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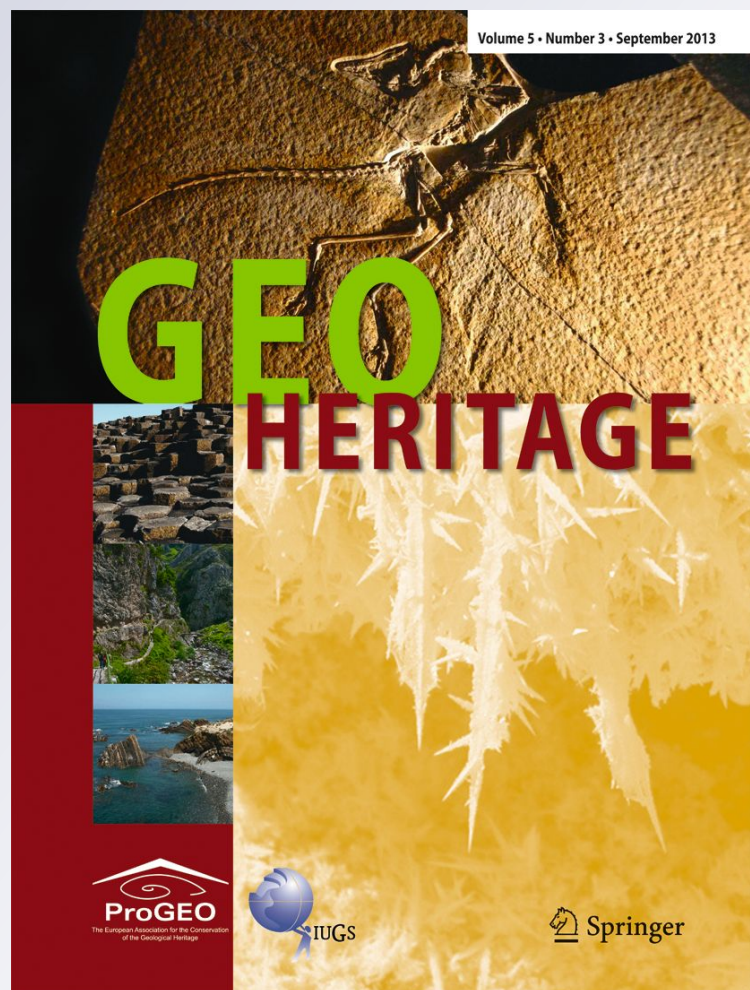
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The Tichoukt Massif: a Geotouristic Play in the Folded Middle Atlas (Morocco)

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Abstract

The Folded Middle Atlas Mountains has rich geomorphologic landscapes and remarkable geological sites, little known by the general public. In this paper, we propose an approximately 60-km geological trail, including several geosites mostly staggered in the sinuous valleys of the Atchane and Guigou rivers, between the Boulemane, Skoura, and El Mers. These geosites, reflecting the geological, geomorphological, and environmental history of the region, and combined with strong esthetic value, give a particular scientific and geotouristic interest to the proposed geotrail. The Boulemane panorama gives the opportunity to observe a case study of geomorphology linked to a knee-fold that corresponds to the SW perianticline of the majestic Tichoukt chain. The geotrail then offers several geosites in the Middle Jurassic regressive sedimentary series of the Skoura Syncline. The NE extremity of the Tichoukt shows the thrusting of the fold crest onto the inverted flank of the Skoura Syncline (Pliocene Alpine tectonic). SE flank of the Tichoukt fold is affected by a Middle Jurassic uplift related to faulting and diapiric activity. The geotrail ends in El Mers, which was the site of the first discovery of sauropod dinosaur in Morocco. This geoheritage has been never used into the traditional tourist trail; it deserves to be valued in the context of projects aimed at developing a sustainable eco-geotourism, and the knowledge of the culture of the Amazigh people in these harsh mountainous areas.

Keywords Geotourism · Geosites · Jurassic sedimentary formations · Folded Middle Atlas · Tichoukt · Skoura · Morocco

Introduction

The Middle Atlas fold belt has rich geomorphological landscapes and remarkable geological sites, with an additional esthetic value making them of particular scientific and geotouristic interests. Most of the tourist itineraries concern the Tabular Middle Atlas and its extinct volcanoes. The Folded Middle Atlas area, never involved into the traditional tourist trails, would deserve to be valued in the context of projects aimed at developing a sustainable geotourism, eco-environment, and the culture of the Amazigh people in these harsh mountainous areas. Here, we propose a geotrail around the gorgeous massif of the Jebel Tichoukt following a loop Boulemane-Skoura-El Mers-Boulemane.

