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ORIGINAL PAPER

Integrating Remotely Sensed and GIS Data for the Detailed Geological Mapping in Semi-Arid Regions: Case of Youks les Bains Area, Tebessa Province, NE Algeria

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Abstract Detailed geologic mapping provides valuable informations about the spatial distribution of lithological outcrops and lineaments; required to carry out the necessary investigations of the geologic, geotechnical and hydrogeological data investigation. The unavailability of geologic coverage at meduim scale in the Nementcha mountains has severely hampered geoscientist to develop and test their hypotheses. In order to exploit multispectral datasets for the characterization of surface materials; Sentinel-2A data was used in the discrimination of geological classes along Youks les Bain area, extreme NE of Algeria. Resampling, orthorectification, atmospheric correction, and radiometric normalization have been applied to the Sentinel-2A radiance data, identified as the first and most important step in processing. The 12/4, 11/3 and 8/4 band ratios combination was adopted to discriminate the different lithologies. Then, to reduce redundant information in highly correlated bands, the principal component analysis has been implemented. The directional filters were applied to undertaken the lineamentary mapping. At last the project was exported and processed in GIS spatial database. The result allows the discrimination of the lithological boundaries and help to a better understanding of the local geology of the study area. The project digital databases represents a key tool to support research activities in the West of Tebessa region.

Keywords Lithological discrimination · Sentinel-2A · Principal component analysis · Band ratio combination · Spectral response

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1 Introduction

Geographic Information System (GIS) and Remote sensing (RS) play a relevant role in geoenvironmental issues such as, geology (Hadji et al. 2014a; Abdelouahad et al. 2018), water (Hamed et al. 2014;

Mokadem et al. 2016), agriculture (Kingra et al. 2016; Hamed et al. 2017a, b; Besser et al. 2018), infrastructure planning (Achour et al. 2017; Dahoua et al. 2017a, b), Mining environment (Zahri et al. 2016; Raïs et al. 2017), natural hazards mitigation (Hadji et al. 2014b; Mouici et al. 2017), and disaster management (Hadji et al. 2017a, b; Dahoua et al. 2017b). Recently satellite imagery, GIS and RS has grown as a relevant hi-tech tools for monitoring and collecting information on almost every aspect on the Earth's surface (Hadji et al. 2017b; Karim et al. 2019; Mahdadi et al. 2018). Recent increases in the availability of earth observation data and the advances made in its processing have opened up new opportunities for earth monitoring studies (Ngcofe and Van Niekerk 2016). RS applications have opened a new era in the identification of rock types and tectonic styles mainly in arid zones with minimal vegetation and culture (Hadji et al. 2013; Hassani et al. 2015; Bersi et al. 2016; Adiri et al. 2017; El Kati et al. 2018). In practice, qualitative and quantitative approaches are the most successfully used techniques to discriminate geological outcrops for a given study area (Van der Meer et al. 2012; Ge et al. 2018). Qualitative approaches depends on stereoscopic examination of monoscopic satellite images by applying a synthetic parallax (Bilotti et al. 2000). Whereas quantitative methods measures the relative distinctiveness of the reflectance spectra of individual lithological classes; wich depends on their minerals composition (Banerjee and Mitra 2004). The reflectance of outcrops are widely controlled by the physical–chemical properties of the rock and soil surfaces. This matter was explicitly addressed by Leverington and Moon (2012).

In the present paper, an attempt has been tested to analyze the capability of the remote sensing and GIS applications for the characterization of geological features in Youks les Bains region, West of Tebessa province. This region and its surroundings lacks a geological mapping/information, which hinders geologists who study geological structures, lithology discrimination, geohazard identification and mitigation, geomorphology and landform processes, and mineral exploration, (Zerrouki et al. 2013; Hadji et al. 2016; Hamed et al. 2017a), (Fig. 1). We preferred to use Sentinel-2A data than common multispectral data, due to its higher spectral and spatial resolutions in the VNIR and SWIR region. The methodology applied in this research offer the opportunity to analyse surface geology in a relatively short time and at reduced cost; and give an overall view of a study area often difficult to obtain from field-based observation alone (Simon et al. 2016).

2 Study Area

The study area used in this remote sensing assessment encompasses the 1/50,000 Youks les bain topographic map area (WGS84: 7°37′45″ to 7°58′10″ E and 35°19′45″ to 35°31′32″ N), and covers approximately 639.684 km^2. The topography is marked by incisions of Oued Chabro in the quaternary cover. The latter bring out Jebel Troubia and Tazbent Eo-miocene and upper Cretaceous formations (Guadri et al. 2015). The study area is located in the East of Algeria, about 50 km West of Tebessa city, (Fig. 2). It belongs to the Saharan Atlas chain composed of Meso-Cenozoic lands folded mainly in the Eocene. The encountered series are entirely sedimentary from Turonian to Ypresian-Lutetian stage. All covered in large part by Quaternary deposits, especially in plains (Fig. 3).

