



Geosites Inventory and Proposal of Georoutes Throughout El Bayadh Area (Saharan Atlas, Algeria)

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Abstract

In recent years, various studies have been conducted on inventory and assessment of geosites as well as proposals of georoutes, leading to the implementation of geoconservation actions worldwide. The aim of this research is to explore the geological heritage and itineraries of the El Bayadh area in Algeria, which exhibits a rich and diverse geology and offers scenic landscapes. The methodology used is to identify and describe three potential geological itineraries, composed of 11 geosites that have scientific, educational, and touristic value. The most important results are that El Bayadh has unique geological features, such as Triassic diapirs, dinosaur footprint sites, oases, dams, and rock engravings that reveal the area's ancient history and geological processes. The geoheritage of El Bayadh can contribute to sustainable development, conservation, and community engagement, by promoting geotourism, geoscience education, and natural heritage preservation.

Keywords El Bayadh · Geological Heritage · Geosites · Geotourism · Geological Itineraries

Introduction

Algeria contains many geosites of great scientific value and geotouristic potential (e.g., Azil et al. 2020; Naimi and Cherif 2021). It has a surface of around 2,381,741 km², with varying rock types, geological structures, coastal types and climates. Examples of major terrains include Sahara desert (western and eastern ergs sand dunes), the Cenozoic volcanic provinces of the Hoggar massif and the Tell Atlas, Triassic diapirs, thermal springs, and dinosaur footprint sites. There are also several exceptional lagerstätten (sedimentary deposits that contain well-preserved fossil biotas) and many karst and cave sites.

The geological history of the El Bayadh region has been studied since the beginning of the 20th century by many authors who have established the stratigraphy, structure and paleontology of the Mesozoic and Cenozoic formations. The pioneering works of Flamand (1911) and Laffitte (1939) have allowed recognizing the main features of the sedimentary and tectonic evolution of the Saharan Atlas and its extensions. Cornet (1952) synthesized the geological map of El Bayadh area at 1/500,000 and highlighted the lateral variation of Jurassic and Cretaceous facies from SW to NE. Several subsequent works have refined the knowledge of the Jurassic- Cretaceous and Cenozoic series of the Djebel Amour Mountains, based on lithological, biostratigraphic and geochronological markers (Abed 1982; Mahboubi 1983; Regagba 2006). Dinosaur footprints have also been discovered in several sites of the El Bayadh area, witnessing the diversity of the Upper Jurassic fauna (Mammeri 2018). Recently, Mahboubi et al. (2021) proposed a new lithostratigraphic nomenclature for the Upper Jurassic of the central Saharan Atlas, using brachiopod levels as timelines and microfauna based on foraminifera (Mahboubi et al. 2023).

A geo-itinerary could be understood as a travel itinerary or route specifically designed to explore and experience geological features, sites, and landscapes (Santangelo et

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al. 2015). It would involve visiting locations of geological significance, rock formations, fossil sites, volcanoes, or any other geological attractions (Wang and Zouros 2021). The purpose of a geo-itinerary would be to provide travelers with a focused exploration of the Earth's geological heritage, allowing them to learn about geological processes, observe unique formations, and gain a deeper understanding of the planet's geological history (Santangelo et al., 2015). The concept of a geological itinerary aligns with the idea of geotourism, which emphasizes travel experiences that are focused on appreciating and learning about the geological aspects of a destination (Duarte et al. 2020).

Previously, several geosites have been proposed from El Bayadh area (Mahboubi 2018). This paper aims to present an inventory of geosites, accompanied with a proposal of three geo-itineraries throughout El Bayadh region, which is characterized by its diversified geology and beautiful landscapes.

Geological Background

The northwestern Algeria comprises three major geological domains that are, from north to south: (i) Tell Atlas; (ii) Tlemcen domain-Oran High Plateaus; and (iii) Saharan Atlas. The study area belongs to the Djebel Amour Mountains, which occupy the central part of the Saharan Atlas. The latter consists of an intra-continental fold belt and constitutes the southern part of the Algerian alpine system. Djebel Amour chain is bordered by Oran High Plateaus to the north, the Saharan Platform to the south, the Ksour Mounts to the west, and the Ouled Nail Mounts to the east. It is located 200 km to the southeast of Oran. This semi-arid region is characterized by its harsh climate, with warm and dry summers and cool and wet winters (Hadeid 2009).

The Saharan Atlas originated at the location of a former subsiding trough, oriented SW-NE, situated between two resistant regions; the Saharan platform to the South and the Oran High Plateaus to the North. Its opening is closely linked to the rifting of the Central Atlantic, with the formation, in a sub-aquatic environment, of tholeiitic basalt flows dated as late Triassic, resulting from fissure volcanic eruptions (Aït Ouali 1991; Meddah et al. 2007). This magmatic event was accompanied by block tilting faulting (Aït Ouali 1991). These volcanic rocks belong to the Central Atlantic Magmatic Province (CAMP) (Meddah et al. 2007). They are overlain by Hettangian carbonates (post-rift phase), signaling the establishment of the Liassic carbonate platform. This marine regime was likely established as early as the Triassic (Bassoulet 1973), at least in the axial zone of the western part of the basin (Elmi 1977). By the Toarcian, the opening of the Atlas Basin reaches its ultimate stage, and

a significant marine transgression becomes widespread, reaching its peak in the Middle Toarcian.