The census of the geosites, included in the geotrail (Table 1), takes into account several criteria of complementary interests. However, the choice and the classification of these geosites is based on the typology standards given by GILGES 1989 (Global Indicative List for Geological Sites); IUGS Geosites Programme, UNESCO 1993

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Table 1 Location, typology and main themes of the selected geosites of the proposed geotrail around the Tichoukt massif in the folded Middle Atlas of Morocco

ID	Locality	Typology	GPS coordinates (a° b' c")	Main themes illustrated
Geosite 1	Boulemane	Geomorphological and structural geosite	N 33 21 52 × W 4 43 21	Jurassic geomorphology. Structure (faults, folds, and perianticline). Unconformity
Geosite 2	Guigou valley	Geomorphological, stratigraphical, and petrological geosite	N 33 24 17 × W 4 43 16 N 33 27 39 × W 4 40 21	Stratigraphy (Middle Jurassic). Quaternary volcanism
Geosite 3	Taferdoust	Geomorphological, palaeontological, and ichnological geosite	N 33 28 25 × W 4 39 16	Lecture of a landscape. Geomorphology. Marine fossils. Ichnology
Geosite 4	Taghrout	Geomorphological, stratigraphical, and structural geosite	N 33 28 59 × W 4 36 27	Lecture of a landscape. Geomorphology. Stratigraphy (Middle Jurassic). Structural geology (Pliocene Alpine tectonic).
Geosite 5	Anchrif	Palaeontological geosite	N 33 28 56 × W 4 37 08	Palaeontological site of Pleistocene
	Skoura	Geomorphological and hydrological geosite	N 33 30 58 × W 4 32 23	Hydrological resources (waterfalls). Sedimentology (Travertine systems)/ Quaternary karst landscapes. Geomorphology
Geosite 6	Tadout		N 33 31 09 × W 4 30 20	
	Tizi-n-Issoulitene	Geomorphological and structural geosite	N 33 29 57 × W 4 27 29	Stratigraphy (Dogger). Structural geology (intra-Bathonian unconformities)
Geosite 7	Mohammed Azeroual	Palaeontological and sedimentological geosite	N 33 29 55 × W 4 28 08	Toarcian-Aalenian hard ground. Marine fossils
Geosite 8	El Mers	Palaeontological and ichnological geosite	N 33 26 40 × W 4 27 00	Palaeontological site of Middle Jurassic (<i>Cetiosaurus</i> , first large Moroccan sauropod dinosaur). Divers dinosaur footprints

(International Union of Geological Sciences), which is modified by Viette (2007).

Geological and Geomorphological Setting

The geotrail crosses several structures of the Folded Middle Atlas (Fig. 1b): the Skoura Syncline (sites 2 to 6), the Tichoukt Anticline (site 1), and the El Mers Syncline (sites 7 and 8). Both synclines are of wide structures with steeply dipping or even inverted flanks (Fig. 1c). The Tichoukt anticline is an asymmetric, NW-verging knee-fold in the Boulemane area, but it changes along strike to the NE into a faulted recumbent anticline whose crest eventually overlaps the Skoura Syncline.

The outcrops display varied types of Mesozoic sedimentary rocks that were deposited in a South Tethyan Gulf: the Middle Atlas rift during the Liassic and the beginning of the Middle Jurassic. During the Middle Jurassic, the marine basin is filled up with deep-marine deposits (Boulemane Marls) that gradually give way to epirecifaal platform limestone (Recifa Fm., Ich Timellaline-Bou Akrabene Fm.) (Fig. 2), which in turn pass to lagoonal and deltaic deposits (El Mers Fm.). During this progressive filling, the open marine areas are localized to the NE.

Description of the Geosites

Boulemane Knee-Fold

The panorama of the Boulemane City, at the southwest end (pericline) of the Tichoukt fold, gives an opportunity to observe a case study of major knee-fold geomorphology (Fig. 3). The cuesta, which makes the backbone of the reliefs surrounding the city, consists of the “Calcaire corniche” (= Recifa Fm., Dresnay 1963). The limestone are shallow dipping to the SE, but verticalized in the northwestern gorges (Fig. 4a). The slopes are eroded into the “Boulemane Marls”, substratum of the city (Colo 1961). Below, the derivative mount is constituted by the Liassic limestones of the Tichoukt fold. Laterally towards the N, W, and S, the Barremian-Aptian lie on various Jurassic strata's. Both Jurassic and Cretaceous formations are folded during tertiary times.

Incised Meanders of the Oued El Atchane and Guigou Valleys

The itinerary offers several sites in the regressive series of the Middle Jurassic Skoura Syncline (Choubert and Faure-Muret 1967). From the SW to the NE, we reach successively (and stratigraphically from the top to the base of the series): (i) The El Mers Fm., characterized by a versicolour aspect

