Origin of clastic dykes and normal faults affecting the lacustrine limestones within the Neogene Saiss basin, Northern Morocco

Origen de diques clásticos y fallas normales en las calizas lacustres de la cuenca neógena Saiss, norte de Marruecos

Hmidou El Ouardi[1], Afaf Amine[2], Selma Zouiten[3], Said El Makrini[1], Mohamed Habibi[1], Hassane El Makrini[1] and Mustapha Boualoul[1]

1 Equipe CartoTec, Department of Geology, Faculty of Sciences, University Moulay Ismail of Meknes, PB. 11201 Zitoune, Morocco. h.elouardi@umi.ac.ma, s.elmakrini22@gmail.com, m.habibi@umi.ac.ma, h.elmakrini@gmail.com, m.boualoul@umi.ac.m
2 Geosciences, water and environment Laboratory, Department of Geology, Faculty of Sciences, Mohammed V University in Rabat, 4 Avenue Ibn Batouta, B.P. 1014-Morocco. a.amine@um5r.ac.ma
3 Centre Régional des Métiers de l'Education et de la Formation (CRMEF), Fès-Meknès, Morocco. selma.zouiten@gmail.com

ABSTRACT

Normal faults and clastic dykes are common structures affecting Plio-Quaternary lacustrine limestones in the foreland Saiss basin, Northern Morocco. These dilational and extensional features follow two preferential directions NNW–SSE and NE–SW and are related to the recent quaternary tectonic episodes occurring within massive limestones and travertines. The tensional features have been studied at different sites in Meknes city and the surrounding areas. The normal faults analyzed at different outcrops are listric-shape faults, affecting both sandstones and limestones, and sometimes determine horst and graben structures. Clastic dykes occur only in the limestone beds, they are filled with red-clays resulting from the leaching of soils, produced by rainwater infiltration and by the rock clasts enclosed in the wall. They are systematically vertical to sub-vertical arranged, and associated to normal faulting and fractures. Our finding defines the late Quaternary extensional tectonics and contributes to understand the origin of these dilational features.

Key-words: *Recent deformation, Clastic dykes, Normal faults, Saiss basin, Northern Morocco.*

RESUMEN

Fallas normales y diques clásticos son estructuras comunes que afectan a las calizas lacustres de la cuenca de antepaís Saiss, al norte de Marruecos. Estas estructuras extensionales y de dilatación tienen dos direcciones principales NNW-SSE y NE-SW y están relacionadas con episodios tectónicos recientes cuaternarios en calizas masivas y travertinos. Estas estructuras tensionales se han analizado en diferentes localizaciones de la ciudad de Meknes y áreas cercanas. Las fallas normales tienen geometría lístrica y afectan a areniscas y calizas, determinando en ocasiones estructuras de tipo horst-graben. Los diques clásticos aparecen solamente en las calizas, rellenos de arcillas rojas resultado de la alteración de suelos por la infiltración de agua de lluvia y clastos procedentes de las paredes. Tienen una disposición vertical a subvertical y están asociados a las fallas normales y fracturas. Estos resultados definen la tectónica extensional del Cuaternario tardío y contribuyen a comprender el origen de estas estructuras tensionales.

Palabras clave: *Deformación reciente, diques clásticos, fallas normales, Cuenca Saiss, norte de Marruecos.*

Geogaceta, 72 (2022), 63-66
ISSN (versión impresa): 0213-683X
ISSN (Internet): 2173-6545

Fecha de recepción: 25/01/2022
Fecha de revisión: 22/04/2022
Fecha de aceptación: 27/05/2022

Introduction

Neptunian dykes, normal faults, fissure-fill features and associated cavern systems are common structures within carbonate sequences worldwide (Lehner, 1991; Cozzi, 2000; Hardman et al., 2020 and references cited there in). Carbonate cavities are commonly attributed to dissolution processes. However, fissure-fill networks and void-like forms are widely recognized like as near-surface dilational fractures (Ferrill and Morris, 2003; Holland et al., 2011). It is important to differentiate them from the injectites, which correspond to clastic fillings from the underlying or lateral sandy series (Monnier et al., 2015). Such features occur widely within the Plio-Quaternary limestones constituting the top of the Saiss Neogene sediment infill. We describe here the nature and significance of many fissure-fill networks hosted in fractured plio-quaternary limestone cropping out in dozens of quarry walls in the urban perimeter of Meknes city, and determine the stress conditions responsible for their formation using WinTensor software (Delvaux and Sperner, 2003).

