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Research Paper

Lineament analysis of South Jenein Area (Southern Tunisia) using remote sensing data and geographic information system

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Abstract Accurate geological and lineament mapping is a critical task for structural analysis and tectonic interpretation in stable platform domain. Efforts in structural mapping and tectonic interpretation in the South Jenein area and its surrounding are hindered by the difficult access to the outcropping features, where some of the stratigraphic sequences and structures are buried under the sand of the "grand Erg oriental". This study involves the use of spot Landsat images and Digital elevation model (DEMs) for lineament and fracture analysis. The obtained lineament results showed two major directions of faults: the main lineament direction was 035–065° (NE–SW) whereas the secondary lineament direction was 110–130° (NW–SE). The other directions were roughly E–W and N–S. These results were confirmed by the measurement and analysis of fracture and lineament on the field of the studied area.

These structures were the origin of the tilted blocks delimited by fracture and folding of the Upper Cretaceous series (i.e., Senonian). An extensive structural analysis was carried out to precise the kinematic and geodynamic contact in terms of stress tensor in a domain that was considered as a stable platform for longtime.

The results will be compared with the surface data in the Mesozoic series of the Tataouine basin and the subsurface data of the northern border of the Palaeozoic Ghadames basin. The fracture measurements and their distribution provided a good opportunity to characterize the petroleum reservoir in this area.

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1. Introduction

The remote sensing techniques play an important role in mapping programs (Farina et al., 2005). These techniques have opened a new era in the field of applied geology. Due to its efficiency in detecting geological structures (e.g., lineaments), the technique of digital image processing proved that remote sensing was a useful tool for mapping lithology. Other techniques were also applied to emphasize the role of remote sensing in detecting lineament (Al Rawashdeh et al., 2006). The availability of multi-spectral and high-resolution data as well as the advanced capabilities of digital image processing techniques in generating enhanced and interpretable images further enlarged the potential of remote sensing in delineating the lithological contacts and geological structure in detail and with better accuracy (Drury, 1987). Many geological studies have employed optical and Radar-optical data (SRTM) to discriminate the various lithology, lineaments and minerals by using hyperspectral laboratory (Abrams, 1984). Subsequent studies confirmed their benefit for lineament and lithology mapping using the remote sensing data and GIS techniques.

The South Jenein area in the Saharan platform of the Southern Tunisia was for a longtime considered as a stable domain. In recent sub-surface mapping two-dimensional (2D) and three-dimensional (3D) seismic data were used as efficient tools to locate the prospective oil and gas fields within underdeveloped basins (Burollet et al., 1991). However, the geological and structural mapping of the Southern Jenein area is still incomplete and not sufficiently precise, in spite of the existence of reconnaissance and general geological maps at 1/500,000 because of the sand dune of "grand Erg oriental" that is covering the outcrops combined with the difficult access in the western part (Fig. 1). Nevertheless, results of these localized studies can be extended through remote sensing to cover larger areas (Pena and Abdesalam Mohamed, 2006) for geological identification and structural analysis.

This research focuses on the geologic lineament mapping which is considered as an important alternative to solve problems of petroleum exploration and structural analysis of the studied area. This can be achieved by using remote sensing data and analysis techniques (Argialas et al., 2003). Therefore, the identification of surface lineaments and their possible relationships with the geological structures and tectonic events that affected Southern Jenein region is needed.

This work has been undertaken to (1) draw the lineaments and various geological maps of the outcropping formations of the southern Jenein area, (2) analyse the lineaments and fracture systems statistically and detect their significance, (3) identify the dominant direction of the most remarkable tectonic events and (4) determine the tectonic regimes that prevailed at the origin of these tectonic markers.

2. Geology context

The Southern Tunisia platform was extensively studied by multiple authors to bring more details about the main geological and morpho-structural features that could be useful for the basic and applied geology (Lapparent, 1951; Castany, 1954; Busson, 1967, 1972; Bouaziz et al., 1994, 2002; Bouaziz, 1995; Kammoun, 1988; Ben Ismail, 1991). During Palaeozoic times, several major sedimentary basins were developed in this domain (Bishop, 1975; Memmi et al., 1986), such as the

