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The parameters controlling the deformation in the structures associated to Gafsa fault (southern-central Tunisian Atlas): Interpretation of “Partitioning deformation” model.

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Abstract. The particularity of the Gafsa basin comes from the direction of belts structures that are NW-SE different to directions of Atlassic structures in Tunisia (NE-SW to EW). These structures are affected on the core by preexisting faults. The field study associated to fine cartography allowed us to interpret the conditions of developments of structures in the Gafsa basin. The study of faults shows the role of tectonic inheritance thus the normal activity of these faults during the Cretaceous faults and its reactivations to reverse and strike-slip faults during compressive phases. The slickenside examination of the preexisting faults shows for the first time in the Gafsa basin the coexistence of thrust and strike-slip faults which is due in particular to the obliquity of the shortening axis to the direction of these faults. The geometry of folds (dissymmetrical flanks affected on the core by preexisting faults) permit to interpret the oblique “fault related fold” model associated to Triassic decollement level. The interpretation of this decollement level was confirmed by the Triassic blades that stake the main faults. The Triassic decollement level allows the separation between the deformation in the base and cover, thus the base allows only a sample passive transport and any deformation will be accommodated in cover. All these interpretations has allowed us to propose for the first time in Tunisia and across the African craton the interpretation of the "partitioning deformation" model in the genesis and development of belts structures in the Gafsa basin.

Keywords: *Gafsa basin, decollement level, partitioning deformation*

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1. introduction

At the end of Paleozoic and following the Hercynian orogeny was formed Pangea, the African continent is attach to future North American one, but the breakup of Pangaea will caused the opening of the Atlantic ocean in the early Triassic. Between the Tethys to the north and the Atlantic Ocean to the west develops a major rift system, which will be aborted during the Jurassic. The deformation is mainly localized on pre-existing inherited accidents during the Hercynian history (Laville et al., 2004). From the Cretaceous, Africa and Europe began their convergence as slow speeds (Resenbaum et al., 2002), which are accompanied by intracontinental deformations. In the south of Tethys, particularly the North African craton, the tectonic inversion begins during the Paleogene marked by the inverted activity of major Atlassic accidents (Laville et al., 2004). The blocking between the European and African plate permits an accentuation of the deformation appearance with different tectonic structures (Decourt et al., 1986; Pichon et al., 1988; Stampfli et al., 1991). The convergence as NW-SE to N-S directions continues and leads to the formation of Atlassic chains in the north of African plate. In the Tunisian Atlas geological structures are subjected to an intense geodynamic activity and a very complex structural evolution during the Mesozoic and Cenozoic (Frizon de lamotte et al., 2009). This activity mainly affects pre-existing faults especially in the southern-central Tunisian atlas and N-S axis (Figures 1a, b and c), that stretches from Agadir in Marroc (Frizon de lamotte et al., 2000; Creuzot et al., 1993). The central-southern Tunisian atlas and N-S axis are the subject of several studies (Zargouni et al., 1985; Soyer et tricart, 1987; Bensalem, 2009; Amamria, 2011). These communities show variable direction of folds WE, NE-SW, NW-SE and EW truncated by tectonic lineaments identified on the surface (Zargouni et al., 1985) and subsurface (Bédir, 1995; Zouaghi, 2011). These tectonic lineaments show the evolution of the main décollement levels from the northern Tunisian margin to the front of deformation, along the Saharan platform (Creuzot et al., 1993; Frizon de lamotte et al., 2000). The main decollement level in the central-southern Tunisian atlas and N-S axis is in the Triassic series (Ouattani et al., 1995; Ahmadi, 2006; Bensalem, 2009; Amamria, 2011).

We focus our study in the Gafsa basin in southern of Tunisian Atlas which is bounded on the north by the Central Atlas and to south by the town of Metlaoui and north range of chott, this area is also determined by UTM coordinates 34°22' to 34°32' in latitude and 8°33' to 8°56' in longitude. Geologically, the Gafsa basin is formed by belts structures of major directions NW-SE to E-W associated to directional faults. This latter forms the eastern boundary of the southern Atlas accidents which spread from Agadir in Morocco to Gabes in Tunisia over a distance of 2000 km. The particularity of the structures associated to Gafsa fault is the NW-SE direction which is different to the direction of Atlassic structures in Tunisia (NE-SW to EW). The NW-SE direction parallel to oblique to the shortening axis permits generation therefore of a transpressional regime.

Based on fine mapping associated to slickenside examination and targeted geological cross-sections it offers an interpretation of the evolution of structures in the Gafsa basin. Consequently the different parameters tested in the field permit to control the evolution of deformation and propose a model of genesis of folds in Gafsa Basin.