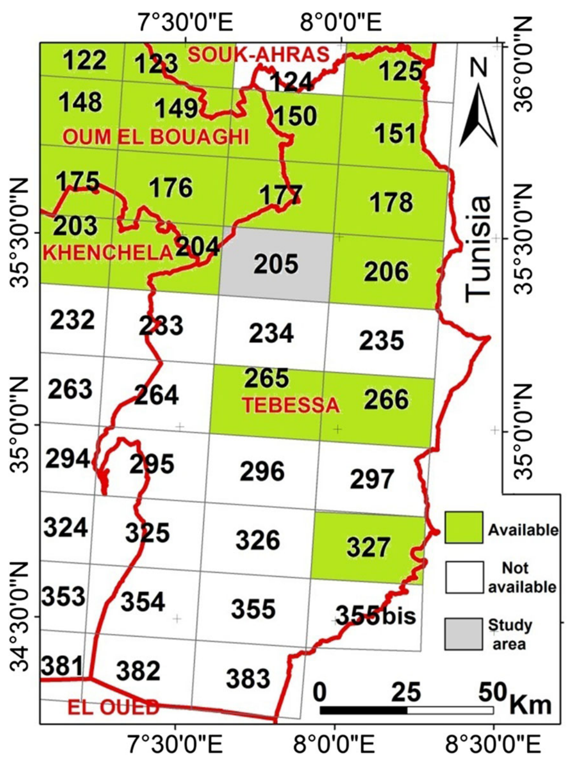

Fig. 1 Assembly of geological maps in Tebessa province (regular cuts in 1/50 000)

Maastrichtian limestones constitute an important aquifer through which manifest springs of fresh water (Rouabhia et al. 2012). The limestone ridge separating the Chott Melghir and Medjerda major catchments with opposite flow, (Demdoum et al. 2015; Hamed et al. 2018).

The principal structure of the region is Gourigueur syncline, wich constitutes the oriental continuity of Babar-Chachar syncline, extendes over more than 90 km from Khenguet Sidi Nadji in the SW to Jebel Serdiès in the NE. This megastructure was setup by the Atlasic phase with maximum stress around 150°E (Kowalski and Hamimed 2002).

The climate is typically semi-arid with an average rainfall of 370 mm per year. The monthly precipitation distribution shows two distinct major seasons: a dry and warm season alternated by a wet and cold season. Spring is the rainiest season, while summer is the driest (Hamad et al. 2018a, b).

3 Materials and Methods

Aiming to evaluate the capability of Sentinel-2A to map geological units. This paper provides a working approach for the discrimination of lithological formations and lineaments inside the "Youks les bains" Topographic map (205) framework. The methodology is based on remotely sensed imagery, GIS as well as a field work and the correlation with the neighbouring geologic maps. The used data consists of a Sentinel-2A scene acquired from USGS website (https://glovis.usgs.gov/), on February 2017, with a Universal Transverse Mercator (UTM) projection and a World Geodetic System WGS 84 datum, one Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with 30 m spatial resolution, and two geological maps in 1/50,000 scale, namely Dalâa (204) and Meskiana (177). Sentinel-2A imagery covers 13 spectral bands in the VNIR and SWIR spectral region, with four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution (Table 1).

The Sentinel-2A imagery used in this study data were automatically atmospheric corrected and orthorectified using the SNAP software. Due to the