The Saharan Atlas Range is subdivided into two tectonically distinct zones: a pre-Atlas zone to the North and an Atlas zone (*sensu stricto*) to the South (Kazi Tani 1986). It exhibits a more brittle style in the west and a more ductile style in the east. This mountain range is characterised by upright-flanked anticlines with a more or less horizontal core (box folds). These anticlines can be narrow or wide and elongated (Douihasni 1976). The Atlasic style is characterised by loose folds, with a small longitudinal development, rapidly alternating, resulting in a *Pine Processionary Caterpillar*-like arrangement (Ritter 1902; Delfaud et al. 1974). This folding style is attributed to evaporitic Triassic rocks that caused a general disharmony between the basement and its sedimentary cover. Diapirs are associated with longitudinal reverse faults or longitudinal and transverse strike-slip faults (Douihasni 1976).

The Saharan Atlas is formed by large kilometeric fold structures, oriented along the general direction of the mountain range (NE-SW), represented by anticline ridges and bowl-shaped synclines. Structural analysis by Douihasni (1976) has revealed various forms of anticline structures, such as asymmetrical, box folds, faulted, or doubly plunging anticlines. The anticlines of the Atlas are narrow and elongated with discontinuous features, and their cores are marked by Jurassic formations. As for synclines, two main types can be distinguished (Douihasni 1976):

- (i) Box-fold synclines with Barremian-Aptian-Albian deposits (Continental Intercalaire series), which are wide, asymmetrical, elongated bowl-shaped structures with nearly flat bottoms, resembling a 'boat hull' and highly fractured. These synclines are located at lower altitudes.
- (ii) Perched synclines with deposits from the Cenomanian-Turonian which become more frequent towards the east. These structures are asymmetrical, generally occupying higher altitudes. They have spoon-shaped forms (Khoundjaïa) to the west and tomb-like shapes (Kébeur) in the central part of the chain. Perched synclines are elongated, continuous, and regular, sometimes triangular, and narrower than box-fold synclines.

Regarding major faults, they generally correspond to post-sedimentary tectonic accidents, often transverse, with a significant strike-slip component, following three different directions (Guiraud 1973):

- (i) Oblique, N-S to N60° oriented faults that border or more frequently overlap anticline or monocline structures. These faults were primarily active before the

- Miocene during the folding associated with the Atlasic phase (Bartonian–Priabonian; Late Eocene);
- (ii) E-W faults, plurikilometric, mostly behave as dextral strike-slip faults and show almost systematic inflection alignments of the folds, suggesting contemporaneity with the Atlasic phase;
 - (iii) Oblique faults that seem to play a minor role. The wide range of directions supports the existence of several tectonic phases.

The stratigraphic succession of the Saharan Atlas is made of Triassic to late Cenozoic mixed marine and continental deposits. The Triassic strata crop out in diapirs. They are characterized by gypsiferous and saliferous marls and red carbonated clays interlayered with a greenish volcanic flow formed by pyroxenes-rich basalts (Meddah et al. 2007). The overlying Middle to Upper Jurassic (Lower Callovian – Upper Kimmeridgian) to Lower Cretaceous series is characterized by an episodic sedimentation, represented by mixed marine and continental deposits which yielded abundant dinosaur tracksites (Mammeri 2018; Mahboubi et al. 2021). The Upper Cretaceous (Cenomanian–Turonian) sedimentary succession in the Western and Central Saharan Atlas records the evolution of a carbonate platform under the influence of global and regional environmental changes. The lithostratigraphic series is composed of three formations (Bassoullet 1973; Benyoucef et al. 2017; Naimi et al. 2021): (i) the Rhelida Formation (Early Cenomanian) consists of dolomitic limestones and dolostones with intercalations of marls and clays as well as sandstone beds that yielded extremely rich vertebrate remains; (ii) the Medaouar Formation (Early to Middle Cenomanian) is the middle unit of the succession. It consists mainly of evaporates alternating with limestones, dolostones and marly levels; (iii) the Rhoundjaïa Formation (Late Cenomanian to Early Turonian) is composed of limestones, marls and shales with abundant fossils. Paleogene strata are represented by the continental highly fossiliferous deposits of El Kohol Formation, attributed to the Middle Ypresian (Mahboubi et al. 1983; Coster et al. 2012). The Neogene continental deposits of represented by the Hamada formations, which consist of clayey-sandstone layers containing gypsum levels attributed to the Miocene–Pliocene. These formations are generally unconformably lying on the Lower Cretaceous sandstones. The Quaternary is characterized by Villafranchian limestone carapaces, as well as tuffs and travertines, ancient silts, piedmont colluviums, ancient and recent alluvial deposits, and aeolian formations (Douhasni 1976).

Guillemot (1972) and Guiraud (1973) have highlighted several tectogenic phases responsible for the uplift and current structuring of the Saharan Atlas. Three major phases can be mentioned:

- (i) Laramian Phase: is much more intense in the Betic Cordillera, Languedoc, and the Eastern Alps. It began from the late Turonian to the Senonian (Guiraud 1973) and probably until the Lower Eocene (Guillemot 1972). It is characterised by significant uplifts, related to strong fault displacements, and accompanied by fractures oriented NW, NE, or ENE. Some faults allowed the emergence of Triassic outcrops;
- (ii) Atlasic Phase: is the major phase that gave rise to the Saharan Atlas, from which it gets its name (Guillemot 1972). It occurred during the Bartonian–Priabonian (Piqué et al. 2002). The fold direction is NE–SW to ENE–WSW. Faults are sometimes parallel to the fold axis, but most are oblique in an E–W, SE–NW, or ESE–WNW direction. Most Triassic diapirs emerged following this tectonic phase.
- (iii) Miocene–Pliocene–Quaternary Phases: Guiraud (1973) identified a Miocene phase that caused only minor deformations, followed by a Pliocene phase (Late Pliocene), considered the most significant along with the Atlasic phase. It is characterised by folds and faults oriented ENE–WSW, with some E–W folds, and finally, a Quaternary phase limited to the reactivation of folds formed during the Pliocene. Also, these latter two phases (Pliocene and Quaternary) are responsible for the emergence of some Triassic outcrops. However, Guillemot (1972) distinguished only a single phase, probably from the Miocene, responsible for the uplift and deformation of Paleogene conglomerate formations resulting from the Atlasic phase.

