

Chapter III: Mesozoic Series (Secondary)

EXAMPLE: THE ALGERIAN SAHARA ATLAS

I. General geographical framework

The Saharan Atlas constitutes the southern part of the vast Atlas mountain system, which extends for nearly 2,000 km from the Agadir region in Morocco to the Gulf of Gabès in Tunisia. In Algeria, it forms an intracontinental chain with a general southwest-northeast (SW–NE) orientation, composed of a succession of elongated mountain ranges extending over a width of 100 to 200 km. It is bordered to the north by the Steppe Highlands and to the south by the Saharan plains, these two boundaries corresponding respectively to the North Atlas Fault (NAF) and the South Atlas Fault (SAF), two major tectonic structures on a continental scale.

II. Subdivisions of the Saharan Atlas

The Saharan Atlas is subdivided, from west to east, into three major geographical units:

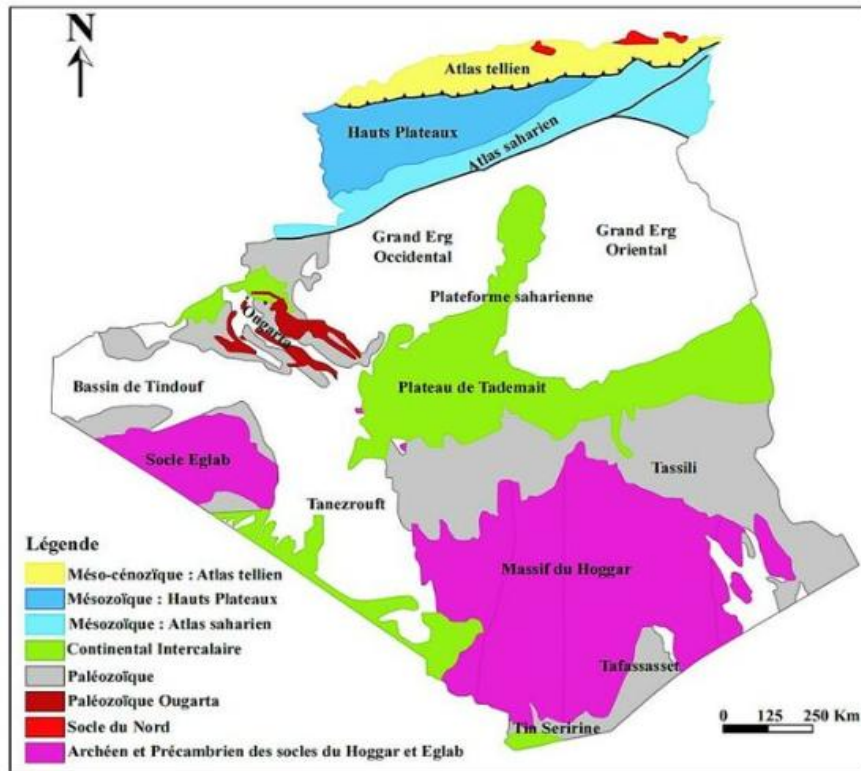
- **The Western Saharan Atlas**, represented by the Ksour Mountains, which peak at 2,236 m at Djebel Aïssa (Wilaya of Naâma). This sector is characterized by a tectonic style dominated by tight folds and synclinal troughs containing significant sandstone aquifers.
- **The central Saharan Atlas**, mainly composed of the Djebel Amour, stretches for about 700 km with a width of 50 to 70 km and peaks at 2,008 m at Djebel Ksel. It represents a zone of contact between the steppes of the High Plateaus to the north and the Saharan margins to the south.
- **The eastern Saharan Atlas**, including the Ouled Naïl Mountains, the Zibans Mountains, the powerful Aurès massif — with Djebel Chélia being the highest point at 2,328 m — as well as the Nemencha Mountains and the Tébessa Mountains.

III. General Geological Framework of the Saharan Atlas:

The Saharan Atlas is composed of an alignment of landforms oriented approximately NE-SW, from the Moroccan High Atlas to the Aurès. It is a structure with a particular structural style: these are often simple folded structures (reliefs resembling processional caterpillars).

The Saharan Atlas is organized along two structural directions: one longitudinal (NE-SW), the other transverse (N-S). It is a chain affected by two major faults: the northern Atlas fault and the southern Atlas fault, which is much more pronounced.