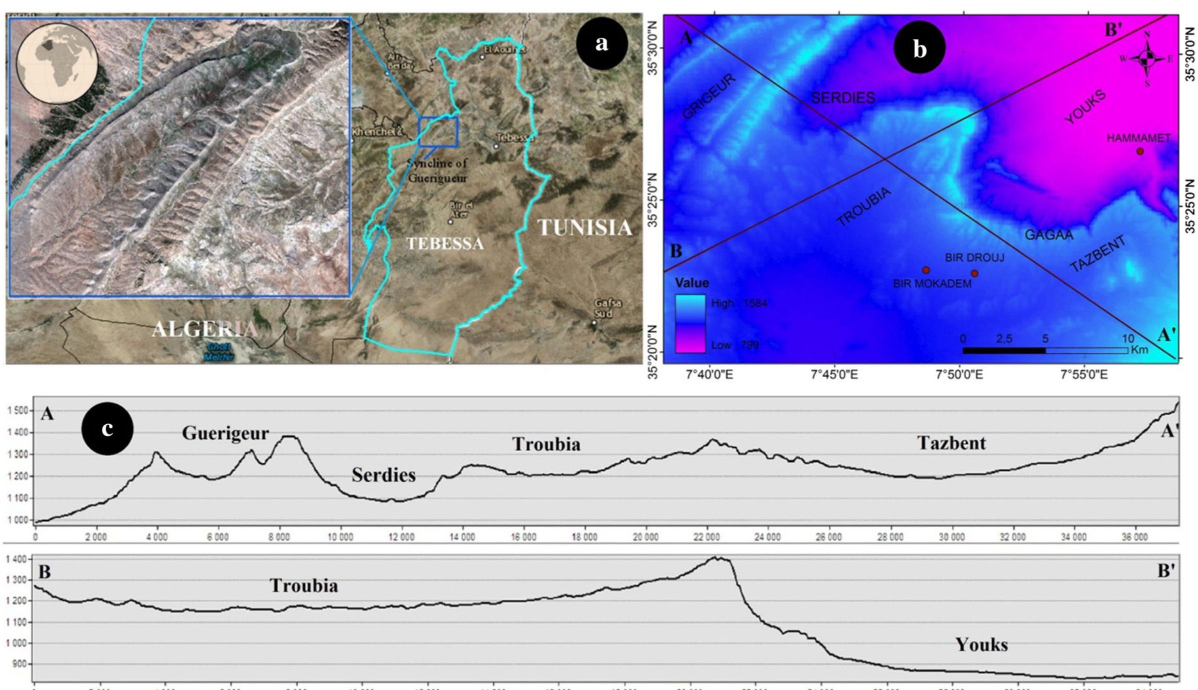

Fig. 2 **a** Geographic localization of the study area on Sentinel-2A color composite image (RGB: bands 4, 3 and 2); **b** the topograpphy of the study area; **c** topograpphical cross sections of the study area

Serie	Thick (m)	Log	Description
q^{-} Quaternary $q^{1\text{-}2}$	?		Scree, gravel and clays. Ancient alluvium.
P^{q} : Plio-quaternary	?		Limestones crust, red clay conglomerates.
$e^{4\text{-}5}$ Ypresian - Lutetian	50 to 80		Limestones and marls, overlain by flint limestones.
$e^{1\text{-}3}$ Paleocene Danian-Thanetian	200		Marl and marly limestones / Flint/ levels of phosphates.
C^{6} Maastrichtian middle	150		Beige Limestone inoceramus with whitish break.
$C^{5\text{-}6}$ Campanian-Maastrich-tian lower	250		Massive limestones alterning with marls.
C^{2} Turonian middle	80 to 100		Beige massive limestones, dolomitic / Redustes.

Fig. 3 Stratigraphic column of the study area

design for atmospheric correction, spectral bands 1, 9 and 10 of Sentinel-2A data with 60 m spatial resolution were removed in the following study. The remained 10 bands were layer stacked to one file and cubically resampled to 10 m spatial resolution. The satellite image was processed using Envi 5.2 software, in order to bring out the contours of geological formations. Different applications allowed us to extract thematic maps; such as PCA and directional filters. All the derived themes from the analysis have been exported in "12-bit GeoTIFF" image enabling the image to be acquired over a range of 0–4095 potential light intensity values, then implemented in a Geodatabase in GIS platform using Arcgis 10.5 software. The morphostructural indicators have been divided in "linear remote structures" and "areal remote structures", referring to brittle geologic structures (faults, fractures, lineaments, joints, etc.) and areal-defined geologic structures (folds, thrust sheets, hörst and graben, etc.), respectively. The work was completed by a correlation with the neighbouring geological maps (Dalâa N°204 and Meskiana N°177) (Fig. 4) and by an extensive field surveys. The adopted method is simply explained in the flow diagram in Fig. 5.

Table 1 Description of the sentinel-2A sensors

Band	Central wave lenth (μm)	Spatial resolution (m)
1	0.443	60
2	0.490	10
3	0.560	10
4	0.665	10
5	0.705	20
6	0.740	20
7	0.783	20
8	0.842	10
8A	0.865	20
9	0.945	60
10	1.380	60
11	1.610	20
12	2.190	20

4 Data Processing

4.1 The Spectral Enhancement

The Sentinel-2 imagery used in this study data were automatically atmospheric corrected and orthorectified. Among bands featured in Sentinel-2A image, 4, 3 and 2 bands were assigned to the red, green and blue

(RGB) channels giving a natural color. This combination highlighted the edges of geological formations, drainage and anomalies.

