jkraus@franconia-geo.com

This is an excerpt of a report assembled by Jürgen Kraus, Mark Cooper, and Darryl Thom for Longreach Oil and Gas in 2013. Text and figures by Jürgen Kraus, unless indicated otherwise. Figure 2.5 by Mark Cooper, Fig. 2.10 by Mark Cooper and Jürgen Kraus. Distributed with permission of Longreach Oil and Gas.

2. Geology

2.1 Geological Setting

Morocco is located at the northwestern passive continental margin of Africa, locally referred to as Maghreb (Arabic: 'west, occident'; Figs. 2.1 & 2.2). It hosts mainly variably deformed to undeformed Mesozoic sedimentary cover rocks. Highly deformed Paleozoic basement crops out in the south (Anti-Atlas) and in isolated inliers north of it in the Meseta domain (Massif Central, Jebilet and Rehamna massifs) and the Central High Atlas (Massif Ancien) (Figs. 2.1 & 2.2). The Anti-Atlas also hosts small inliers of Precambrian basement.

2.1.1 Regional Tectonostratigraphic Overview

Morocco was affected by two orogenies, the Hercynian or Variscan orogeny in the Carboniferous, and the Alpine/Atlasic orogeny in the Tertiary (*Hercynian after the Harz Mountains of Germany; Variscan after 'Curia Variscorum', the Bavarian city of Hof;* both terms are used equally in the literature). Intermittent rifting occurred from the Permian to the Lower/Mid Liassic. The Hercynian orogeny was related to the assembly of the supercontinent Pangea, and the rifting to its demise.

2.1.1.1 Paleozoic

Hercynian Events

The area of Morocco's Atlantic basins originated as part of the submerged northwestern passive margin of the southern continent of Gondwana. The mainly silty-muddy Paleozoic lithologies point to an outer shelf setting. During the Hercynian terminal collision between Gondwana and Laurussia (Old Red continent), the shelf was telescoped into a west-northwest facing fold-and-thrust belt but its tectonostratigraphy is not well constrained (e.g. Piqué 2001, Michard et al., 2010). The now peneplained thrust belt is most coherently exposed in the Massif Central (Fig. 2.2). While it is referred to Zizi (2012) for a more detailed treatment of the Hercynian crustal dynamics, a tectonic correlation of the Meseta domain with its European counterpart is attempted in the following.

Paleozoic Regional Correlation

While knowledge the Hercynian/Variscan orogeny in northwestern Africa is still emerging, it has been relatively well understood for over 80 years around the type locations (Kossmat, 1927). A large-scale zonation of the wide collision zone according to tectonic affinity exists for central Europe and can be used for regional correlation (Fig. 2.3; Kossmat, 1927; Franke, 2000; Simancas et al., 2005). The individual segments constitute tectonic slivers of varying affinities that had been detached from the northern margin of Gondwana and later trapped farther north in its terminal collision with Laurussia (Old Red continent) that was part of the assembly of the supercontinent Pangea. A good regional marker is the Rhenohercynian zone, a structurally inverted backarc basin that hosts the large Harz-Giessen nappes (Fig. 2.3). The zone continues to the west into southern England (Carrick nappe in Cornwall), from where it swings south, outcropping along the southwesternmost promontory of the Portugese coast. It continues south towards the Moroccan coast, where it has fallen victim to the Atlantic opening. In analogy, the idea is entertained here that the Moroccan coastal areas with the Essaouira basin could correspond to the Moldanubian zone immediately north of the Alps. The Moldanubian has been interpreted as being part of the (inverted) thinned passive northern margin of Gondwana (Franke, 2000).

2.1.1.2 Mesozoic to Recent

Since the Mesozoic, Morocco has been located in a triple junction between a continent (Africa), an ocean (the Atlantic), and an active plate collision (Alpine belt system). It has witnessed a complete Wilson cycle that started with the breakup of Pangea (opening of Atlantic and Tethys) and ended with the Tethys closure and the associated Alpine orogeny during terminal continental collision.

The Mesozoic rocks record Pangea's breakup from the Permian onward, and Maghreb's convergence with Europe during the Alpine/Atlasic orogeny. A long initial period of extensional tectonics accompanied by short-lived basaltic magmatism is followed, in most areas, by weak compressional overprinting during the Tertiary Atlasic/Alpine orogeny.

Atlantic Rifting

Continental rifting started in the Permian (based on vertebrate footprints in Argana valley (Jalil and Dutuit, 1996, and references therein; Figs. 2.2 & 2.4). It involved the formation of rift-related basins along both conjugate margins, e.g. Newark and Fundy basins (e.g. Olsen et al., 2000) along Laurentia. The margin of western Morocco constitutes a series of north-northeast trending rift basins that are segmented along east-west trending transfer faults (e.g. Le Roy & Piqué, 2001). Rifting was asymmetrical with a southeast-dipping main detachment: Morocco was on the upper plate, Nova Scotia on the lower plate (Michard et al. 2008, and references therein).

It is proposed here that the original north-northeast–south-southwest Atlantic basin trough (and the west-southwest–east-northeast High Atlas trough formed as a conjugate pair of large shear fractures in northeast-southwest extension quasi-simultaneously during the Permian (grey inset in Fig. 2.2). This is speculative and based on the comparison of the (not-well constrained) ages of rift-controlled sedimentation in both. It is consistent with the development of rhombic depocentres in sinistral transtensional basins in the Central High Atlas (Brede et al., 1992; Pique et al., 2002).

The west-southwest–east-northeast trending High Atlas trough developed into a failed arm that closed during the Tertiary Atlasic/Alpine orogeny. Both trends appear to intersect at Argana valley (Figs. 2.2 & 2.4).

In the Atlantic basins, horsts and half-grabens formed along east-southeasterly dipping faults tracking the underlying Hercynian fold-and-thrust belt. Deformation and therefore depocentres are believed to have migrated subsequently to the west (Le Roy et al., 1998). These half-grabens record local subsidence and are filled with continental syn-rift sediments. Continued extension gave way to Triassic post-rift sedimentation, when the Atlantic basins started subsiding as a whole (sag basin development *sensu* Allen & Allen, 2005). Intermittent Upper Triassic marine influences were recorded by evaporites. At its peak, extension was accompanied by thick Central Atlantic Magmatic Province (CAMP) basaltic rocks at both sides of the opening Atlantic. The bulk of these coincide with the Triassic/Liassic boundary at around 200 Ma (e.g. Knight et al., 2004; Marzoli et al. 2004). The Atlantic drift stage commenced thereafter in the Lower/Middle Liassic. The onset of drifting is locally manifested by the breakup unconformity, an erosional surface characterized by intermediate relief, that records an abrupt change from continental clastic (fluvial) rocks to marine, dominantly chemical sediments (collectively referred to as the drift sequence).

Atlasic/Alpine Orogeny

At 84 Ma, the African plate changed its trajectory and moved towards Europe (Piqué at al., 2002). Terminal collision, i.e. the Alpine orogeny) began at the end of the Eocene and continues until today. Its main effect in Morocco was the closing and extrusion of the High Atlas trough. In the Atlantic basins, this approximately north–south shortening resulted in very gentle, large-scale undulations and the inversion of half-grabens. The Alpine/Atlasic deformation is still ongoing, which is expressed in a continued north-northeast–south-southwest orientation of the *in-situ* principal maximum stress vector.

Discussion: Significance of the Regional Structural Trends

Two structural trends mentioned above are associated with initial Permian extension:

1. North-northeast–south-southwest (Atlantic basin trend)
2. West-southwest–east-northeast (High Atlas trend)

Both mimic their underlying Hercynian structural grains and constitute the main regional trends south of the Rif orogeny (Fig. 2.2; e.g. Brede, 1992; Brede et al., 1992,).

The prominent northeast–southwest trending Middle Atlas, a mountain belt of Atlasic/Alpine age does not follow either direction (Fig. 2.2).