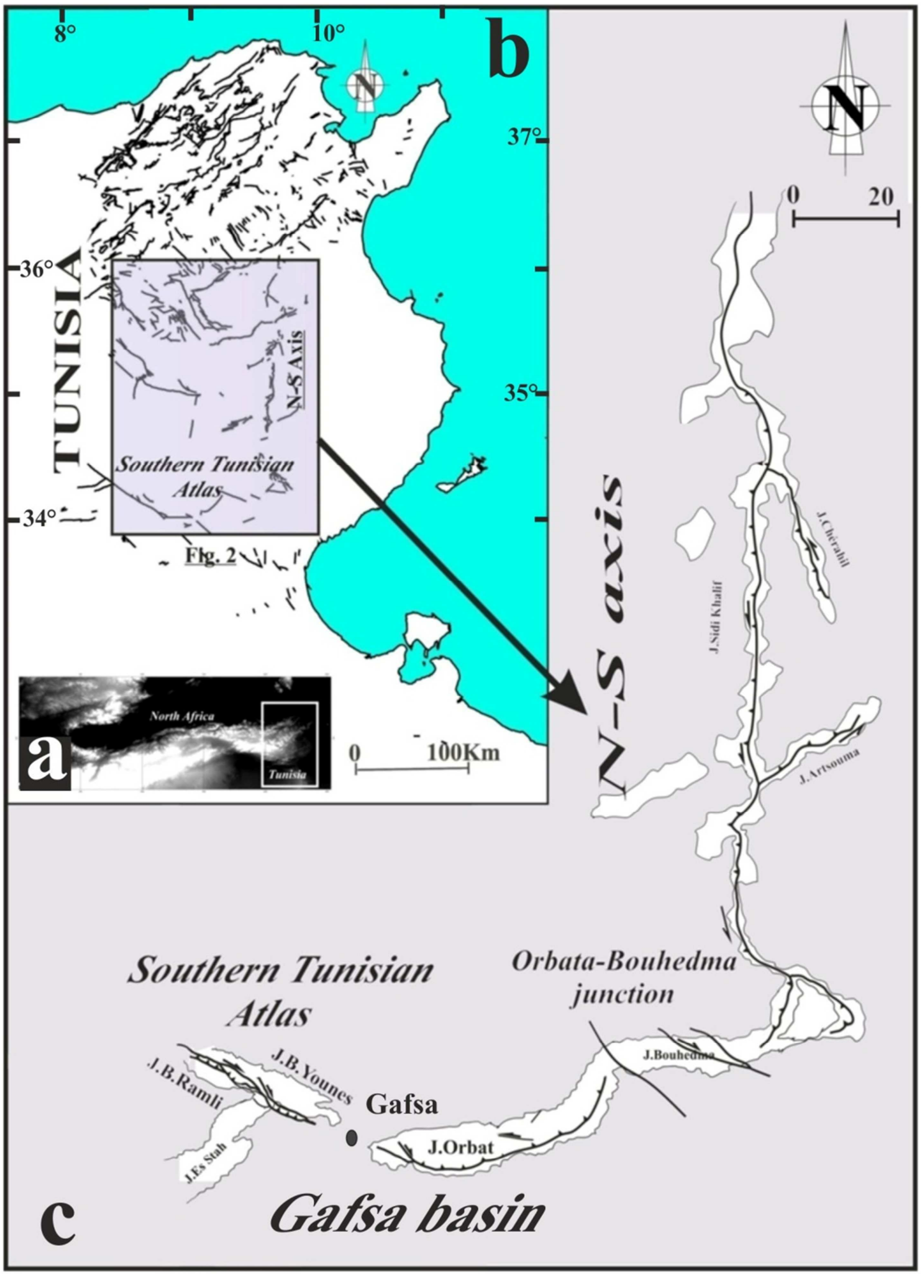

Figure 1: Localization of studied sector: (a) The Tunisian Atlas occupied the eastern limit Atlassic chains (satellite imagery); (b): The Structural map of Tunisia shows the central position of southern-central Tunisian Atlas delimited to the north by tectonized structures of northern Tunisian Atlas and to the south by Saharan platform; (c): The particularly NW-SE direction of Gafsa faults compared to direction of Orbata, Bouhedma chains and the N-S structures.

2. Geodynamics settings

2.1. Parameters Controlling the Development of Structures

According Ouali et al. (1987), the N-S axis corresponds to preexisting old normal faults was controlled the Cretaceous series. During compressive phase these faults are reactivated to strike-slip faults even thrust faults in its SW limit. To the south the Orbata-Bouhedma junction the pre-existing faults (ElMich faults) show a clear thrusting of northern compartment during in the compressive phases (Bensalem et al., 2011).

In the western part of the atlas central-southern Tunisia, the Gafsa faults correspond to dextral strike-slip faults with reverse component of N120-130 direction. This corridor faults manifests by shearing and thrusting structures. We focus our study in this zone because its particular direction parallel to shortening, that the reactivation of pre-existing permits the development of two case of thrusting systems and strike-slip faults.

In Jebel Bou Ramli, Jebel Ben younes and Jbel Jbel Orbat the Gafsa fault corresponds to a basement accident that occur during extensive periods of normal faults with sagging generally of north compartments. The normal activity of these faults is registered in their slickenside thus controlling the facies and thickness of Cretaceous series and especially Aptian to Albian age (gap of series of Orbata Formation of Aptian age).

In the NW extremity of Jbal BenYounes the units stratigraphic of Orbata Formation and the lower member of the Zebbag Formation are affected by faults in varying directions N45 to N150. The Synsedimentary activity of these faults is marked by sedimentary gap of series of Sidi Aich and Orbata Formation; in fact, in the west compartment of this fault the series of Bouhedma Formation are in direct contact with the lower member of the Zebbag Formation (Figure 2). The slickenside examination of the fault of Jbal BenYounes shows striation indicates its normal activity and confirms the extensive regime in this area during deposits the series of Sidi Aich and Orbata Formaion that is to say above Barremian Aptian.