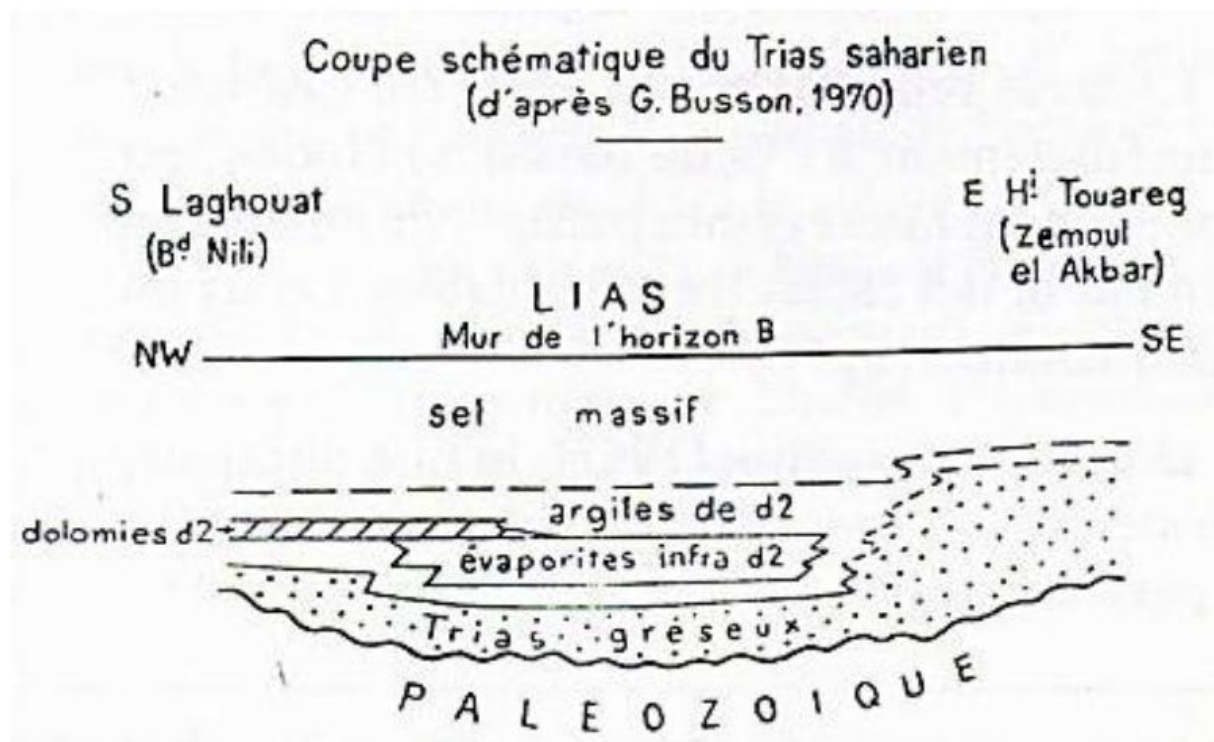
Geologically, the Saharan Atlas was formed in the location of a subsiding trough where powerful marine and continental deposits accumulated during the Mesozoic and part of the Cenozoic.



1. The Triassic:

It is of Germanic type, represented by variegated multicolored clays, salt, and green rocks. It generally outcrops, favorably, due to geological accidents at Ain Ouarka (Ksour Mountains) and Kérakda (Djebel Amour).

The Germanic Triassic is a geological supergroup of the Lower Mesozoic in Central Europe, north of the Alps, corresponding to continental and shallow marine deposits. It is composed of the lithostratigraphic units of Buntsandstein (variegated sandstone), Muschelkalk (shell limestone), and Keuper (variegated marl).



The appearance of reefs and the spread of detrital sheets heralds, as early as the Bajocian (Jurassic), the beginning of a large and long deltaic cycle (Delfaud, 1974b) progressing from West to East. This dynamic framework foreshadows the fluctuations of the boundaries between marine and continental domains and will last until the Late Cretaceous (Upper Albian).

2. The Bathonian (Dogger):

Formed by sandstones and dolomites in Aïn Ourka to the West, and by limestones and marls with ammonites in El Bayadh.

3. The Callovian (Dogger):

Gravelly and dolomitic in the Ksour Mountains, begins with marls and marl-limestone with ammonites from the basin at El Bayadh.