To the north of the Jebilet massif, the north-northeast–south-southwest Atlantic basin trend curves into the northeast–southwest Middle Atlas trend, approximately at the Rehamna massif (Fig. 1.2). The trend becomes very prominent farther north in the strongly deformed Massif Central. It is obvious after careful observation that the Middle Atlas trend constitutes a local deflection of the Atlantic basin trend in approach to the rigid Tertiary/Alpine Rif orogen. The Middle Atlas trend is therefore the locally deflected Atlantic basin trend.

2.1.3 Geology of the Essaouira Basin

Basin Geometry

The Essaouira basin, which contains the Sidi Moktar license, represents a north-northeast–south-southwest trending segment of the passive continental margin of western Morocco (Figs. 2.4 & 2.5), built on the aforementioned Hercynian fold-and-thrust belt.

It is separated from the Doukkala basin to the north by the Safi strike-slip fault and from the Souss basin to the south by the Agadir canyon system and the South Atlasic fault. To the east, it borders the Haouz basin. In terms of orogenic domains, the Essaouira basin belongs to the Western High Atlas (Hafid, 2006, fig. 3.73).

The basin consists of a central north-northeast trending horst (Meskala horst) separating a series of half-grabens facing away from it (Fig. 2.5 & 2.6).

The Essaouria basin is inverted by a single generation of structures related to the approximate north–south compression during the Atlasic/Alpine orogeny: today it constitutes a gentle north–south anticlinorium between compressional uplifts overprinting north-northeast–south-southwest-trending Triassic half-grabens. The anticlinorium is segmented by east-west trending transfer faults.

On a local scale, the half-grabens east of Meskala, Atlasic/Alpine inversion and overprinting produced gentle east–west trending folds (Jeer, N'Dark; Fig. 2.5), and, in special circumstances, north-south trending folds such as Kechoula (see discussion at the end of section 2.1) Some of these structures were traditionally believed to be enhanced by diapiric salt pillows.

Tectonostratigraphic Sequences

12 deep wells through the Hercynian unconformity (e.g. MKL-102, MKL-104; *MKL: acronym for Meskala*) penetrated strongly deformed Paleozoic limestones, mainly fine-to medium grained clastic rocks, and granitic intrusions. These are overlain by Permian to Lower Liassic continental red beds that have been subdivided into 10 members (T1–T10) at Argana Valley (Tixeront, 1973; Hofmann et al., 2000)). These, together with the overlying rocks, are grouped into three sequences separated by major unconformities: syn-rift (T1–T5), post-rift/lower sag sequence (T6–T8), post-rift/upper sag sequence (T9–T10) (The term 'sag sequence' *sensu* Allen & Allen, 2005, is used to designate a basin that experienced regional subsidence during the waning stages of an underlying rifting event). The Atlantic breakup unconformity (top T10) separates the latter from the overlying drift sequence (the Lower/Middle Lias: J2-1 of Fig. 2.7). T1–T2 were originally considered as belonging to the Triassic (Tixeront, 1973). Based on vertebrate fossils, they are actually Permian in age (Jalil and Dutuit, 1996, and references therein).

Hafid (2000, 2006), who conducted the groundbreaking work on the seismic stratigraphy in the Essaouria subsurface, established a terminology more pragmatic for the subsurface interpretation. He refers to the syn-rift (T1–T5) as Tr1a, the lower sag (T6–T8) as Tr1b, and the upper sag (T9–T10) as Tr2 (Figs. 2.7 & 2.8).Yet another classification was created by Le Roy (1997, 1998). All of these are correlated in Bouatmani et al. (2004; Fig. 2.8; note that T8 is here considered as the base of Tr2).

The syn-rift sequence (T1–T5) of up to 6000 m is restricted to easterly facing half-grabens that record local subsidence during initial rifting (Fig. 2.5). The sequence sits on the Hercynian unconformity and contains clastic red beds with untested hydrocarbon potential. It frequently contains one or two levels of basaltic/doleritic magmatic rocks.

The syn-rift sequence has been incompletely drilled through in 5 wells (IMD-1, JRP-1, NDK-2, OTA-3, ZEL-1-1bis) (Fig. 1.1). JRP-1 has penetrated the most complete Triassic sequence in the Essaouria basin (Fig. 1.1).. It is believed that it is the analog to the syn-rift sequence is exposed in Argana Valley.

At Argana Valley (Figs. 2.2, 2.4 & 2.6), T1 constitutes alluvial fans with conglomerates, overlain by more conglomerates, sandstones and mudstones deposited by meandering rivers (T2) and braided rivers (T3). T4 sandstones and silty mudstones reflect playa/alluvial fans/meandering rivers facies. The half-graben fill is topped by T5 sandstones and mudstones of meandering rivers.

The sag sequence/postrift sequence (T6–T10) sits unconformably on top of the half-grabens. It has been penetrated by 49 wells (incl MKL-110) in the Essaouria basin. It is subdivided into a lower (T6–T8) and an upper (T9–T10)

Its lower part (T6–T7a), the lower sag sequence constitutes a fining upward megasequence owing to relative sea-level rise, from fluvial channels through bar deposits to salt lake/sabkha environments. It contains up to two regionally widespread basalt layers.

At the Meskala horst structure (Figs. 1.1, 2.5 & 2.6), the top T5/base T6 (d1; Fig. 2.8) unconformity coincides with the Paleozoic unconformity. This indicates that Paleo-highs such as the Meskala horst were local centres of erosion during T1–T5 half-graben deposition. Therefore, the top Paleozoic may be older on the horsts compared to the half-graben depocentres.

T6a fines upwards from meandering river channels (T6a) to bars (T6b). Fine-grained T6a sandstones contain the Meskala gas reserves.

T7a is a lagoonal sequence of salt with shale and silt intercalations, marking intermittent marine influences. Salt has been found always above T6 with the exception of JRP-1. In JRP-1 the lowermost salt occurs at T4, in the syn-rift sequence. T7b comprises a meandering channel sequence overlain by bar sequences.

The upper sag sequence (T9–T10) is a fluvial fining-up sequence, sandwiched between two unconformities, the top of the T8 CAMP basalt (see above) and the breakup unconformity truncating T10.

T8 is a tholeiitic basaltic sequence that, according to Hafid (2006) correlates with Tixeront's (1973) *basaltes á structure doléritique* at Argana Valley. The latter were recently identified as a succession of pahoehoe flows and simple flows (El Hachimi et al., 2011). Interpreting logs of Meskala and JRP-1 wells reveals repetitive cycles, each characterized by decrease in sonic velocity, resistivity, and density towards the top. Each cycle is terminates upwards by a GR spike slightly underneath a combined jump in resistivity and density to levels at the cycle's base. This trend is interpreted as an increase in vesicles (and fractures) towards a flow top and two flows are separated by paleoregolith. This consistent with the interpretation at Argana of El Hachimi et al. (2011).

T10 consists mainly of fluvial channel sequences grading upwards into bar sequences. Drainage was believed to have been south to north into a delta (Bouatmani et al., 2004), but granitic clasts point to a north to south flow, presumably originating from the granitic part of the Jebilet massif. Despite their 'T' label and albeit being below the breakup unconformity, these rocks belong to lowermost Jurassic (Hettangian). T10 is truncated by the breakup unconformity at the base of J2-1 (Fig. 2.7).

J2-1 constitutes the base of the drift sequence. It consists of interbedded anhydritic carbonates, shales, and marls and acts as a seal for the Triassic reservoirs (Figs. 2.7 & 2.10).

Discussion: Regional Stratigraphic Correlation and Provenance

The Triassic clastic rocks of interest are not exposed in Essaouira basin. The nearest Triassic outcrops are in the Jebilet massif to the north and the Argana valley to the south (Fig. 2.2, 2.5 & 2.6). The well-exposed sequences of the Argana valley are generally used as analogs. It is noted however that Argana valley and Essaouira basin have different provenance. The Argana Triassic sediments are entirely derived from the Massif Ancien, a Paleozoic basement inlier to the east with southern axial-trough drainage in the Triassic (Mader & Redfern, 2011; Figs. 2.2 & 2.6) and today.