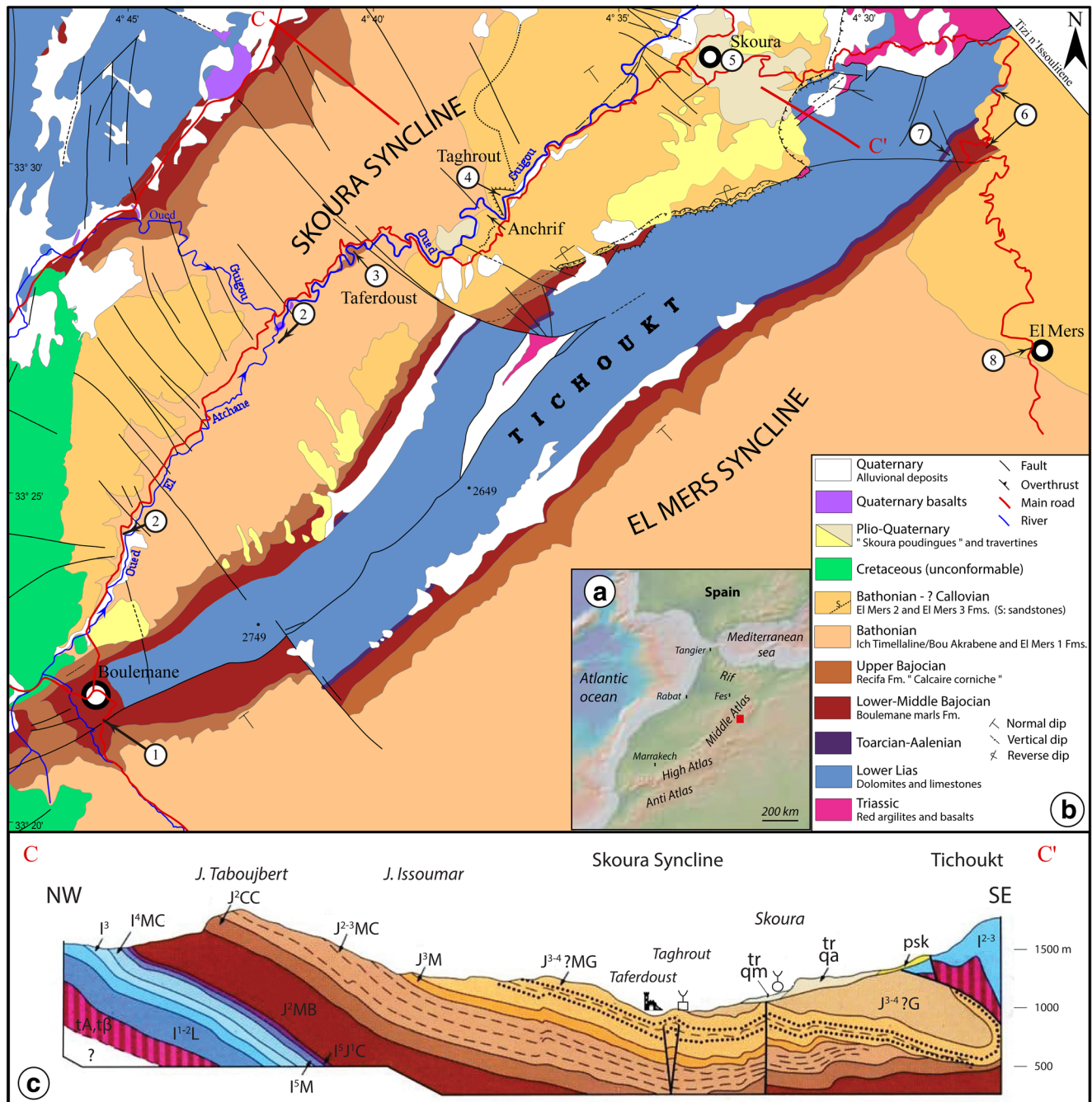


Fig. 1 a Structural domains of Morocco, with location of the proposed geoheritage trail. b Road and geosites location of the geoheritage trail, plotted on the geological map of the studied geoheritage area. c Cross-

section of the Skoura Syncline and Tichoukt thrust anticline in the folded Middle Atlas, Morocco (extracted from the geological map of Sefrou, scale 1/100,000)