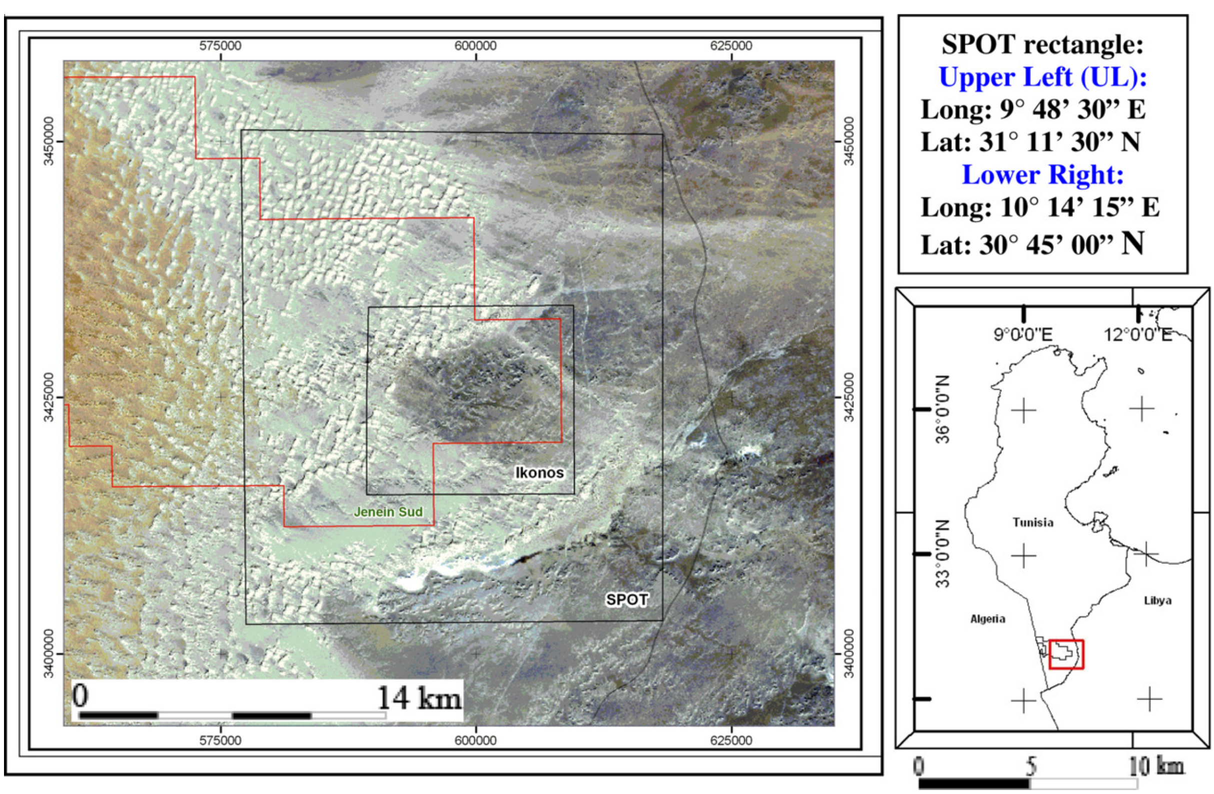

Figure 1 Localisation of suggested study area IKENOS/SPOT at Scale 1: 350,000.

Ghadames basin which is the subject of the present study. We distinguished two morpho-tectonic domains:

- The Jeffara domain is the NW–SE trending coastal plain. Its development resulted from a normal faulting along a single direction. The corresponding subsiding Jeffara basin was thus filled up by thick Cenozoic sedimentary sequences;
- The Dahar plateau is a gentle large scale sub tabular dipping westward of 1–2° that may be considered as tabular at regional scale. The Dahar, belonging to the Saharan platform domain, is constituted by outcropping succession sequences ranging in age from Late Permian to Late Cretaceous. These sequences constitute the Southern Tunisian basin or the "Tataouine basin" of Busson (1967). They are well exposed along the continuous cliffs bordering the plateau to the north along the Jeffara Coastal plain, and they are covered to the West and to the South by the dunes of the Eastern Saharan Erg.

The studied area, belonging to the Southern Tunisia platform, constitutes the northern edge of the Tunisian Ghadames basin; that is considered the main petroleum prospect. This basin is an intracratonic depression encompassing more than 350,000 km^2 in the western part of North Africa, limited to the north by the West–East trending Telemzane Arch, the Naffusa Arch and to the East by the Mesozoic Tataouine basin. To the southwest and southeast, it is separated from the Illizi and Murzuk basins by the long living structural highs (Ferjaoui et al., 2001). In this part of the basin was experienced a complex tectonic history (Alem et al., 1998; Echikh, 1998; Klett, 2000) allowed a structural features beginning with the late Precambrian pan-African orogeny, and continuing throughout the phanerozoic with repeated reactivation older structures (Ghabtni et al., 2006).

The cumulative result of tectonic activities in the area of the Ghadames basin was a series of fault bounded structural highs, with complex histories, surrounding a central depression whose specific morphology differs for sediments at different structural levels (Acheche et al., 2001). This domain has been considered by previous authors as a stable platform (Fig. 2).

The stratigraphic sequence of the southern platform, Tunisia, ranges from Palaeozoic to Late Quaternary – Tertiary hiatus and is well known as the northern edge of the Palaeozoic Ghadames basin and the Mesozoic Tataouine basin. The Mesozoic sequence in the Dahar plateau, started by the Early–Middle Triassic sequence, is mainly constituted by continental sandstone, conglomerate and clay; whereas the Late Triassic outcrops exhibit shallow marine carbonate extending over a major part of the Saharan Platform in Southern Tunisia, Algeria and western Libya (Busson, 1972). The Jurassic series is characterized by a thick Liassic evaporitic sequence, Dogger marine carbonate and late