Triassic continental deposition in western Morocco was partly controlled by the semi-arid climate with the characteristic Pangean winter monsoon (e.g. Hofmann et al., 2000). Easterly winds prevailed. At Argana, sediments record a generally drying upward/coarsening upward trend. They were in the rain shadow of the Massif Ancien. Rivers were ephemeric and Aeolian sands were deposited during the summers. It is not clear whether Meskala was in the rain shadow of an eastern basement high. A locally wetter climate could explain the increased shale deposition.

Discussion: The Kechoula Structure – Salt Dome or Tectonic Fold?

The Kechoula structure is an inverted east-facing Permo triassic half-graben ca. 10 km northeast of the producing Meskala field (Figs. 1.1, 2.5, 2.9 & 2.11). The half-graben was inverted during north–south compression related to the Tertiary Atlasic/Alpine orogeny. This compression resulted regionally in a single generation of large gentle folds, most of which are east–west trending (e.g. Jeer, N'Dark; Fig. 2.5). The Kechoula fold, in contrast, trends north–south, approximately parallel to the Atlasic/Alpine compression direction. This points to its formation in an approximate east–west compression direction, which never existed. It has been widely believed that Kechoula folding was irregular and triggered by an ascending salt pillow. As a consequence, this 'salt structure' was not drilled below the breakup unconformity.

New seismic mapping yielded evidence for a purely tectonic origin of the fold with a salt pillow lacking. Evidence number 1 is the continuation of the T6a Meskala reservoir horizon, the geometry of which excludes salt doming (Fig. 2.9; see also section 2.4).

Evidence 2 is the presence of asymmetric, parasitic 2nd order folds in competent dolerites that face both westerly and northerly (Fig. 2.9). These folds can only have formed tectonically and in the same single regional north–south stress field that has prevailed from the Tertiary to today.

The Kechoula fold's northerly trend can be explained by the lack of parallelism between the shortening direction and the trend of the half-graben bounding fault, combined with slight curvature of the latter. During north–south shortening, slip along this fault led to sinistral oblique inversion resulting in a local transpression that caused the main shortening across the fault. This resulted in the local development of two simultaneous generations of parasitic 2nd order faults restricted to this inverted half-graben.

The untested Triassic of the Kechoula structure offers new opportunities in the lowermost Liassic T10 fluvial sandstones, and the lateral, here thicker, continuation of the Meskala Upper Triassic T6a fluvial sandstone reservoir (see section 2.4.2).

The Paleozoic-Lower Liassic T10 and the Paleozoic-Upper Triassic T6a petroleum systems share a common source, maturation, and timing of migration. They vary, however, in their reservoir properties, traps and seals.

References

Allen, P.A., Allen, J.R. (2005). Basin Analysis: Principles and Applications. John Wiley & Sons, 549 pp.

Brede, R., (1992). Structural aspects of the Middle and the High Atlas (Morocco), phenomena and causalities *Geologische Rundschau,* 81, 171-184, 1992.

Brede R., Hauptmann M. , and H. Herbig (1992). Plate Tectonics and intracratonic mountain ranges in Morocco-The Mesozoic-Cenozoic development of the Central High Atlas and the Middle Atlas, *Geologische Rundschau ,* 81, 127-141.

Bouatmani, R.; Ahmamou, M. ; El Ouarghioui, A. ; Medina, F. ; El Mourabit, A. & Daoudi, L. (2004). Les environnements de dépôt des formations triasiques de la région de Meskala (bassin d'Essaouira, Maroc) : apport de l'analyse des diagraphies et des carottes. *Bull. Inst. Sci.,* Rabat, section Sci. Terre, 26, 49-67.

El Hachimi, H. ; Youbi,, N. ; Madeira, J. ; Bensalah, M.K. ; Martins, L. ; Mata, J. ; Medina, F. ; Bertrand, H. ; Marzoli, A. ; Munhá, J. ; Bellieni, J. ; Mahmoudi, A.; Ben Abbou, M. & Assafar, H. (2011)- Morphology, internal architecture, and emplacement mechanisms of lava flows from the Central Atlantic Magmatic Province (CAMP) of Argana basin (Morocco). *In* : Van Hinsbergen, D.J.J. ; Buiter, S. ; Torsvik, T.H. ; Gaina, C. & Webb, S. (eds) : *The formation and evolution of Africa : A Synopsis of 3.8 Ga of Earth History*. The Geological Society of London, Special Publication 357, 167-193.

Franke, W., 2000, The mid-European segment of the Variscides: Tectonostratigraphic units, terrane boundaries and plate tectonic evolution, in W. Franke, V. Haak, O. Oncken, and D. Tanner, eds., Orogenic processes: Quantification and modeling in the Variscan belt: Geological Society (London) Special Publication 179, 1–3.

Hafid, M. (2000) : Triassic early jurassic extensional systems and their tertiary inversion, Essaouira basin (Morocco). *Marine and Petroleum Geology,* 17, 409-429.

Hafid, M. (2006). Styles structuraux du Haut Atlas de Cap Tafelney et de la partie septentrionale du Haut Atlas Occidental:tectoniquesalif_ereetrelationentrel'Atlas et l'Atlantique. Notes M_em. Serv. G_eol. Maroc, 465, 174 pp.

Hafid, M., Bally, A.W., Ait Salem. A., Toto, E. (2012). Salt tectonics and structural styles of the western High Atlas and the intersecting Essaouira-Cap Tafelney segments of the Moroccan Atlantic margin. Int. Assoc. Sedimentol. Spec. Publ. (2011) 43, 405–420.

Hofmann, A., Tourani, A. and Gaupp, R. (2000) Cyclicity of Triassic to Lower Jurassic continental red beds of the Arg- ana Valley, Morocco: implications for palaeoclimate and basin evolution. Palaeogeogr. Palaeoclimatol. Palaeoecol., 161, 226–266.

Jalil, N.E., Dutuit, J.-M. (1996). Permian captorhinid reptiles from the Argana formation, Morocco. *Palaeontology*, 39, 907–918.

Knight, K.B.; Nomade, S.; Renne, P.R.; Marzoli, A.; Betrand, H.; Youbi, N. (2004). "The Central Atlantic magmatic province at the Triassic–Jurassic boundary: paleomagnetic and 40Ar/30Ar evidence from Morocco for brief, episodic volcanism". *Earth and Planetary Science Letters*, 22, 143–160.

Kossmat, F., (1927). Gliederung des variszischen Gebirgsbaus. Abh. Sächsisches Geol. Landesamt, 1: 39.

Le Roy, P. (1997) : Les bassms ouest marocams ; leur formation ct leur évolution dans le cadre de l'ouverture et du dévelopcment de l'Atlantique central (marge africame) Thèse Univ. Université de Bretagne Occidentale, France. 326 p

Le Roy, P., Guillocheau, F., Piqué, AA., Morabet, A.M., (1998). Subsidence of the Atlantic Moroccan margin during the Mesozoic. *Can. J. Earth Sci.* ,35, 476–493.

Le Roy, P., Piqué, A. (2001). Triassic–Liassic Western Moroccan synrift basins in relation to the Central Atlantic opening. *Marine Geology*, 172 ,359–381

Mader, N.K., Redfern, J., (2011). A sedimentological model for the continental Upper Triassic Tadrart Ouadou Sandstone Member: recording an interplay of climate and tectonics (Argana Valley; South-west Morocco). *Sedimentology*, 58, 1247–1282.

Marzoli, A.; Bertrand, H.; Knight, K.B.; Cirilli, S.; N. Buratti, C. Vérati, S. Nomade, P.R. Renne, N. Youbi, R. Martini, K. Allenbach, R. Neuwerth, C. Rapaille, L. Zaninetti, G. Bellieni (2004). "Synchrony of the Central Atlantic magmatic province and the Triassic-Jurassic boundary climatic and biotic crisis". *Geology*, 32, 973–976.