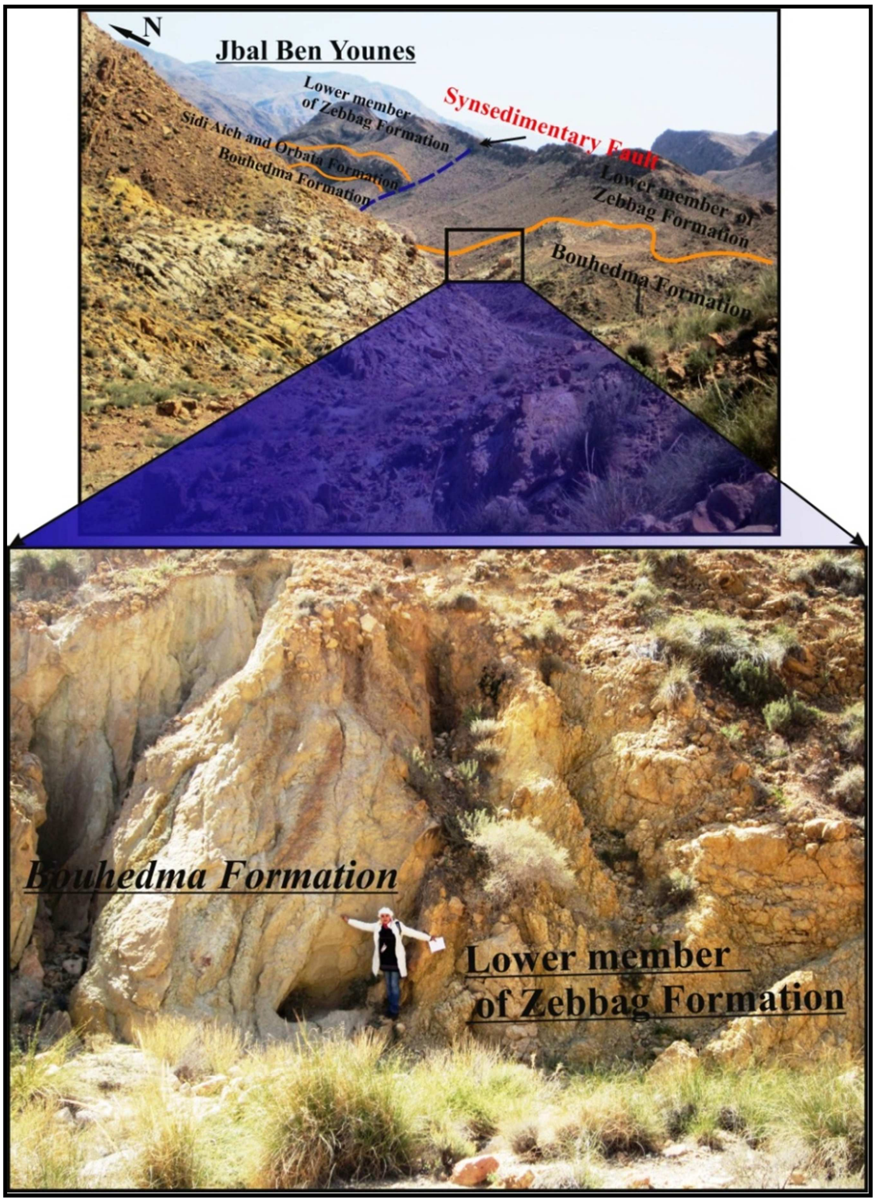

Figure 2: The sedimentary control of Faults in Jbal Ben Younes : the normal activity of fault in Jbal Ben Younes permit the downthrown of northern compartment and lacuna of series of Sidi Aich and Orbata Formation in the uplift southern compartment; So the direct contact between Zebbag and Bouhedma Formation.

The extensive tectonic regime during Cretaceous is also shown by normal faults forming half-grabens and extensional dykes. This extensive phase during the Cretaceous was already confirmed in the Central-southern Atlas by Zghal et al. (1998). During Apto-Albian period and can be correlated to the one that begins in the late Triassic who is responsible to the opening of the Tethys (Decourt et al., 1986).

The compressive recovery in this area is distinguished by the rejuvenation of ancient normal faults and development of belts structures. This recovery of old normal is verified by thrust and strike-slip faults. The structural chart elaborated in this zone (Figure 3) confirms the activity of these two types of faults.

In Figures 3 and 4, the FBR, Fb2 and FO faults show a thrusting component with vertical striate whose pitch exceeds 75 °. These faults are N140 direction parallel to oblique the shortening axis, it is also directional faults parallel to fold axis.