Our finding sheds light on the recent tectonic evolution of the Saiss foreland basin.

Geological setting

Regional context and stratigraphy

The Saiss basin, Northern Morocco, (Fig. 1a) lies within the south Rifian corridor stretching c. 300 km from the Atlantic Ocean westwards to Taza city to the East (Capella et al., 2017). It is considered as a foreland Neogene basin with an assymetric Cenozoic infill sequence, the foredeep part is located to the North flank of the basin, close to the southern Rifian Ridges between the two famous cities of Fes and Meknes. Cenozoic sequences form well-bedded sedimentary succession (Fig.1a, b and c) starting with Blue marls Fm. of Tortonian age, overlying directly the Liassic carbonates of the Tabular cover, before sharply transitioning to cross-bedded sandstones and sands attributed to the upper Miocene-Pliocene. The latter are overlain by Plio-Quaternary lacustrine limestones and sometimes by calcareous tuffs and travertines.

In this paper, we focus the urban zone of Meknes city and surrounding area (Western part of the Saiss basin), where typical stratigraphic column are established from several quarries. Two sections from ''Oued Boufekrane" (south sector) and ''Belle Vue" (north sector) are presented (Fig.2).

In Oued Boufekrane site (Figs. 1c and 2), sedimentary succession outcrops begin with thick cross-bedded yellow-fawn sandstones and sands (c. 40 m), the later are overlain by sandy-tuffs (3 m) and then by a reddish level of clays (40 cm), followed by massive milky-white limestones (3 m), calcareous tuffs (2 m), tuffs are overlain by another limestone bed (40 cm) and finally at the top of the serie a thick red soil (60 cm).

In the Belle vue (Figs. 1b, 2), the Neogene sequence begins with blue marls Fm. overlain by conglomerates (30 cm) and sands and sandstones (2 m), massive limestones (3 m) and red soils (50 cm).

Structural evolution of Saiss basin

Since the end of Liassic, this area of the present Saiss basin has been emerged. From the Upper Miocene, the Saiss basin subsided in response to the structuring of the Rif chain following the North-South convergence between the African and Eurasian plates (Morel, 1989). Saiss basin is thus thought to be related to the southward rifian tectonic escape (Chalouan et al., 1986; Poujol, 2014 and references cited therin). It is a typical foreland basin experiencing one or more phases of extensional tectonics, subsidence and sedimentation, leading to the formation of large, listric, steeply dipping to sub-vertical NE-SW and NNW-SSE faults and fractures.

Saiss basin is affected by two main regional faults: the NW-SE Taoujdate fault (or flexure) collapsing the eastern part of the basin (Saiss of Fes) compared to the raised plateau of Meknes, and the NE-SW trending Ain Orma fault limiting the plateau of Meknes on the west side and having controlled the sedimentation since the Jurassic and during the Neogene (Sani et al., 2007).

In the Saiss basin, the marine blue Tortonian-Messinian marls cover directly Liassic carbonates, they are overlain by Mio-Pliocene sands and sandstones and finally by Plio-Quaternary lacustrine limestones. Miocene marine sedimentation is substituted by Plio-Quaternary continental sedimentation testifying a generalized regression in this basin following the closure of the south Rifian corridor to the East during Messinian times (Krigjman et al., 1999; Capella et al., 2018), which ensured communication between the Atlantic and the Mediterranean.