Michard, A., Frizon de Lamotte, D., Saddiqi, O., Chaloun, A. (2008). An Outline of the Geology of Morocco. In: Michard, A., Saddiqi, O., Chaloun, A., Frizon de Lamotte, D. (Eds.), Continental Evolution: The Geology of Morocco, 1– 32.

Michard, A., Soulaimani, A., C. Hoepffner, C., Ouanaimi, H., Baidder, L., E.C., Saddiqi, O. (2010). The South-Western Branch of the Variscan Belt: Evidence from Morocco. *Tectononphysics*, 492, 1–24.

Olsen, P.E., Kent, D.V., Fowell, S.J., Schlische, R.W., With- jack, M.O. and LeTourneau, P.M. (2000). Implications of a comparison of the stratigraphy and depositional environ- ments of the Argana (Morocco) and Fundy (Nova Scotia, Canada) Permian-Jurassic basins. Actes de la Premiere Reunion du Groupe Marocain du Permien et du Trias. Hilal Impression, Oujda, 165–183.

Pique, A. (2001). Geology of Northwest Africa. Beiträge zur regionalen Geologie der Erde, Band 29. Schweizerbart Science Publishers. 310 pp.

Piqué A., Tricart P., Guiraud R., Laville E., Bouaziz S., Amrhar M., A ̈it Ouali R., (2002).The Mesozoic-Cenozoic Atlas belt (North Africa): An overview. *Geodinamica Acta* 15 185–208

Schlüter, Th. (2008). Geological Atlas of Africa. 2nd Edition. Sprinter-Verlag Berlin Heidelberg.

Simancas, J.F., Tahiri, A., Azor, A., González Lodeiro, F., Martinez Poyatos, D., El Hadi, H. (2005).The tectonic frame of the Variscan-Alleghanian Orogen in Southern Europe and Northern Africa. *Tectonophysics,* 398, 181-198.

Tanner, D.C., Brandes, Ch., Leiss, B. (2010). Structure and kinematics of an outcrop-scale fold-cored triangle zone. *AAPG Bulletin*, 94, 1799–1809.

Tixeront, M., (1973). Lithostratigraphie et mineralisations cupriferes et uraniferes syngenetiques et familieres des forma- tions detritiques permo-triasiques du couloir d'Argana (Haut- Atlas occidental, Maroc). *Notes Serv. Géol. Maroc*, 33, 249, 147-177.

Zizi, M. (2012). Pre-prospectivity report Sidi Moktar Exploration Permit. Longreach Oil and Gas internal report.

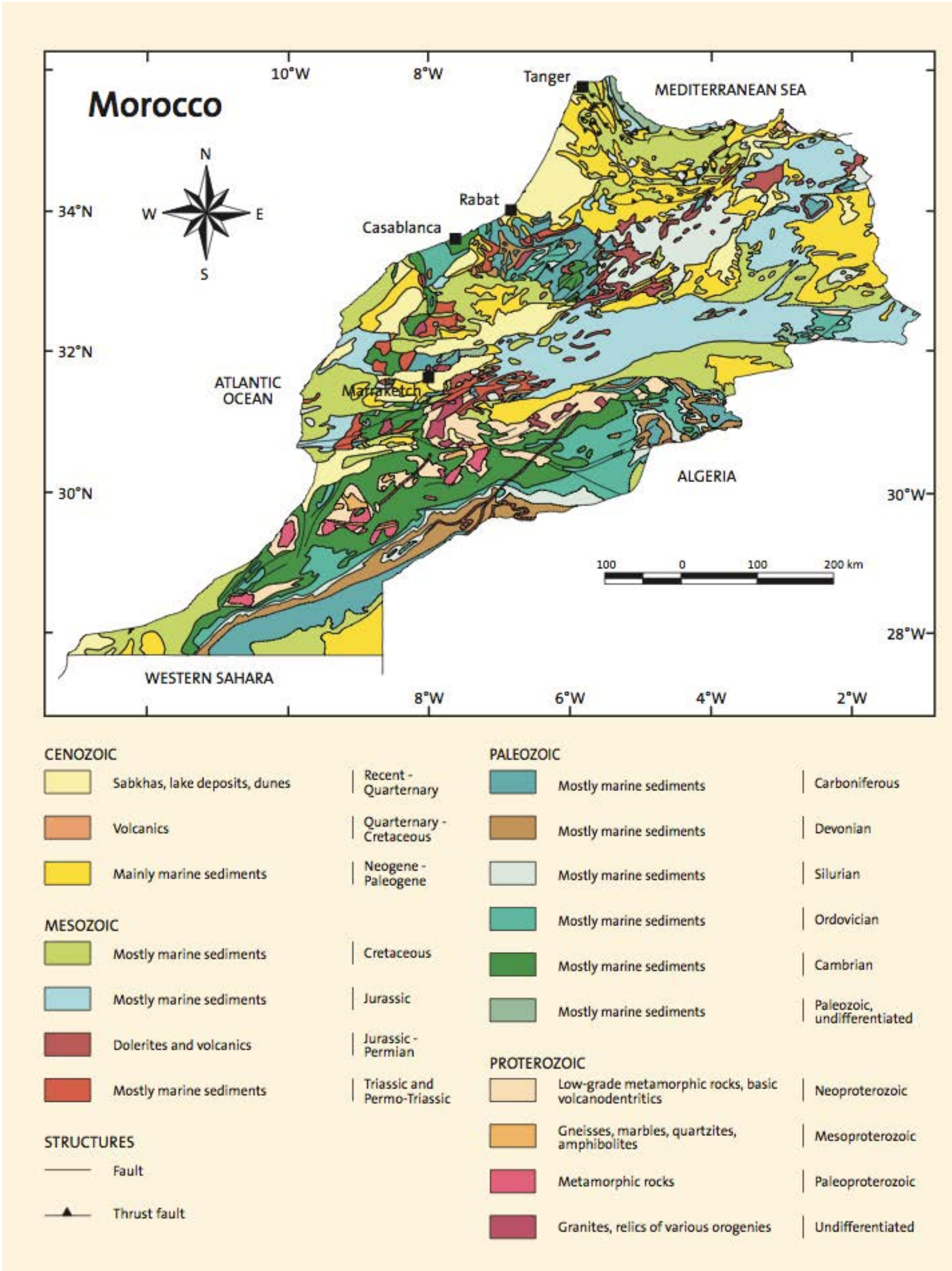

Fig. 2.1: Geological overview map of Morocco (from Schlüter, 2008).