4.2 Ratios Bands Analysis

Different ratio combinations obtained from past researchers and that was produced from this study were tested on the image of the hammamet region to identify the best ratio combinations that were able to discriminate the different lithologies. A total of 20 combinations were performed to examine which combinations are the most effective. From all the combination, 12/4 11/3 and 8/4 ratios was identified as the most suitable; in the RGB sequence. These combinations enhanced the spectral differences of each lithology unit so that it can be distinguished easily. Apart from the difference in the spectral response, the texture of the lithologies was also enhanced to assist in discriminating the different units.

4.3 Principal Component Analysis

The PCA is an effective technical to accentuate a multispectral image for geological interpretation. It consists on the transformation of interrelated variables into new uncorrelated variables, based on the covariance analysis of the data correlation matrix (Lamri 2017). These new variables are called "main components". It reduces the information contained in several bands, sometimes highly correlated into a smaller number of components (Aouragh et al. 2012). Statistically, the first components produced best explanation of the data variability (Gasmi et al. 2016). For the variable K, it is noted:

$$\text{The overage:}\ \overline{X}_k = \frac{1}{I}\sum_{i=1}^{I} X_i k$$

$$\text{Standard deviation:}\ \ S_k = \sqrt{\frac{1}{I}\sum_{i=1}^{I}\left(X_{ik} - \bar{X}_k\right)^2}$$

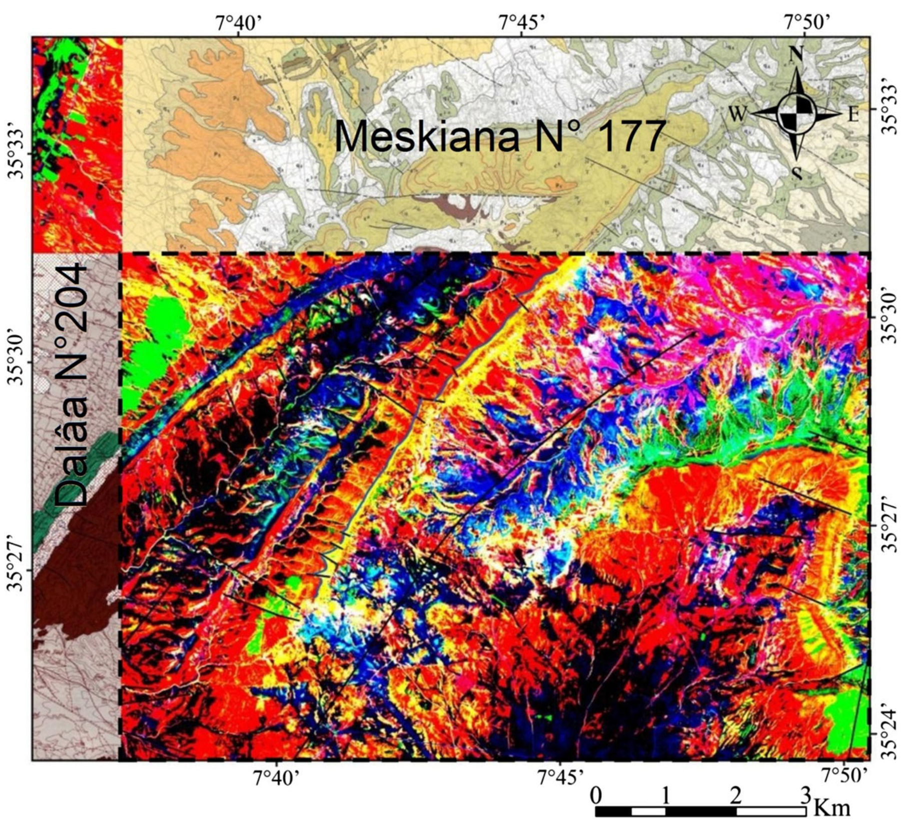

Fig. 4 The correlation between the used image (RGB: PC1, PC2, PC3) and the bordering geological maps of Meskiana (top) and Dalâa (left)