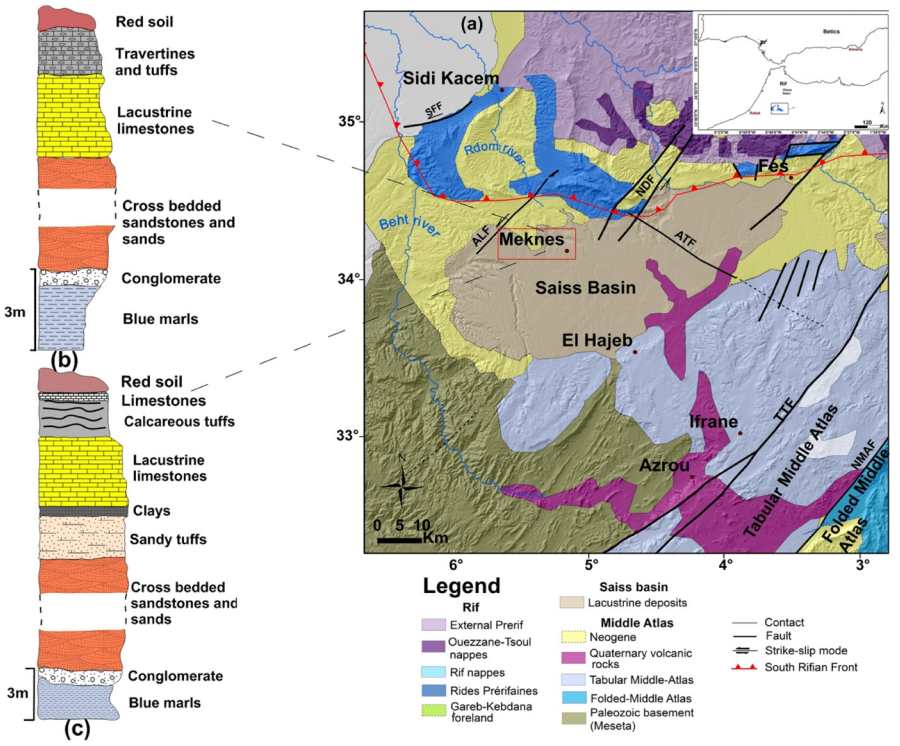

Fig. 1.- (a) Structural map of the Saiss basin, South Rifian Ridges-Middle Atlas from Michard (1976) and Chalouan et al. (2014), mapped upon a shaded relief. Location of Fig.2 is shownALF- Ain Lorma Fault; NDF-Nzala Des Oudayas Fault; NMAF-North-Middle-Atlas Fault; SFF-Sidi Fili fault; TTF-Tizi-n-Trattene Fault. (b) and (c) Stratigraphic columns for the Saiss Basin. See figure in colour on the web.

Fig. 1.- (a) Mapa geológico de la de la cuenca de Saiss. Cordillera sur-Rifeña-Atlas Medio, de Michard (1976) y Chalouan et al. (2014), sobre relieve sombreado. Localización de la Fig. 2 en recuadro rojo. ALF- Falla Ain Lorman; NDF- Falla Nzala Des Oudayas; NMAF-Falla Nor-Medio Atlas; SFF- Falla Sidi Fili; TTF- Falla Tizi-n-Trattene. (b) y (c) Columnas estratigráficas de la cuenca Saiss. Ver figura en color en la web.

