is attested by the recent activity of Mascara and Temouchent reverse faults related to the Mascara (18/08/1994, Ms 6.0) and Ain Temouchent (22/12/1999, Ms 5.8) earthquakes.

Zone (B): The recent tectonic activity in the Cheliff basin is attested by the El Asnam thrust fault responsible of the October 10th 1980 Ms 7.3 earthquake. The plio-quaternary Cheliff basin is limited towards the SW by the Relizane activefault leading in NNE-SSW direction. To the north the basin is affected by compressive deformations with asymmetrical flexures and folds which reflect the predominance of the tectonic compressive phase in this area

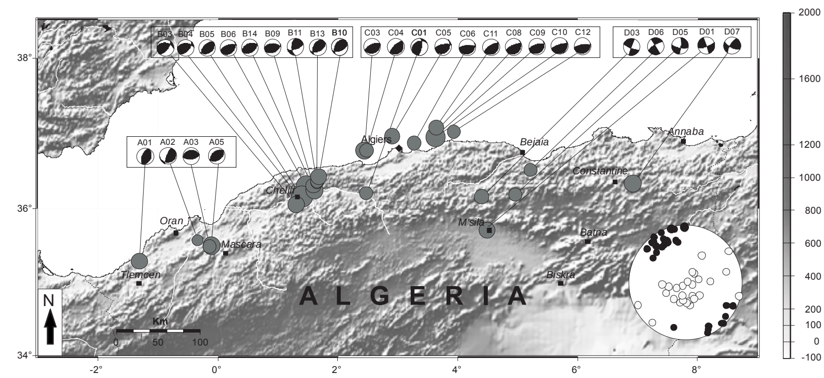
Zone (C): The central part of the Tell Atlas corresponds mainly to the Mitidja basin, an east-northeast-trending, fold-and-thrust belt. Bounded to the south by the Blida fold-and thrust system, which corresponds to imbricate southeast dipping thrust sheets and limited to the north by the Sahel anticline which is an active fold related fault parallel to the coast. The western segment of this structure was reactivated during the Tipasa-Chenoua earthquake (29/10/1989, Ms 6.0) .

Zone (D): It contains several basins: the Soummam basin corresponds to a Neogene basin characterized by a moderate and continuos seismicity. The Guelma pull-appart basin is formed between two major dextral strike slip faults with E-W trending and bordered from east and west by normal faults striking NS to NNW-SSE. The Hodna basin located in the the

Bibans mounts is characterized by compressive structures; folds and related faults, with a NE-SW and E-W trending.



The examination of the principal Algerian focal mechanisms shows the predominance of reverse component for the majority of the events in the central part and in the western area, which is in agreement with the compressive tectonic mode in the area. To the east the strike component is more observed as for the Constantine, October 27, 1985 earthquake with a NE-SW left later strike-slip component or that of the Guelma, February 10, 1937 earthquake with E-W a dextral component. The change of the mode of deformation from the west to the east is due to the closing of the sedimentary basins.



Description of the cumulated seismic moment release method:

The average displacement on a faulted area with respect to the cumulative seismic moment is given by the formula: ***M0 = μSD***

M0 is the scalar seismic moment, μ is the rigidity coefficient of the crust, S is faulted surface. According to Brune (1968), If an area includes N earthquakes of scalar moments M0i (i=1,N), the average slip D generated by all these events on the area of surface S, would be the sum of the displacements along the faults δi generated by each event separately (with the condition that all these events should have the same faulting mechanism):

$$D = \sum_{i=1}^{n} \delta_i = \frac{1}{\mu S} \sum_{i=1}^{n} M_{0i}$$

The displacement D is the average seismic slip in the considered faulted volume. The velocity is calculated by dividing the total displacement D by the ∆T representing the time span of seismic data used:

$$\mathbf{v} = \left[\frac{1}{\mu S \Delta T} \sum_{i=1}^{n} M_{0i} \right]$$

The results of the computation is given in the table bellow and compared with the other studies.

Authors	Velocity (mm/y)				method used
	A	B	C	D	
McKenzie (1972)	10.0				spreading rates around the Mid-Atlantic ridge
Meghraoui (1988)		4.5			paleoseismology
DeMets et al., (1994)	6.0				Nuvel-1/1A
Lammali et al., (1997)	7.6				cumulative seismic moment
Anzidei et al., (1999)	3.0		3.5		GPS measurments
Henares et al., (2003)	5.8				Angelier and Mechler
Buforn et al., (2004)	2.7				cumulative seismic moment
This study	0.3	4.4	1.3	0.2	cumulative seismic moment

The direction of the velocity vector is deduced from the average orientation of the P-axes of the available focal solutions of the seismic events recorded in northern Algeria. The figure above gives the velocity vectors considering all the seismic data, historical+instrumental data (black arrow) and using only instrumental data (white arrow). The convergence between Africa and Eurasia is represented by to the horizontal shortening velocity. To obtain this value we should use formula below:

$$v_H = v . \cos \theta$$

A compilation of 28 focal solutions in northern Algeria we present in table 4 lead us to determine the direction of the velocity vector. We deduce the direction from the velocity vector according to the average orientation of the P-axes of the focal mechanisms available for the considered zone.

