

MIO-PLIOCENE TECTONICS IN MOROCCAN RIFIAN FORELAND: COEXISTENCE OF COMPRESSIVE AND EXTENSIONAL STRUCTURES

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Abstract: Structural evolution of northern Morocco during Late Miocene to Pliocene times indicates a sub-meridian compressive regime. This stress field produces the split of the north eastern Morocco into two compressive and extensive wedges, bounded by conjugated dextral NW-SE and sinistral NE-SW strike-slip faults. Northern and southern wedges in blocking position were compressed, folded and pulled up; whereas eastern and western asymmetric wedges are laterally extruded. N-S trending normal faults are associated with volcanism. This geodynamic evolution can explain the juxtaposition and superimposition of volcanic structures and thrusts in a general compressive context, dominated by the convergence between Africa and Europe plates.

Key words: Paleostress, Tectonics, North-eastern Morocco.

Resumen: La evolución estructural de Marruecos septentrional durante el Mioceno superior-Plioceno indica un régimen compresivo casi N-S. Este campo de esfuerzo produce la subdivisión de Marruecos norte oriental en dos compartimientos, limitados por fallas de desgarre conjugadas NW-SE dextrosas y NE-SW sinistras. Los dos bloques Norte y Sur en una posición de bloqueo fueran comprimidos, plegados y levantados sin embargo los bloques asimétricos oriental y occidental fueran expulsados lateralmente. Fallas normales de dirección N-S se asocian al volcanismo. Esta evolución geodinámica puede explicar la juxtaposición y la superposición de las estructuras volcánicas y los cabalgamientos en un contexto general compresivo, debido a la convergencia de las placas africana y europea.

Palabras clave: Paleoesfuerzo, Tectónica, Marruecos nororiental.

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Two orogenic belts compose the north-western part of Africa (Fig. 1A): in the north, the Rif-Tell chain constitutes a major segment (Maghrebides) of the peri-Mediterranean chains (Durand Delga, 1963). This chain is characterized by HP metamorphism in its internal zones and by south to southwest vergent thrust sheets. To the south, the Atlas is an intracontinental belt, developed within the alpine tectonic foreland (Mattauer *et al.*, 1977). These two folded chains are separated by two sub-tabular fields: the western meseta (coastal Palaeozoic basement) and the eastern meseta (High Plateau). In the junction between these structural domains: the Rif-Tell belt, the Middle Atlas and the High Plateau, three structural units directed ENE-WSW are identified which are from north to south (Fig. 1B):

- The eastern-rifian foreland composed of Gareb chaotic unit near the active Rif chain and a little deformed tectonic foreland (Terni Masgout, Beni Bou Yahi, Beni Mahiou and Beni Snassen), prolonged towards the east (in Algeria) by the Traras mounts.
- The Guercif and Taourirt-Oujda basins which show sediments of middle Miocene

to Quaternary age (Colleta, 1977; Wernli, 1988), and are connected to the Tafna basin to the east (Algeria).

- The Taourirt-Oujda mounts which show sub-horizontal Jurassic sediments affected by fault systems whose development and geometry are strongly dependent on the pre-existing structures in hercynian basement. They are prolonged to the east by the pre-tellian foreland of Tlemcen.

One of the characteristics of these units is the complexity of its Late Miocene to Pliocene tectonics, which exhibit both compressive and extensional structures. These tectonic manifestations often differ by their orientation, their geometry and their kinematics. Their evolution is dictated by their belonging to one of the varied structural domains. We present, in this paper, the evolution of the entire area during the Late Miocene to the Pliocene on the basis of new results of detailed analysis of satellite images along with data collected in literature and in geological field campaigns.

