Trabajos de Geología, Universidad de Oviedo, 30 : 261-265 (2010)

Plio-Quaternary deformation pattern along the Algerian margin: insights from multibeam bathymetry and seismic reflection profiles (Maradja 1 and Samra cruises)

P. STRZERZYNSKI[1*], A. DOMZIG[2], K. YELLES[3], A. CATTANEO[4], J. DEVERCHERE[1], N. BABONNEAU[1], B. MERCIER DE LEPINAY[5], A. CAPRON[1], A. BOUDIAF[2] AND R. BRACENE[6]

[1]*Domaines Oceaniques, UBO-I.U.E.M., Plouzane, France.*

[2]*Laboratoire de Planetologie et Geodynamique, Universite de Nantes, France.*

[3]*CRAAG, Algiers, Algeria.*

[4]*IFREMER, Plouzane, France.*

[5]*Geosciences Azur, Valbonne, France.*

[6]*SONATRACH, Boumerdes, Algeria.*

[*]*Now at: Pierre.strzerzynski@univ-lemans.fr*

Abstract : Offshore Algeria, multichannel bathymetry and seismic reflection profiles provide evidence for tectonic activity during the Pliocene and the Quaternary. Between Cherchell and Dellys (Algiers region), we show that the evolution of the structural pattern along strike is controlled by inherited structures. On the basis of relative timing offshore and absolute timing onshore, we propose that the initiation of the shortening of the Algerian margin starts at ~3Ma in direct relationship with a change of the direction of movement between the African and European plates.

Keywords: Algerian margin, deformation pattern, seismic reflection, bathymetry, Plio-Quaternary.

Algeria is the most active seismic zone of the western Mediterranean basin (El Asnam 1980 earthquake, Mw = 7.3). Onshore, many active tectonic structures have been recognized (see e.g. Yelles-Chaouche *et al.*, 2006 for a synthesis). Offshore, the Tipaza (1989, Mw = 6.0) and Bourmerdes (2003, Mw = 6.9) earthquakes (Fig. 1) highlighted the potential occurrence of active tectonics events along the margin. In the present note, we combined the deformation pattern onshore and offshore in order to discuss the overall tectonic style and the timing of deformation. We propose that deformation is strongly influenced by inherited structures and that the initiation of the shortening of the Algerian margin starts at ~3 Ma in direct relationship with a change of the direction of movement between the African and European plates (Calais *et al.*, 2003). Our tectonic interpretation is mostly based on data acquired in 2003 (Maradja 1 cruises), consisting of multichannel bathymetry at 50 m spatial resolution (Fig. 1), seismic reflection profiles with accurate imag-