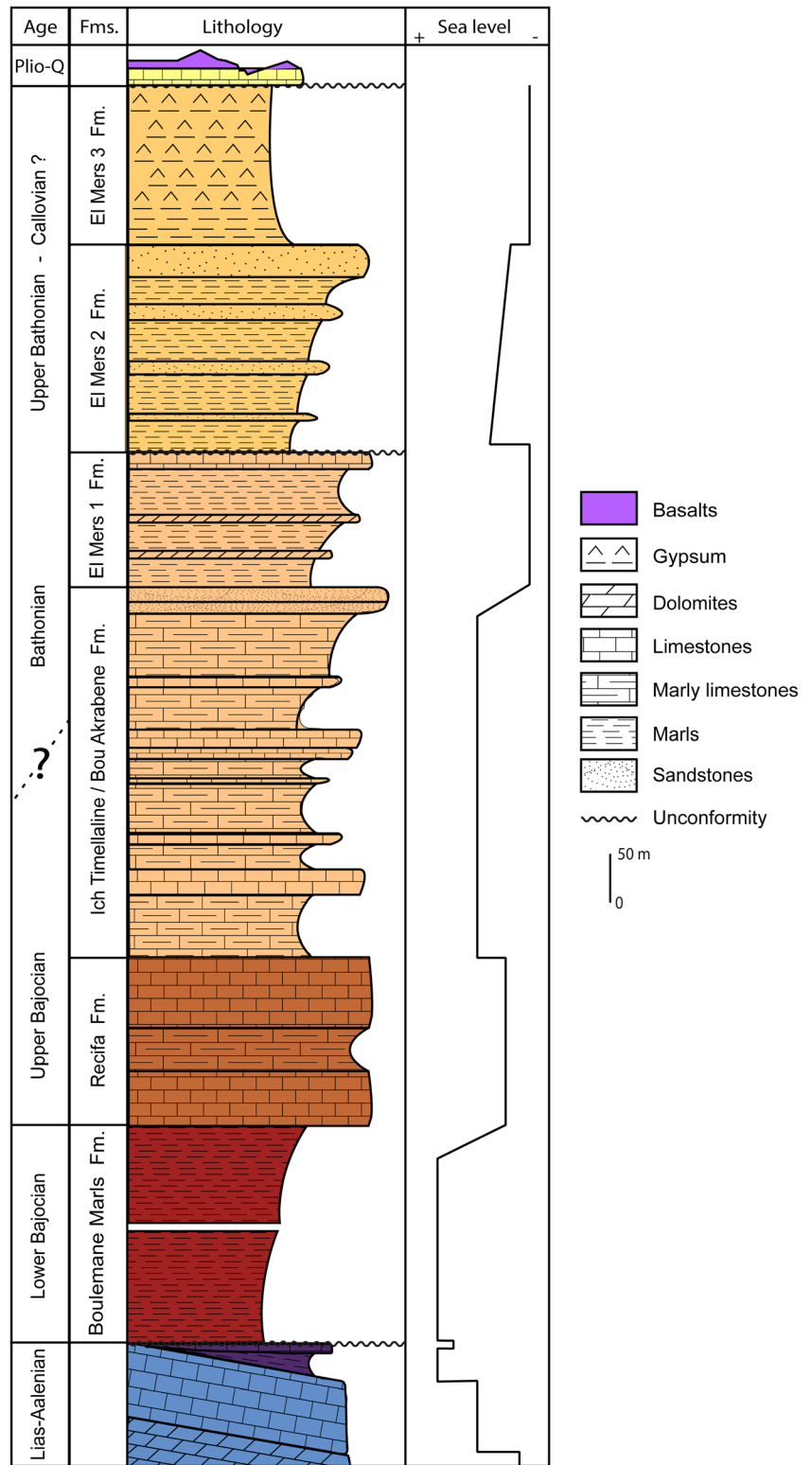
indicating continental and lagoonal palaeoenvironments, followed by an ultimate marine recurrence (Charriere et al. 1994); (ii) the summit of the marine Bou Akrabene strata with lumachellic, highly fossiliferous limestone beds (brachiopods, corals, etc.); (iii) a succession of superposed cuestas of oolitic and bioclastic limestones alternating with the marly-calcareous beds (cyclical marine deposits) of the Ich Timellaline-Bou Akrabene Fm. (Fig. 4b). Near the confluence of the El Atchane and Guigou rivers, (Douar

Al Faddane), a palaeomeander of the Guigou valley filled up by a basaltic flow of Quaternary age can be observed (Fig. 4c).

Spur of the Oldest Taferdoust Kasbah

The beautiful old Kasbah is perched on a spur-shaped rocky outcrop surrounded by steep cliffs (Fig. 4d). These are incised into a narrow meander of the Oued Guigou hosted in the

Fig. 2 Lithostratigraphic subdivision of the studied area



“Calcaire corniche”, which reappears here, being uplifted south of the Taferdoust fault. From this point, we can reach by mule trail (1-h walk) the *Selenichnites* ichnosite: first Jurassic horseshoe crab (Limulids) trace, discovered in the Maghreb (Oukassou et al. 2016). The *Selenichnites*

(crescentic trace) is formed when the head shield of horseshoe crab touches the substrate. Its occurrence indicates resting and feeding behaviors of medium-size horseshoe crab during this remote times (Fig. 4d). The present-day horseshoe crab is regarded as a “living-fossil”.