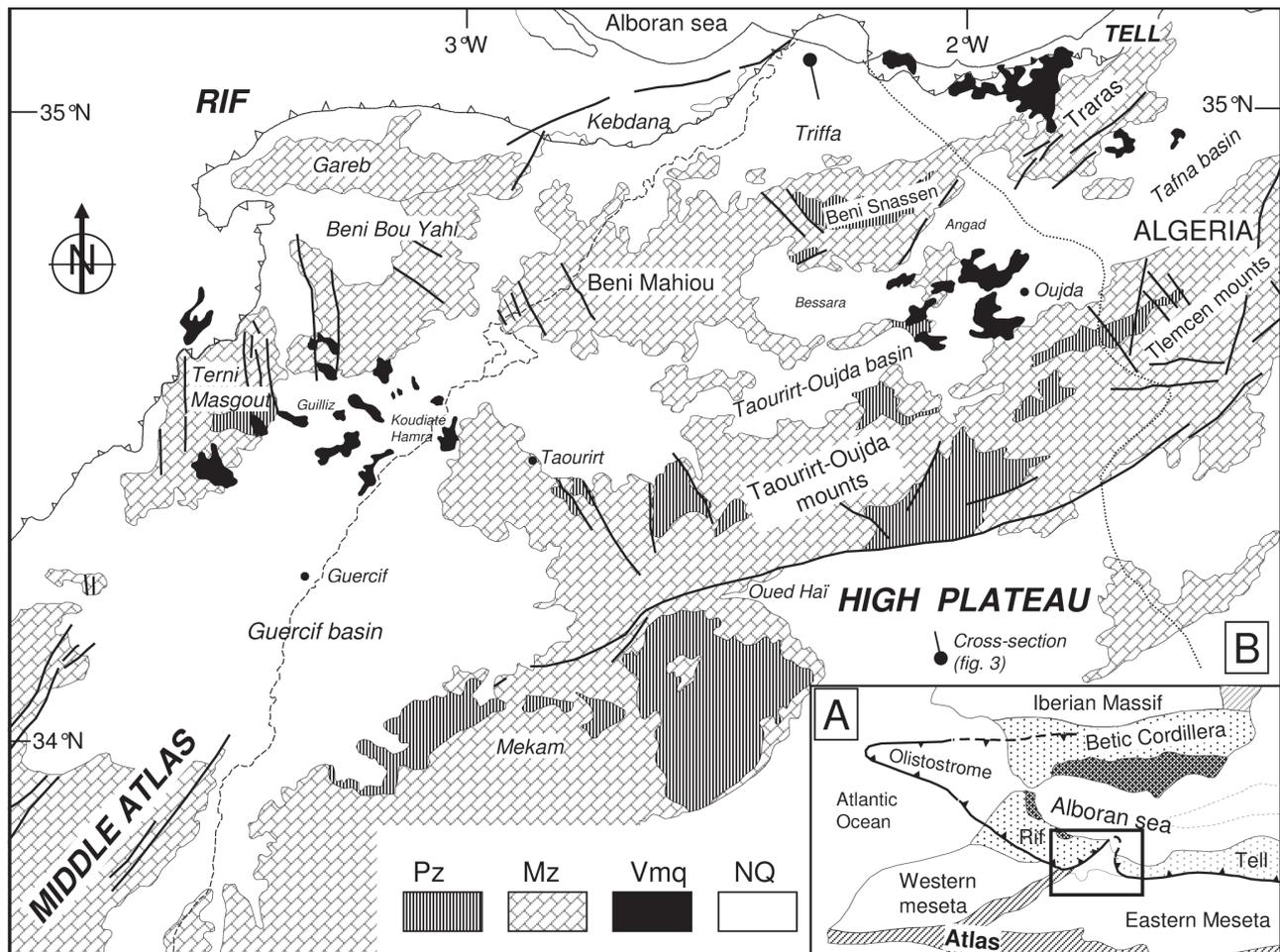


Figure 1.— General location (A) and main structural domains of north-eastern Morocco (B). Pz: Palaeozoic, Mz: Mesozoic, Vmq: Late Miocene to Quaternary volcanics, NQ: Neogene to Quaternary sediments.

Geological setting

Although the major aim of this paper deals with Late Miocene to Pliocene tectonics, it is necessary to give a brief geologic and lithologic overview. In the region under study, the Palaeozoic basement crops out in the Terni-Masgout, the Beni Snassen and the Taourirt-Oujda mounts (Fig. 1B). It is represented by rocks belonging to the Hercynian belt (Hoepffner, 1987) where the deformation concentrated within shear zones trending ENE-WSW to E-W (Torbi and Gelard, 1994). These zones acted later as weakness zones. Fault reactivation of these structures initiates in the Late Triassic. They show a normal motion in tensional stress regime with σ_3 directed NNW-SSE (Chotin *et al.*, 2000). The deposits of this age (red mudstones, carbonates and tholeiitic basalts) characterize the first marine incursion of the Tethyan Ocean over the north-western African margin (Tabyaoui *et al.*, 2000). In the Early Liassic, a carbonate platform developed, and during Late Liassic, the area was cut by a series of extensional faults bounding a mosaic of horsts and grabens oriented ENE-WSW to E-W. From Late Jurassic to Early Cretaceous, tilted blocs appeared (Cattaneo, 1987). This period is characterized by a

major NNW-SSE extension (Chotin *et al.*, 2000). In the Late Cretaceous, the whole region emerged (Hervouet, 1985; Cattaneo and Gelard, 1989) and a strike slip tectonic regime prevailed. The calculated tensors (Chotin *et al.*, 2000) show a maximal compressive stress σ_1 oriented E-W. This setting is contemporary to a short dextral displacement of Africa relatively to Iberia (Olivet *et al.*, 1984). During the Eocene, a compressive event (σ_1 horizontal of azimuth N-S) (Chotin *et al.*, 2000) created NNE-SSW and NW-SE strike-slip faults and ENE-WSW to E-W folds. Compression extended from Oligocene to Middle Miocene. In the north of Gareb mount, N120°-130°E fracture cleavage affects the Serravalian delta formation (Hervouet, 1985). After the Middle Miocene syn-metamorphic event, the system is characterized by a stress tensor with σ_1 oriented NE-SW. A σ_2/σ_3 permutation (σ_3 horizontal) occurred during Early Late Miocene (Ait Brahim, 1991). It permits the creation of intramontane basins (basins of Guercif, Taourirt-Oujda, Triffa, Oued Hai) (Fig. 1B), separated by emerged zones (Gareb, Kebdana, Terni Masgout, Beni Bou Yahi, Beni Mahiou, Beni Snassen and Taourirt-Oujda mount). Strike slip faults (ENE-WSW trending left lateral and NNE-SSW trending right lateral), associated

with NE-SW trending normal faults occur in the pre-Late Miocene deposits (pre-Messinian) (Ait Brahim and Chotin, 1989). From Late Miocene to Quaternary time, the region is deformed by compressive strike-slip regime. The direction of paleostress tensors will be discussed below.