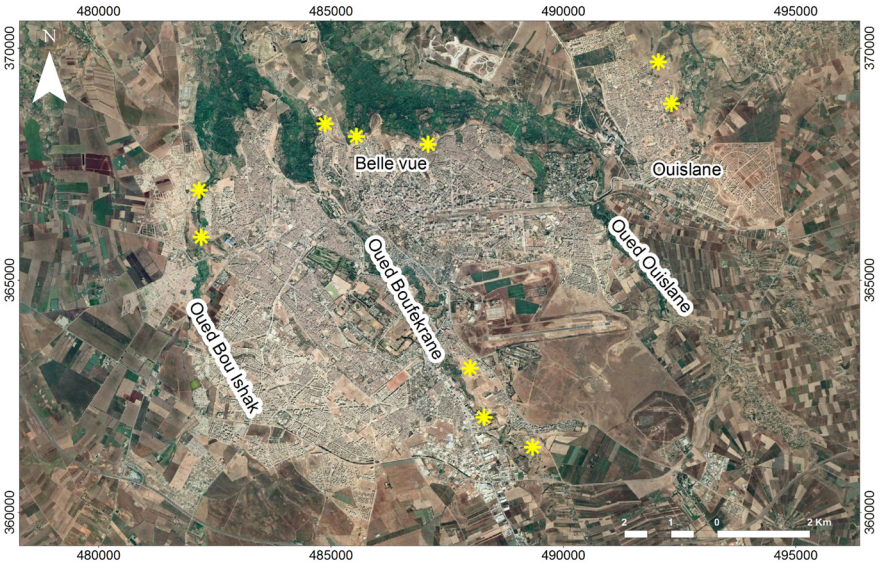

Fig. 2- Google Earth image showing the location of field studied sites in the Meknes área, Saiss basin. See figure in colour on the web.

Fig. 2.- Imagen de Google Earth mostrando las localizaciones de los sitios de estudio en el área de Meknes, cuenca Saiss. Ver figura en color en la web.

Field geological data

Normal faults, fracture systems and their fills were studied in 10 localities in Meknes city and surrounding area, where they are well exposed in lacustrine limestones mainly along quarry cut-fronts and along the banks of steep-sided valleys of Bou Ishak, Boufekrane and Ouislane crossing Meknes city.

Shallow-dipping normal faults

Listric-shaped normal faults occur in different sites along Bou Ishak and Boufekrane valleys and in "Belle Vue" (Fig.3). Locality determining the northernmost edge of lacustrine limestone outcrops. These faults affect both the blue marls Fm. deposits and the overlying strata (sandstones and limestones) in the Bou Ishak valley and determine horst and graben structures affecting sandstones and lacustrine limestones. Sometimes, they determine tilted blocks where they affect massive limestone beds (Oued Boufekrane) (Fig.4b). The whole measured fault planes are oriented NW-SE to NNW-SSE, some fault planes show slickenlines displaying normal shear sense, with a rake varying from 80 to 86°, along planes that strike from 140° to 160° and dip from 60° to 25° E or W.

Vertical to sub-vertical forms

Brittle fractures are well-preserved, cross-cutting lacustrine limestones and underlying sands and sandstones (Fig.3). These structures are characteristically highly dilational in character and consist of vertical to sub-vertical clastic dykes, gashes and kite-shaped vertical fractures. Red clastic sediments and brecciated wall limestone rocks fill the fault fissures. A large lacustrine limestone clasts lie suspended in a red matrix suggesting that the emplacement of wall blocks was contemporaneous with the infilling with red soil sediments (Fig.4). Some of the exposed fracture planes appear to have been smoothed (Fig.3k), other margins of these fractures are rough surfaces showing sub-angular asperities as like as jigsaw-type brecciation (Fig.4-l) (Hardman et al., 2020). Fractures showing smoothed cavity walls suggest some minor karstification prior to soil infilling.