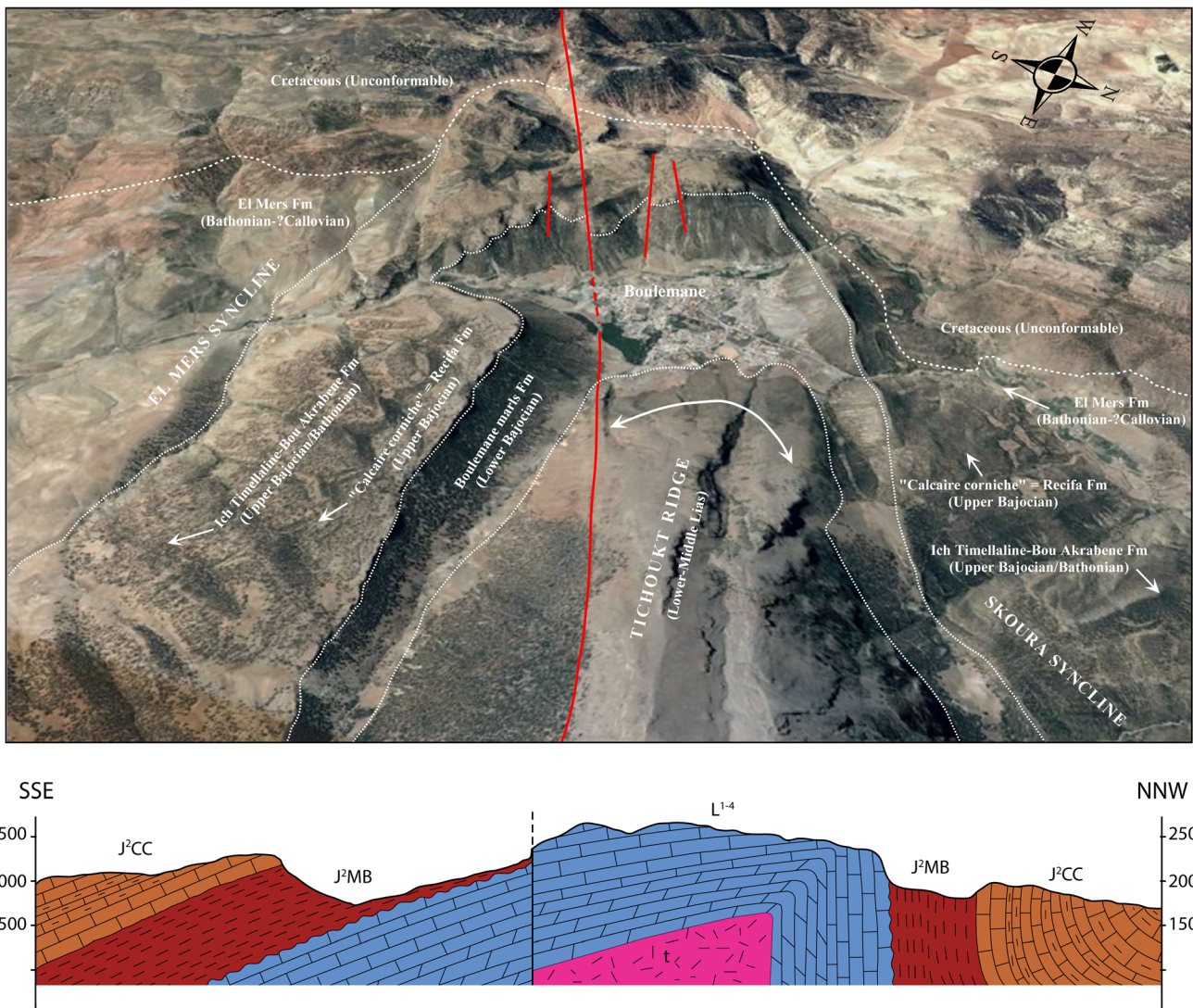


Fig. 3 Oblique Google Earth view and cross-section of the Boulemane area, looking towards the axis of the Tichoukt anticline

Sandstones Rafters with Picturesque Taghrouit Ksar and Frontal View of the Tichoukt Thrust

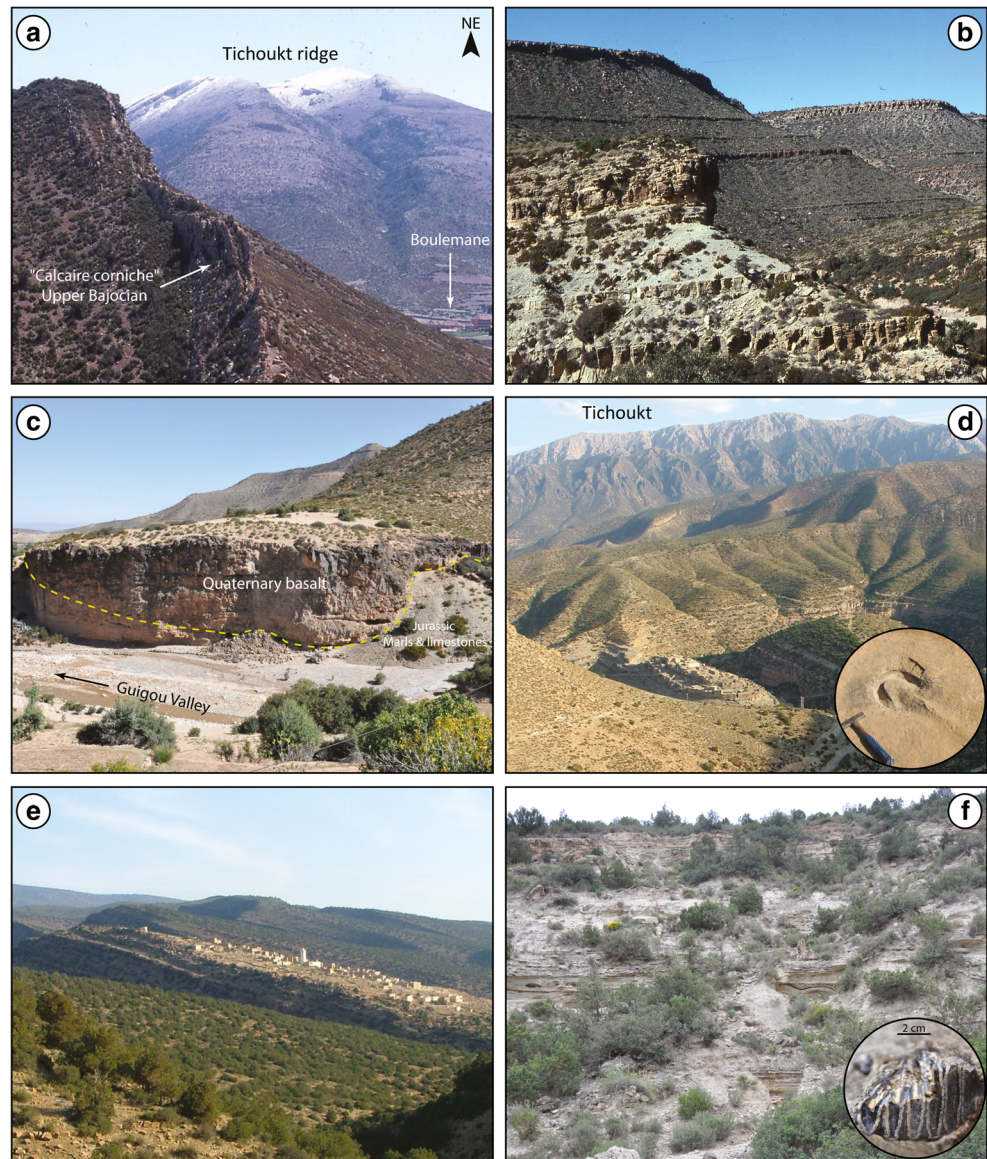
The surprising Taghrouit Ksar is staggered over the uppermost intercalation of Taghrouit sandstone (the last marine incursion in the El Mers Fm.) which forms a gently dipping slab in the northwest flank of the Skoura Syncline (Fig. 4e). The Taghrouit sandstone slab is overlain to the NE by the thick marls and gypsum series of Skoura (Choubert and Faure-Muret 1967). It is noteworthy that on the SE flank of the syncline, towards the Tichoukt summit, the Taghrouit sandstone and the interbedded marls are inverted beneath the thrust crest of the Tichoukt faulted anticline due to the last Alpine (Pliocene) shortening (section CC', Fig. 1; Charrière 1989 and 1990). Laterally, upstream the Oued Guigou, we could reach the Pleistocene lacustrine deposits of Anchrif that has yielded various continental reptiles