Late Miocene to Pliocene structural features

The whole area is affected by regional scale faults. These faults cross-cut the Palaeozoic basement, the Mesozoic sedimentary rocks and locally the Tertiary deposits, sometimes with calc-alkaline volcanic rocks. The first Tertiary deposits are composed of conglomerates and sandy marls ranging in age from Burdigalian to Aquitanian (Monition, 1952), directly laying on Late Jurassic deposits of the Beni Bou Yahi, Beni Mahiou and the Beni Snassen. Late Miocene (Tortonian and Messinian) formations are discontinuously located both on the Middle Miocene outcrops and along the extensional basins of Guercif, Taourirt-Oujda, Triffa and Gareb (Colleta, 1977, Ait Brahim, 1991, Tabyaoui *et al.*, 1996). They are made up of marine marl, limestone and carbonate (Wernli, 1988). South of the studied area, the Neogene is represented by continental lacustrine formations (Stretta, 1952). Successions composed of conglomerate, gypseous marl and sandy marl referable

to Middle-Late Miocene to Pliocene (Aquitainian to Pliocene) out-crop within the Oued Haï basin. Conglomerates are represented by coarse polygenic clastic deposits and are referable to continental environments.

The Cenozoic evolution is also volcanogenic. Late Miocene to Pliocene volcanic activities correspond to a shoshonitic edifices in the Guilliz and Koudiat Hamra (near Taourirt) (Fig. 1B) with age ranging from 8 to 4.5 My (Hernández and Bellon 1985) and calcalkaline centres in the Oujda area (Fig. 1B), with age ranging from 6,2 to 4,8 My (Bellon, 1976; Tisserant *et al.*, 1985).

Fracture patterns

Landsat image analysis has been carried out in order to define the regional framework and to compare it with the data obtained through the detailed Spot image analysis (Ait Brahim *et al.*, 1994) and radar ERS1-SAR interpretation (Tabyaoui and Ait Brahim, 1997), and from structural field analysis.

We tried to distinguish lineament bearing a clear structural meaning, possibly in connection with the Neogene fracture field. A field map was obtained by the optical examination of all lineaments characterized by marked continuity, and taking into account their relationships with the geological units reported in the

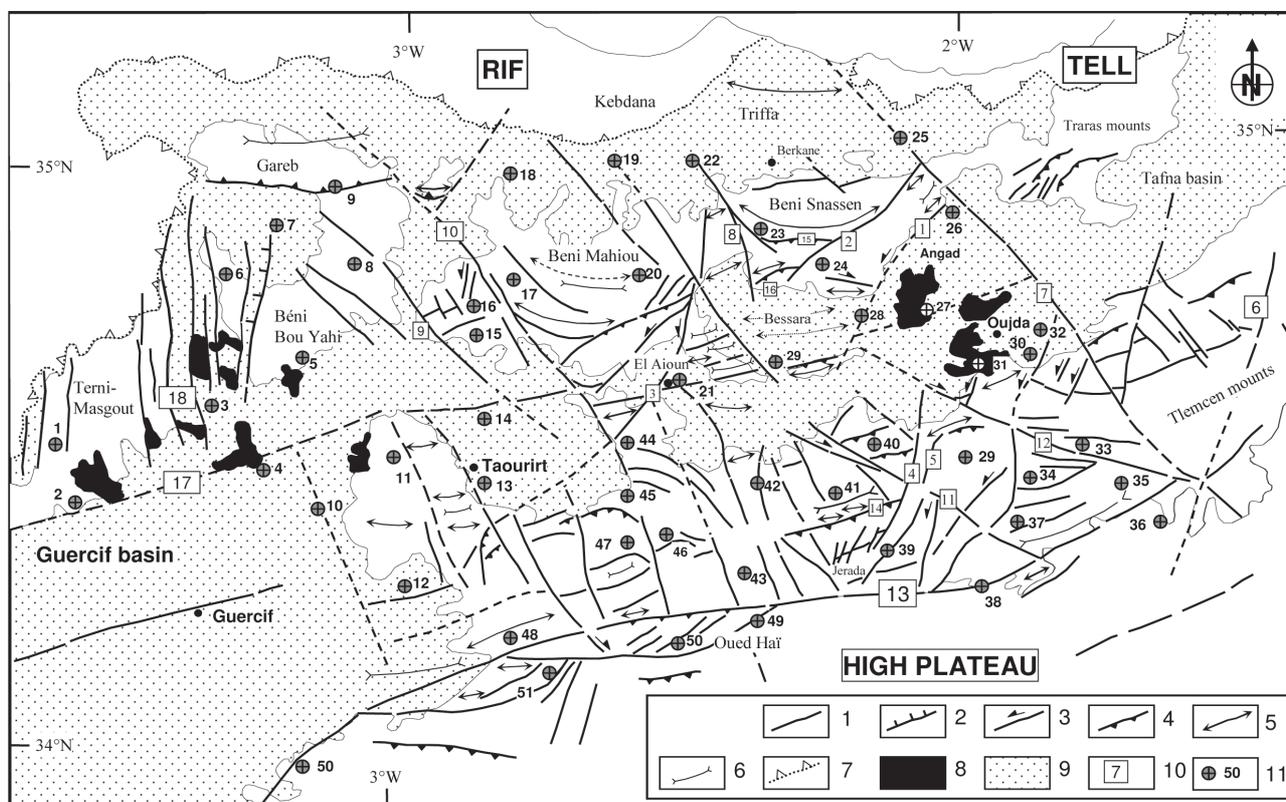


Figure 2.- Structural map of north eastern Morocco, constructed through the observation of Landsat imagery and from Spot and radar ERS-1 analysis (Ait Brahim *et al.*, 1994; Tabyaoui and Ait Brahim, 1997), and field data (Algerian area is from the Geological map of Morocco at 1:1000 000 scale). Black dots correspond to the sites where structural field analysis have been performed, the number of each site are reported close to the dots. 1) Fault, 2) Normal fault, 3) Strike-slip fault, 4) Neogene thrust, 5) Anticline, 6) Syncline, 7) Limit of the Rif chain, 8) Late Miocene volcanics, 9) Neogene to Quaternary sediments, 10 and 11) Location of faults and the sites of measurements.