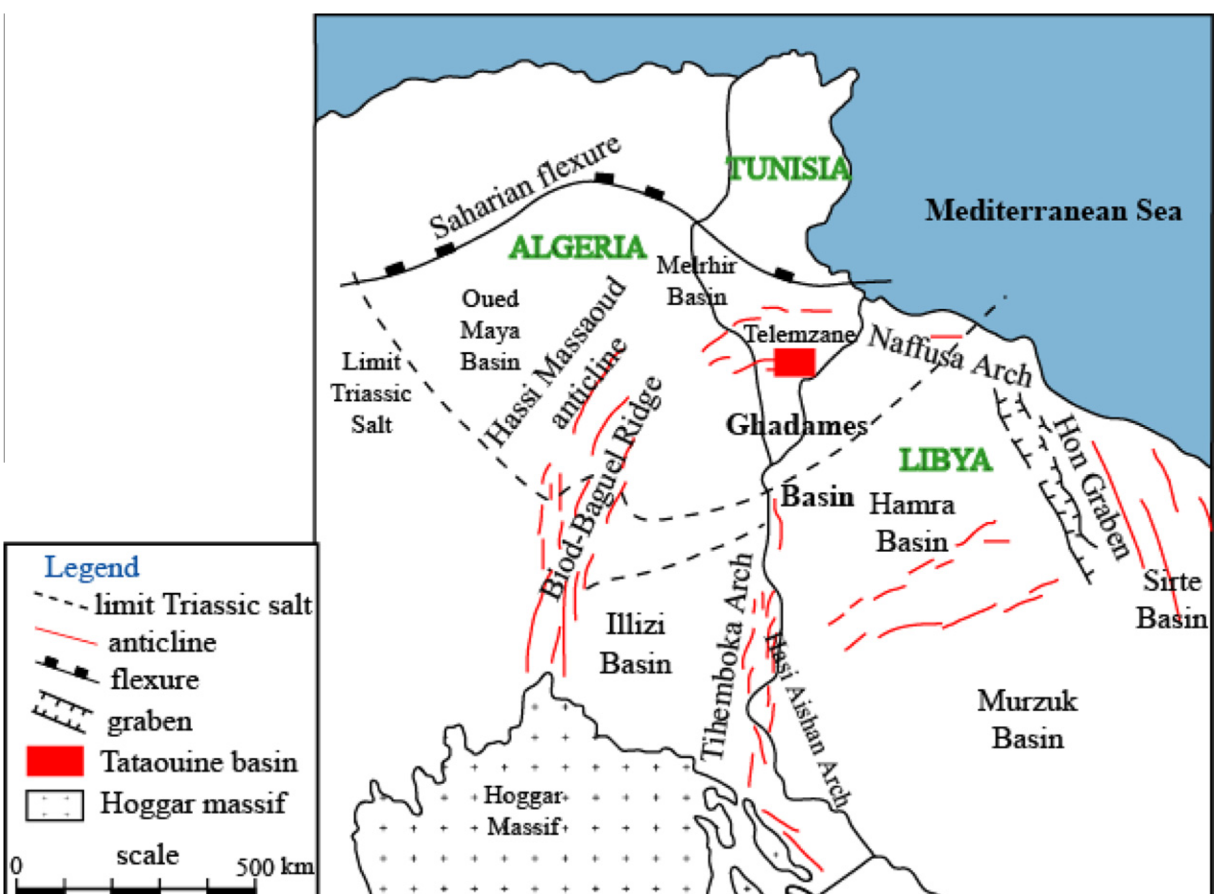

Figure 2 Major tectonic elements and locations of major basins in North Africa (modified after Bishop, 1975).

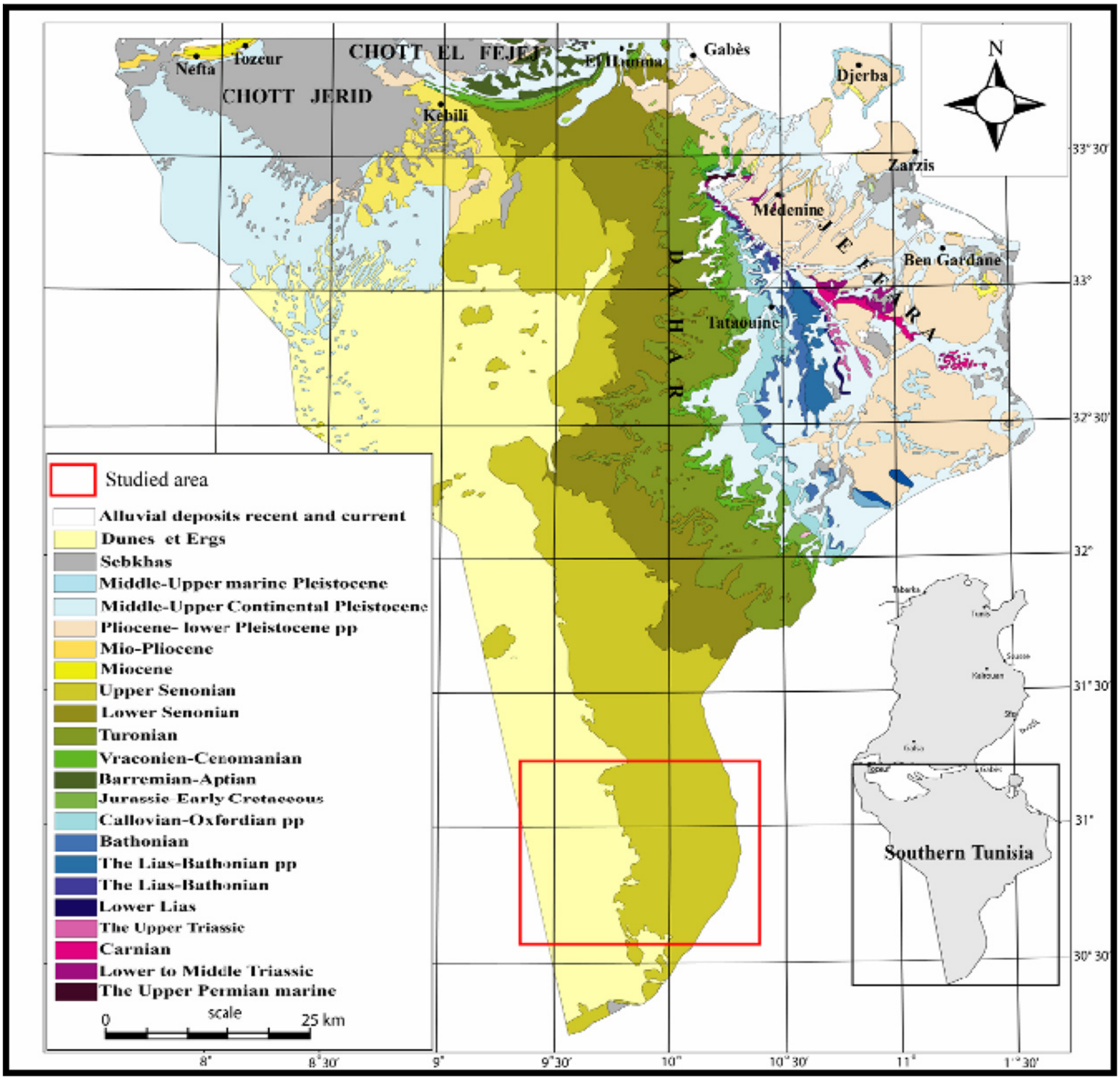

Figure 3 Geological map of Southern Tunisia at scale 1/500,000 (Ben Hadj Ali et al., 1985).

Jurassic–Neocomian mixed facies with continental predominance (Bouaziz et al., 2002). The Cretaceous series outcrop largely in the Saharan platform Tunisia, is a general gradation from the neritic, lagoonal and continental facies (Mejri et al., 2006). The Cenomanian sequence corresponds to a marine and to a shallow marine carbonate, which recorded a major transgression expanding southward on the Saharan platform before reaching a maximum in Turonian. The last marine deposits on the Dahar Plateau are campanian in age, characterized by thick shallow carbonates-marl marine sequences deposited in the Late Cretaceous and covered by sand dunes (Fig. 3).

The outcrops of the studied sequence probably attributed to the Miocene regression constituted only by sandstone and conglomerate. In the frame of structural point of view, this area is characterized by major and minor faults and foldings.