(chelonian, snails), artiodactyls, as well as bones and teeth of *Elephas* (Fig. 4f, Marinheiro et al. 2014).

Waterfall and Travertine Systems in the Skoura Area

At Skoura village, we observe a layered travertine system. The city is located on a tuffs and travertine flat ascribed to the Middle Quaternary (Fig. 1b, c) and dominated in the SE by a Late Villafranchian travertine cliff (Martin 1981). This travertine system, overlying the Pliocene conglomeratic Skoura Fm., shows a great morphological variety of algal crusting (cylindrical, spherical, laminated, etc.). These formations contain several cavities and caves (Fig. 5b). The waterfalls, flowing currently into this relief, are supplied by the Tadout water source (Fig. 5a). They represent the vestige of the vast waterfalls that occurred during the Plio-Quaternary.

Fig. 4 Geosites from 1 to 4. **a** View from southwestern part of Tichoukt anticlinal ridge. Note the verticalization of the “Calcaire corniche” in the northwestern flank. **b** Limestone cuestas in the sedimentary succession of the Ich Timellaline-Bou Akrabene Fm. (Late Bajocian-Bathonian). **c** Quaternary basalt flow in the Oued Guigou valley (white dashed line: palaeomeander). **d** Panoramic view towards the SE showing the Tichoukt anticline overlying the Skoura Syncline. Note the Taferdoust Kasbah surrounded by Guigou meander, close-up of “*Selenichnites*” traces of limulids. **e** Panoramic view of Taghrouit Ksar on top of the Taghrouit sandstones (El Mers 2 Fm., Late Bathonian-? Callovian). **f** Site from Anchrif: white marly lacustrine deposits with Quaternary Elephantid fossil, close-up of molar in apical view



The ascent to the Tizi-n-Issoultene pass offers a wide panorama on the Neogene basin of Skoura, situated in the plain to the north. Towards the NE, the view extends up to the Jurassic crests of the Jbel Bou Iblane (3192 m). Not far from this site, we can observe Jbel Bou Naceur (3340 m), the culmination of the Middle Atlas (Fig. 1a).