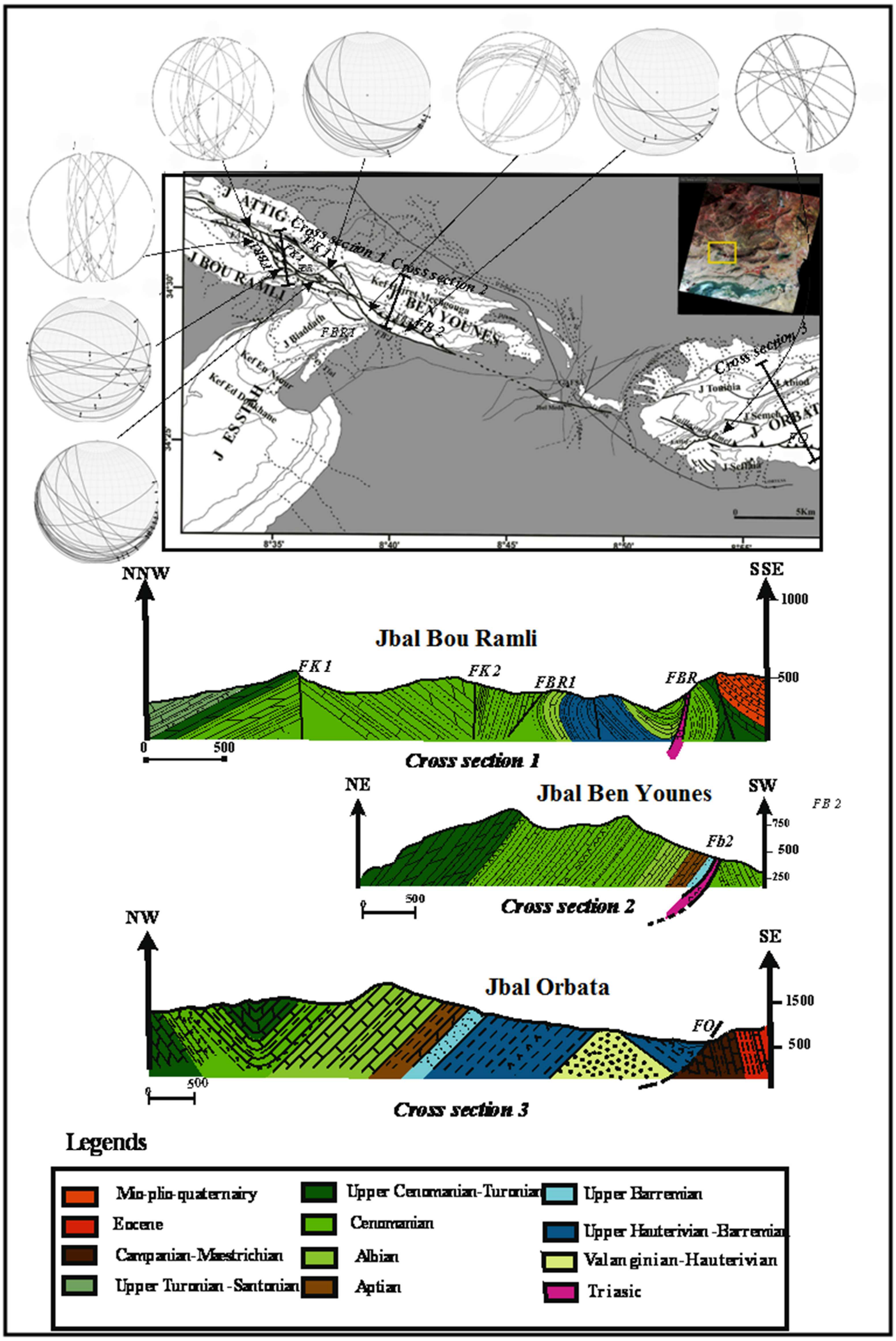

Figure 3: Structural map of Gafsa Bassin associated to Canevas of wulf indicate the coexistence of thrust and strike-slip faults activity of major thrusting and strike slip faults in Gafsa basin.

The three cross-section demonstrate the role of preexisting faults and its reactivation during compressive and confirms the model of “fault related fold” according to Triassic decollement level.
The cross-section 1 in Jebel Bou Ramli presented a monocline limited in its southern part by FBR2 permeated the thrusting of north compartment. The thrust recovery of this ancient basement fault is associated to rise of Triassic blades of metric thickness. The rising of the Triassic blades resulted of strong tightening in this zone.

Similarly the cross-section 2 in Jebel Ben Younes shows the thrust activity of ancient basement fault Fb2 permeated always the overlapping of northern flank on the southern one, this fault is marked by a metric Triassic blade.

The cross-section 3 confirms the rejuvenation of ancient normal fault to thrust one permeated the overlapping of long northern flank of low dip on short southern flank of fort dip. It is a geometry which corresponds to a model of “fault propagation fold”.

From Late Miocene (Tortonian) the compression is widespread in the Gafsa basin essentially marked by the angular discordance mismatch of the Segui Formation series on older series. The deformation during the Post-Villafranchian phase is much more complicated because of the obliquity of the axis of shortening, NNW-SSE N-S direction, to the NW-SE direction of axes of folds and direction of faults.

In the Gafsa basin, there are reverse faults at small scales in the phosphate layers of the Eocene. These issues are caused by local compression due to a block system. Studies (Hamadi et al., 1996; El Ghali et al., 2003; Lajnef., 2005) interpreted the Eocene period as a compressive phase, but this hypothesis is not verified throughout the Gafsa basin.

Different previous work in central-southern Tunisian Atlas (Ahmadi, 2006; Bensalem et al, 2011; Amamria, 2011) has confirmed the application of the model of “fault related fold” by the reactivation of normal faults, thus generally the thrusting of north compartment on southern one. These works interpret the evolution of “fault related fold” according to a decollement level in Triassic series particularly the Late Triassic. The outcrop of Triassic blades that marks these pre-existing faults confirms the interpretation of Triassic decollement level, which its rising is due to the strong tightening during the overlapping (Figure 4).