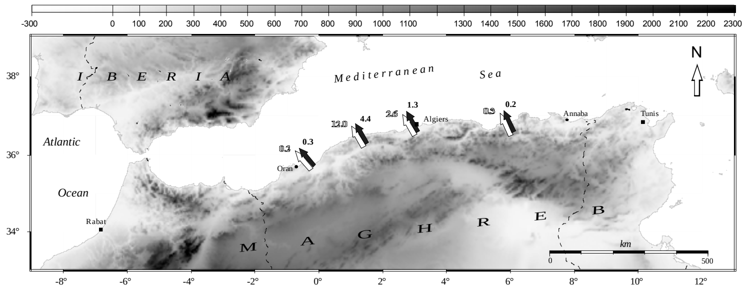
Zone A, we have considered this zone with a length L~ 250 km, a width W ~12 km as suggested by an average depth Z = 10 km and an average dip θ = 60°. The average orientation of the P-axes of the 4 focal mechanisms available for this area shows a N320° direction.

Zone B, we have considered this zone with a length L~150 km, a width W ~13 km suggested by an average depth Z = 10 km and an average dip θ = 50°. The average orientation of the P-axes of 9 earthquakes gives a direction of about N330°.

Zone C, corresponds to an overall length L ~ 200 km and a width W~13 km considering an average depth Z = 10 km and an average dip θ = 50°. The velocity vector direction given by the average orientation of 10 P-axes is about N330°.

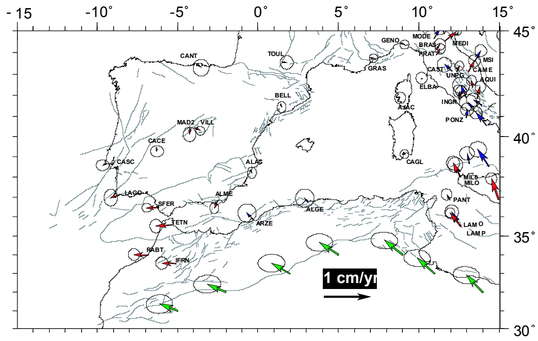
Zone D, is considered with a length of L ~ 400 km and width W ~10 km, average depth Z = 10 km and average dip δ = 70°. The analysis of 5 focal mechanisms gives an average azimuth about N335° for the velocity vector.

According to these results, we can observe a considerable difference between the velocity value obtained by using the instrumental seismicity and that taking into account the historical events. In our case, we think that the obvious gaps that the historical seismicity of Algeria presents introduces great errors on the velocity values which we obtained by introducing the historical period. The values of the velocity rate are weak with respect to that given by the others studies. In fact, the different authors consider all the seismic database of the Tell Atlas to compute the velocity rate. In our case we have divided the area in 04 zones, that's why we have low value for the western part of Algeria. We can explain that by a deficiency in seismicity for that area since the last strong earthquake of Oran 1790.



GPS measurements in Algeria:

The only GPS study (Anzedai et al., 1999) that have been conducted in Algeria was done within a TYRGEONET project, a collaboration between CNTS (Centre des Techniques Spatiales, Arzew, Algeria) and INGV (Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy), two stations (Algiers and arzew) were measured. The restricted computing time (2) years with 2 campaigns of measurement) was not sufficient to get results with minimum errors. The figure bellow from Serpelloni et al., (2007), presents a compilation of the Kinematics of the western africa-Eurasia plate boundary from GPS data including the stations of Algiers and Arzew used during the TYRGEONET experiment. This figure shows the active seismic deformation is mainly described by a N30°W oriented shortenning. This region is caracterized by purely compressive and strike-slip tectonic regimes.



Discussion and Conclusion:

The scalar seismic moment summation seems to be an appropriate method to have preliminary results on the strain rate along the Tell Atlas of Algeria. The differences between the velocity values obtain in this study and those estimated by other authors using the same method, are due primarily to the quality of the seismic data used; and the considered time span and the choice of the parameters (length, width, average focal depth, average dip) of the considered zone. The differences observed between velocity values in this study and those proposed by the authors using the different methods, are mainly due to the fact that the velocities obtained by the method of the scalar seismic moment summation represent only the displacement generated by earthquakes (seismic slip). The aseismic slip should be evaluated using permanent GPS networks. The velocity vectors obtained along the northern Algeria show an orientation of 320°N- 335°N and confirm the results presented by other studies. These later, give a NNW-SSE direction for the regional stress regime in northern Algeria. The values of shortening velocity show that the deformation is not uniform from west to east and are specific to each zone. The results obtained shows low velocity values which only considered the slip generated by seismic rupture. We suppose that most of the deformation in the Tell Atlas occurs in aseismic way, which is not considered by the method we used. The best way to get an estimation of the aseismic deformation or creeping is to have reliable and continuous GPS measurements in this part of the Western Mediterranean.

In the zone A in the westernmost part of Algeria seems to be a region were a seismic quietness have been observed since 1790 Oran earthquake, for events with magnitude greater than 5.5 For more than 3 centuries only Mascara earthquake have reached magnitude Ms=6.0. The rest of the seismicity is reported to be of weak magnitude. This is the reason why the value of shortening velocity is low in this zone. In the zone D, corresponding to the eastern part of Tell Atlas, the low velocity obtained could be related to the tectonic context. In this zone, the active Neogene basins have reached the final stage of closure and were elevated at hundred of meters above sea level. The stress regime, in this zone, makes that old reverse faults were reactivated now days in strike slip mode. A special attention must be given to the strain rate due to creeping around seismogenic zones, this will give consistency to the calculated velocities using scalar moment summation method.

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