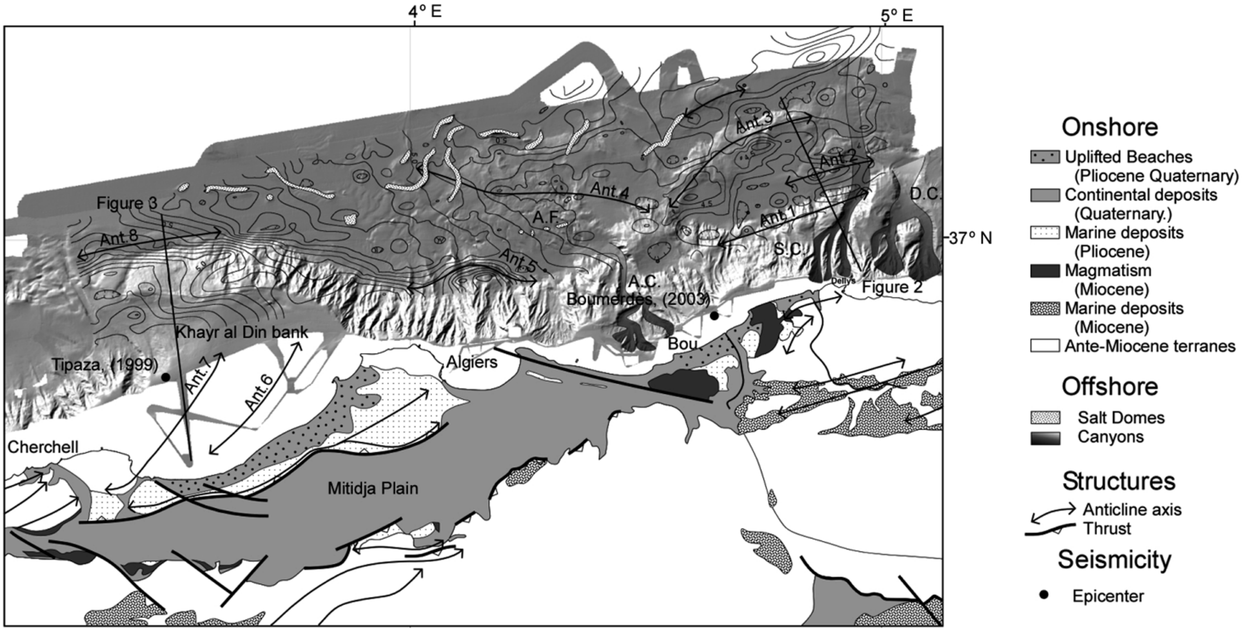

Figure 1. Structural overview of the Algerian margin in the region of Algiers, Algeria. Offshore: annoted isobath map of base of the Messinian displayed above a shaded bathymetric map (Maradja 2003 cruise). Onshore: tectonic map depicting the Miocene structures (modified after Boudiaf *et al.*, 1998). A.C.: Algiers Canyon, A.F.: Algiers Fan, Bou.: Boumerdes City, D.C.: Dellys Canyon, S.C.: Sebaou Canyon.

ing at depth down to 2-3 s twtt bsb (Figs. 2 and 3), as well as additional onshore data.

Regional tectonic setting and Plio-Quaternary kinematics

The tectonic evolution of the Algerian Alpine belt starts during the Eocene with the subduction of the Tethyan oceanic domain (Roca *et al.*, 2004) in a context of a 15 mm a^{-1} N-S convergence between the European and African plates (Dewey *et al.*, 1989). Simultaneously, the opening of the Algerian basin commences in a back-arc position and is associated with the Tethysian slab roll-back and possibly with slab break-off (Carminati *et al.*, 1998). After the splitting of the forearc and closure of the Tethyan ocean, the convergence rate between the European and African plates decreases to 5 mm a^{-1} and deformation occurs onshore mostly on S-dipping thrusts progressively sealed by Miocene deposits and volcanic rocks (Fig. 1).

In the same way as for the whole Mediterranean basin, the Algerian margin is affected by a Messinian sea-level fall responsible for subaerial erosion expressed by fluvial canyons. After the subsequent final sea level rise, the building of prograding Gilbert-type fan deltas induces the infill of Early Pliocene rias in coastal basins such as the Mitidja basin (Fig. 1). A coeval change of the motion of Africa relative to Europe, ~3 Ma ago, is documented from geological and GPS data (Calais *et al.*, 2003): the convergence direction rotates about 20º counter-clockwise and becomes NW-SE at the longitude of the central Algerian margin.

Onshore, the late Pliocene to Quaternary deformation is expressed by the folding of the Early Pliocene Mitidja deposits at its southern boundary and near the Algiers Sahel anticline, where Late Pliocene to Quaternary beach deposits are located up to 350 m and are directly correlated to the anticline growth (Fig. 1). East of Algiers, Late Pliocene to Quaternary deformation is also evidenced by eastward migration of the Isser River bed and uplifted beaches (Boudiaf *et al.*, 1998). A first estimate of the beginning of the new deformation regime is given by the Piancenzian, i.e. 2.6 Ma, age of the last deposits below the uplifted beach sediments (Boudiaf *et al*, 1998).

Margin morphology

The margin shows significant morphological differences east and west of Algiers:

East of Algiers, the margin width is 20 km maximum with a narrow continental platform and a ~N70º striking slope. The continental slope is strongly irregular, with seafloor escarpements of diverse length, width and orientation. Three main canyons are observed (Fig.1). To the west, the meandering Algiers canyon is prolongated by a channel-levee system located along the foot of the continental slope (Babonneau *et al.*, 2007). To the east, the rather straight Sebaou and Dellys canyons are prolonged in the deep basin by turbidity channels and sedimentary ridges orthogonal to the slope.