Methodological Approach

Geosites were identified based on their geological significance, unique features, or cultural value (Table 1). After the inventory of the geosites, we: (i) conducted a comprehensive geoscientific assessment of each selected geosite; (ii) analyzed the geological context, stratigraphy, structures, and geomorphological features; (iii) identified and documented key geological features, fossils, or specific landforms; (iv) assessed the geological processes and their significance in shaping the geosite; and (v) used field observations, measurements, and laboratory analyses to gather data and characterized the geosite's geology. The values of these geosites were assessed using a semi-quantitative method that considered many factors such as accessibility, state of preservation, scientific worth, and education (Table 2). The method involved assigning scores to each factor and calculating the total value of each geosite. The selection process was done after the consultation of geological maps, literature,

Table 1 Inventory of the proposed remarkable geosites from the El Bayadh area

Geosite	Trip 1			Trip 2			Trip 3				
	Djebel Khoundjia perched syncline	Theniet El-Temar Formation	El-Mezioned dinosaur tracksite	Brezina dam, oasis, and South Atlas Fault	The Gour of Brezina	El Kohol	Boualem Ram	Sidi Tifour Diapir	North Atlas Fault	Macrocephalites level	Grarij dinosaur tracksite
Latitude/longitude	33°33'3.91"N; 1°7'15.48"E	33°19'10.94"N; 1°15'31.57"E	33°11'3.83"N; 1°12'7.08"E	33°8'27.80"N; 1°15'4.31"E / 33°5'58.96"N; 1°16'10.15"E	33°4'28.39"N; 1°15'53.62"E	33°3'8.39"N; 1°25'35.10"E	33°42'56.68"N; 1°30'20.02"E	33°38'50.33"N; 1°51'38.34"E	33°41'31.55"N; 0°58'56.80"E	33°41'31.55"N; 0°58'56.80"E	0°58'56.80"N; 1°2'2.35"E
Interest	Tectonic Heritage	Sedimentological and Stratigraphic Heritage	Ichnological Heritage	Hydrological, Natural and Tectonic Heritage	Geomorphological and Tectonic Heritage	Sedimentologic and Palaeontological Heritage	Archaeological Heritage	Geodynamic Heritage	Tectonic Heritage	Palaeontological Heritage	Ichnological Heritage

expert (geologists) opinions, as well as local knowledge. The choice of these geosites was based on scientific, pedagogical and touristic criteria. From a scientific-geoeducational point of view, some key aspects such as stratigraphy, ichnology, palaeontology, geomorphology or archaeology, among others have been considered. Tourist issues such as accessibility have been also addressed. To assess the values of the geosites in a more objective and systematic way, we applied the method proposed by Brilha (2005) which consists of assigning scores to each geosite according to a set of indicators that reflect its scientific, educational, and touristic potential. The indicators include aspects such as rarity, representativeness, diversity, integrity, vulnerability, visibility, interpretability, attractiveness, and facilities. The scores range from 0 to 5, where 0 means no value and 5 means very high value. The total value of each geosite is calculated by summing the scores of all the indicators. The results of the assessment are shown in Table 2, where the geosites are ranked according to their total value. The table also shows the values of the geosites in comparison with other similar sites in the region or in the world, using the categories of local, regional, national, and international. The valorization of the geoeducation values and geotouristic potential are based on four criteria which are: (i) accessibility; (ii) state of preservation; (iii) scientific worth; and (iv) education. All these criteria have 5 to 1 points.