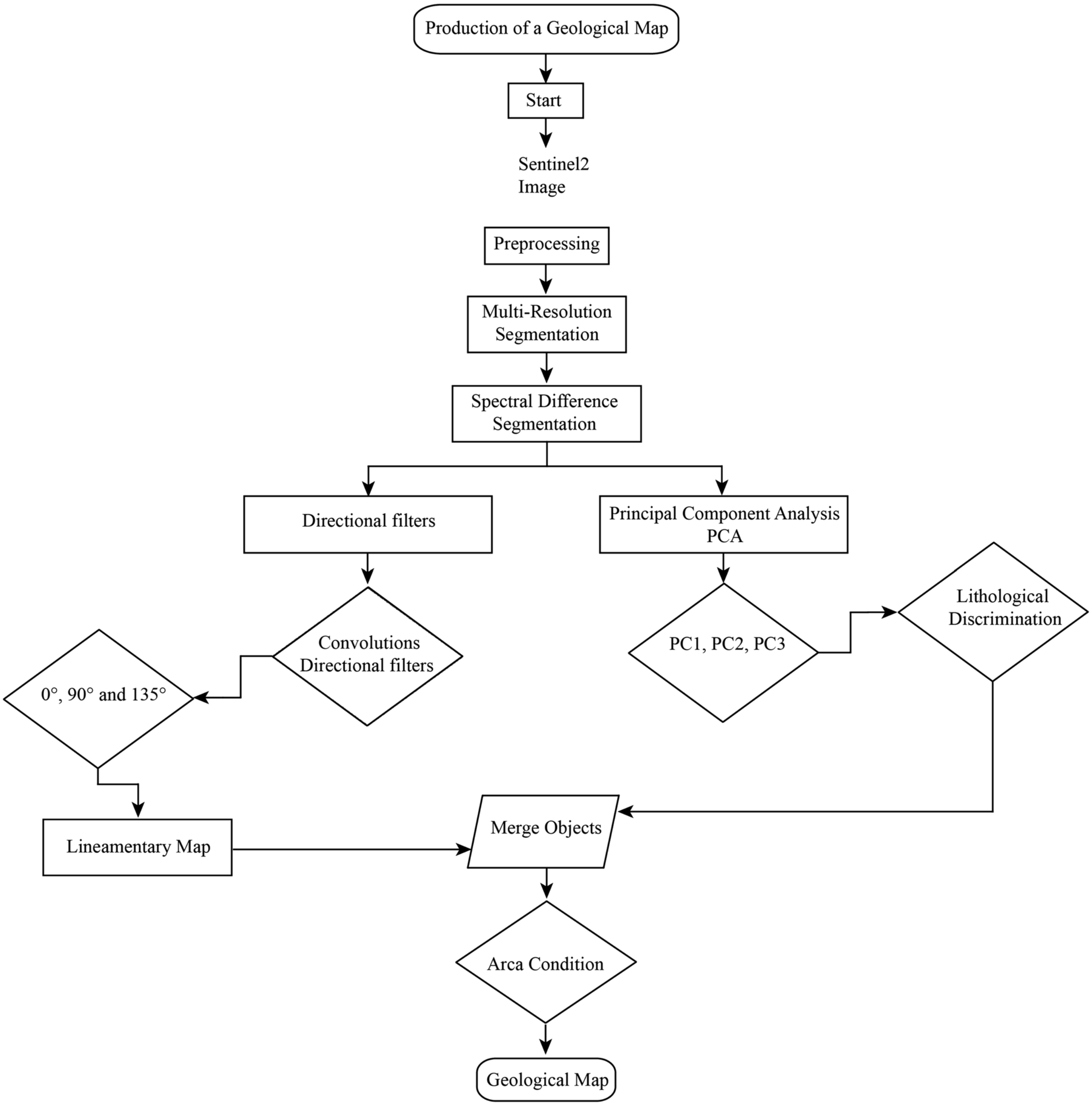

Fig. 5 Methodological flowchart of the adopted method

The PCA allowed us to identify different color ranges. The Maastrichtian limestone bar was discriminated by the blue fringe in the PCA image (Fig. 6a, b). The lithological formations outcroping in the study area were determined in accordance with our own field observations (Fig. 7).

4.4 Directional Filters Application

The directional filters are used strictly for the structural analysis. This technique improves the perception of lineaments; causing an optical effect of shade worn on the image as if it were illuminated by light grazing (Hammad et al. 2016). It can enhance lineaments that are not favoured by the illumination source. In our case the use of the Band8-NIR (0.842 µm, 10 m)

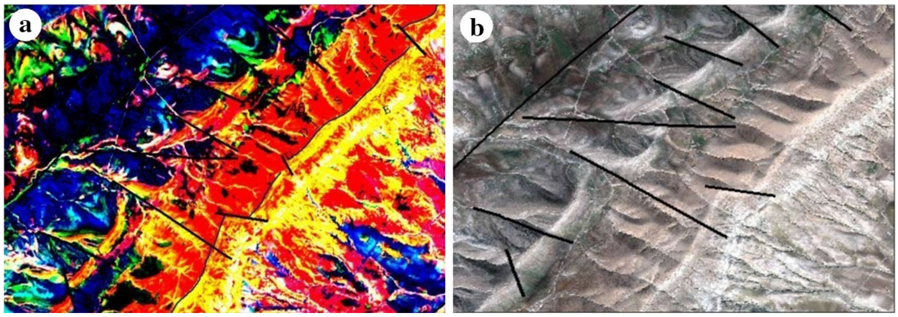

Fig. 6 **a** Selective PCA applied on an extract of Sentinel-2A scene; **b** lineaments and anticlines/synclines axes extracted Sentinel-2A image

image enlighten several structural details. The convolutions filters according to three directions: 0°, 90°, and 135° allows to identify lineaments corresponding to lithological or structural discontinuities (Fig. 8). As an alternative procedure, the automatic lineaments extraction can be applied based on, the use of a filter for the detection of contours. This can identify areas with unexpected changes in the values of nearest pixels, wich indicating lineaments (Hashim et al. 2013).