3. Methodology and data

3.1. Data collection

For the purpose of this study, the topographic map scale 1: 200,000 was used as a base map. Landsat ETM^+ acquired on 23rd May 2003, SPOT scene 068–288 taken on 18th October 2002, recent image with no cloud cover and digital elevation model (DEM), extracted from Shuttle Radar Topography Mission (SRTM), data available at the United States Geological Survey website were also utilized (www.usgs.gov). The DEM is a digital representation of the earth surface terrain (Abou El-Magd et al., 2010) that could be beneficially integrated in the structural geology for the identification of lineaments and fracture systems that may represent the surface expression of geological structures (Pena and Abdesalam Mohamed, 2006). In this topic, the results of

DEMs interpretation were confirmed by other remote sensing data such as optical multi-spectral data (Landsat 7, Spot 5). The lineaments might be associated with a significant geological structure, linearly pronounced escarpments (cliffs) and linear topographic highs or lows elongated zones of alternated colors in Landsat image.

3.2. Processing of remote sensing data

The remote sensing processing techniques and data extraction algorithms have been significantly developed and advanced in recent years (Michaela et al., 2006). The digital image processing can be defined as the manipulation of digital data by the aid of computer in order to produce a more appealing image (Drury, 1993).

The Landsat, Spot images and DEM of the south Jenein area and its surrounding were geometrically co registered using GIS software with scanned topographic map of the studied area (with a scale of 1: 200,000) and geodetically transformed into the Universal Transverse Marcator projection of Clarke 1880 (UTM) in Carthage 32 N datum.

For the study area two image-processing steps were proposed to increase the sharpness of the image and clarify the features and obtain more reliable information.

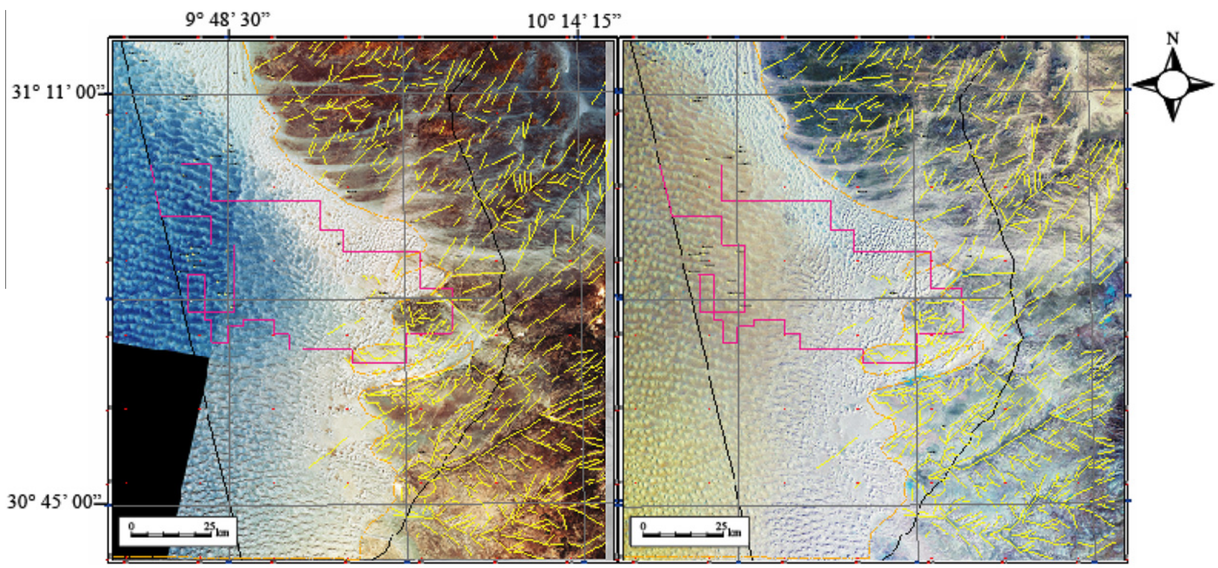

Figure 4a Lineament map from Landsat data.

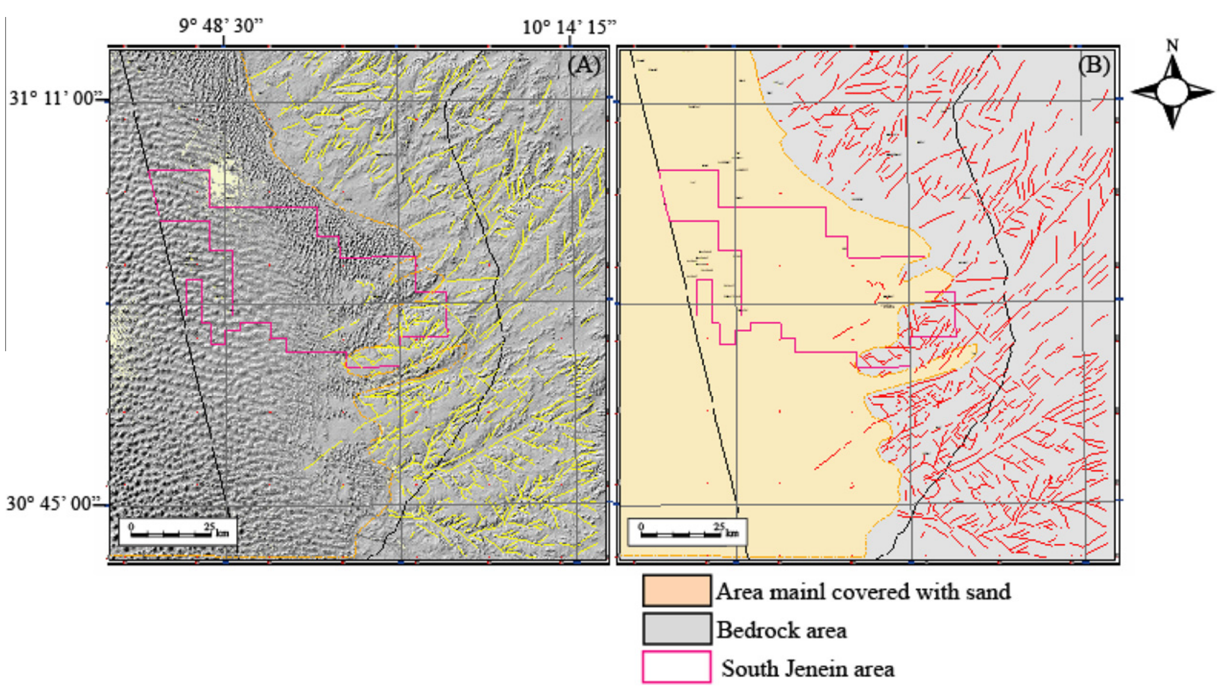

Figure 4b Lineament map from SRTM data (DEMs).