The Geoitineraries

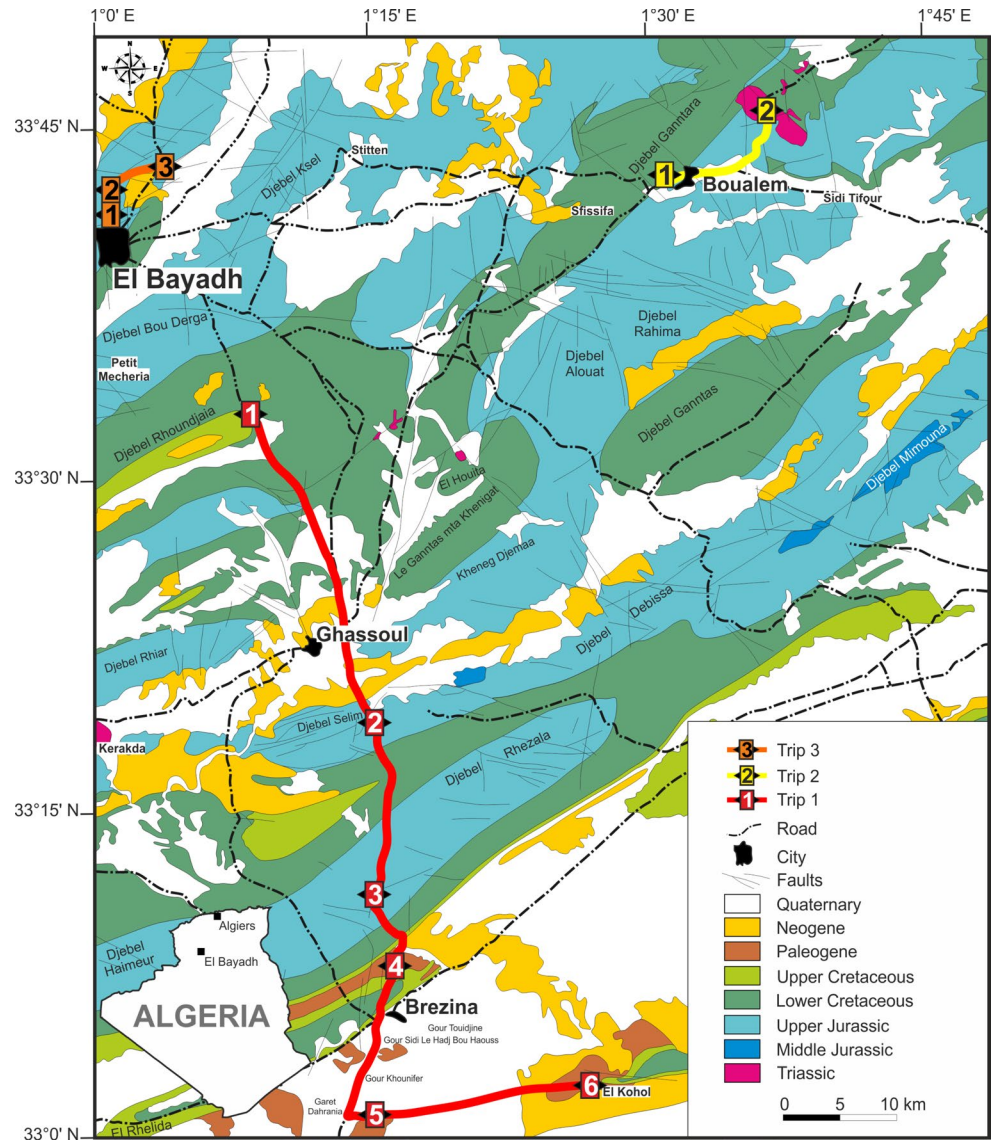
The geological itineraries in El Bayadh area are summarized below (Table 1). Three main well-planned itineraries could be used for educational and touristic purposes. They show the beauty and richness of the landscapes and outcrops of this fascinating region. The first itinerary links El Bayadh and Brezina following a North-South transect. The second geotrail starts at El Bayadh city and reaches Sidi Tifour and it is oriented broadly SW-NE, whereas the last one targets the northern part of El Bayadh area (Fig. 1).

As can be seen from the table, the geosites have different levels of value, depending on the indicators considered. The highest valued geosites are Sidi Tifour diapir and Grarij dinosaur tracksite, which have a total value of 19 and an international scientific value, due to their unique features and significance for the understanding of the geological history of the area. The lowest valued geosite is the *Macrocephalites* level, which has a total value of 11 and a local scientific value, due to its common features and low representativeness. The other geosites have intermediate values, ranging from 12 to 15, and varying degrees of scientific, educational, and touristic value. The assessment method allows us to identify the strengths and weaknesses of each

Table 2 Valorization of the geosites of El Bayadh area

Id	Trips	Geosite	Criteria				
			Accessibility	State of preservation	Scientific worth	Education	Summarized value
1	Trip 1	Djebel Khoundjaïa perched syncline	2	4	4	3	13
2		Theniet Et-Temar Formation type series	5	3	4	3	15
3		El Mezioued dinosaur tracksite	1	3	5	5	14
4		Brezina dam, oasis, and the South Atlas fault	5	5	3	2	15
5		The Gour of Brezina	3	5	3	3	14
6		El Kohol	1	4	5	4	14
7	Trip 2	Boualem Ram	5	3	4	3	15
8		Sidi Tifour diapir	5	5	4	5	19
9	Trip 3	North Atlas fault	5	3	2	2	12
10		<i>Macrocephalites</i> level	2	3	3	3	11
11		Grarij dinosaur tracksite	4	5	5	5	19

Fig. 1 Geological map of the studied area showing the three proposed geo-routes



geosite, as well as the opportunities and threats for their conservation and management.

The starting point of the three trails corresponds to the center of El Bayadh city that includes comfortable tourist facilities (Fig. 1).

Trip 1 (El Bayadh – El Kohol)

Time: 1 day, by car or bus.

Main geological topics: sedimentology, palaeontology, ichnology, karst morphology, structural geology, ecology and geomorphology.

Stop 1: Djebel Khoundjaïa Perched Syncline

The perched synclines (Fig. 2A) are fascinating structural features shaped by different mechanisms under various geological conditions such as the structure and the rheology of the rocks, tectonic and erosional processes, as well as halokinetic movements (Saadi et al. 2021). The Saharan Atlas is characterized by the presence of perched synclines showing well-exposed Cenomanian-Turonian deposits. These structures are common in the western part of the chain. They form dissymmetric dish structures which occupy the highest altitudes. Djebel Khoundjaïa perched syncline is strait, elongated, continuous, and regular, made of Cenomanian–Turonian carbonate and evaporitic deposits assigned classically to the Rhelida, Rhoundjaïa and Medaouar Formations. In El Bayadh area, this syncline has been named

Khoundjaïa which means spoon due to its shape. Further west, in the Ksour Mountains, these synclines resemble tombs, and they are called Kébeur (Douihasni 1976).