5 Results and Discussions

The results allowed the discrimination of the structures boundaries of the outcropping formations in the study area. The lithology indexes applied to Sentinel-2A multispectral images, give us a fast detection of the land surface saved as an 12-bit GeoTIFF raster image. Which can be imported to a GIS environment from which a simple vectorization area and perimeter are easily obtained. The geographical extension of the outcropping features is obtained. The lithologic map was thereby obtained from the compilation of the different facies of the study area with the image processing, completed by our own field observations (Fig. 9). The stratigraphic limits were determined by correlating the satellite images of the region with the adjacent geological maps. The Campanian limestones (59.02 km^2) and Maastrichtian limestones and marls (56.28 km^2) constitute the most representative formations.

A direct extraction of lineaments was performed to identify all structures and linear areas using directional filters. For the expression of ridge lines, boundaries between geological formations, and shear corridors,

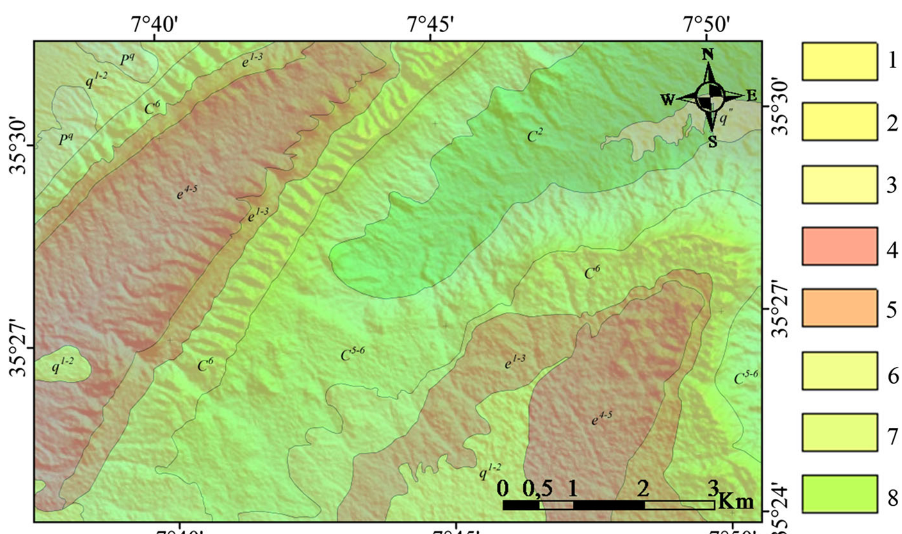

Fig. 7 Lithological Map of the study area. Legend: 1: ancient Alluvuim: 2: Scree, Gravel and Clay; 3: Limestone crust, red clay and conglomerate; 4: Limestone and Marls, overlayed by flint limestone; 5: Marl and marly limestone/Flint/levels of phosphate; 6: Beige limestone inoceraus with whitish Break; 7: Massive limestone alterning with marls; 8; Beige massive limestone, dolomitic/ Redustes