West of Algiers, the margin width increases up to 45 km, allowing a large continental shelf to develop. From east to west, the continental slope strikes from N140° to N70°. It forms the boundaries of a large submarine high, the Khair al Din bank (KADB). On its eastern flank, the canyons are narrow, dense, and straight and look like gullies. Its northwestern side consists of a smooth area without canyons. Such morphological differences are related to variations in the tectonic regime and lithology of the margin basement, i.e. Oligo-Miocene deposits and volcanic rocks and maybe flyschs east of Algiers, and probably the Kabylian basement draped by recent sediment accumulations west of Algiers (Domzig *et al.*, 2006).

Architecture of the continental margin and deep basin, and evidence of active tectonics

Two seismic lines (Figs. 2 and 3) allow us to describe the internal organization of the main sedimentary units of the Algerian basin and margin, namely, the Plio-Quaternary sequence and the Messinian (and older Miocene) deposits, and to image the basement. During the deposition of the Plio-Quaternary sequence, salt migrated and formed a salt dome network (Fig. 1). Salt doming activity is clearly diachronous: it ends early in the piggy-back basin of the Boumerdes area (Fig. 2) whereas it is still active around the Algiers Fan and at the foot of the KADB slope. Near the foot-slope, a chaotic unit is interpreted as a Messinian detritic fan (Fig. 2). On the KADB, the Messinian emersion event is evidenced by an irregular surface (Fig. 3) probably eroding the Kabylian basement (Domzig *et al.*, 2006). Under the Messinian deposits, well organized reflectors are interpreted as older Miocene deposits. Even if Plio-Quaternary deformations are recognized throughout the Cherchell and Dellys area, several changes of position, orientation, vergence and style are inferred from the structures detailed below.