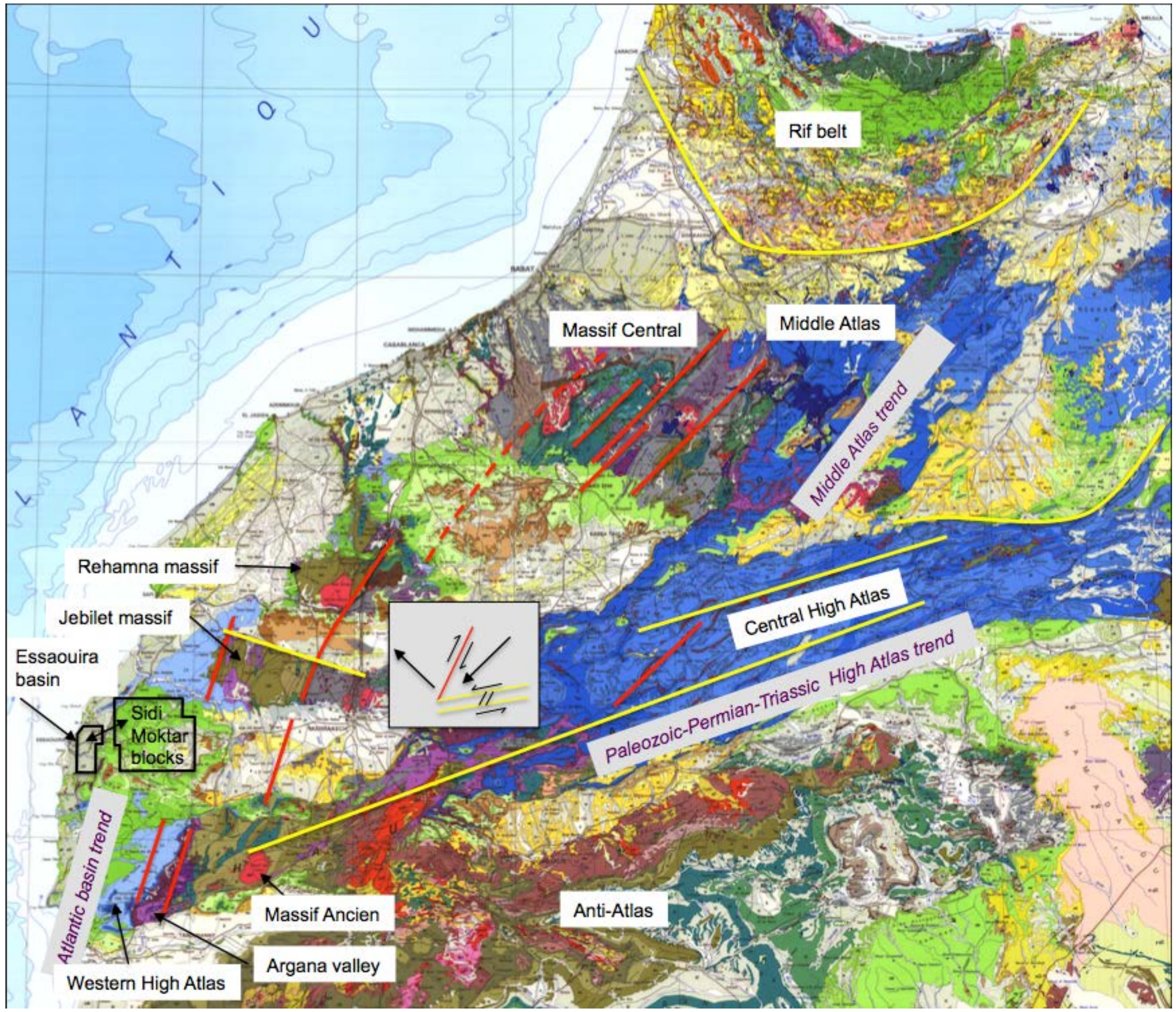

Fig. 2.2: Geological map of northwestern Morocco annotated with the main the structural trends. Inset shows compression direction during initial Permo-Triassic rifting leading to a conjugate set of large fractures (Atlantic trough and High Atlas).

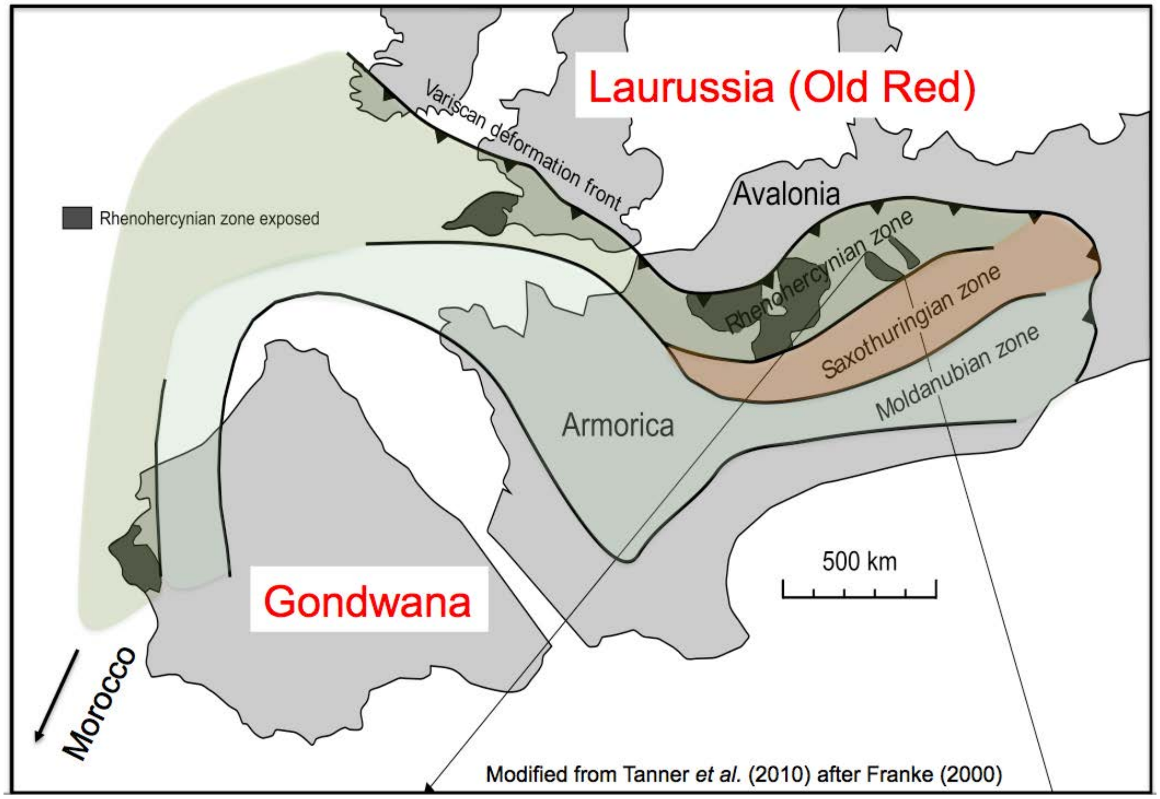

Fig. 2.3: Variscan tectonic zones of central to southwestern Europe.