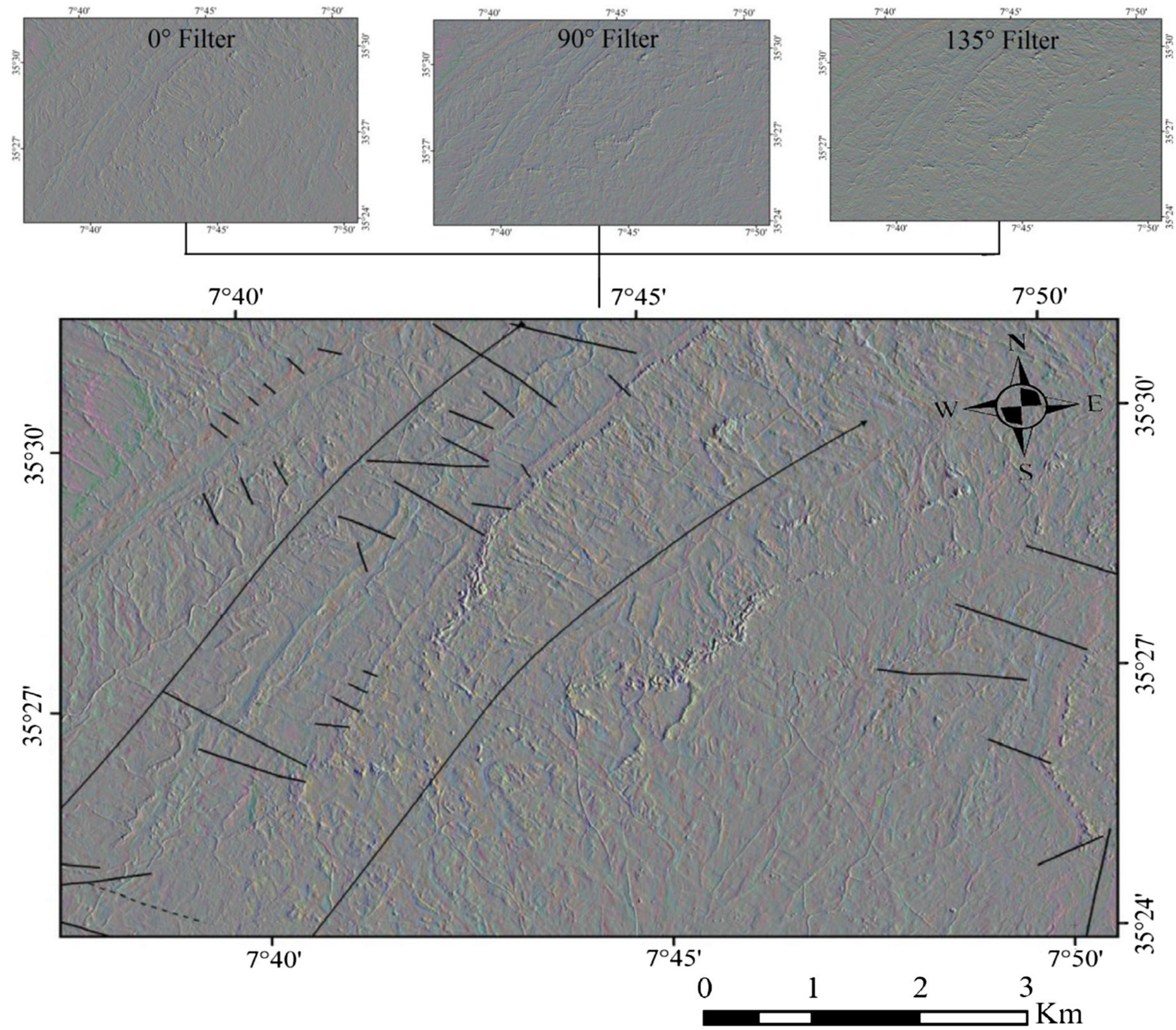

Fig. 8 Directional filters application and lineaments map of the study area

the N0°, N90°, and N135° filters were applied to Sentinel-2A bands using Cetin and Kavak (2007) approach. The filter N45° was not considered because of its poor quality. A synthesis map of the lineaments with more than 41 feature of varying sizes representing all the segments is obtained by the overlap of the information contained in all the filtered images. It indicates two important families of lineament orientations: primary NE-SW and secondary NW–SE. The displacement directions of these shears were determined with a field work.

For the completion of the geological map of the study area (Fig. 10), the lineaments map obtened from directional filters application was overlaid to the lithologic map.

The most important structures of the region are concentrated in Guerigueur, Serdies, Es Stah, Gaâgâ and Troubia mountains in the western part of the study framwork. These structures are essentially developed in anticlines and synclines, they often meet where they take a wavy appearance. The cores of some pleats consist of Maastrichtian limestones, others of Palaeogene deposits. The formation of the pleated structures was accompanied by many disjunctive accidents, divided into two families oriented in SE and NW directions.