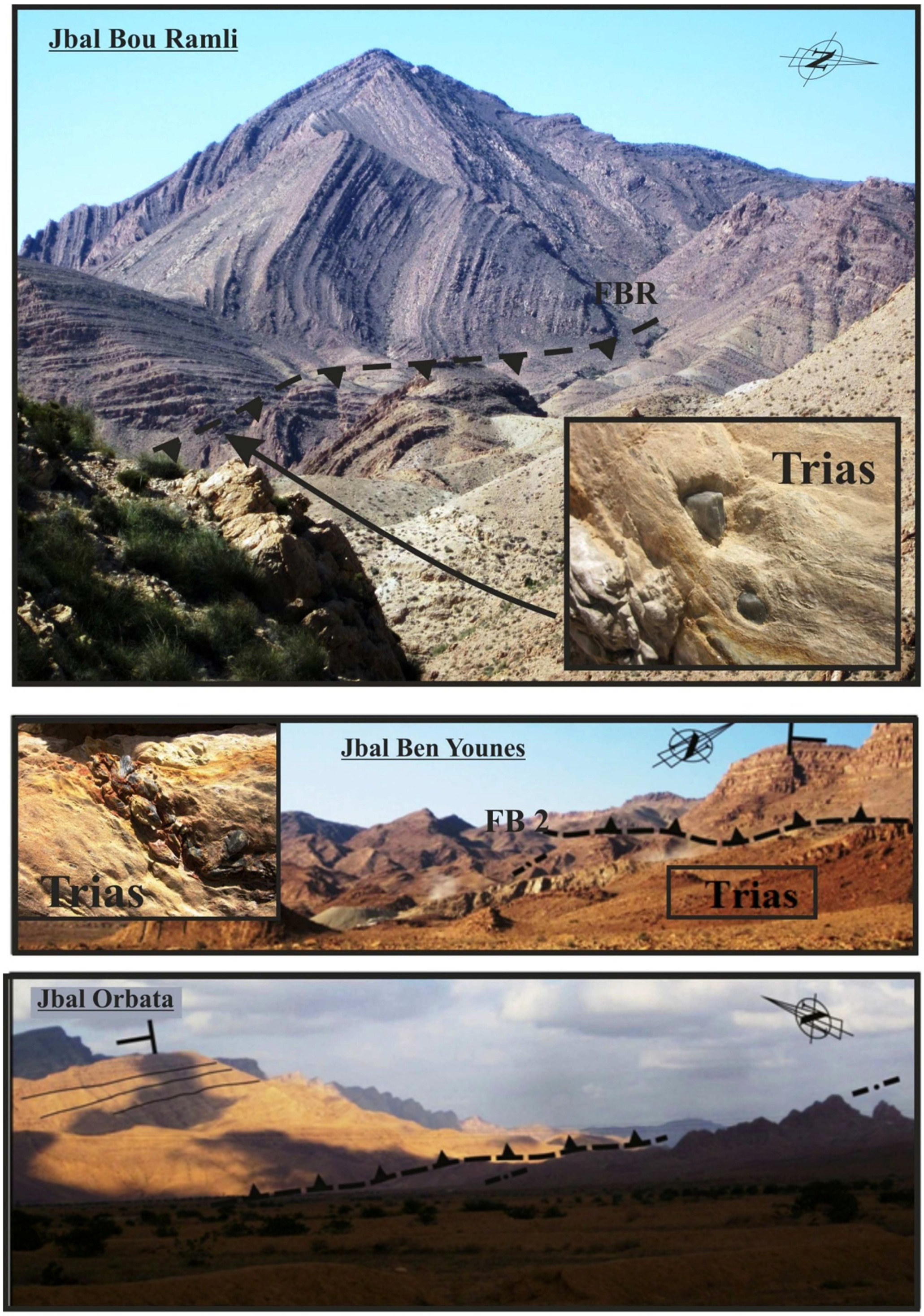

Figure 4: The thrusting faults affected Jbal Bou Ramli, Ben Younes and Orbata associated to outcrop of the Triassic blades. The thrust affect the core of structures.

The Triassic decollement level permits the separation between the deformation in base thick-skinned and other in the cover thin-skinned. Indeed any deformation, tardily to the creation of this decollement level, will accommodates in the cover and the base allows only a sample lateral and vertical passive transport of deformation.

The cross-section 1 also shows the strike-slip activity of faults FK1, FK2 and FBR1. It should be noted that this activity is resulting from compression during the compressive phases cited (Alpine and Post-Villafranchian). Thus the strike-slip faults are contemporaries to thrusting. So we suggest in the first time the coexistence of thrusting and strike-slip faults. As against, the previous studies have shown that the thrust faults are resulting from the activity of Gafsa strike-slip fault in transpressional mode (Zargouni et al., 1985).

At the Jbel Meda, outcrop on the SE of Jbal Ben Younes, we distinguish the strike-slip faults activity of the Quaternary glaze in same direction as the NW-SE direction of faults affecting the southern slope of Jbal Ben Younes. This fault is associated to grooves that indicate a very important tectonic activity. So this strike-slip fault activity manifest until current. Consequently the global phenomenon that affect the Gafsa basin is related to the coexistence of thurust and strike-slip faults; the recent activity of thrust faults was confirmed by seismicity and the actual strike-slip faults activity is verified in the grooves in the quaternary glaze (Figures 5a and b). The coexistence of thrust and strike-slip is verified also by the Canvas of Wulf that the examination of slickenside indicates the existence of two generation of striation; shown thrust and dextral strike-slip faults.

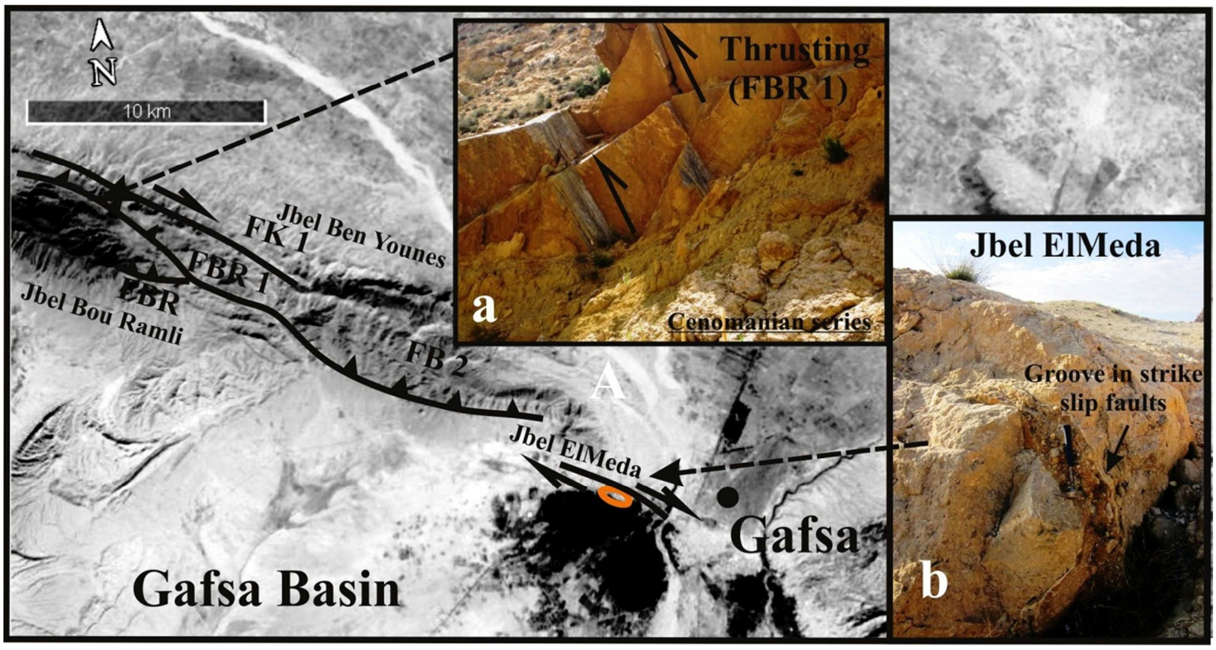

Figure 5: The coexistence of Thrust and strike slip faults: The same fault of N120 direction shows the thrust systems in the north of Jbal Bou Ramli (a) and strike-slip fault in Jbal ElMeda(b).

2.2. Tectonics Inheritance

The central-southern Tunisian Atlas consists of folds of variable directions NE-SW, EW and NW-SE; its tectonic style is characterized by an abundance of transpressional structures associated to thrust and strike-slip component. This tectonic style is related to the oblique direction of shortening axis compared to the preexisting faults; this shortening axis is of NW-SE to N-S direction, correspond respectively to Atlassic (Late Miocene) and post-Villafranchian compressive phases (Figure 6).