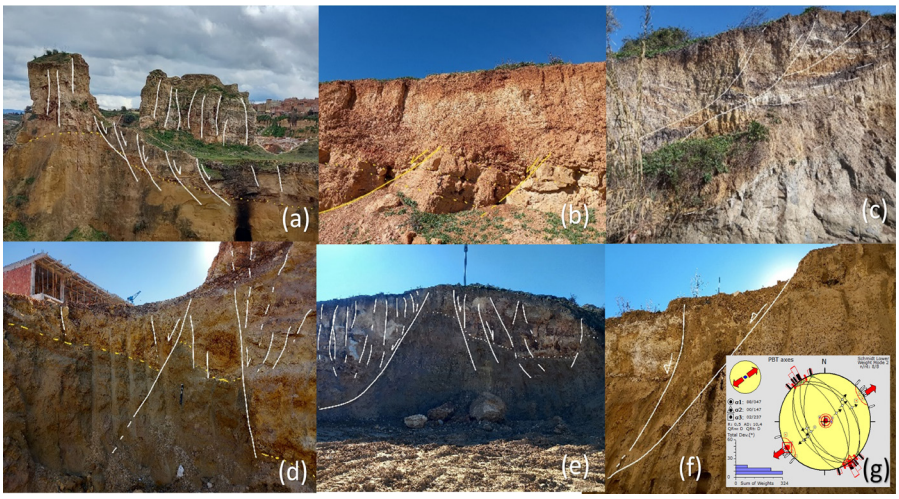

Fig. 3.- Normal faults affecting neogene sediments within Meknes area: (a) and (b). Oued Boufekrane, (C). Oued Bou Ishak, (d), (e) and (f). « Belle Vue » locality. (g). Stereoplot corresponding to normal faults measured at Oued Boufekrane showing the NE-SW extensional direction. See figure in colour on the web.

Fig. 3.- Fallas normales afectando a sedimentos neógenos en el área de Meknes: (a) y (b). Oued Boufekrane. (c) Oued Ishak, (d) y (f). Localidad "Bella vista" (g). Stereoplot correspondiente a las fallas normales medidas en Oued Boufekrane que muestra la dirección extensional NE-SO. Ver figura en color en la web.

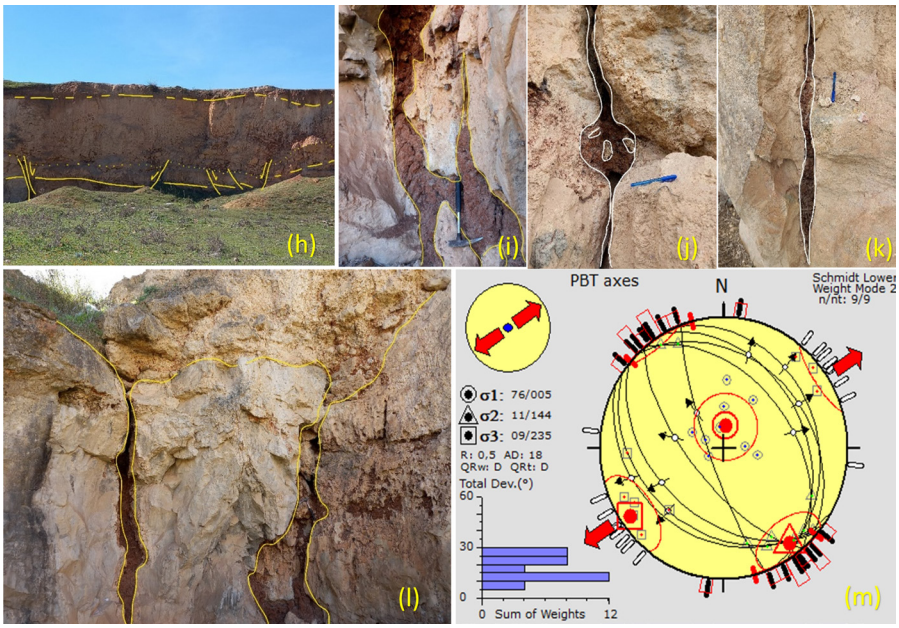

Fig. 4.- Features analyzed at Oued Boufekrane site : (h) panoramic vue of quarry-cut section, (i) fissure-fill within limestones, (j) kite-shaped fracture filled with red clays and limestone clasts, (k) vertical single gash filled with red clays, (l) clastic dykes with sediment infilling, (m) Stereoplot of the whole features showing the NE-SW corresponding extension). See figure in colour on the web.

Fig. 4.- Elementos analizados en la zona de Oued Boufekrane: (h) vista panorámica de una sección en cantera,(i) fisura en calizas rellena (j) fractura rellena con arcillas rojas y clastos de caliza, (k) fractura rellena con arcillas rojas, (l) diques clásticos con relleno sedimentario, (m) stereoplot con el total de fracturas mostrando la extensión con dirección NE-SO. Ver figura en color en la web.