Stop 2: Theniet Et-Temar Formation Type Series

The locality of Theniet Et-Temar is situated between the Selim and Cherak Mountains (co-ordinates: 33°19'9.84"N, 1°15'31.66"E), about 8 km south of Ghassoul village. The formation consists mainly of marl-limestone alternations (Mahboubi et al. 2024a, b) (Fig. 2B). The marly interlayers are greyish to black in colour. The limestone beds are partially dolomitized and blue to black in colour. The lowermost and middle parts of the Theniet Et-Temar Formation are highly fossiliferous with bivalves, gastropods. Two brachiopod species *Lacunosella (Lacunosella) arolica* and *Moeschia alata* have been recorded for the first time not only in Algeria but also in Africa, and allowed attributing this formation to the middle Oxfordian (Mahboubi et al. 2021a).

Stop 3: El Mezioued Dinosaur Tracksite

Dinosaur footprints provide valuable insights into the behavior and movement patterns of these ancient creatures.

This dinosaur tracksite is located 2.5 km to the south-east of Douar El Mezioued. It shows seven trackways, ten isolated tracks and a total of sixty-five theropod footprints, within an area of 727.83 m² (Mammeri 2018). The facies

Fig. 2 A: Djebel Khoundjaïa perched syncline; B: Theniet Et-Temar Formation type series; C: Brezina dam; D: the South Atlas Fault; E: Brezina oasis; F: The Gour of Brezina



consists of fine-grained, 40 cm-thick sandstones. The longest trackway, including ten footprints, measures 27 m. The tracks may reach length of 23 cm and a width of about 19 cm. Also, these footprints present well-preserved claw marks, and they have been assigned to the ichnogenus *Megalosauripus*, *Megalosauropus*, and *Therangospodus* (Mammeri 2018). El Mezioued tracksite is included in the upper Oxfordian – lower Kimmeridgian in the top of Ksel and Laguermi Formations (Mahboubi et al. 2021a).

Stop 4: Brezina Dam, Oasis, and the South Atlas Fault

The Brezina dam is located to the south of El Bayadh city. The watershed of the Brezina dam covers an area of 3677.5 km², which is drained by the Ghassoul and Oued Rahoul valleys tributary to the Seggueur valley. The main valley rises further north, in the Atlas Mountains, and travels 160 km before emerging at the dam site, at a place called “Khang Larouia”.

Most of this dam is made in the Lower Cretaceous successions. These successions are composed of fluvial sandstones of the *Continental Intercalaire*, Cenomanian gypsum clays, and Turonian massive limestones with natural caverns, wonderful stalactites, stalagmites and animal bones from the Neolithic period. The downstream side of the dam is characterized by microconglomerates, sandstones and red clay beds of Eocene age.

In this area, we have an excellent example for the principal fault in the Atlas system, which is the South Atlas Fault, corresponding to a succession of accidents of general orientation ENE-WSW (Fig. 2D) which take turns and stretch from Agadir in Morocco to the Gabes Gulf in Tunisia. It separates the relatively stable Saharan domain from the folded Atlas domain.

The Brezina dam (Fig. 2C) arouses the vocation of fishermen among many young people in the region. This activity is thus developing in the wake of the success of the aquaculture experiment, launched in early 2008, with the stocking of more than 270,000 salmon and carps.

The Brezina oasis, a perfect place for hiking, offers tourists a colorful and captivating panorama. Oases are areas in deserts where water is available, typically forming lush and habitable spots amidst arid surroundings. They often serve as vital stopping points for travelers in desert regions. The palm grove of the Brezina oasis once had more than 30,000 palm trees. Its irrigation system includes foggaras, basins, interchanges, and canals (Fig. 2E).

Stop 5: The Gour of Brezina

Gour is the plural of Gara (rock pinnacles or towers) that are formed by wind erosion (Fig. 2F). They are widespread

in the Djebel Amour Mounts and the southeastern part of Ksour Mounts. The Brezina Gour are characterized by terrigenous detrital deposits formed by poorly consolidated pebbles, made up of detrital blocks. They correspond to old colluviums preserved from erosion, constituting mounds. These have been assigned to the Lutetian (Jodot, 1952). Because they are not affected by the Atlasic tectonic phase, the Gour may be post-Lutetian, and most probably Neogene. Besides, Mahboubi (1983) attributed this « formation » to the Miocene on the basis of gastropods belonging to the Genus *Helix*.

Stop 6: El Kohol

The best-studied Paleogene deposits in the Saharan Atlas correspond to those at the El Kohol locality, situated in the Brezina region to the south of El Bayadh. This fossil-rich site has yielded the first African marsupial (Mahboubi et al., 1983) named *Garatherium mahboubii* Crochet, 1984, the oldest African creodont *Koholia atlasense* Crochet, 1988, the oldest and most basal known hyracoid *Seggeurius amourensis* Crochet, 1986 (in Mahboubi et al. 1986), one of the most basal proboscidians *Numidotherium koholense* Jaeger, 1986 (in Mahboubi et al., 1984a 1986), as well as the oldest bat fauna in Africa (Ravel et al., 2011). El Kohol Formation is divided into four units: (i) Gypsiferous Transitional unit; (ii) Inferior Red Detrital unit; (iii) Intermediate Marly and Calcareous unit; and (iv) Upper Red Detrital unit. Initially, this formation was considered as Ypresian (= Ilerdian-Cuisian) based on the charophyte assemblage (Mebrouk et al., 1997). This age was later specified as Lower Ypresian (= Ilerdian) still based on this floral association (Mebrouk, 2010). Coster et al. (2012) conducted a magnetostratigraphic study, attributing an age of 51 – 50 million years (= Middle Ypresian) to the El Kohol Formation.