The first step concerned the image sharpening and was applied to present the utility of multi-spectral optical band images for lineament analysis and lithological mapping. This was applied through fusion of panchromatic band with the multispectral bands of LANDSAT ETM^+ image. The fused image is presented as colour composite by assigning 7, 4, 2 to RGB. This image had a spatial resolution of 14,25 m which enables the delineation of the geological lineament in the study area.

The second one, used for the interpretation of the SRTM and DEMs, was applied to extract the lineaments through the creation of hill-shading. DEM, applied for the interpretation of the DEMs of the study area, was extracted from the Shuttle Radar Topography Mission (SRTM). It was applied with different azimuth direction and sun angle. This technique is effective in creating images that enhance geological and geomorphical features. The hill-shading image was calculated from a grey scale DEM using an azimuth direction and an

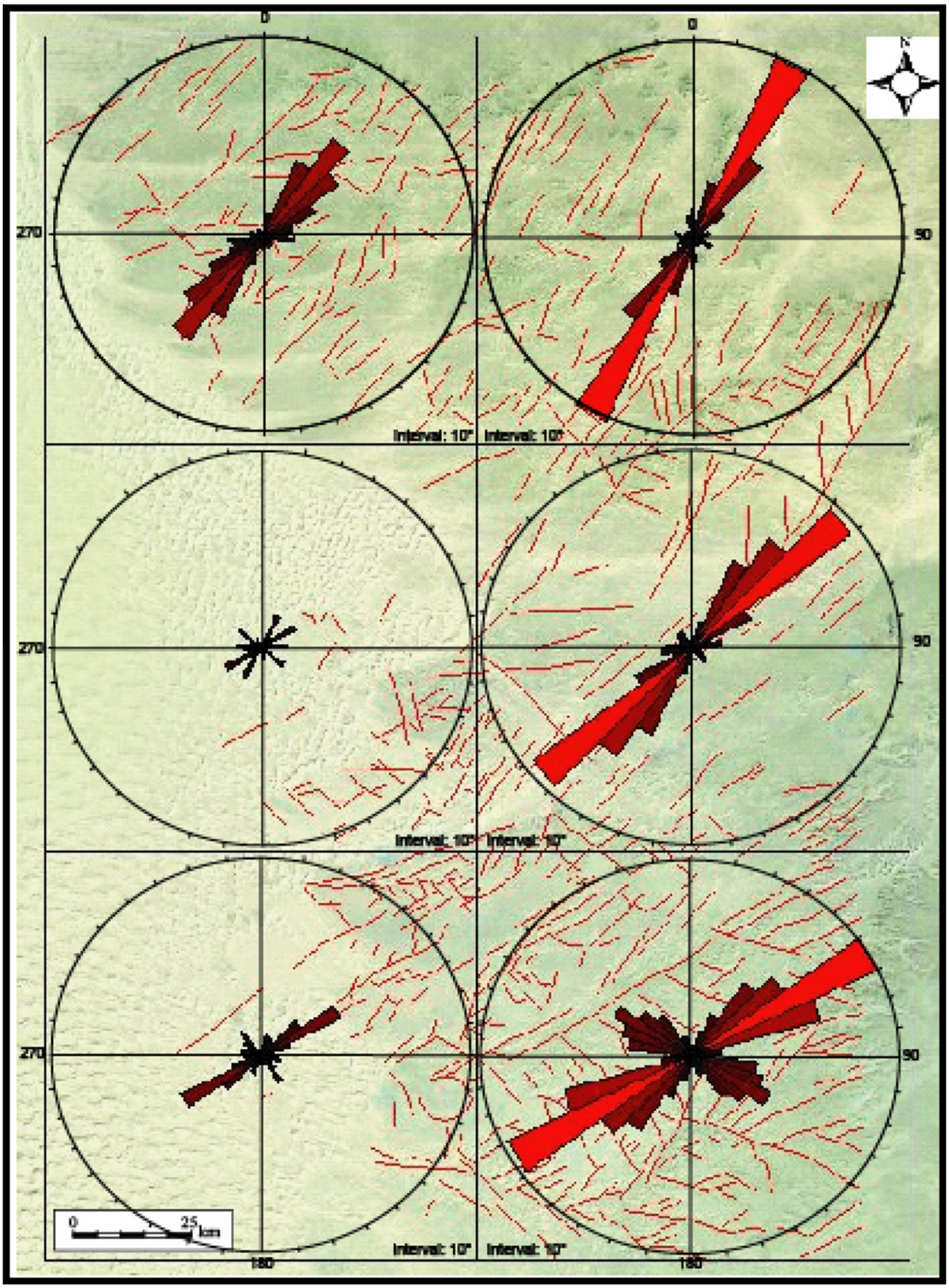

Figure 5 Map of lineament analysis associated with rose diagram obtained from DEM of the study area.

input sun angle. Illumination sun angles of less than 10° are the most effective in enhancing topography in low relief areas such as that of the study area, hence they are used for lineament analysis (Pena and Abdesalam Mohamed, 2006).

3.3. Lineament analysis

The regional map of lineaments in the studied area was established from Landsat and DEMs using visual process. The method applied for the interpretation is simple, but subjective and easy to distinguish the kinds of lineaments. The indicative result of lineament analysis used in Landsat data is illustrated in Fig. 4a. On this map is shown a major number of lineaments present in the study area. To confirm this result, DEMs were applied to lineament analysis as the following lineament map was allowed from these data Fig. 4b.

The lineament map showing all the strike directions can be extracted from remote sensing SRTM data. In This work, the study area was subdivided into six subareas associated with rose diagram of orientation of lineaments (Fig. 5). The interpretation of all lineaments allowed dominance of NE–SW as a main lineament direction and NW–SE striking as a secondary lineament direction (Fig. 6). Subsequently, all these directions were correlated and related within the regional context of the Southern Tunisian platform based on previous studies linked to the analysis of brittle tectonic structures (Bouaziz et al., 2002). The presence of a dominant NW-trending fracture system might be related to NE–SW extension (Ben Ayed, 1993; Bouaziz, 1995). However, the palaeostress reconstructions and analysis of brittle tectonic structures were initiated by (Bouaziz et al., 2002; Barrier et al., 1993 and Bouaziz, 1999), the Dahar plateau and the Jeffara plain indicate dominant E–W, NW–SE, NE–SW and N–S trending fracture system. In addition, major E–W trending normal faults were identified by (Etap, 2003) from seismic studies (Pena and Abdesalam Mohamed, 2006). The comparison between these studies and lineament analysis of remote sensing data of this study area are in good agreement.