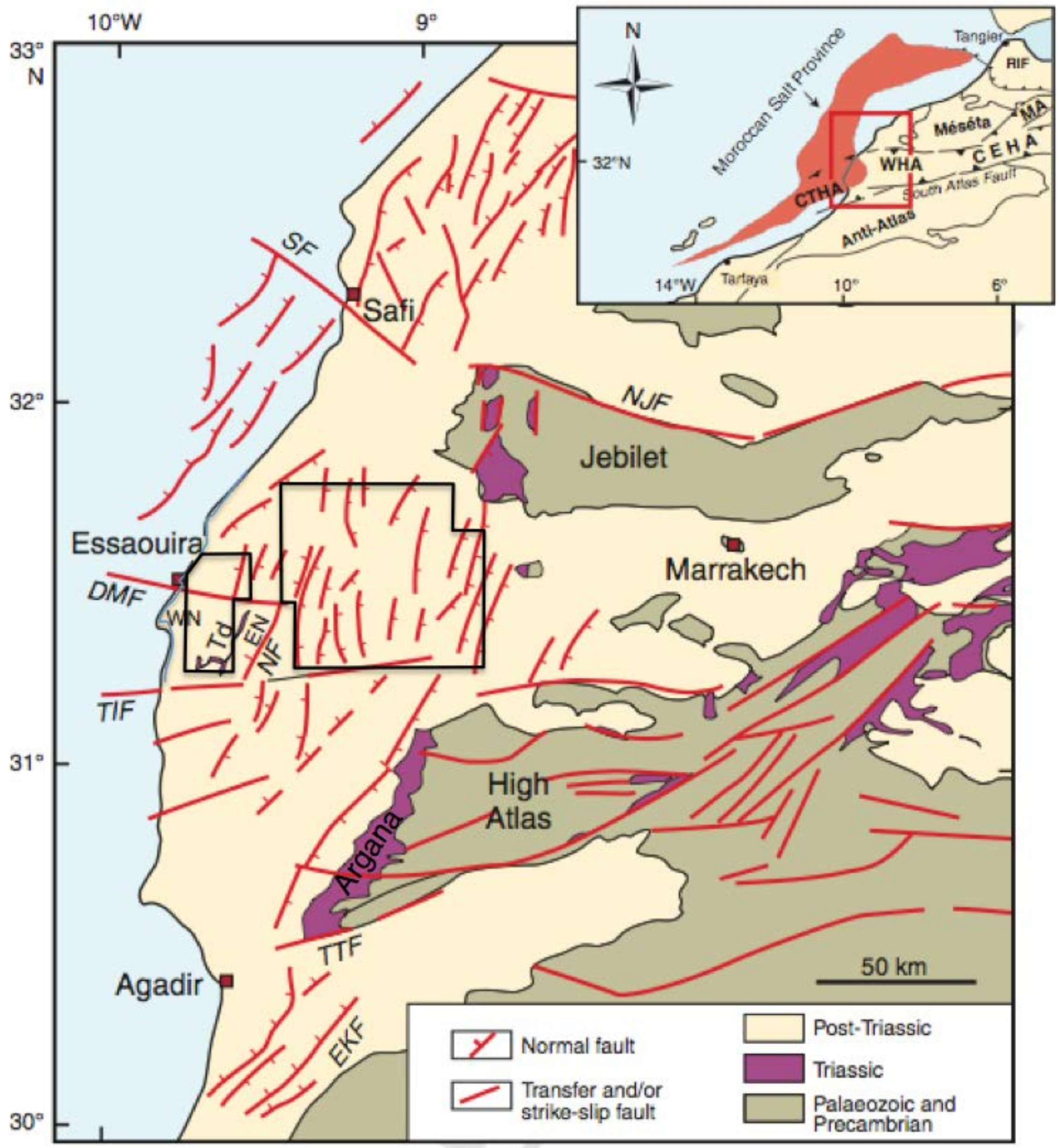

Fig. 2.4: Structural map of Western Morocco with the Sidi Moktar block boundaries. From Hafid et al. (2012).

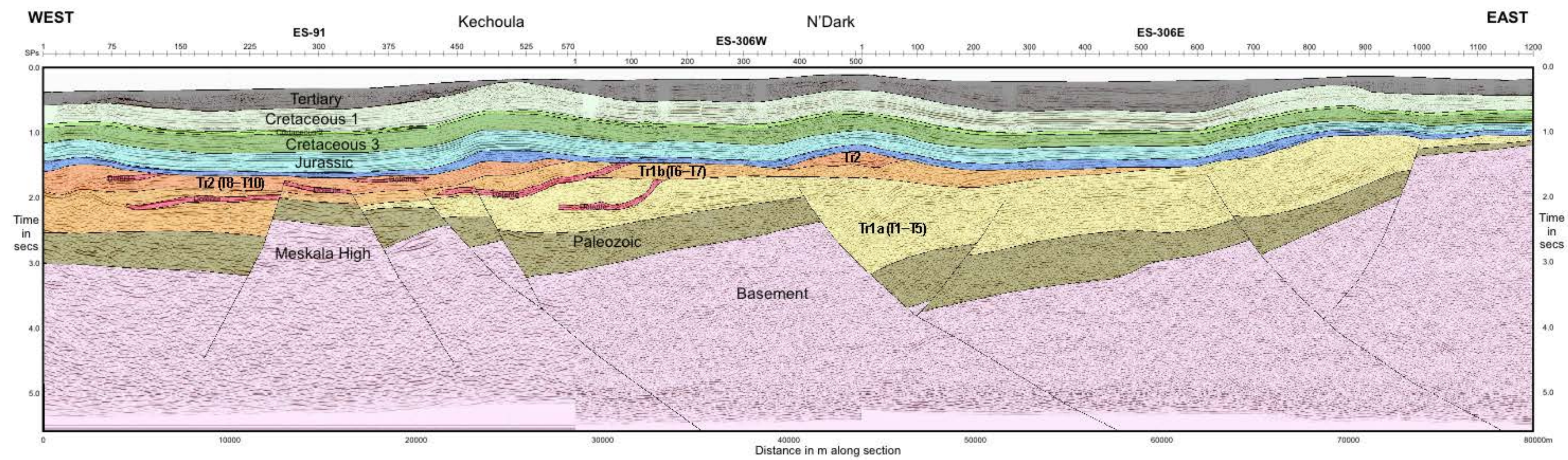

Fig. 2.5: Regional East–West cross section.