Trip 2 (El Bayadh – Sidi Tifour)

Time: 1 day, by car or bus.

Main geological topics: petrology, geodynamics, structural geology, geomorphology and archaeology.

Stop 1: Boualem Ram

Rock engravings, also known as petroglyphs, are images or designs carved into rock surfaces by ancient cultures. These engravings provide valuable insights into prehistoric art, symbolism, and cultural practices. The rock engravings of Boualem Ram, called locally as *Kebch Boualem* are located in El Ouediane locality between Sfisifa and Boualem town, situated 54 km from El Bayadh city. This site was discovered in 1898 by the geologist

G.M.B Flamand. It was referenced for the first time on 1929 in a correspondence with the Academy of Sculpture and Fine Arts of Paris, where was mentioned that this masterpiece deserves to be represented in the artistic heritage of humanity, but unfortunately it is threatened by nature such as the water leaks which destroyed the last part of the animal and human acts as the rock engravings. This stone with a sculpture of a ram goes back to 6000 years before J-C. It is approximately 1.50 m according to French geologist Flamand. The Boualem Ram is located in a vast field area of exploration for scientists and researchers. This archaeological site is classified in the list of Algerian cultural heritage in the Official Journal, published on May 8th, 2016 (Fig. 3A).

Stop 2: Sidi Tifour Diapir

The Sidi Tifour Triassic diapir is part of Central Saharan Atlas. It is located in the Sidi Tifour town, which is located approximately 92 km from the south east of El Bayadh city close to the local road of Sidi Tifour-Tadrouna. The Triassic outcrop is formed since the birth of the central Atlantic rifting, at the Triassic–Jurassic (Tr–J) boundary (Meddah et al. 2007) and represented by green basaltic volcanic units, with ophitic texture (tholeiitic basalts), separated by silico-clastic sedimentary intervals represented by varicolored clays with evaporites

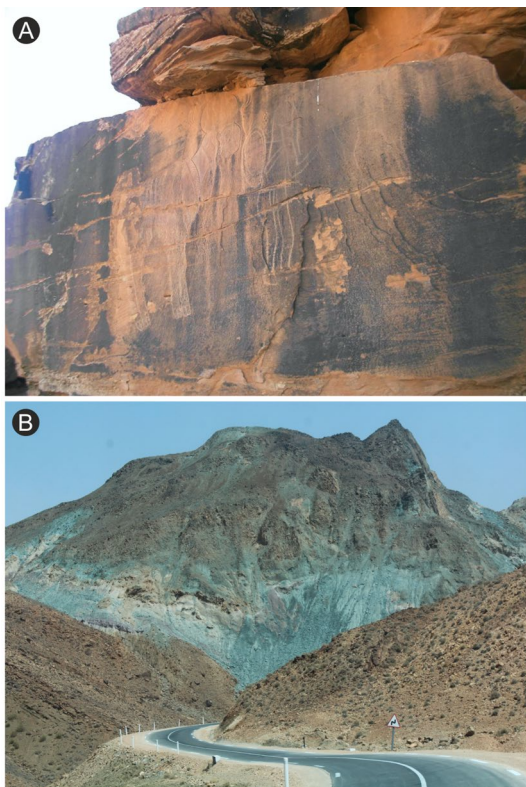


Fig. 3 A: Boualem Ram; B: Sidi Tifour Diapir

(Meddah et al. 2007). These basaltic rocks are related to the central Atlantic magmatic province (CAMP) (Meddah et al. 2017). The Triassic outcrop is uncomfortably covered by Jurassic formations and controlled by NE–SW anticlines and includes many salt caverns created by dissolution of salt and salty water source such as Ain Ben Tounsi ((Fig. 3B).

Trip 3 (El Bayadh City)

Time: 1 day, by car or bus.

Main geological topics: structural geology, paleontology, stratigraphy and ichnology.

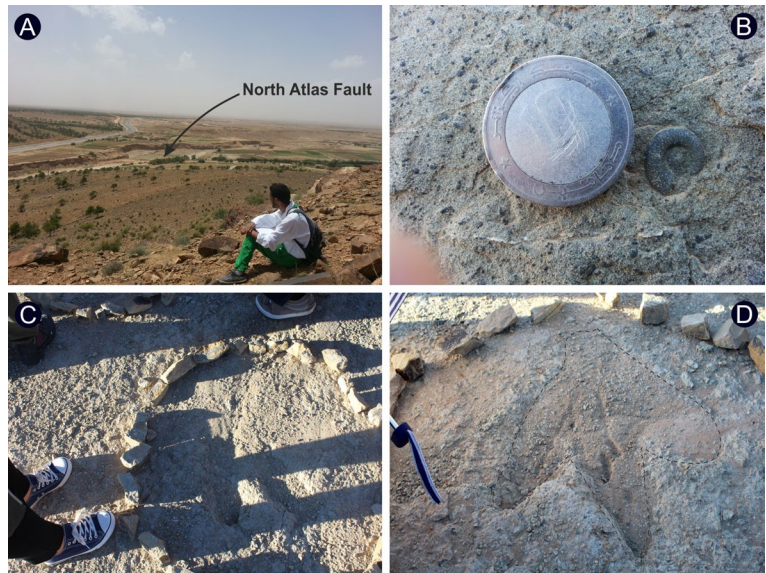
Stop 1: North Atlas Fault

The site is located approximately 1.5 km from northwest El Bayadh city in the of El Bayadh city. The North Atlas fault separates the Atlasic domain folded in the South from another domain slightly deformed in the North. This accident direction NE-SW from Bou Arfa (Morocco) to Chott Zahrez Chergui (Algeria). In the Central Saharan Atlas, it extends from the NE of El Bayadh city to the north of Aflou city (Fig. 4A).