4. The Kimmeridgian (Lower Malm):

Geological stage of the Upper Jurassic Sandy to the West up to Mécheria, only partially so in El Bayadh. In this latter locality, it begins with fossiliferous blue limestones evolving, in its upper part, into sandstones with intercalations of green marl transitions. These are more frequent and reddish toward the top.

5. The Infra-Cretaceous:

It is completely sandy from Aïn Ouarka in the West to Mecheria and shows marly levels toward its summit in El Bayadh.

6. The Valanginian (Lower Cretaceous):

Transgressive, characterized by gypsum marls, dolomites, and clayey limestones in El Bayadh. Its thickness gradually decreases toward the West where sandstones become increasingly important. Toward the East, it becomes more marly (Aflou) and then completely limestone (Laghout).

7. The Hauterivian (Lower Cretaceous):

Completely sandy in the West, represented by continental sandstones followed by marls and marine limestones from El Bayadh to Aflou, and reappears sandy further East (Laghout).

8. In the Barremian-Aptian-Albian (Lower Cretaceous)

The series is entirely detrital and continental both in the Ksour Mountains and in the Djebel Amour. On the other hand, it shows a marine incursion that deposited limestones and marls further to the east in the Ouled Nail. The post-Lutetian Alpine orogenic phase marks the end of the secondary cycle (Ritter, 1902).

III. Lithostratigraphic division of the Atlas formations:

Numerous geological studies conducted on the Saharan Atlas have made it possible to establish an important lithostratigraphic division. However, the stratigraphic attributions of the various defined formations vary from one author to another.

1. In the Ksour Mountains:

In the Ksour Mountains, the typical Mesozoic series (Bassoullet, 1973) shows a lithological succession ranging from the Triassic to the Upper Cenomanian-Lower Turonian. In this region, the Rhaetian-Hettangian (Triassic-Jurassic) is represented by marly-limestones with desiccation cracks belonging to the proximal internal carbonate platform.

2. In Djebel Amour:

In this part of the Saharan Atlas, Cornet (1952) describes in the Secondary series:

- the Kimmeridgian, represented by 100 meters of reef limestone and blue limestones rich in Brachiopods. These deposits are topped by an alternation of marl-limestone and marl-sandstone with current ripples;

- The Barremian-Aptian-Albian, a series 700 to 1500 meters thick; this unit is essentially sandstone of fluvio-deltaic type;

- The Cenomanian-Turonian, particularly limestone, sometimes shows fenestral structures at its base, followed by levels with ammonites.

3. In the Ouled Nail Mountains: (Djelfa)

The secondary layers offering ichnite sites (Dinosaur Tracks) are represented by 220 meters of limestone and marl attributable to the Cenomanian (Flandrin, 1952). The base of the limestones shows condensed surfaces of bivalves and desiccation cracks.

IV. DINOSAUR SITES IN THE ALGERIAN SAHARA ATLAS:

1. Djebel Amour:

It is the area richest in ichnite sites, and the El Bayadh province contains the largest number. There are eight (08) sites discovered in recent years. **The most important site is that of:**

* **Brezina Sites (El-Bayad):** To the south of the city of El Bayadh, in the municipality of Brezina, 5 sites with dinosaur footprints have been counted (fig.)

2. Ouled Naïl Mountains: (Djelfa):

The sites of the Amoura region: These are 3 sites, located 80 km Southeast of Djelfa (fig.) and circumscribed at the level of Ksar d'Amoura (fig.):