available geological map (1/500 000 Geological map of Morocco, map of Oujda). A field analysis of Neogene faulting was then conducted at different scales. The map obtained (Fig. 2) shows an homogeneous distribution of the faults with respect to their strike and relative frequency in most of the region. Four systems of faults are depicted:

a) The first system, NE-SW oriented, is well developed and represented by several faults with regional importance (faults of Ain Sfa (n°1), Jbel Farouane (n°2), El Aïoun (n°3), Beni Yala (n°4), Oum Lahcen (n°5), Tafna (n°6) and those of Oujda area) (Fig. 2), some times longer than 10 km. Slip vectors along these faults are marked by several kinds of kinematic indicators, such as slickensides, cataclasites along tectonic contacts, etc. In the Beni Snassen, the Jbel Farouane fault (n°2) (Fig. 2) affects conglomerates and sandstones of Middle Miocene age. Along this fault, «S-C» structures are very clear and indicate prevailing left strike-slip movement, as testified also by sub-horizontal slickensides. Moreover, in the Taourirt-Oujda mounts, the NE-SW Beni Yala trending fault (n°4) (Fig. 2) has an arcuate trend. It strikes from about N10°E in the north to N50°E in the south. In the north, left strike-slip movement is associated to normal components. This fault marks a contact between Palaeozoic and Jurassic formations. In the south (in the coal carboniferous basin of Jerada) this fault exhibits systematic left strike-slip offsets of E-W Hercynian faults and folds.

Horizontal sinistral offsets by the NE-SW fault system are well developed in Late Miocene formations. Detailed field work show patterns of *en échelon* structures (El Aïoun area). These structures, involving Tortonian to Messinian formations, are fossilized by quaternary deposits.

b) NW-SE (N135°E to N160°E) trending faults are the other important features of this area (Fig. 2). They are often longer than 15 km and extend the southern sector (faults of Oued Kiss (n°7), Tafouralt (n°8), Mechra Klila (n°9), Mechra Homadi (n°10), Zekkara (n°11), Touissit (n°12), etc.). Occasionally they produce long linear morphological steps up to 120 m high. One of the most noteworthy systems is represented by Oued Kiss fault (n°7) (Fig. 2). This fault cross-cut the Palaeozoic basement and the Mesozoic rocks and marks the contact between the major structural units of the eastern area: Beni Snassen with Traras mounts in the north and Taourirt-Oujda with Tlemcen mounts in the south. Seismic reflexion profiles interpretation (Tabyaoui *et al.*, 1996) show

that Neogene deposits are involved by this fault even in the Triffa and the Angad basins. Field investigations show that kinematic indicators (e.g. slickensides, drag folds, stratigraphic offset, etc.) along faults planes, affecting pre-Late Miocene deposits, indicate that these faults recorded a late horizontal dextral strike-slip motion.

c) The third system in this sector, is represented by arcuate ENE-WSW to E-W trending faults (faults of Guefait-Tiouli (n°13), Metroh (n°14), Trhasrout (n°15), Azrou Azizar (n°16) and those of the Taourirt-Oujda mounts). Among the most significant, the Guefait-Tiouli fault (n°13) (Figs. 2 and 3) is well developed. This fault is longer than 120 km and shows a subvertical dip (Stretta, 1952; Medioni, 1980). In the west, this fault isolates the Taourirt-Oujda mounts and the Oued Haï basin. It shows a reverse slip component in this area. Mesozoic rocks, widespread in the Taourirt-Oujda mounts, are subhorizontal and only near the fault dips of Jurassic and Late Miocene bedding up to 35° can be observed in the Oued Haï basin. Other E-W trending faults show similar kinematics. These faults (e.g. fault of Metroh, n°14) (Figs. 2 and 3) locally developed along the overturned limbs of asymmetric E-W oriented folds. Other faults running in the same direction show a reverse component in the Beni Snassen (Trhasrout, n°15 and Azrou Azizar, n°16) (Figs. 2 and 3). They are often offset by the NE-SW and the NW-SE oriented conjugate fault network.

d) The last fault system, affecting especially the western side of the studied area (Beni Bou Yahi, Terni Masgout), is represented by faults (e.g. 18) (Fig. 2) trending N-S. These faults are clear and long lineaments. Kinematic indicators and vertical offsets testify normal movements. These faults cross-cut the Late Miocene deposits. Locally, Late Miocene calc-alkaline volcanic rocks are complicated by these faults, as in the Oujda region.

Fold systems

Mesozoic rocks, with their overlying Tertiary formations are affected by several fold systems, showing a great orientation scatter (Fig. 2). Most of them have axial directions between ENE-WSW to E-W. Locally NE-SW oriented folding systems are present in north-eastern side of the Beni Snassen. Fold axes are often sub-vertical.