Stop 2: *Macrocephalites* Level

The level outcrops in the Kheneg locality at the exit of the El Bayadh gorges, 2 km west from El Bayadh city-center. It belongs to the Lower Callovian Kheneg Formation (Mahboubi et al. 2024c). The site is scientifically remarkable for its abundance of ammonite fossils. It exhibits clay and sandstone alternations, with the clays being grayish to blackish, more or less schistose, and showing evidence medium-scale slump folds and olistoliths. The sandstones are fine-grained, ranging from millimeter to centimeter in thickness, and display parallel laminations. The base of the sandstone beds is characterized by sole marks such as flute-casts, while the top is marked by ripple marks and turbiditic sequences. A limestone bed with a rich assemblage of gastropods, brachiopods, and ammonites *Macrocephalites macrocephalus* and *Parapatoceras* cf. *tuberculatum* caps the formation (Fig. 4B) (Mahboubi et al. 2024c). *Parapatoceras* specimens have been recorded in this area for the first time from North Africa. Their occurrence coincides with the lower Callovian sea-level highstand JCa2 (Mahboubi et al. 2024c). This level is correlated with coeval levels from the Déglène and Ben Kmer localities, both located in the Tlemcen basin in the northwesternmost Algeria.

Fig. 4 **A:** North Atlas Fault in El Bayadh City; **B:** Ammonite level (*Macrocephalites macrocephalus*); **C, D:** Grarij dinosaur tracksites



Stop 3: Grarij Dinosaur Tracksite

Grarij dinosaur tracksites have been discovered near El Bayadh (Mahboubi et al. 2004, 2007; Bensalah et al. 2005; Bessedik et al. 2008; Mammeri 2008, 2018; Mammeri et al. 2011). They are located on Upper Jurassic limestone, and show different types of footprints. Is the largest and most diverse site, covering an area of about 1 km². It is near the road to Rogassa, 2 km northeast of El Bayadh. It has two track levels with about 100 tridactyl footprints of theropod dinosaurs and 20 half-moon-shaped footprints of sauropod dinosaurs. The tracks are well-preserved and have clawed digits (Fig. 4C and D).

Discussion

Geoeducation is a form of education focused on geosciences. According to National Geographic, this term is used in order to describe the in-school and out-of-school experiences where students learn about how the world functions (Ríos et al. 2020). In this study, a total of 11 geosites were proposed. The choice of these geosites was based on scientific, pedagogical and touristic criteria. From a scientific-geoeducational point of view, some key aspects such as stratigraphy, ichnology, palaeontology, geomorphology or archaeology, among others have been considered. Tourist issues such as accessibility have been also addressed.

The landscapes of El Bayadh area are unique, from the Atlas peaks to the Sahara desert, and from the countryside

to the city. The great visibility, the perfect exposures, and the lack of vegetable cover offer great research potential in these locations. El Bayadh area offers a new view that will enable visitors to appreciate such high geodiversity. Most of the studied geosites are accessible to visitors and show important educational and touristic values.

Valorization of the Geoheritage of the Saharan Atlas Cultural Park

Many natural and cultural parks were established, among others, the Saharan Atlas Cultural Park, created in 2008 and which covers a wide area along the Saharan Atlas Mountain belt in which is situated our study area. In this cultural park, several strategies must be followed for the valorization and preservation of the geoheritage of the region:

Valuation of Geosites

- a. *Geosite inventory and assessment:* by conducting a comprehensive geological assessment of the area to identify and document its unique geological features, including rock formations, fossils, landforms, and geological processes;
- b. *Geoscientific research and monitoring:* encourage scientific research and monitoring activities within the region. Foster partnerships with geoscientific institutions and researchers to deepen the understanding of the geological processes, heritage conservation, and sustainable development practices within the park.

Preservation

- a. *Collaboration and stakeholder engagement*: engage with local communities, experts, universities, and relevant organizations (e.g., Algerian Geological Survey Agency) to foster collaboration and gather diverse perspectives. Involve cultural and historical groups to ensure the preservation and interpretation of the area's cultural heritage within the context of its geological importance;
- b. *Sustainable development and conservation*: adopt sustainable development practices to ensure the long-term preservation of the park's geological and cultural heritage. Implement measures to minimize environmental impact, promote conservation of natural resources, and support local communities in sustainable economic activities that respect the area's heritage. Economically, the cultural park promotion is often geared toward the geoproducts that enable the local agriculture and handicraft to have chances of becoming value-added. Local products represent a reflection of the cultural and natural heritage of the territory (Ríos et al. 2020). Park communities will be partially dependant on agricultural activities for living, because this region is characterized by rural or semi-rural areas. Some fruits (e.g., date) may be labeled as geoproducts. The park promotion includes also the improvement of people's living conditions, improved school education, and creating employment opportunities.

Geotourism

Develop geotourism initiatives that highlight the geological features and cultural heritage of the area. Create well-designed visitor experiences, such as guided tours, interactive exhibits, and interpretation centers, to engage visitors and educate them about the geological significance and cultural context of the area.