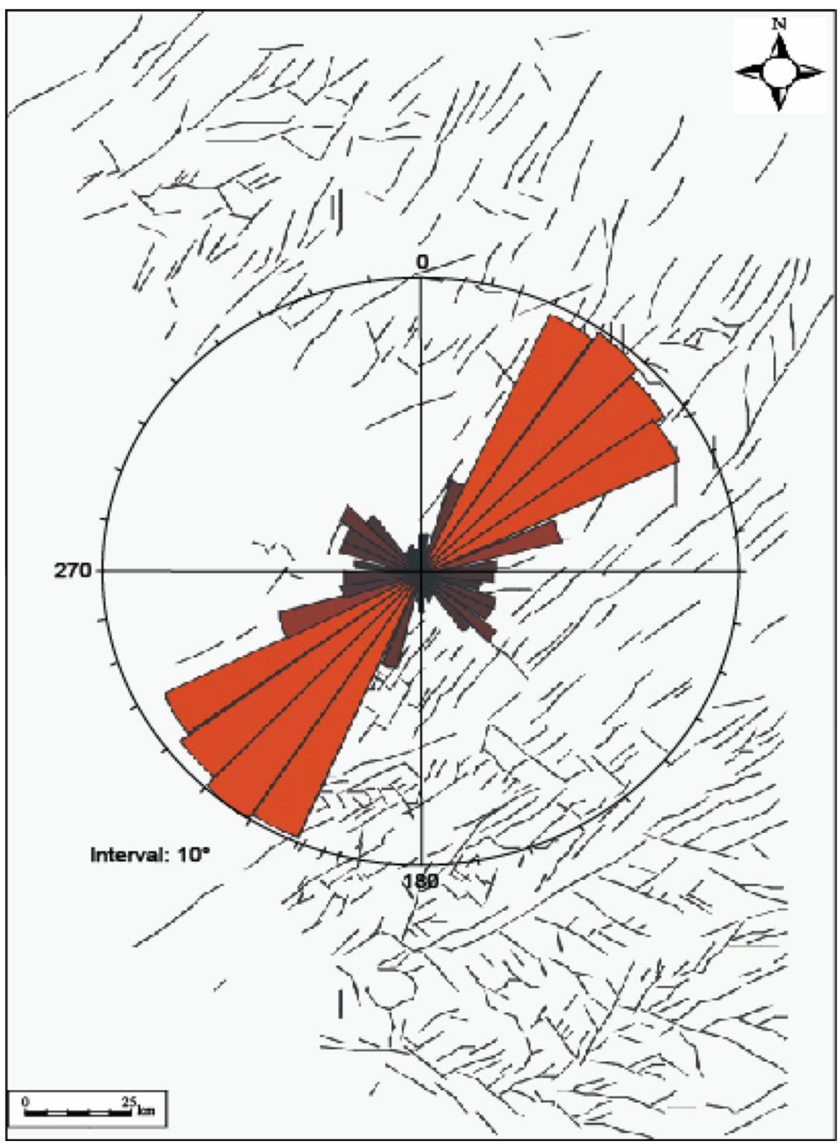

Figure 6 Synthetic map of all lineament strike direction.

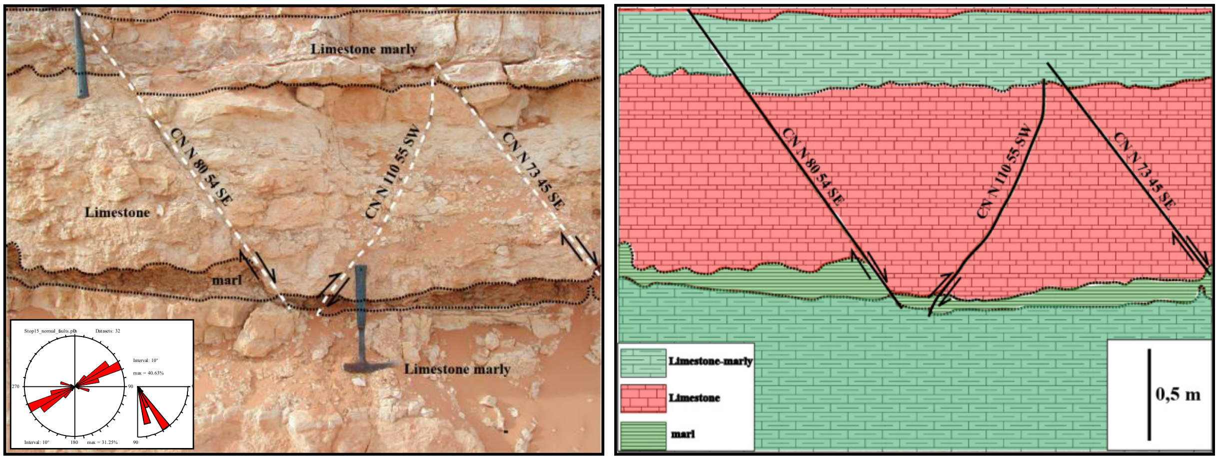

Figure 7 Syn-sedimentary normal faults trending NE–SW and NW–SE (Upper Cretaceous, Senonian with diagram orientation.

The main fault systems strike NE–SW, NW–SE, E–W, N–S are associated with two main trending axes (NW–SE and NE–SW) in the study area affecting the Upper Cretaceous deposits (limestones and marls). These features can be interpreted as a result of tilted block and the dipping of regional outcrops. In terms of tectonic regime, these folding can be attributed to the Atlasic phase recognized by previous authors (Bouaziz, 1995; Ben Ayed, 1986 and Zargouni, 1985), all of them considered the Southern Tunisia platform as a stable domain. However, based on brittle tectonic analysis and sedimentary approach, (Bouaziz et al., 2002) were recognized the major tectonic events in the central Tunisia which affect this domain. The tectonic evolution in terms of stress tensor of the Southern Tunisia was established by (Bouaziz et al., 2002).