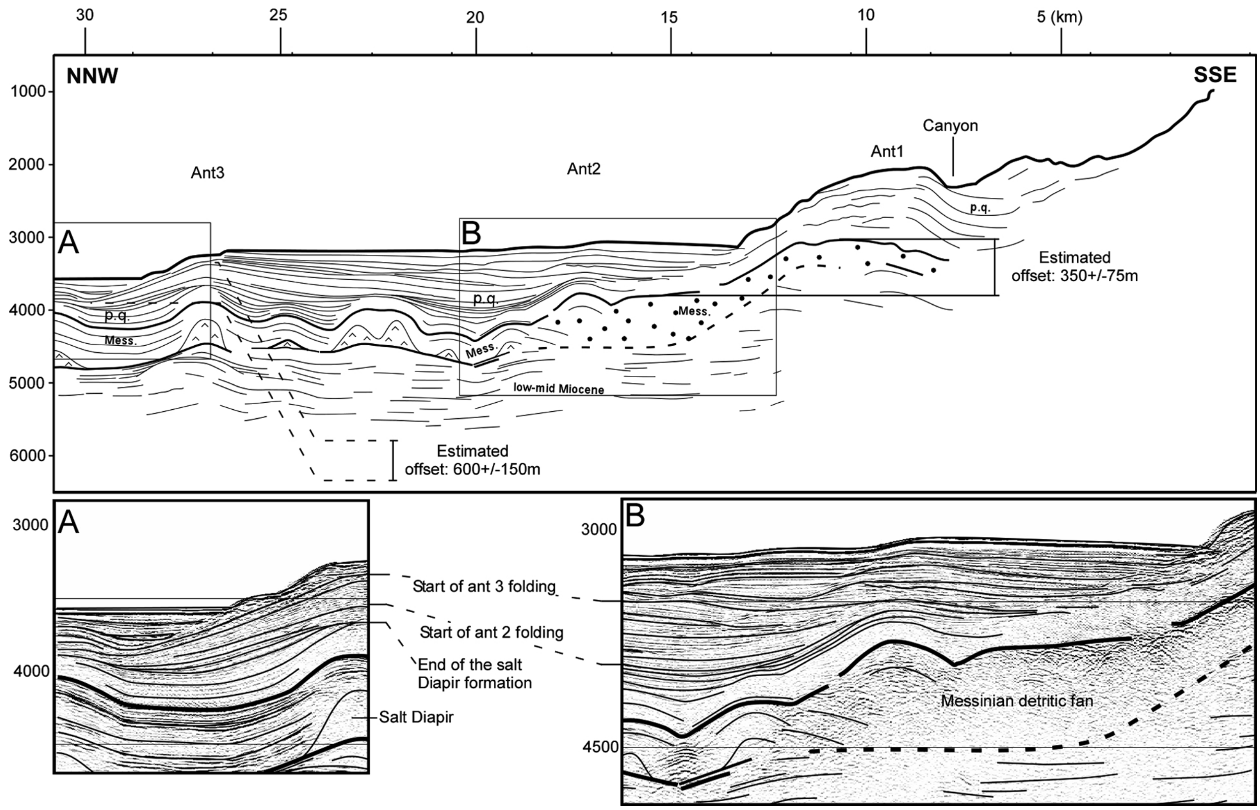

Figure 2. Representative 6-channel seismic profile across the Algerian margin, east of Algiers, off Dellys, crossing the Sebaou canyon on the slope (see location in figure 1). Top: line drawing of the whole section; bottom: interpreted enlargements of the seismic line. p.q.: Plio-Quaternary deposits, Mess.: Messinian deposits, Ant 1, 2 and 3: anticlines, see text for details. Vertical scale is twtt in ms.

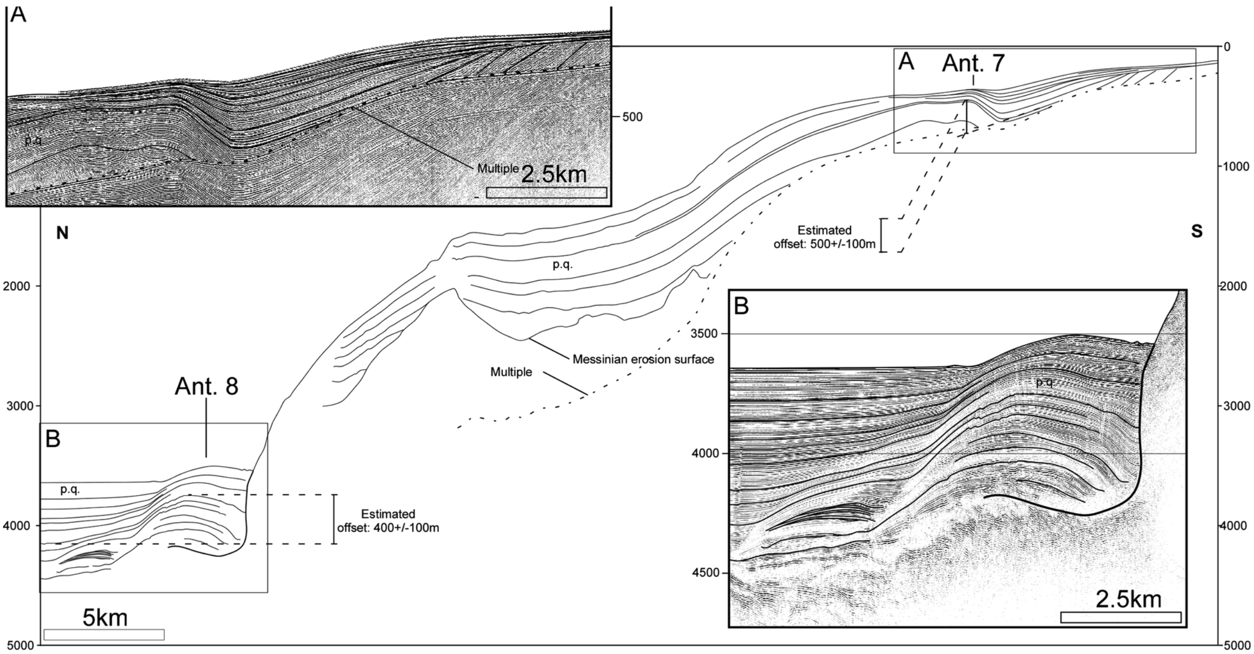

Figure 3. Line-drawing of a 24-channel seismic reflection profile across the Khair al Din bank, west of Algiers (see location in figure 1), with two interpreted enlargements of the seismic line as insets. Vertical scale is twtt in ms.