Nature of infills

Sedimentary fills in subvertical V-shape fractures, gashes and kite-shaped fractures are red soil sediments constituting the matrix of lacustrine limestone blocks of different sizes and shapes. The whole infilling sediments (Fig. 3i-l) are a chaotic breccia fills with angular clasts of wall rock limestone formed by collapse of the wall rock into open fractures, suggesting that brecciation occurs coevally with sediment infilling. These features suggest that fissure-hosted clast sediments, listric-shape normal faults and rock wall collapses are contemporaneous, sometimes later than minor karstification caused may be by rainwater infiltration.

Interpretation and discussion

Our observations indicate that clastic dykes and fault-related fissures formed within lacustrine limestones are common features in Meknes area and the Saiss basin. Open fissures and cavities are infilled with red soil clays and wall rock limestones fallen downwards along the subvertical fracture planes. Smoothed cavity walls suggest that some minor karstification occurred prior to infilling sediments. Normal listric faults are accompanied by slight tilting blocks and disappear upwards within fine sediments. Sometimes, void and filled cavities are aligned along the surfaces of normal faults (Benedicto et al., 2003), as like as the same feature shallowly dipping within thin bedded sediments and steeply dipping within underlying thick limestone beds (Van Gent et al., 2010). The overlying fine sediments appear disrupted and are folded over the normal faults determining very open roll-over anticlines. Most of the fracture cavities and sediment fills show both rough and sometimes smoothed walls with evidence of tectonic aperture widening and karstification, maybe prior to infilling sediments. Some local faults preserve slickenlines and shear offsets suggesting tectonic faulting contemporaneous to open fissure formation. The results suggest that the NNW-SSE normal faults and subvertical tensile fractures corresponding to clastic dykes filled with red soil sediments are formed under a recent NE-SW extensional stress. Vertical tensile fissures filled with red soil clays in the near surface massive limestones are linked at depth to inclined hybrid and shear fractures with dilational jogs at the base of lacustrine limestones becoming shallowly dipping in the underlying blue marls. These features are of tectonic origin inferred to recent Quaternary southwestwards escape of the alpine Rif belt (Amine et al., 2020, 2021) leading to the formation of the adjacent extensional Cenozoic foreland Saiss basin. This suggests that they grew parallel to the NNW-SSE (Poujol et al., 2017) regional compressional axis (σ1) perpendicularly to the ~~local~~ NE-SW extensional axis (σ3).

Conclusions

Vertical tensile features, clastic dykes and normal faults occurring mainly within lacustrine limestones can very well be the geological record for tectonic instability front of the Rif belt. They are related to an extensional tectonic regime characterizing the foreland Saiss basin that may be contemporaneous with the recent southward escape of the South rifian ridges. Using the data from these tensional features in the stress analysis for this portion of the Saiss basin has enabled a better understanding the recent evolution of this basin according to the NNW-SSE shortening direction causing a NE-SW extensional direction within the Saiss basin. The geometry of fissure-fill network, their density and distribution mainly along the northern flank of the basin can argue this interpretation, without forgetting to point out that the Upper Pliocene-Quaternary shortening phase has been widely well ascertained in the region.

Author contributions

All authors contributed to the field works and their interpretation. Hmidou El Ouardi and Afaf Amine wrote the manuscript.

References

Amine, A., El Ouardi, H., Zebari, M., El Makrini, H., (2020). J. African Earth Sci. 167, 103833 https://doi.org/10.1016/j.jafrearsci.2020.103833.

Amine A., El Ouardi H., Mazouar M., Habibi M. and Boualoul M. (2021). Geogaceta 70, 11-14.

Benedicto, A., Schultz R. A. and Soliva, A. (2003). Geophysical Research Letters 30, (20), 2076, 1-4. https://doi.org/10.1016/S0191-8141(96)00060.