3.4. Field investigation analysis

The geological outcropping of the study area has been systematically analysed in some sites of measurement to confirm the result of lineament analysis obtained from remote sensing data. The beds observed on the field are cut by normal faults, and then we notice extensional faults. These faults allowed the succession of horst and graben. Most of the collected data were measured in the Senonian marly Limestone (Upper Cretaceous). The majority of lineaments distinguished are joints observed in the field are conjugate joints associated with normal faults. These joints are either perpendicular to bedding, or sub-vertical to the inferred palaeo horizontal; they are interpreted as faulted joints (e.g., joints that were reactivated

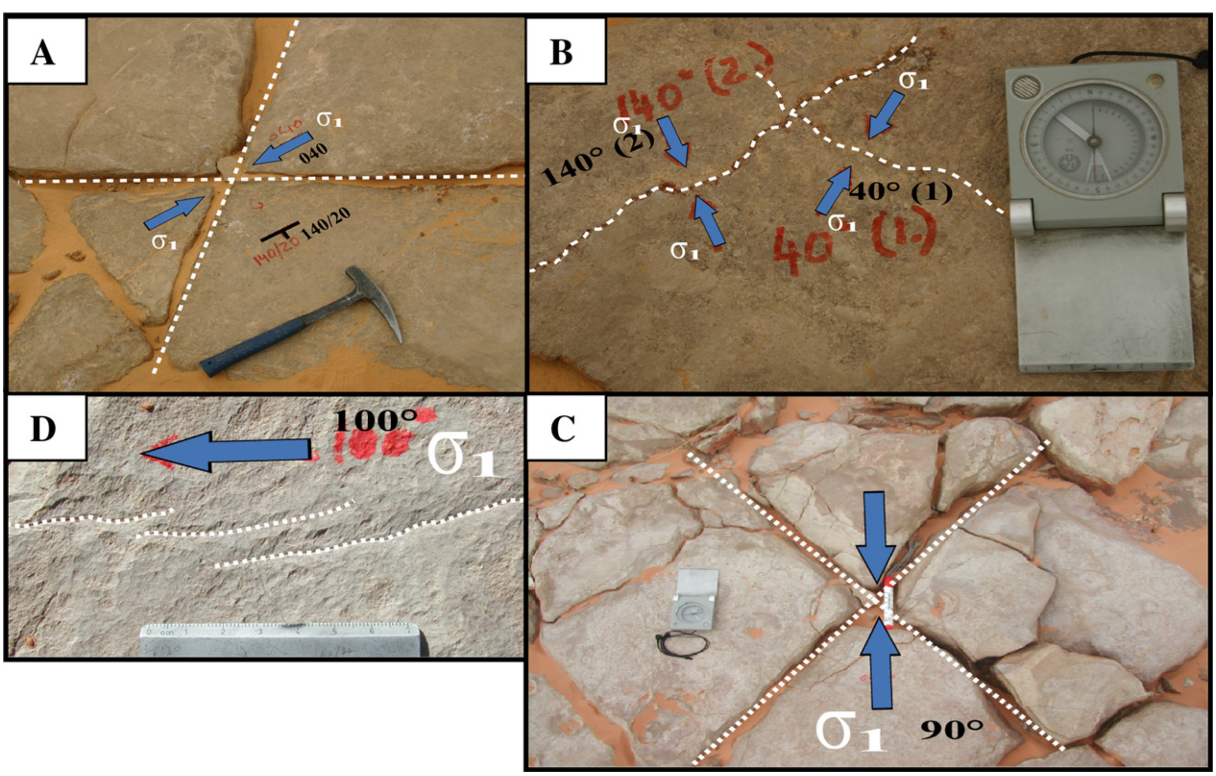

Figure 8 (a) conjugate joints, (b) sub-vertical n stylolites joints, (c) vertical conjugate joints, (d) En echelons shear joints.

by subsequent shear due to a relative change in stress orientation) (Figs. 7 and 8).

The measured direction of the normal fault was NE–SW and NW–SE direction was more important. The rough directions are E–W and N–S that control the sedimentation appeared in the southern (Tataouine basin) domain during Late Triassic to Early Aptian submeridian extensional period. These structures are the origin of the tilted blocks and the dipping of the Upper Cretaceous series, Senonian in age.

4. Conclusion

The combination of multi-spectral remote sensing data and DEMs (SRTM) is an effective tool for lineament and structural analysis in the Saharan platform domain. From this study, the result of newly lineament mapped area of the southern Jenein Block showed two lineament strike directions as the following: NE–SW as a main lineament direction and NW–SE striking as a secondary lineament direction the E–W and N–S direction are less represented. These main strike directions were associated with two trending NW–SE and N–S. These structures can be proposed as the origin of the tilted blocks and the dipping of the Upper Cretaceous outcrops (i.e., Senonian). In terms of tectonic regime, these foldings can be attributed to the Atlasic, Cretaceous, Miocene and Early Quaternary compressions.

The results of lineament analysis in the south Jenein area obtained from remote sensing data were in agreement with previous studies carried out on the Dahar plateau and the Jeffara plain. The Jeffara plain is considered as NW–SE trending coastal plain. Its development resulted from normal faulting along a single direction.

These results were completed by field investigation and geophysics data, it is an important factor to understand a trap distribution and petroleum reservoir characterization. In this respect, fracture analysis in terms of tectonics stress field is fundamentally important for localization and determination of a new petroleum prospect.

References

Abrams, M., 1984. Recent developments in lithologic mapping using remote sensing data. Bureau de Recherches Géologiques et Minieres 82, 177–189.

Acheche, M.H., M'Rabet, A.M., Ghariani, H., Ouahchi, A., Montgomery, S.L., 2001. Ghadames basin, Southern Tunisia: a reappraisal of Triassic reservoirs and future prospectivity. The American Association of Petroleum Geologists Bulletin 85, 765–780.

Al Rawashdeh, S., Bassam, S., Hamzah, M., 2006. The use of Remote Sensing Technology in geological Investigation and mineral detection in El Azraq-Jordan. European Journal of Geography, Systèmes, Modélisation, Géostatistiques 2856, 203–219.