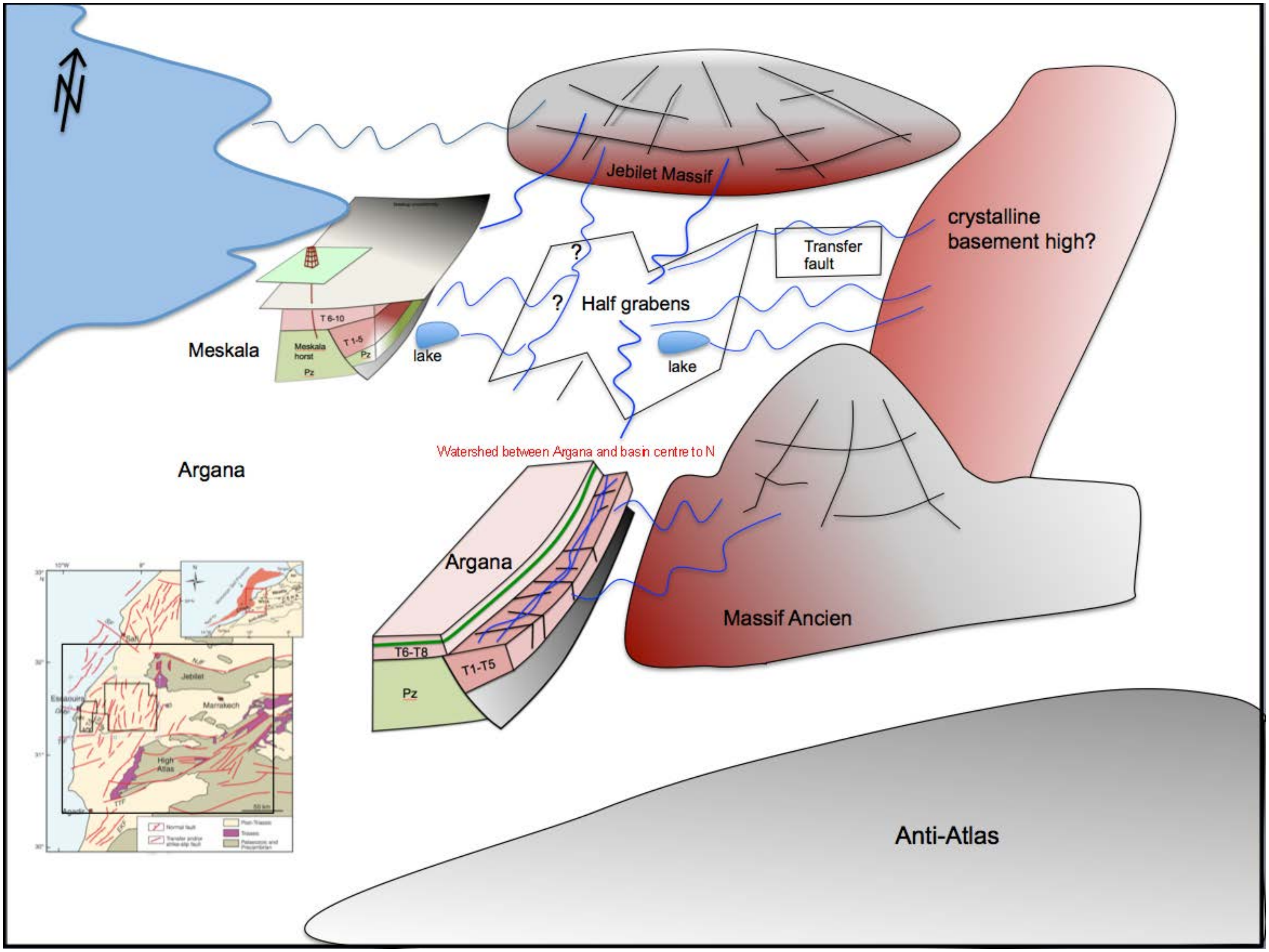

Fig.2.6: Schematic Triassic paleogeography of the Essaouira basin**.**

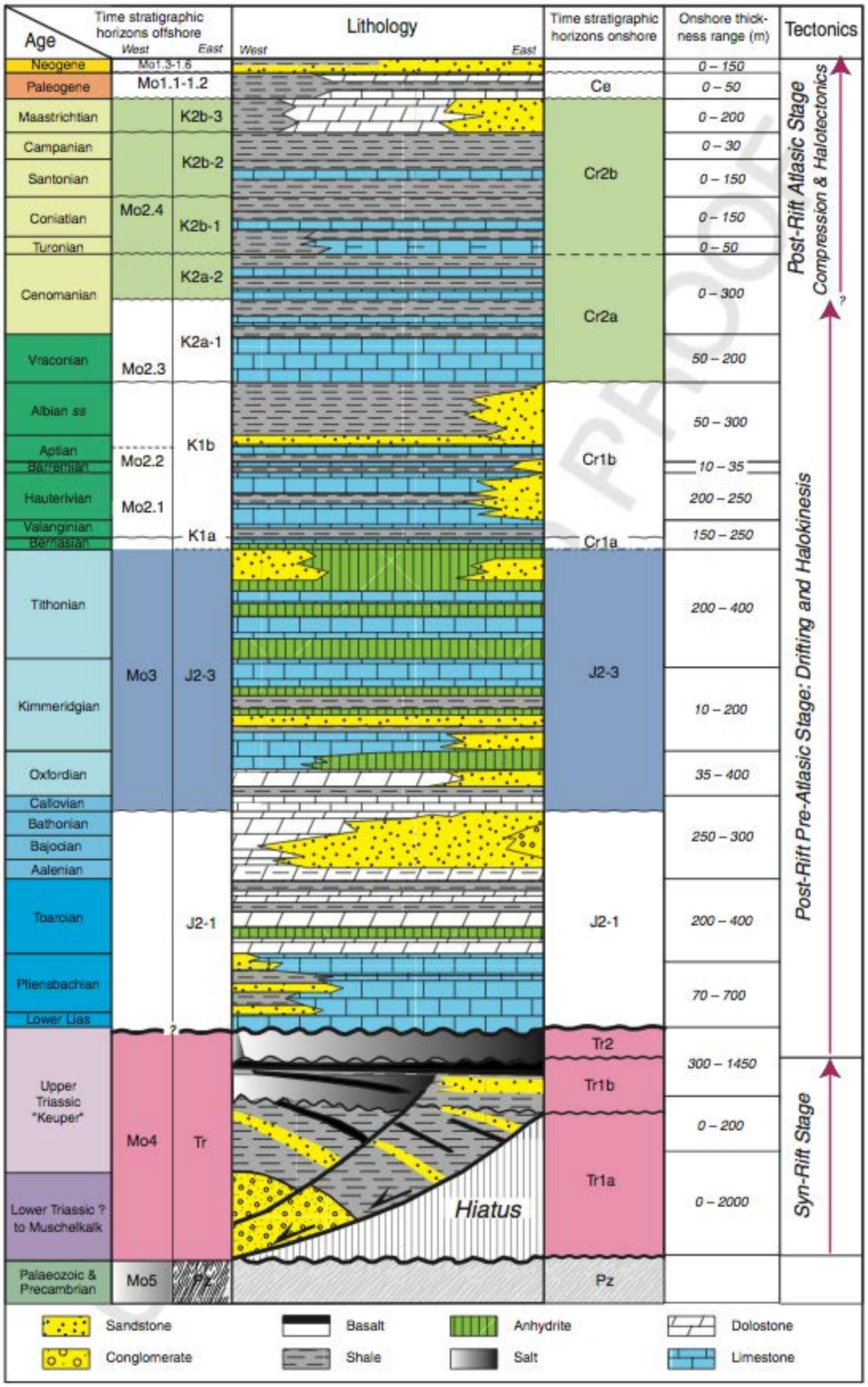

Fig. 2.7: Synthetic stratigraphic column of the onshore Essaouira Basin with age and correlation of seismostratigraphic subdivisions. From Hafid et al. (2012).

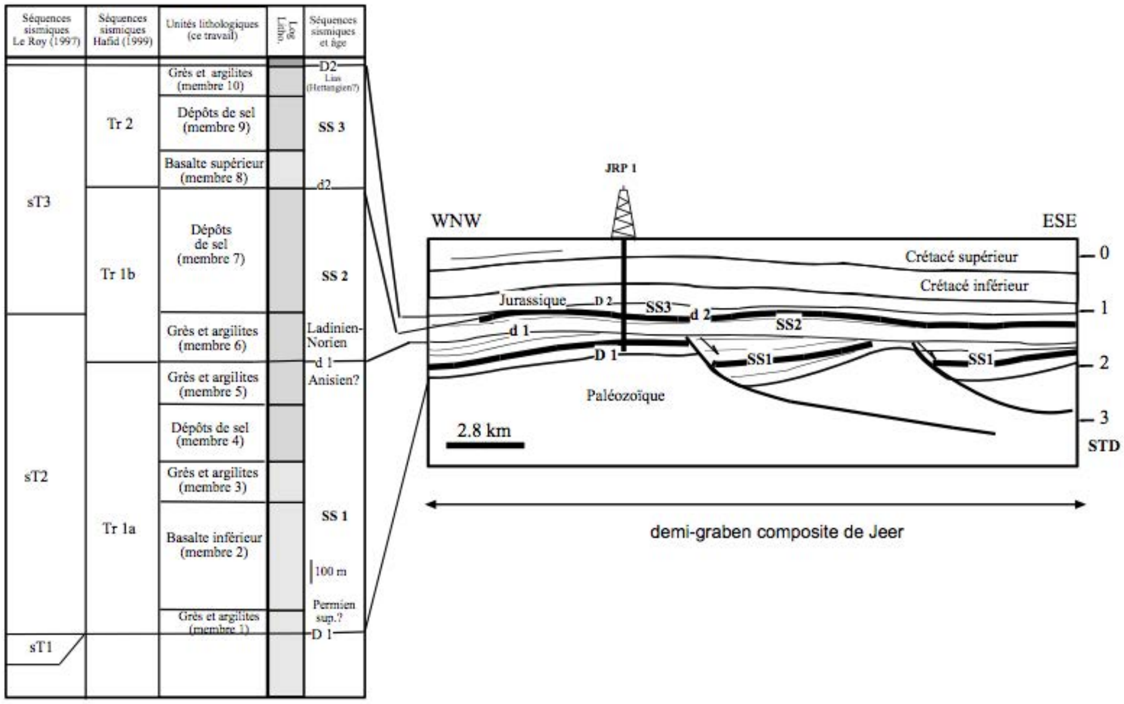

Fig. 2.8: Permo-Triassic lithological sequences in JRP-1 and their subdiivision according to different authors. D1 and D2 are the Hercynian unconformity and the breakup unconformity, respectively; d1 and d2 are intra-Triassic unconformities. From Bouatmani et al. (2004).