Capella W., Matenco L., Dmitrieva E., Roest W.M.J., Hessels S., Hssain M., Chakor-Alami A., Sierro F.J., and Krijgsman W. (2017). Tectonophysics 710–711, 249–265. http://dx.doi.org/10.1016/j.tecto.2016.09.028.

Capella W., Barhoun N., Flecker R., Hilgen F.J., Kouwenhoven T.J., Matenco L., Sierro F.J., Tulbure M.A., Yousfi M.Z. and Krijgsman W. (2018). Earth Sci. Rev. 180, 37–59. http://dx.doi.org/10.1016/j.earscirev.2018.02.017.

Chalouan, A., Galindo-Zald var, J., Akil, M., Mar n, C., Chabli, A., Ruano, P., Bargach, K., De Galdeano, C.S., Benmakhlouf, M., Ahmamou, M., Gourari, L., 2006. T In: Moratti, G., Chalouan, A. (Eds.), Tectonics of the Western Mediterranean and North Africa. Geological Society Publishing House, Bath, pp. 101–118.

Cozzi, A. (2000). Basin Research, 12, 133–146. https://doi.org/10.1046/j.1365-2117.2000.00117.x

Delvaux, D. and Sperner, B. (2003). In: New Insights into Structural Interpretation and Modelling (D. Nieuwland Ed.). Geological Society, London, Special Publications, 212: 75-100.

Ferrill, D.A. and Morris, A.P. (2003). Journal of Structural Geology, 25, 183-196, https://doi.org/10.1016/S0191-8141(02)00029-9.

Hardman K., Holdsworth R.E., Dempsey E. and McCaffrey K. (2020). Journal of the Geological Society, 177, 1168-1185. https://doi.org/10;1144/jgs2020-70.

Holland, M., Van Gent, H.W., Bazalgette, L., Yassir, N., Hoogerduijn-Strating, E.H., and Urai, J.L. (2011). Earth and Planetary Science Letters, 304, 399-406, https://doi.org/10.1016/j.epsl.2011.02.017.

Holdsworth, R.E., Trice, R., Hardman, K., McCaffrey, K.J.W., Morton, A., Frei, D., Dempsey, E., Bird, A. and Rogers, S. (2019). Journal of the Geological Society, DOI: https://doi.org/10.1144/jgs2019-142.

Krijgsman, W.; Langereis, C.G., Zachariasse, W.J., Boccaletti, M., Moratti, G., Gelati, R., Iaccarino, S., Papani, G., Villa, G. (1999). Marine Geology 153(1-4): 147-160.

Lehner B. L. (1991). Terra Nova, 3, (6), 593-602. https://doi.org/10.1111/j.1365-3121.1991.tb00201.x.

Monnier, D., Gay, A., Imbert, P., Cavailhes, T., Soliva, R. and Lopez, M. (2015). Journal of Structural Geology 79 (2015) p. 1-18. https://doi.org/10.1016/j.jsg.2015.07.001.

Morel, J.-L. (1989). Geodinamica Acta, 3, (4), 283–294. doi:10.1080/09853111.1989.1110519.

Poujol, A. (2014). Analyse des déformations actuelles dans le Rif (Maroc): approche morphotectonique. Géomorphologie. Université Montpellier II - Sciences et Techniques du Languedoc, 284p.

Poujol, A., Ritz, J.F., Vernant, P., Huot, S., Maate, S., Tahayt, A., (2017). Tectonophysics 712– 713, 303–311. https://doi.org/10.1016/j.tecto.2017.05.036.

Sani, F., Ventisette, C. Del, Montanari, D., Bendkik, A., Chenakeb, M. (2007). Int. J. Earth Sci. 96, 685–706. https://doi.org/10.1007/s00531-006-0118-2.

Van Gent H.W., Holland M., Urai J.L. and Loosveld R. (2010). Journal of Structural Geology, 32, 1375-1391, https://doi.org/10.1016/j.jgs.2009.05.006.