Alem, N., Assassi, S., Benhebouche, S., Kadi, B., 1998. Controls on hydrocarbon occurrence and productivity in the F6 reservoir, Tin Fouy-Tabankort area, NW Illizi Basin. In: MacGregor, D.S., Moody, R.T.J., Clark-Lowes, D.D. (Eds.), Petroleum Geology of North Africa. Geological Society Special Publication, London, pp. 175–186, Vol. 132.

Argialas, D., Mavrantza, O., Stefouli, M., 2003. Automatic mapping of tectonic lineaments (faults) using methods and techniques of photointerpretation/digital remote sensing and expert Systems, THALES Project No. 1174.

Barrier, E., Bouaziz, S., Angelier, J., Creuzot, J., Ouali, J., Tricart, P., 1993. Paleostress evolution in the Saharan platform (Southern Tunisia). Geodynamica Acta 6 (1), 39–57.

Ben Ayed, N., 1986. Evolution tectonique de l'avant pays de la chaîne alpine de Tunisie du début du Mésozoïque à l'Actuel. Thèse Doc. Etat, Univ. Paris Sud, France, p. 328.

Ben Hadj Ali, M., Jédui, Y., Ben Salem, H., Memmi, L., 1985. La carte géologique de la Tunisie 1/500,000, Office Nationale des Mines, Service Géologique.

Ben Ismail, H., 1991. Les bassins mésozoïques (Trias à Aptien) du Sud de la Tunisie: stratigraphie intégré, caractéristiques géophysiques et évolutions géodynamiques. Doctorat. D'Etat, Université Tunis II, p. 446.

Bishop, W.F., 1975. Geology of Tunisia and adjacent parts of Algeria and Libya. American Association of Petroleum Geologists Bulletin 59, 413–450.

Bouaziz, S., 1995. Etude de la tectonique cassante dans la plate forme et l'Atlas sahariens (Tunisie méridionale): évolution des paléochamps de contraintes et implications. Thèse Doc. Etat, Univ. Tunis II, Tunisia, 485.

Bouaziz, S., 1999. La tectonique permo-mésozique (anté-Vraconien) dans la marge sud téthysienne en Tunisie méridionale. Bulletin de la Societe Geologique de France 170 (1), 45–56.

Bouaziz, S., Barrier, E., Angelier, J., Turki, M.M., 1994. Paleostress in the Southern Tunisian platform. In: Roure, F. (Ed.), Peri-Tethyan Platforms. Technip Editions, France, pp. 179–196.

Bouaziz, S., Barrier, E., Soussi, M., Turki, M.M., Zouari, H., 2002. Tectonic evolution of the northern African margin in Tunisia from paleostress data and sedimentary record. Tectonophysics 357, 227–253.

Burollet, P., Ben Ferjani, A., Mejri, F., 1991. New concepts for exploration in Tunisia. American Association of Petroleum Geologists Bulletin 75, 1407.

Busson, G., 1967. Le Mésozoïque saharien, 1re partie: l'extrême Sud tunisien, Centre de Recherches sur les zones arides, Série Géologie, No. 8, CNRS, 194.

Busson, G., 1972. Le Mésozoïque saharien. 2ème partie: Essai de Synthèse de données des sondages algéro-tunisiens: 2 tomes, vol. 11, C.N.R.S. Geol., Paris.

Castany, G., 1954. L'accident Sud tunisien, son âge et ses relations avec l'accident Sud atlasique d'Algérie. Compte Rendue de Sciences (Paris) 238, 916–918.

Drury, S.A., 1987. Image Interpretation in Geology, second ed. Allen & Unwin, London, UK, p. 243.

Drury, S.A., 1993. Image interpretation in geology, second ed. Chapman and hall, London, UK, p. 271.

Abou El-Magd, I., Hermas, E., El Bastawesy, M, 2010. GIS-modeling of the spatial variability of flash flood hazard in Abu Dabbab catchment, Red Sea Region, Egypt. The Egyptian Journal of Remote Sensing and Space Sciences 13, 81–88.

Entreprise Tunisienne d'Activités Pétrolières (ETAP), 2003. Tunisia open acreage. Conception and Printing SIMPACT Publishing Co., p. 83.

Farina, P., Catani, F., Colombo, D., Fumagalli, A., Kukavicic, M., Marks, F., Moretti, S., 2005. Remote sensing: a tool for landslide investigations at a basin scale. Geophysical Research Abstracts 7, 10157–10168.

Ferjaoui, M., Meskini, A., Acheche, M.H., 2001. Modeling of Hydrocarbon Generation and Expulsion from Tannezuft and Aouinet Ouenine Formations in Southern Tunisia–North Africa, Rock the Foundation Convention, June 18–21. Canadian Society of Petroleum Geologists.

Kammoun, F., 1988. Le Jurassique du Sud Tunisien, témoin de la marge africaine de la Thétys: stratigraphie, sédimentologie et micropaléontologie, thèse 3e cycle vol. 2. Université Toulouse, France, pp. 330.

Lapparent, Albert F., 1951. Discovery of dinosaurs, associated with a reptile and fish fauna, in the Lower Cretaceous of extreme southern Tunisia. Comptes Rendus de l'Académie des Sciences, 1430–1432.

Mejri, F., Burollet, P.F., Ben Ferjani, A., 2006. Petroleum Geology of Tunisia: A Renewed Synthesis, ETAP Memoir (Eds.), vol. 22, Tunis, p. 230.

Memmi, L., Burollet, P.F., Vitterbo, I., 1986. Lexique stratigraphique de la Tunisie. Première partie: Précambrien et Paléozoïque. Notes du Service géologique de Tunisie 53, 66.

Michaela, F., Mohamed, G.A, Nicolas, B., 2006. Remote sensing applications to geological problems in Africa. Journal of African Earth Sciences 44 (2), vii–x.

Pena, S.A., Abdesalam Mohamed, G., 2006. Orbital remote sensing for geological mapping in southern Tunisia: implication for oil and gas exploration. Journal of African Earth Sciences 44 (2), 203–219 (www.usgs.gov).

Zargouni, F., 1985, Tectonique de l'Atlas méridional de Tunisie, évolution géométrique et cinématique des structures en zone de cisaillement. Thèse Doc. Etat, Université, Louis Pasteur. Strasbourg. Mem. INRST., vol. 5(3), p. 302.