Unconformity at Tizi-n-Issoultene Pass

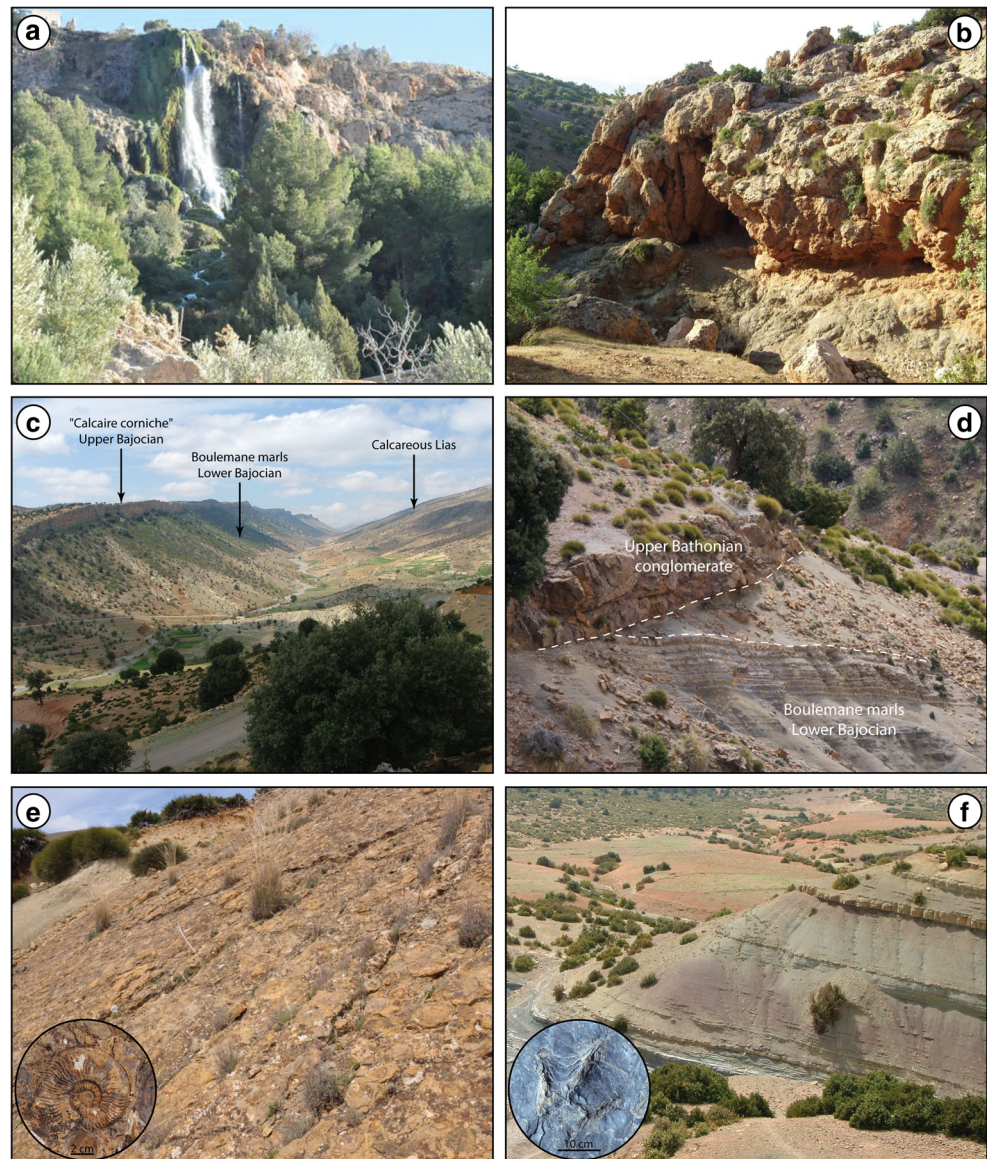
From the hills at the NE end of Jbel Tichoukt, we can bypass the fold axis and thus attain the NW flank of the El Mers Syncline. The unconformity of Tizi-n-Issoultene is defined by the angle that from the higher marly-sandstone deposits of the El Mers Fm. (Late Bathonian-? Callovian) on to the differently dipping strata of the Jurassic marine series, i.e. “Calcaire corniche”,

Boulemane Marls (Fig. 5d), Aaleno-Bajocian limestones, Toarcian gray marls, and finally Liassic limestones. The detailed tectono-sedimentary analysis indicates the occurrence of unconformities within the marly-sandstone series themselves, pointing to the progressive uplift of the north-east part of the Tichoukt during Bathonian sedimentation. This synsedimentary deformation results from the slow diapiric ascent of the Triassic evaporitic formations likely controlled by a normal fault in the underlying basement.

Hard Ground at Mohamed Azeroual Site

The road goes down the hill in the Boulemane Marls that overlay a bed of yellowish limestone well exposed north of the road. This approximately 2-m-thick marker bed consists of highly fossiliferous limestone whose uppermost

Fig. 5 Geosites from 5 to 8. **a** Waterfall and upper travertine deposit on the Skoura area. **b** The entrance to the Tadout cave in the same travertine. **c** Panoramic view of the stratigraphic succession in the southeastern flank of Tichoukt. **d** Example of the Bathonian unconformities in the Tizi-n-Issoulitene pass. **e** Toarcian-Aalenian hard ground of the Mohammed Azeroual site, see the flat stromatolitic beds; close-up of the ammonites. **f** Panoramic view of the varicoloured marls building the lower part of the El Mers Fm., close-up of tridactyl dinosaur footprint



part presents a remarkable “hard ground”, i.e. a system of perforated, extremely bioturbated, flat stromatolitic beds, and ferruginous crusts. The abundant marine macrofauna consists of bivalves, brachiopods, nautilus, belemnites, and ammonites (Fig. 5e). The detailed study of these fossils demonstrates that we deal with a condensed level, involving the latest Toarcian, Aalenian, and earliest Bajocian (Benshili 1987). The seabed of the region remained relatively high with respect to the adjoining sea floor throughout this time span (from ca. 175 to 170 Ma).

Dinosaur Tracks in the El Mers Historical Geosite

After having intersected the “Calcaire corniche”, the descent continues in the Bathonian deltaic marly-sandstone

series (Soufiani and Fedan 2002). The geotrail passes through El Mers locality, where the earliest discovery of dinosaur remains in Morocco has been performed (De Lapparent 1955). The sauropod bone remains were localized in the median part of the varicoloured marls of the El Mers Fm. (Fedan 1993), but several dinosaur trackways are preserved in the lower carbonate beds. Additionally, in the bottom of the thalweg below the locality, limestone sediments with bluish surface show oscillation ridges mud-cracks and tridactyl footprints of Theropods and Ornithopods (Fig. 5f), while the overlying surfaces are rich in invertebrate traces assigned to *Rhizocorallium* and several tetradactyl footprints. Hadri and Perez-Lorente (2012) made a detailed description of the theropod trackways of El Mers.