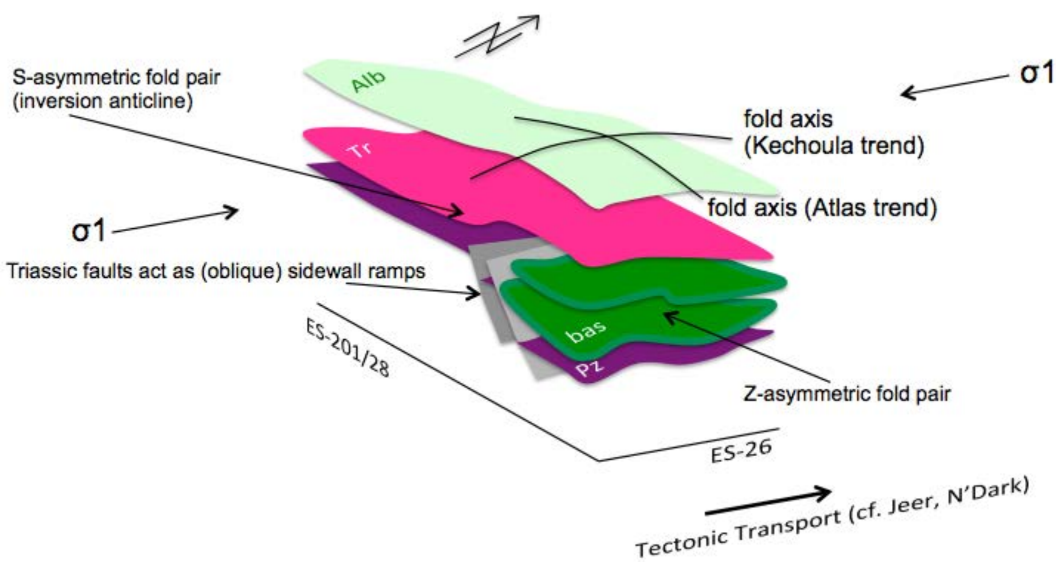

Fig. 2.9: Kechoula structure Atlasic/Alpine deformation model: simultaneous initiation of two 2nd order fold generations.

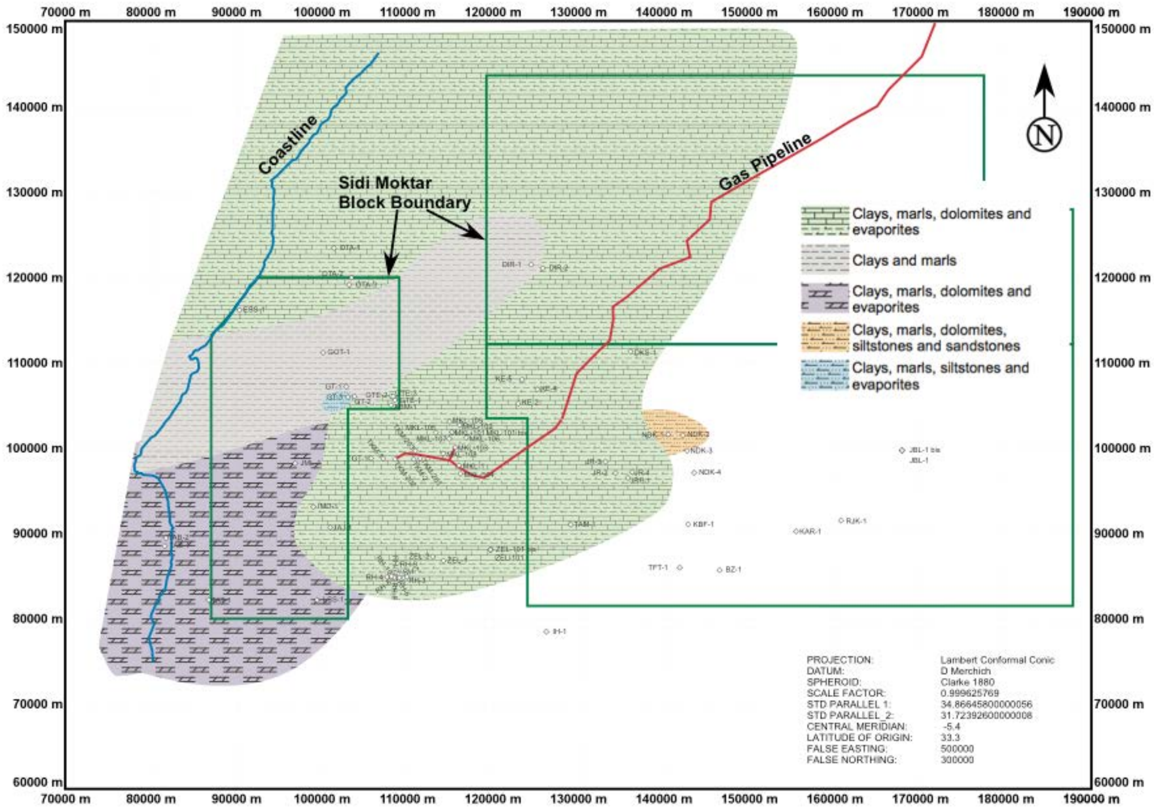

Fig. 2.10: Map showing sealing rocks directly overlying the breakup unconformity.

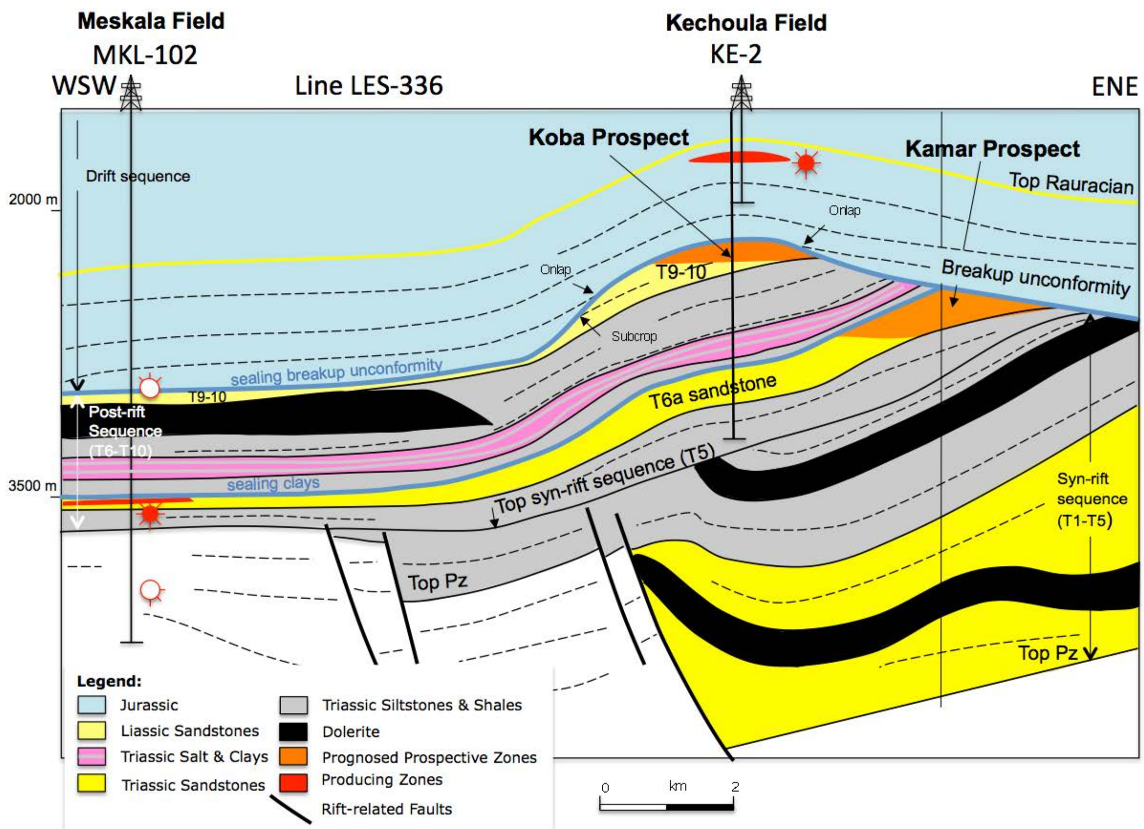

Fig. 2.11: Cross section showing the Koba and Kamar prospects in relationship to the Kechoula and Meskala structures.