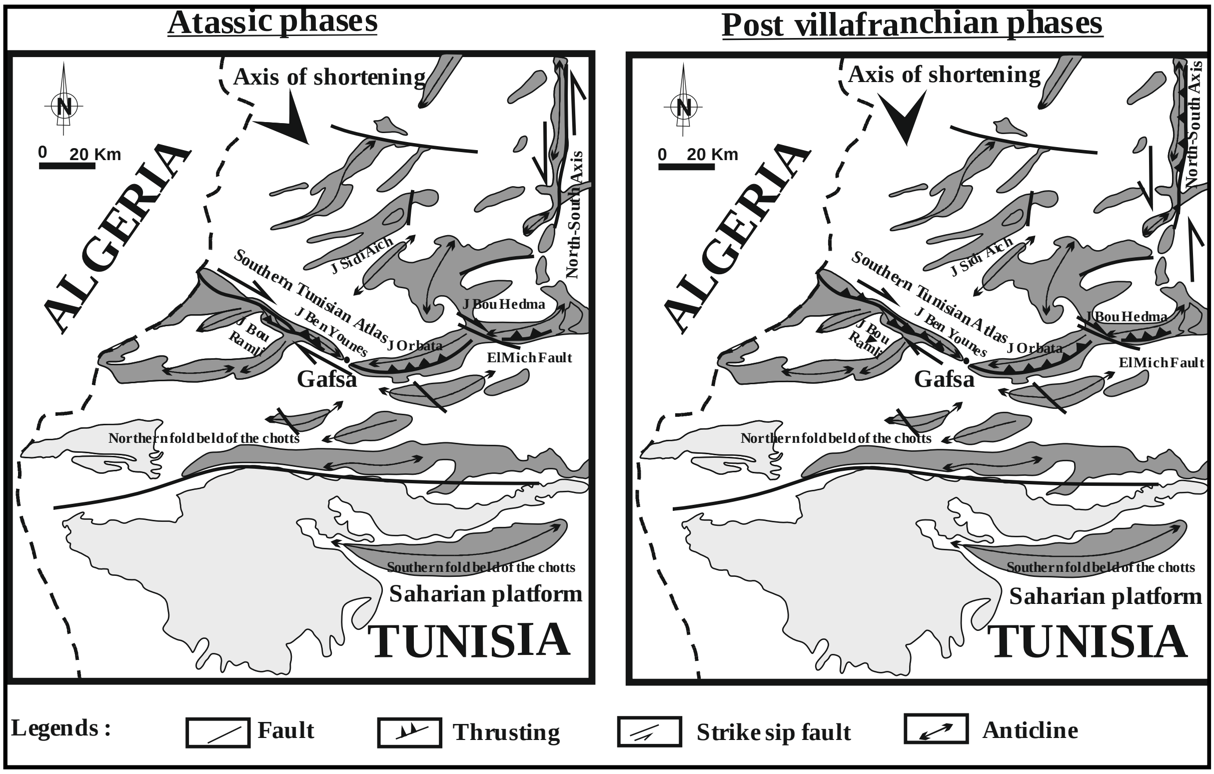

Figure 6: The particular direction of Gafsa fault parallel to oblique to principal compressive phase and its comparison to Orbata-Bouhedma junction and N-S axis.

The N-S axis consists of folds of N-S direction associated to transpressive structures in flower (Zouaghi, 2011), this style of deformation is probably related to the reactivation in reverse strike slip faults of the basement accident. The principals shortening axis of compressive phases (NW-SE and N-S) is expressed by the geometry of folds dumped to the South and to the East, intercepted by reverse senestral strike-slip faults and sometimes dextral strike-slip faults (Ouali, 1987).

Thus the tectonic style of deformation in this zone depends of the orientation of the direction of preexistent faults to the direction of shortening axis; dominance of transpressive deformation: reverse strike-slip faults in central-southern Tunisian Atlas and senestral strike slip faults in the N-S axis.

3. Particularity of studied sector in southern-central-central Tunisian Atlas

The study area is located particularly in the southern-central Tunisian Atlas bounded to the east by the two largest chains that of Orbata and Bouhedma and the North-South Axis. Consequently it is important to compare the condition of evolution of structure associated to Gafsa fault that occupied the only NW-SE direction to others principals structures in southern-central Tunisian Atlas.

The Sub-meridian direction of the N-S axis has caught the attention of several authors; for Laffite (1939), the N-S axis is the continuity of the southern Atlas accident, other authors, describes the structures in this zone us broken fold. Ouali (1985) spoke of the tangential tectonics in the N-S axis, while Ouali (1985) and Ouali et al. (1987) have interpreted that all structures have truncated at the base by a large overlap and proposed the model of "fault propagation fold". Recently, in the same region Creusot et al. (1993) proposed the model of "Breakthrough" to explain the genesis of folds according to sub-meridian direction.

All proposed models are based on the interpretation of the reactivation of ancient normal faults during the compressive phases and therefore the direction of these faults to the main shortening axis. While all the proposals are based on the reactivation of the N-S axis to sinisteral strike-slip fault because of the obliquity of shortening axis to faults. This strike-slip fault is associated according Creusot et al. (1993) to thrusting with application of the model of "fault propagation fold" with Breakthrough in a basal decollement level in Triassic series, which explains the strong tightening due to blocking (Figure 7).