The most folding structures of the whole sector are represented by anticlines in the Beni Snassen and the Beni Mahiou, which are about 20 km long (Fig. 3). The axial planes are arcuate, trending N120°E to N090°E to N060°E. Folding affecting Late Miocene to Pliocene

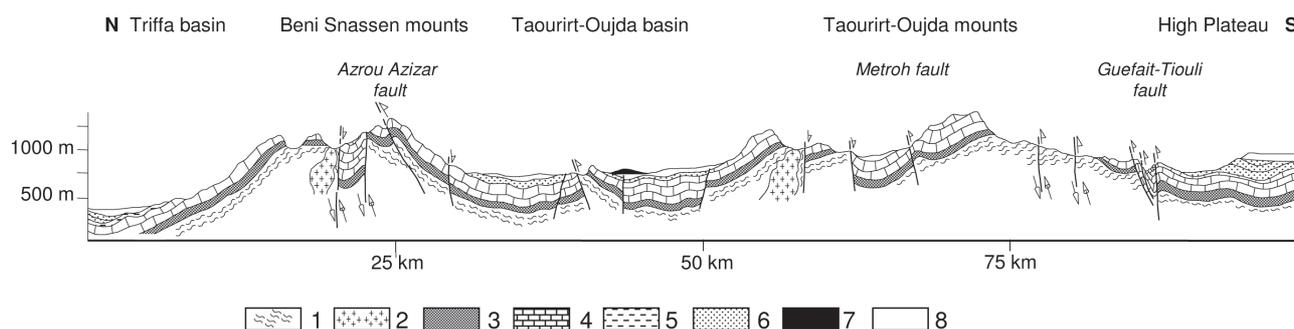


Figure 3.- N-S cross-section of north-eastern Morocco along the transect shown on figure 1B. 1) Hercynian metamorphic rocks, 2) Hercynian granites, 3) Triassic volcanic and sedimentary rocks, 4) Jurassic formation, 5) Lower Cretaceous sediments, 6) Neogene formations, 7) Late Miocene to Quaternary basalts, 8) Quaternary sediments.

deposits is well visible in outcrop and at map scale, especially in the centre of the Taourirt-Oujda basin (El Aïoun area) (Fig. 2). Moreover, seismic reflexion profiles (Tabyaoui *et al.*, 1996) show symmetrical folds with a kilometric scale in the sector of Bessara. These folds, involving Late Miocene to Pliocene formations are fossilized by Quaternary deposits.

The remarkable development of localized Late Miocene to Pliocene folding structures in the central sector of the study area has to be related to the kinematics of strike-slip faults. Folding structures concentrate and show the greatest deformations were NW-SE and NE-SW dextral and sinistral strike-slip faults converge. These faults produce a slight dragging of folding structures, so that their axial planes are often rotated coherently with the strike-slip kinematics of these faults.

Fault mechanisms

We collected more than 1200 faults striations measurements in 50 sites located in Mesozoic and Miocene to Pliocene sedimentary rocks and in Late Miocene to Pliocene volcanic formations. Other criteria used include Riedel-type fractures or asymmetric facets, e.g., polished knobs facing the movement of the opposite block and rough facets on the opposite side of the fault surface (c.f. Petit, 1987). Conjugated fault sets without striations, joints, and tension gashes have been interpreted according to the geometrical criteria proposed by Hancock (1985).

Analysis of these faults by using the direct inversion methods (INVD) proposed by Angelier (1990) permits to calculate 50 significant paleostress tensors including 22 in the Late Miocene to Pliocene sedimentary and volcanic formations. Stress axes ($\sigma_1 > \sigma_2 > \sigma_3$), computed ratio $\Phi = (\sigma_2 - \sigma_3) / (\sigma_1 - \sigma_3)$, number of faults accounting for the solution (N), and mean angle (α) between the theoretical shear stress on the fault plane and the actual striation are reported in table I.

Two main structural stages have been recorded by fault motions in Late Miocene to Pliocene formations; the older stage consists in a compressive strike-slip regime characterized by N-S horizontal σ_1 . This stage is illustrated by graphical examples of observed sets of

faults and corresponding tensors in figure 4. The younger stage shows a compressive strike-slip regime with σ_1 trending NW-SE to NNW-SSE. This last event will not be detailed here. Their relative chronology (e.g. superposition of slickensides), and their relative orientations allow to correlate them with well-known events in the Rif belt (Ait Brahim and Chotin 1989, Chaouni, 1996), the Rif foreland (Hervouet, 1985; Barathon, 1987) and northern Algeria (Ait Ouramdan and Gelard, 1997). They correlate to the Messinian to Pliocene compressive regime with σ_1 oriented N-S and to Plio-quaternary NW-SE to NNW-SSE compressive regime.

The N-S compressive regime is the most widespread event, recognizable in the entire area. Conjugated strike-slip faults related to this tectonic phase have been measured everywhere in the Late Miocene and in the Mesozoic formations along numerous quarry outcrops. The fault association is generally represented by NW-SE (N150°-170°E) dextral strike-slip fault conjugated with NE-SW (N15°-45°E) sinistral ones. This is illustrated by the site S21 (Fig. 4) in calcareous formations of Late Tortonian age in the El Aïoun area (Fig. 2). The same diagrams are represented by the sites S17, S22, S34, S39, S42, S49 and S50 (Figs. 2 and 4, Table I).