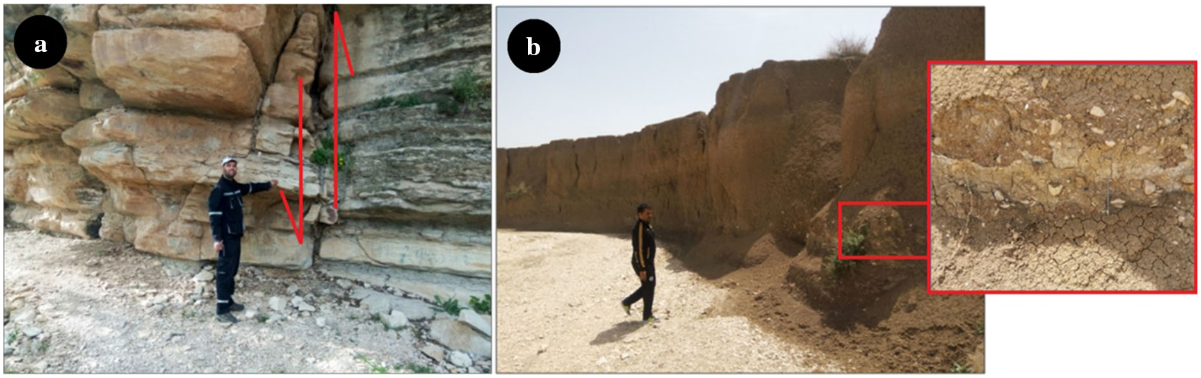

Fig. 9 **a** Shear zone between the Maestrichtian limestones and the Campanian marls, (35°24′42″N, 07°58′17″E.1007 m); **b** alluvium and Clay of Serdies Wadi (35°30′02″ N, 07°49′51″E. 924 m)

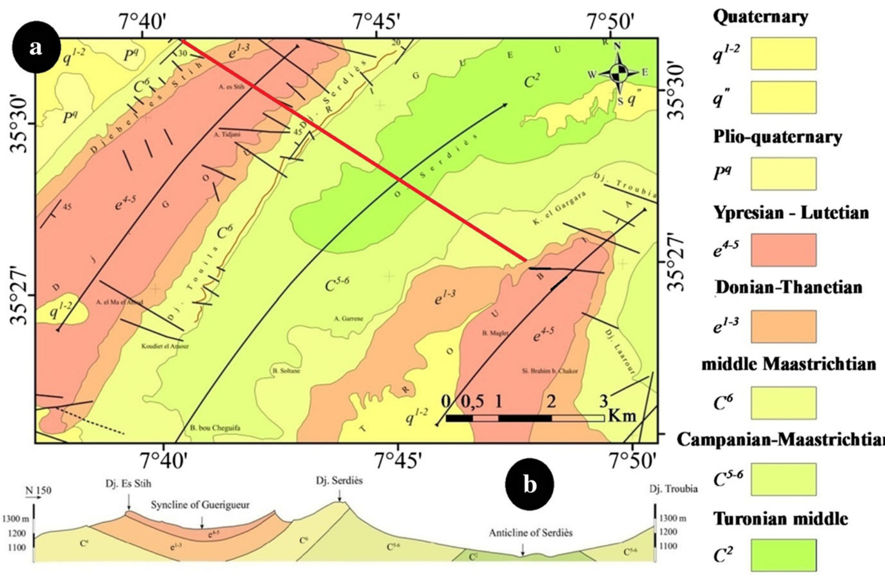

Fig. 10 **a** Geological map and of the study area; **b** geological section of Guerigueur syncline. Legend: q^{1-2}: ancient Alluvuim: q'': Scree, Gravel and Clay; P^{q}: Limestone crust, red clay and conglomerate; e^{4-5}: Limestone and Marls, overlayed by flint limestone; e^{1-3}: Marl and marly limestone/Flint/levels of phosphate; C^{6}: Beige limestone inoceraus with whitish Break; C^{5-6}: Massive limestone alterning with marls; C^{2}; Beige massive limestone, dolomitic/Redustes

With the PCA, many facies are distinguishable within the study Area. The Turonian limestones; the Maastrichtian limestones and marls; the Danian marls and limestones; the Montian marls; the Thanetian phosphates; the Ypresian limestones and flint marl; the Lutetian marls with gypsum; the Miocene Sandstone-clayey sediments and the Quaternary deposits were identified and delineated.

6 Conclusion

The study allowed us to test the efficiency of specific processing applied to Sentinel-2A images (spectral heightening, band rationing and PCA analysis) in the Youks les Bains region (NE Algeria). The structures boundaries of the outcropping formations were confronted to the published (Dalâa and Meskiana) geological maps as well as to the field observations in order to perform a lithological discrimination along the study framwork. As the most efficient image processing result, we were able to recognize a lithological diversity with different facies: the Turonian limestones; the Maastrichtian limestones and marls; the Danian marls and limestones; the Montian marls; the Thanetian phosphates; the Ypresian limestones and flint marl; the Lutetian marls with gypsum; the Miocene Sandstone-clayey sediments and the Quaternary formations. This study gives information for identifying some lithological units corresponding to superficial formations previously undetermined.

The structural study used directional filters, to define more than 41 lineaments mostly regrouped into two groups NW–SE and NE–SW. The use of Sentinel-2A for gelogical descrimination gives good results for geological mapping in particular when it is combining field data.

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