East of Algiers, the deformation is located at the foot of the continental slope where the Messinian detrital fan and part of the underlying Miocene deposits are folded and tilted towards the continent (Ant 1 in figure 2) leading to the formation of an uplifted basin. According to the internal organization of the strata, and whatever the absolute timing, folding appears clearly to start during the Plio-Quaternary after a period without significant tectonic activity immediately following the Messinian unit. A vertical offset of this surface of 350±75 m is obtained when considering an initial slope of 4° of the top of the detrital fan slope, as observed in other parts of the Mediterranean basin (Sage *et al.*, 2005), and a mean V_P of 2000±500 m s^{-1} for the Plio-Quaternary deposits.

The deformation is also widely extended in the deep basin as evidenced by the folding of the salt base and by seafloor morphology (Fig. 1). Two main Plio-Quaternary folds are highlighted by the salt base isopach map. The one is a 30 km-long, N70-trending anticline (Deverchere *et al.*, 2005), denoted Ant 3 in figure 2. It commences after the onset of deformation at the footwall of the continental slope (Fig. 2) and grows until a vertical offset of 600±150 m is reached for the pre-tectonic deposits. The second anticline (Ant 4) is a 40 km-long, N110-trending anticline located immediately north of the Algiers sedimentary ridge (Fig. 1). The clear spatial link between the sedimentary ridge and this latter fold in position and strike (Fig. 1) suggests that the Algiers deep-sea fan is strongly influenced by tectonic processes (Babonneau *et al.*, 2007).

West of Algiers (Fig. 3), the Plio-Quaternary deformation is located at the top and the base of the KADB (Domzig *et al.*, 2006). At its top, Plio-Quaternary deposits initially dipping towards the north are in the upper part of the margin, truncated and sealed by thin deposits (Fig. 3), indicating a relative uplift of the margin. The Plio-Quaternary sequence is also affected by ~20 km-long and N45- to N70-trending folds. The recognition of pre- and syn-tectonic sediments allow us to date the deformation as Plio-Quaternary (Fig. 3A). Considering an initial northward dip direction of the strata, a vertical offset of 500±125 m is inferred for this upper fold (Fig. 3). Asymmetry of the fold system suggests that a blind N-dipping thrust at depth is associated with folding near the surface, as suggested by Domzig *et al.*, (2006). A second Plio-Quaternary fold follows the foot of the KADB. It is an 80 km-long fold oriented N70°, consistent with a blind S-dipping thrust at depth. An offset of 400±100 m is inferred from the shift of the last pre-tectonic deposit (Fig. 3B) located inside the Plio-Quaternary unit.

Discussion and conclusion

The Quaternary deformation pattern of the central Algerian margin displays strong changes along strike. East of Algiers (Boumerdes area), the deformation mainly takes place at the foot of the margin. The vergence of growth strata, the wide extent of the deformation in the Algerian basin, the development of uplifted basins and the progressive migration of the deformation to the deep basin are strong arguments favoring the occurrence of folds and S-dipping blind thrusts (Deverchere *et al.*, 2005). Thrust ramps and flats may occur in the basement and are expressed by folds in the younger sedimentary cover. West of Algiers, the deformation occurs both onshore, on the continental shelf and at the foot of the margin. Onshore and on the continental shelf, folds are probably associated with blind thrusts dipping to the north, whereas S-dipping blind thrusts may be related to the fold located at the foot of the KADB. Inherited structures such as the KADB appear therefore as responsible for lateral variations of the deformation pattern east and west of Algiers.