Complex motions related to the same event have been also observed at site S30, where conjugated NW-SE and NE-SW strike-slip faults coexist with N-S (N175°-10°E) normal faults. No chronological criteria for separating the two different kinds of fault systems were available in this site. Mixing of faults permits calculation of stress tensors σ_1 and σ_3 sub-horizontal with N-S and E-W trend respectively (S30) (Fig. 4). The same case of direction of extension is recognized also at the sites S13, S15 and S26 (Fig. 2), through the analysis of conjugated strike-slip and normal faults.

Moreover, Late Miocene to Pliocene volcanic formations are affected by normal faults trending N-S (site S27) (Fig. 4). The stress tensor determination gives in this case an E-W trending horizontal σ_3 and subvertical σ_1 , consistent with the orientation of tension gashes measured along the fault scarp. The same kind of solution is obtained in the western part of the study area (S3 to S7) (Fig. 2). The average direction

Site	N	σ_1		σ_2		σ_3		Φ	α
		Tr.	Pl.	Tr.	Pl.	Tr.	Pl.		
S3	15	279	77	182	2	91	13	0.306	15
S4	10	106	72	12	1	282	18	0.334	4
S5	11	273	74	178	2	87	16	0.227	3
S6	9	274	75	179	1	88	15	0.211	6
S7	12	359	78	178	12	268	0	0.217	19
S13	18	6	4	213	86	96	2	0.847	17
S14	14	5	7	212	84	95	2	0.833	14
S15	15	2	6	209	82	92	4	0.801	11
S17	13	184	2	331	87	89	9	0.407	13
S21	25	179	1	294	87	88	2	0.338	4
S22	8	358	8	227	78	89	9	0.407	13
S23	17	175	11	267	9	35	76	0.160	16
S26	11	356	6	111	77	266	5	0.822	13
S27	14	11	86	194	4	104	0	0.309	14
S29	16	175	14	267	7	21	74	0.456	15
S30	13	359	5	114	79	269	10	0.841	13
S34	9	184	21	87	19	318	61	0.235	17
S39	8	356	3	97	74	264	16	0.338	12
S40	13	187	7	279	11	68	77	0.458	1
S42	11	190	0	94	87	277	3	0.313	18
S49	18	4	5	110	72	272	18	0.232	11
S50	16	175	9	355	81	265	0	0.404	14

Table I.- Characteristic parameters of stress ellipsoids of the studied sites. In Table are reported: reference number (see figure 2) (Site), number of faults planes (N), method for data inversion (Function: see Angelier, 1990), stress axes ($\sigma_1 > \sigma_2 > \sigma_3$) as trend (Tr.) and plunge (Pl.) values, shape ratio among the main axes $\Phi = (\sigma_2 - \sigma_3) / (\sigma_1 - \sigma_3)$ and mean angle between the theoretical shear stress on the fault plane and the actual striation (α).

of extension, i.e., the computed σ_3 axis, is E-W, and is the same for normal and strike-slip faults. This suggests that the separation between dominant strike-slip and dominant normal dip-slip faulting, made within our data sets on the basis of geometrical analysis, does not reflect necessarily contrasting tectonic events. It rather reflects stress permutations between δ_1 and δ_2 related to variations in the Φ ratio between the principal stresses (Table I).

In the central part of the study area, conjugated NW-SE and NE-SW strike-slip faults occur. At some sites (S23, S29, S40) (Fig. 2) reverse faults trending E-W have been found in Late Miocene formations. There, superposition of slickensides indicates that previous Late-Tortonian E-W trending normal faults have been reactivated by reverse movements. Most of the solutions obtained through numerical computations indicate a N-S trending horizontal σ_1 axis and a sub-vertical σ_3 axis. This substitution is probably due to small differences between the absolute values of σ_2 and σ_3 .

Discussion and conclusion

The particular feature of Late Miocene to Pliocene tectonics in the region situated between the Rif-Tell chain, the intracontinental Middle Atlas and the eastern meseta is the juxtaposition strike slip and volcanic structures in a general compressive context. All these

structures can be associated to the same deformational event. Detailed field analysis of fault kinematics shows that the entire region was affected by compressive regime with σ_1 trending N-S from Messinian to Pliocene time.

Deformation is strongly controlled by major dextral NW-SE trending faults and sinistral NE-SW trending faults. These regional faults produce the creation of two types of triangular wedges. Compressive structures are mainly located in the northern and southern wedges (Fig. 5). The northern sector (Beni Mahiou, Beni Snassen) displays folds, reverse faults trending E-W limited by dextral NW-SE trending faults and sinistral strike-slip faults trending NE-SW. on the other hand, extensive structures are mainly located in eastern and western triangular wedges. The movement of these wedges show an extensional direction σ_3 trending E-W as a result of an average N-S shortening direction, in accordance to theoretic (Tapponnier and Molnar, 1976) experimental models (Peltzer and Tapponnier, 1988; Ratschbacher *et al.*, 1991) and other regional examples (Rebaï *et al.*, 1993), and in agreement with the orientation and the relative kinematics of fault systems affecting this area.

In the eastern and western wedges, deformation is mostly represented by normal faults trending N-S. In the eastern sector (Oujda region) (Fig. 5), volcanic formations of Late Miocene age (6.1 to 3.0 My) show normal faults trending N170°E to N10°E. Also, the calc-alkaline flows are aligned along tension megafissures running N-S (Chotin and Ait Brahim, 1988). In western blocs (Terni Masgout, Beni Bou Yahi, Guercif basin), normal faults trending N-S are also well developed. They control the Late Miocene (4.5 My) flow of shoshonitic volcanic activity of Guilliz. Some shoshonitic volcanic edifices appear in the corners formed at the intersection between ENE-WSW strike-slip faults with reverse component (n° 17) and N-S normal faults (n°18).