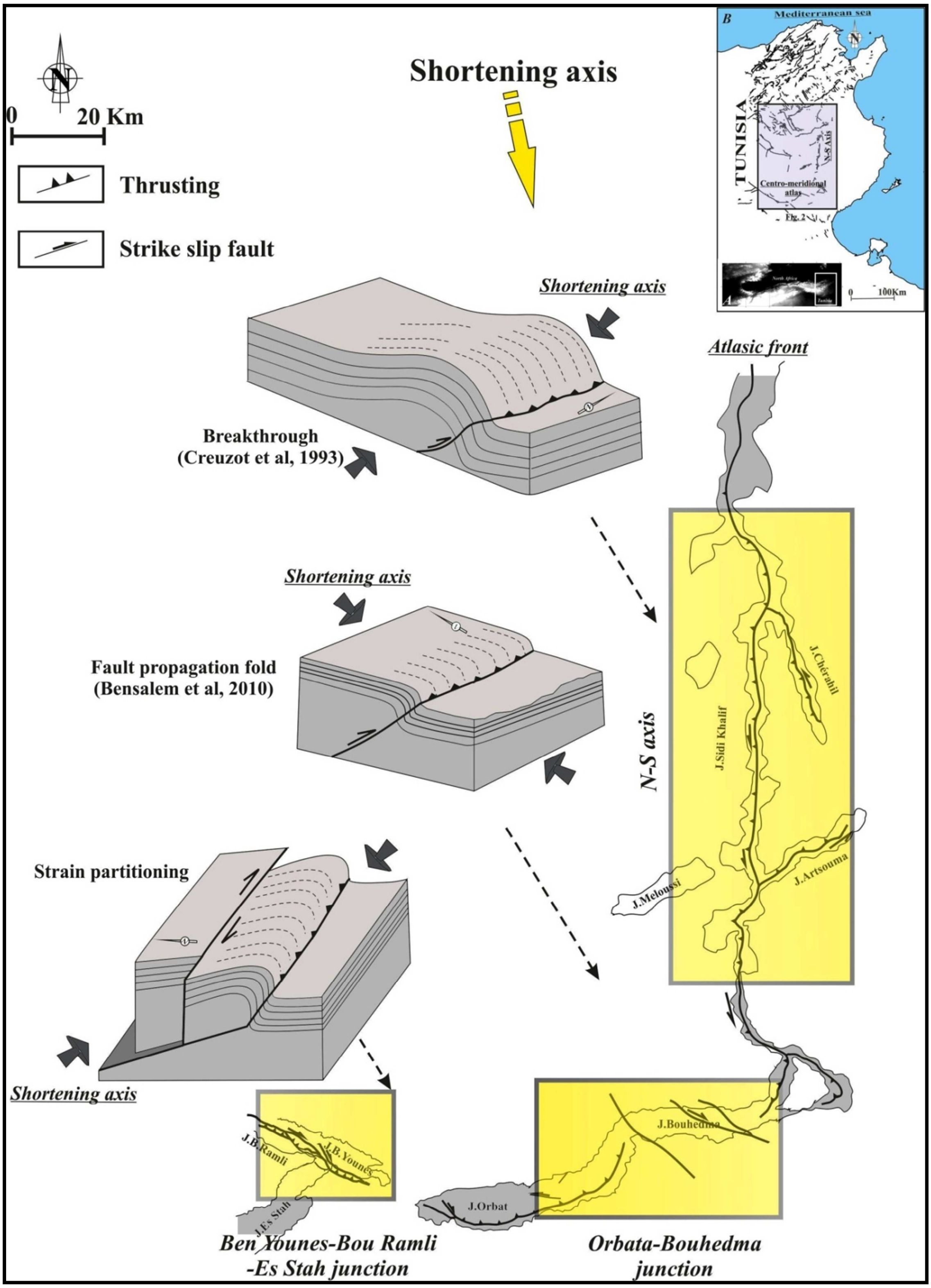

Figure7: The principal model interpreted the development of structure in the southern-central Tunisian Atlas: the “fault propagation fold” in the Orbata-Bouhedma junction, the “fault propagation fold” with “breakthrough” and the new interpretation of “Partitioning of deformation” in the Gafsa fault.

More to the SW and studying the Orbata-Bouhedma junction Bensalem et al. (2009) and Bensalem et al. (2011), basing on numerical modeling, suggested that the genesis of folds is related to a model of "fault propagation fold "confirming that the basal decollement level is within Late Triassic series. In this interpretation this model is also based on the reactivation of ancient normal faults during the compressive phase. Indeed shortening axis is perpendicular to the E-W normal faults which create overlapping generally north compartments of shallow dipping on South compartments of steeply dipping. The intensity of the deformation in this zone was interpreted by Bensalem et al. (2011) by the development of duplex structures associated to tear-fault.

The particularity of the structures associated to Gafsa fault is that preexisting fault of NW-SE direction are parallel to oblique to the major shortening axis. Several studies have shown that these faults were reactivated in dextral strike-slip fault associated later to an overlapping component (Zargouni et al., 1985; Zouari et al., 1990). Several parameters to be discussed in the interpretation of establishment model of structures associated to Gafsa fault. Among the main parameters is the notion of tectonics inheritance and reactivation of ancient normal faults during the compressive phase; consequently the direction of shortening axis to the preexisting faults what related to oblique convergence between Africa and Europe. In addition the examination of major faults show the coexistence of thrust with the strike-slip faults associated to main decollement level in Triassic series, what have an important role to interpret the relation thin and thick-skinned deformation.

All these parameters associated geometry of folds allowed us to propose for the first time the model of "partitioning deformation" to interpret the geodynamic evolution of belts structures associated to Gafsa fault.

4. Discussion and synthesis

Several limits of plates are oblique to the direction of convergence, and in most case, the active faults partitioning this movement. McKenzie and Jackson (1983) suggest that if the upper crust is deformed, then the partitioning is mechanically the easiest way to accommodate oblique convergence. It is in the intra-oceanic subduction zones where the parameters of partitioning were defined for the first time (Fitch, 1972). A typical example of the strike-slip fault in Sumatra Sunda arc has been studied later by Bellier et al. (1996). In a collision range, the suture zone is an ideal discontinuity to partition the movement. Besides the "partitioning deformation" is well studied in intracratonic scale limiting preexisting faults. In this case, the control parameters are the axis shortening and margins blocks where the faults are localized (Dewey et al., 1998). Several structural models at the scale of chains have been proposed (Audemard and Audemard., 2002); citing the Alpine fault in the south of New-Zealand (Norris et al., 1990), the transition zone Zagros/Makran in Iran (Regard et al., 2003), in

Anatolia (Chorowicz et al., 1999), in the Alps (Ratschbacher et al., 1991) and in Irian Jaya (Pubellier and Ego, 2002).

In intracratonic chains, the “partitioning of deformation” may be associated to the oblique ramp in this case the strike-slip fault has a passive role of the transfer movement coexisted with thrusting system. Through this, the shortening movement is transferred from one line of overlap to another facilitated by a basal decollement level. The oblique ramp is localized in an area where the mechanical properties of rocks vary. This can be realized by a change in thickness of the cover, or by the presence of a pre-existing discontinuity.