Interest of the Geoheritage of Tichoukt Geotrail

Landscape and Ethnography

Besides the important esthetic value of the landscape of the entire geotrail, we note the ethnographic and immaterial cultural heritage of the Boulemane-Skoura region. The rural habitat is agglomerated on defensive strategic sites, where most houses are built from local materials, which directly reflects the current and past lifestyle of the local population. The geotrail may extend with a cultural approach and history of the Amazigh civilization of the Atlas Mountains.

Geomorphology

The landscape sculpture primarily results from the perpetual hydrodynamics of surface waters. The runoff resulted in a pickling of soft substrates, mainly marls, so leading to the highlighting of the consolidated substrates (e.g. limestone and sandstone). Correlatively, the tectonic structure of the substratum is made clearly visible both in subtabular and tilted (folded) domains. In the axial part of Skoura Syncline, fluvial erosion associated with an uprise of the whole area has caused the great depth of the meandriform stream of the Oued Guigou, previously developed in a plain environment (geosite 2, antecedence phenomenon).

Tectonic Structures

Alpine Major Shortening

The Tichoukt massif illustrates a beautiful example of an anticlinal fold whose cross-section changes along the axis. At its SW pericline (Bouemane site), it exhibits a knee-bend shape with a northern flank verticalized (3.1, Fig. 3) whereas going to the NE, from Taghrout (3.4) to Skoura (3.5), the asymmetry of the north-verging fold increases and finally results in the overlap of the northern flank of the anticline on the overturned strata of the Skoura Syncline (section CC', Fig. 1; Charrière 1989 and 1990).

Jurassic Syndimentary Deformations

The ammonite-rich condensed series (3.7) in the Aaleno-Bajocian series and the Bathonian progressive unconformity (3.6) record the uplift of the northeastern part of the Tichoukt massif during the Middle Jurassic (Benshili 1987), probably linked to normal faulting and diapiric ascent of the Triassic evaporites.

Palaeontological Heritage and Palaeoenvironment

Invertebrates Fossils

The marine successions of Middle Jurassic are particularly rich in coastline fossils, and the brachiopods are locally very abundant. Besides these frequent invertebrate fossils, we note the exceptional and significant presence of limulid traces assigned to the ichnogenus *Selenichnites* and referred to the horseshoe crab that points to shallow marine conditions (Oukassou et al. 2016).

Secondary Reptiles

El Mers geosite (3.8) is considered the locality where the skeletal remains of a large sauropod dinosaur were first discovered in Morocco. The lowermost beds of the succession yielded a moderately diverse dinosaur ichnofauna that consists of Theropod, Ornithopod, and Sauropod trackways. Other trace fossils may be occurring in the same locality.

Mammals The discovery of elephantid fossils and other continental vertebrates in the Pleistocene from lacustrine deposits of the Taghrout region (3.4) is an additional palaeontological data of great palaeoenvironmental interest (Marinheiro et al. 2014).

Educational and Pedagogical Aspects

At the Level “General Public”

The quality of the landscape allows non-initiated public to immediately understand several basic geological concepts, such as the rock's cycle and the origin of some special kind of the rocks (e.g. travertines) (3.5), the architecture and organization of sedimentary outcrops (3.2 and 3.6), the setting up of volcanic lava flows (3.2), and the observation of fossiliferous sites (3.7 and 3.8), indicating a rich and diverse palaeolife of the area that evokes directly ancient ecosystems.

At the Specialized Level

Students, teachers, and researchers: The region offers an important geodiversity and geobiodiversity (e.g. sedimentary formations, structures, geomorphological and tectonic and a rich palaeoichnological heritage) particularly of great didactic interest. The area is not completely explored yet and detailed research projects remain open, particularly in the sedimentology, biostratigraphy and the paleoecology.

Recommendations with Geotourism Development

The geotrail proposed herein corresponds to a generic and descriptive term applied to geosites of geological features with significant scientific, educational, cultural, and/or aesthetic value. Scientifically and educationally significant geosites include geological features and landscapes, distinctive strata and deposits, unique horseshoe crab trace fossils, which are significant to the education and research. Therefore, these geoheritage sites should play a role in cultural or historical events that can be tourist destinations and provide local and regional economic benefits and should serve the public interest. They have high potential for scientific studies, use as field-classrooms, enhancing public understanding of science, recreational and educational tourism, and economic support to local communities. Therefore, for the enhancement and the promotion of this geoheritage and geotrail, we recommend several decisions.

Infrastructure

In order to make the geotrail accessible with normal car, we recommend the achievement of the road infrastructure between Boulemane City and Skoura village.

Accommodation Structures

The local government and authority should encourage the local population to establish hotel infrastructures in Boulemane City, as well as in Skoura village. The implantation of guest houses along the geotrail would allow the development of a green tourism involving the local population into the whole process.

Integrating Geotourism into the Regional Ecology

Integrating the proposed geotrail into the current conservation program of national natural reserve of Jbel Tichoukt (Tichoukt SIBE 1996), relating to wildlife and forest cover.

Liaison with Other Geotouristic Trail in the Middle Atlas

The proposed geotrail here could be extended to other touristic trails in the surrounding sectors, e.g. the classic touristic trail of Dayets (lakes) in the tabular Middle Atlas (between Sefrou-Imouzzar Kandar-Ifrane) and/or more specialized geologic trail in the volcanic province of Azrou-Timahdite region.

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