Tectonic escape (Burke and Sengör, 1986) or extrusion tectonics (Tapponnier *et al.*, 1982), was proposed for northern Africa by the Mediterranean indenter (Tapponnier, 1977) and is a typical deformational mechanism in continental collision areas. According to this mechanism, we suggest that the study area constitutes the western side of the Maghrebian indenter of Piqué *et al.*, (1998) and is subjected to lateral tectonic escarpe.

Indeed, the eastern meseta is commonly regarded as a flat stable block (Michard, 1976). During Late Miocene to Pliocene, the African plate was moving northward with respect to the Iberian plate (Ziegler, 1988). The eastern meseta slides towards the north along NE-SW strike-slip faults zones. The most important of these are the Tafna fault zone (n° 6) (Fig. 5) and those which limit the High Plateau with the intracontinental Middle Atlas chain. The sinistral strike-slip movement of these faults was dated of Late Miocene age (Ait Brahim, 1986). In the north, the

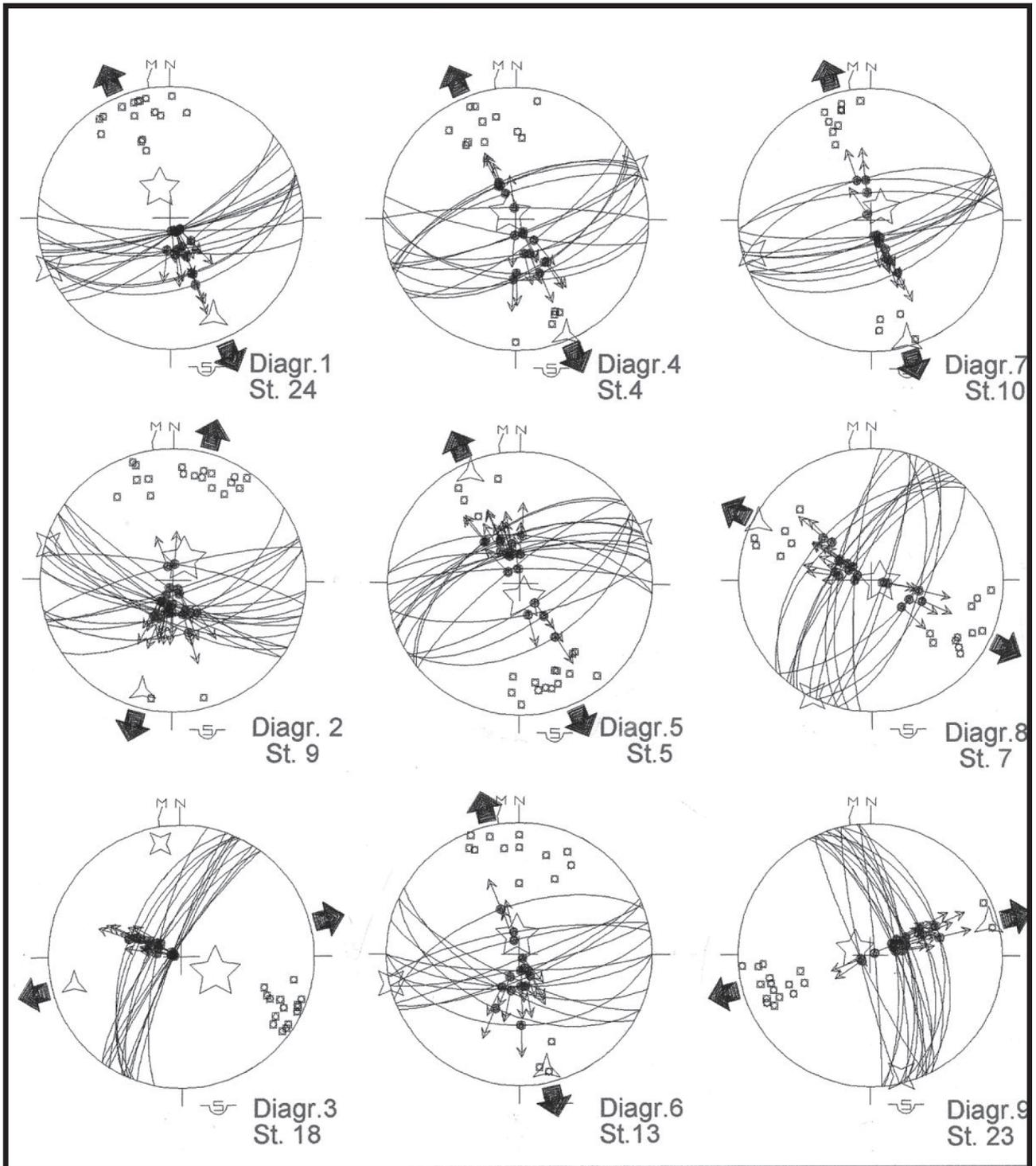


Figure 4.- Some characteristic examples of the main fault systems for the N-S compressive regime, (Schmidt's projection, lower hemisphere). Faults are shown as thin lines, slickenside lineations as dots with arrows indicating the sense of motion. Stress axes ($\sigma_1 > \sigma_2 > \sigma_3$) are represented as stars with five, four and three branches respectively. Large convergent and divergent black arrows indicate the horizontal direction of σ_1 and σ_3 respectively. Number of each stereoplot refers to sites in figure 2.

movement of convergence is partly blocked along E-W fault zones (like the Guefait-Tiouli). These faults, with subvertical dip, present locally a reverse component. The N-S compressional direction is supported also by the arcuate geometry of these faults. To the north, northern and southern wedges were compressed, folded and pulled up causing the outcrop of Palaeozoic basement. E-W trending faults are reactivated on

reverse faults verging towards the north, opposing the regional southern vergence of the Rif chain. On the contrary, eastern and western asymmetric wedges are laterally extruded. Deformation mostly represented by normal faults is associated with volcanism activity. The western moving wedge is related to a modest continental escape of northern Morocco toward the Atlantic.