Whatever the differences between both areas, the deformation described here depicts the same order of cumulative vertical offsets on the folded structure, ranging from 400 to 600 m, onshore and offshore. Offshore, the deformation starts during the Plio-Quaternary and migrates towards the basin. According to the 2.6 Ma age (Boudiaf *et al.*, 1998) proposed onland, we assume that the Plio-Quaternary deformation of the Algerian margin between Cherchell and Dellys starts during the Gelasian. Such an age is consistent with the post 3.16 Ma age of the change of motion direction between the European and African Plates of Calais *et al.*, (2003). We propose that this change of kinematics could be responsible for a tectonic adjustment at the northern boundary of the African plate and initiated a shortening of the Algerian margin which is expressed both at the ocean-continent transition and within the margin itself.

References

BABONNEAU, N., CATTANEO, A., HARSTER, M., DEVERCHERE, J., YELLES, K., SAVOYE, B. and DOMZIG, A. (2007): Morphology and Structure of the Algiers Deep-Sea Fan and Possible Sedimentary Record of the 2003 Boumerdes Earthquake (Maradja Project), *Eos Trans, Am. Geophys. Union, 88, 52, Fall Meeting 2007, Abstract* H41F-0840.

BOUDIAF A., RITZ J. F. and PHILIP H. (1998): Drainage diversions as evidence of propagating active faults: example of the El Asnam and Thenia faults, Algeria. *Terra Nova*, 10: 236-244.

CALAIS, E., DEMETS, C. and NOCQUET, J. M. (2003): Evidence for a post-3.16 Ma change in Nubia-Eurasia plate motion. *Earth Planet. Sc. Lett.*, 216: 81-92.

CARMINATI, E., WORTEL, M. J. R., SPAKMAN, W. and SABADINI, R. (1998): The role of slab detachment process in the opening of the western-central Mediterranean basins: some geological and geophysical evidence. *Earth Planet. Sc. Lett.*, 160: 651-665.

DEVERCHERE, J., YELLES, K., DOMZIG, A., MERCIER DE LEPINAY, B., BOUILLIN, J. P., GAULLIER, V., BRACENE, R., CALAIS, E., SAVOYE, B., KHERROUBI, A., LE ROY, P., PAUC, H. and DAN G. (2005): Active thrust faulting offshore Boumerdes, Algeria, and its relations to the 2003 Mw 6.9 earthquake. *Geophys. Res. Lett.*, 32, L04311. doi: 10.1029/2004GL021646.

DEWEY, J. F., HELMAN, M, TURCO, E., HUTTON, D. and KNOTT, S. (1989): Kinematics of the western Mediterranean. In: M. COWARD, D. DIETRICH and R. PARK (eds): *Alpine tectonics, Geol. Soc. London*: 265-283.

DOMZIG, A., YELLES, K., LE ROY, C., DEVERCHERE, J., BOUILLIN, J. P., BRACENE, R., MERCIER DE LEPINAY, B., LE ROY, P., CALAIS, E., KHERROUBI, A., GAULLIER, V., SAVOYE, B. and PAUC, H. (2006): Searching for the Africa-Eurasia Miocene boundary offshore western Algeria (MARADJA'03 cruise). *C. R. Geosci.*, 338: 80-91.

ROCA, E., FRIZON DE LAMOTTE, D., MAUFFRET, A., BRACENE, R., VERGES, J., BENAOUALI, N., FERNANDEZ, M., MUÑOZ, J. A. and ZEYEN, H. (2004): TRANSMED Transect II. In: W. CAVAZZA, F. ROURE, W. SPAKMAN, G. M. STAMPFLI, and P. A. ZIEGLER (eds): *The TRANSMED Atlas – The Mediterranean region from crust to mantle*. Springer-Verlag, Berlin, 141 pp.

SAGE, F., VON GRONEFELD, G., DEVERCHERE, J., GAULLIER, V., MAILLARD, A. and GORINI, C. (2005): Seismic evidence for Messinian detrital deposits at the western Sardinia margin, northwestern Mediterranean. *Mar. Petrol. Geol.*, 22: 757-773.

YELLES-CHAOUCHE A. K., BOUDIAF A., DJELLIT A. and BRACENE R. (2006): La tectonique active de la region nord-algerienne. *C. R. Geosci.*, 338: 126-139.