Interpretation and Education

Implement educational programs that emphasize the geological and cultural values of the area. Offer guided tours, workshops, and educational materials to educate visitors about the geology, history, and cultural heritage. Foster partnerships with educational institutions to promote research and learning opportunities within the area.

Marketing and Promotion

Develop a comprehensive marketing and promotion strategy to raise awareness about the park's geological and cultural

significance. Utilize various channels, including websites, social media, brochures, and partnerships with travel agencies, to attract visitors interested in the unique combination of geological and cultural experiences.

Geotourism and Complementary Experiences

Here are some activities that local inhabitants of the El Bayadh area can offer to geotourists:

1. *Guided geological tours*: locals with knowledge of the area's geology can provide guided tours to geological sites of interest, offering insights into the interesting formations, fossils, dinosaur tracks and the geological history of the region;
2. *Cultural experiences*: local inhabitants can offer cultural experiences such as traditional music and dance performances, storytelling sessions, cooking classes to learn local cuisine, handicraft workshops, or visits to local markets and festivals. These activities allow geotourists to immerse themselves in the local culture and gain a deeper understanding of the area's traditions and way of life;
3. *Nature walks and hikes*: locals can lead nature walks or hikes through scenic trails, sharing their knowledge about local geology, flora, fauna (Fig. 5A) and ecological systems. They can highlight interesting features, point out wildlife, and educate visitors about the importance of conservation and sustainability;
4. *Traditional crafts and artisan workshops*: artisans from the local community can offer workshops where tourists can learn traditional crafts (Fig. 5B) such as pottery, weaving, carving, or painting. This provides an opportunity for visitors to engage in hands-on activities and learn about the cultural heritage associated with these crafts;
5. *Farm visits and agricultural experiences*: local farmers can organize visits to their farms (and oases), giving geotourists a chance to learn about traditional agricultural practices, participate in activities like harvesting or planting, and taste locally grown produce. This provides insight into the region's agricultural traditions and sustainable farming methods;
6. *Community homestays*: local inhabitants can offer homestay accommodations, allowing geotourists to live with a local family and experience daily life in the community. This immersive experience offers a unique cultural exchange and a deeper understanding of local customs, traditions, and hospitality;
7. *Traditional music and dance workshops*: local musicians (Fig. 5C) and dancers can conduct workshops

Fig. 5 **A:** Camels in the Sahara Desert; **B:** Traditional Algerian fantasia with horsemen wearing uniform costumes and firing gunpowder rifles. **C:** Traditional music (El Ghaita); **D:** The Art of Making Traditional Algerian Couscous



to teach tourists traditional music instruments, dance styles, or vocal techniques. This interactive experience enables visitors to appreciate the richness of the local performing arts and actively participate in cultural traditions;

8. *Storytelling and local legends:* local storytellers can share captivating tales and legends passed down through generations, providing tourists with insight into the region's history, mythology, and folklore. This activity adds an element of storytelling and oral traditions to the visitor experience;
9. *Ecotourism initiatives:* locals can organize ecotourism activities such as bird-watching tours, wildlife spotting expeditions, or nature photography workshops. They can guide tourists through protected areas, sharing their knowledge of the local ecosystem and promoting environmental awareness;
10. *Culinary experiences:* local inhabitants can offer cooking (Fig. 5D) classes or food tours, introducing geotourists to traditional recipes, local ingredients, and culinary techniques. This allows visitors to savor authentic flavors and learn about the region's gastronomic heritage (e.g., Couscous, Méchoui).

These activities offer tourists a chance to engage with the local community, learn from their expertise, and develop a deeper appreciation for the area's culture, traditions, and natural heritage.

Conclusion

El Bayadh area is characterized by diversified and fascinating geology and landscapes. Throughout this article, three potential geological itineraries have been described, showcasing the beauty and richness of the region's geological

heritage. These itineraries encompass a total of eleven (11) geosites, each offering unique scientific, educational, and touristic attractions.

The geological itineraries in El Bayadh provide visitors with the opportunity to explore the fascinating geological history of the region. This area offers a diverse range of landscapes and geological formations. The geological itineraries have been carefully designed to showcase the region's geological features, such as the Triassic diapirs, dinosaur footprint sites, geomorphological structures, oases, dams, and rock engravings. The assessment of the studied geosites (Table 2) showed that the best evaluated geosites are the Sidi Tifour Diapir as well as Grarij dinosaur tracksite. In contrast, the lowest valued geosite is the *Macrocephalites* level.

By following these itineraries, visitors can embark on a journey through time, unraveling the secrets of Earth's ancient history. The geosites included in the itineraries offer valuable educational experiences, allowing visitors to learn about geological processes, observe unique formations, and gain a deeper understanding of the geological evolution of the area. The presence of dinosaur footprint sites, in particular, provides a remarkable opportunity to witness direct evidence of the prehistoric world and marvel at the diversity of life that once existed.

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Declarations

Informed Consent All human participants gave their informed consent to take part in this study.

Human and Animal Rights This study was approved by the ethics committee of the institution XXX and followed the ethical principles of the Declaration of Helsinki. No animals were used in this study.

Compliance with Publication Standards The authors affirm that the work described has not been published before and that it is not under review for publication elsewhere. Its publication has been approved by all co-authors and by the responsible authorities of the institution where the work was carried out. Where applicable, the authors have obtained permission from the copyright holders to include figures, tables or text passages that have already been published elsewhere.

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