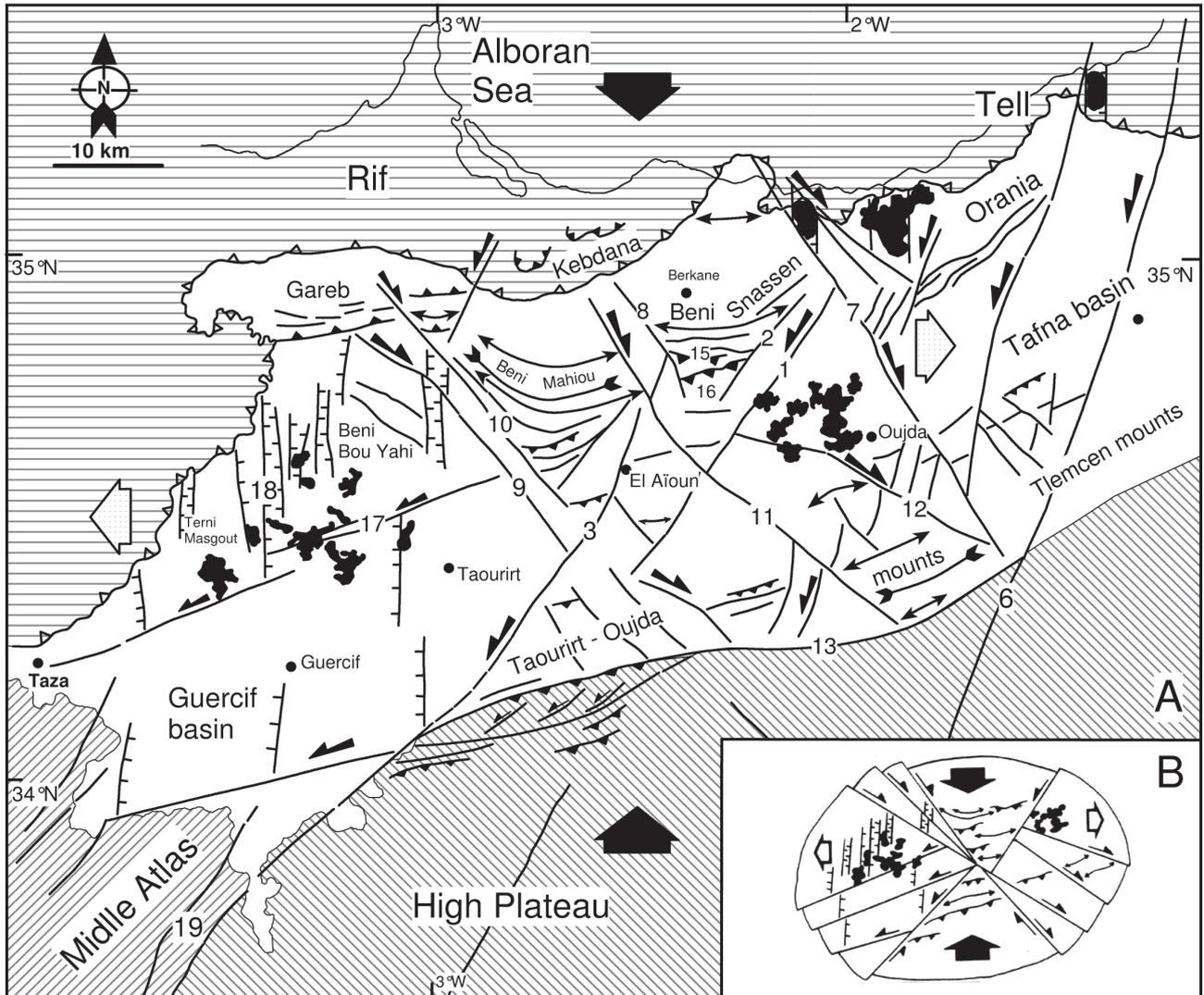


Figure 5.- A) N-S shortening direction (represented by the black arrows) of Late Miocene to Pliocene structures. The number of faults is as referred in the text. B) Sketch model showing the kinematic relationship between compressive structures (in northern and southern wedges) and extensional features (in western and eastern wedges).

This deformation model, which takes into account the structural evolution, constitutes a part of the Mediterranean indenter and the smaller-scale Maghrebien indenter. Associated volcanism may be related, as envisaged by Maury *et al.*, (2000) to crustal tears along which occurs partial melting of subcontinental mantle by the progressive upwelling of the asthenosphere. However, as the N-S normal faults are small, we think that the mantle processes which developed such volcanism are, as developed by Teixell *et al.*, (2005), a result of a mantle upwelling, probably with a deep root, but focused by upper mantle flow influenced by the thickening of the lithosphere between the Iberia-Africa convergent plate boundary and the Saharan craton.

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