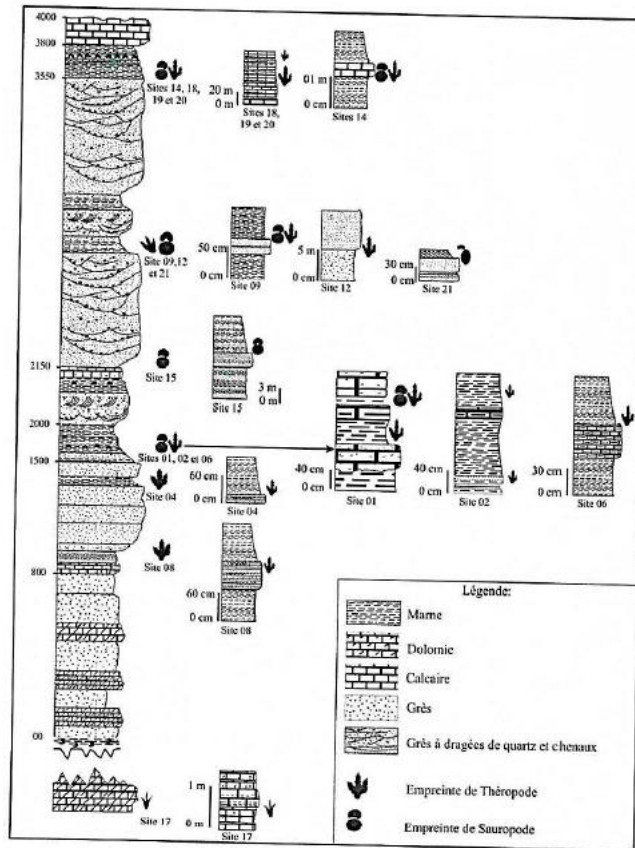


Fig. 32 : Position lithostratigraphique des principaux sites à empreintes de dinosauriens dans la coupe synthétique de l'Atlas saharien (Cornet, 1952 ; Bassoulet, 1973 ; modifiée).

V. LITHOLOGY OF THE ICHNITE LEVELS

1. El Bayadh Site-(El Kheneg 3):

At this locality, sedimentation is represented by the following succession from bottom to top:

- Green marls topped by red marls;

- A sandstone formation (0.60 m) made up of medium to fine sandstones and consisting of two layers (0.30 m each).

*The first, at the base, shows fine, parallel, and regular current ripples, whereas the second, with the same grain size and color, is marked on its upper surface by desiccation cracks and two imprints.

* The surface with impressions is overlain by a succession of red marls, green marls, and then red-brown sandstones with current ripples. All these deposits are dated to the top of the Kimmeridgian (Upper Jurassic).

2. Brezina Site-(Garet Echiheb):

It appears on a reddish surface at the top of a set (1.5 m) of yellowish sandstone benches, decimetric, with oblique stratifications.

This surface with impressions is covered by a thin layer of green marls (0.10 m). These two facies are attributed, respectively, to the sandstones and limestones of the Hauterivian (Lower Cretaceous).

3. Brezina Site-(Mouilah El Fougani):

The footprints are preserved on a reddish surface at the top of a greenish sandstone bench. It is topped by a fine yellowish sandstone layer (0.05 m), followed by a succession of fine-grained yellowish sandstone layers.

The trace fossil level is located toward the top of the first third of the sandstone series of Barrémian-Aptian-Albian age (top of the Lower Cretaceous).

4. Brezina Site-(Hamiet Boulafea):

It is located on a (0.20 m) white micritic limestone bench at the beginning of the Ghoundjaïa formation, from the Upper Cenomanian-Lower Turonian (base of the Upper Cretaceous).

5. Brezina Site-(Daïet Sid El Arbi):

The footprints appear on a hardened (hard) surface, at the top of a (0.40 m) micritic limestone bench with desiccation cracks. This bench is preceded, from bottom to top, by:

- A significant thickness of coarse yellow, white, or pink sandstones with quartz pebbles and some layers of sandy red marls
- Green marls (2 m);
- Yellow and white sandstones with oblique stratifications and soft pebbles (7 m).
- The level with footprints is followed by green and red marls (3 m) on which rest white sandstone banks with channels (5 m), which have yielded remains of crocodylians and dinosaurs.
- Stratigraphically, the site is located at the top of the Continental Intercalary and would be of Upper Albian-Cenomanian age (late Lower Cretaceous-early Upper Cretaceous).