The “partitioning deformation” model has not yet been verified in the North African craton despite it has been well tested in intracratonic chains in alpine structures across the European craton, although also that the Atlas chain is affected by an ancient preexisting fault is the southern Atlas accident that is spread over a very large distance. The choice of the study area is not arbitrary, in fact in the Gafsa basin is defined by the eastern limit of the southern Atlas accident and receives the maximum deformation due to the African convergence, In addition it has a particular direction NW-SE different from that of atlasiques structures. This area was interpreted by several authors as old preexisting fault reactivated to dextral strike-slip fault during compressive phases (Zargouni et al., 1985; Zouari et al., 1990). The study of the field and the slickenside exam shows the coexistence of generations’ striations indicating firstly the thrusting and also the strike slip-faults which have not been proven in earlier work, confirming the coexistence of thrusting and strike-slip faults against the previous ideas that assume the thrusting is later result from a transpressional activity. The coexistence of thrust and strike-slip faults are detected at the old preexisting faults, these later show also the indices of normal activity during the Cretaceous (Synsedimentary control). Hence confirm the importance of the heritage tectonic concept and the reactivation of ancient normal faults during the later compressive phases.

Note that the thrusting levels are observed in several series such as Hauterivian Cenomanian Coniacian series and which are all connected by a horizontal basal surface is the decollement level. The study of the major thrusts of Jbal Bouramli, Jbal Ben Younes (FBR, FBR 2, Fb 2) (Figure 8) shows that they are marked by Triassic blades of metric order. As made, the outcrop of these Triassic blades result of the strong blocking during the overlap and indicates the nature of decollement level within the Triassic series. This decollement level was confirmed by several previous works (Ahmadi et al., 2006 Bensalem et al., 2011, Amamria et al., 2015). All these surface and subsurface data has allowed us to provide for the first time, across Tunisian scale and the North African craton, the model of "partitioning deformation", to interpret the evolution of deformation and development of structures in the Gafsa basin.

This interpretation is also proved by the particular geometry of the Gafsa basin that has a NW-SE direction different to the direction of atlassic structures in Tunisia (NE-SW to EW). Therefore the old preexisting normal faults are subjected during compressive phase to compression whose shortening axis is parallel to oblique to these preexisting faults promote the development of oblique “fault relate folds”, what has been already shown in previous studies (Amamria et al., 2013). Indeed, in the intracratonic chains, the model of "partitioning deformation" is generally associated with an oblique ramp (Pubellier and Ego, 2002).

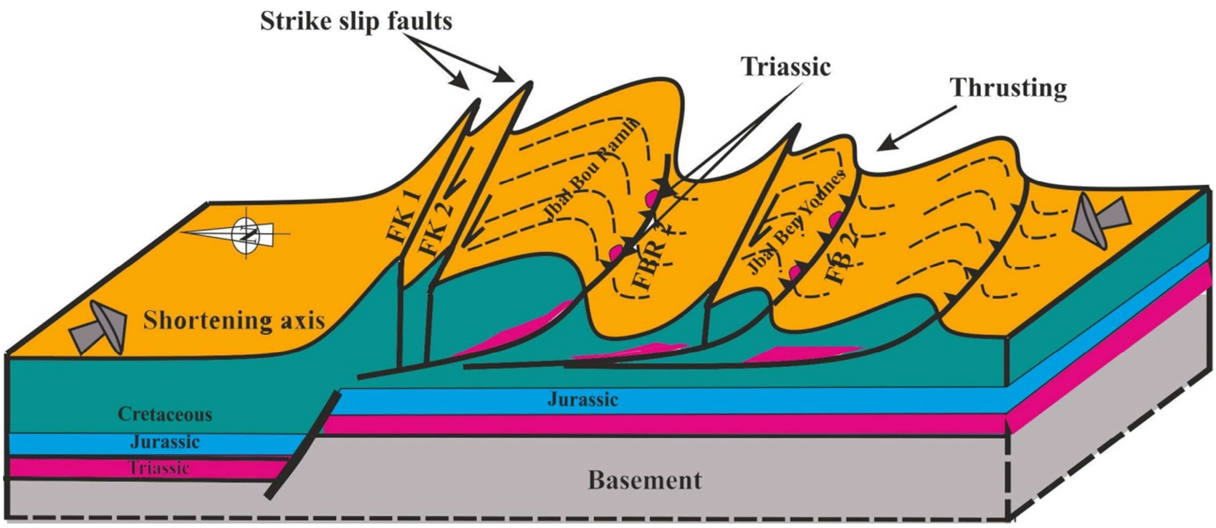

Figure 8: Diagram block interpreted the model of “partitioning deformation” responsible to genesis of belts structures: the basement is separated from cover by a decollement level in Triassic series and all deformation is transported to the cover permeated the coexistence of thrust and strike-slip faults.

5. Conclusion.

The model of "partitioning of the deformation" proposed in the Gafsa basin verify the field data. This model suggest a basal decollement level in the Triassic series which allows firstly to delimits the base from the cover and all deformation will spread in the cover and the base undergoes a simple passive transport. Secondly the decollement level connects multiple thrusting levels which explain the outcropping of Triassic blades within the limits of thrust faults and in several stratigraphic levels.

Comparing the Gafsa basin for the surrounding communities we do not distinguish the same interpretations. Indeed, in the Orbata-Bouhedma junction the shortening axis is perpendicular to the preexisting faults permits the development of folds according a mode of "fault propagation fold" (Bensalem et al., 2011). In the N-S axis the shortening axis is oblique to the preexisting faults giving rise to folds in "fault proppagation fold" mode with “Breakthrough” of ramp (Creuzot et al., 1993). In Gafsa basin and despite that the decollement level is the same (Triassic) the proposal model is "partitioning deformation" which allows the coexistence of thrust and strike-slip faults. This variability is especially due to the variation of the friction angle between the shortening axis and the preexisting fault during compressive phases.

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