2. The environments of fossilization of footprints:

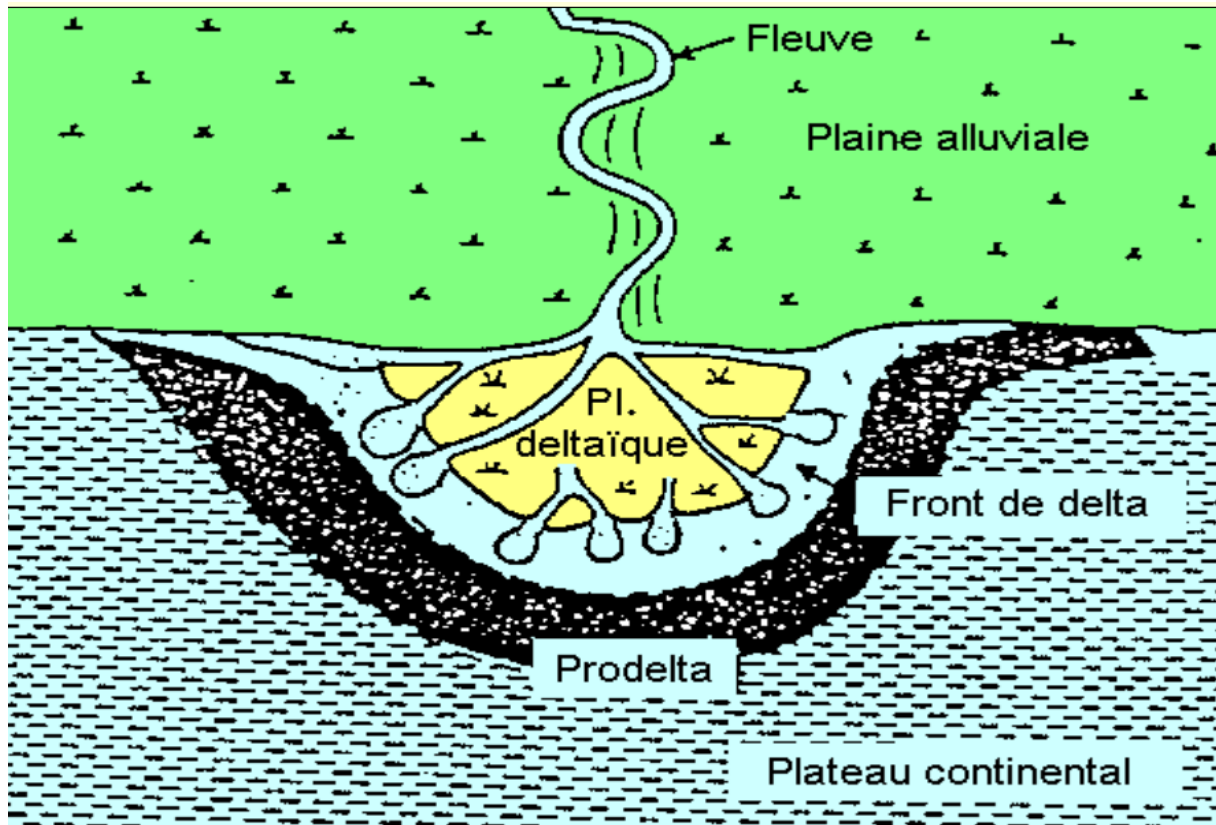
The location of well-preserved footprints is one situated at the boundaries of marine and continental domains.

Indeed, the sectors of the Saharan Atlas of the Ksour Mountains, in the Triassic, and those of Ouled Nail in the Cenomanian, experience a proximal internal carbonate platform.

Footprints are also located in coastal environments where the marine domain penetrates the continental domain following a transgressive episode.

Other footprint sites are located in the supra-deltaic domain in areas of floodplains during floods.

The deltaic facies (Ksours sandstones) show, from West to East, a progressive paleogeographic and stratigraphic evolution, from open sea facies to continental facies. The deltaic cycle begins with pro-deltaic facies (oolitic limestones, dolomites, and marls alternating with sandstones). These deposits evolve into detrital terms (alternations of coarse sandstones sometimes with quartz pebbles and sandy marls) from a mid- to supra-deltaic environment.



3. In summary

The general Atlas series evolves according to three megasequences:

- the first, transgressive, begins to form from the Rhétien-Hettangien and continues until the Bajocien with the arrival of the first detrital discharges;

- the second, **regressive**, follows it from the Bajocien to the terminal Albian, representing the establishment and development of the delta of the Monts de Ksours;
- the third, Cenomanian, is **transgressive**.

During this long deltaic cycle culminating with the great Cenomanian transgression, the delta experienced periods of progradation (Bajocian-Kimmeridgian, infra-Cretaceous, sandy Hauterivian, Barremian, Albian) and periods of retrogradation (upper Kimmeridgian, Valanginian to Berriasian, "limestone" Hauterivian, Aptian).

Moreover, stabilization phases (Upper Tithonian: Delfaud, 1975) are observable during which the boundaries between the marine and deltaic domains remain immobile.

This dynamic offers fluctuations in the boundaries of marine and continental domains, privileged sites for the preservation of dinosaur footprints.

Indeed, the boundaries of the sequences related to the geodynamic evolution of the Atlas basin quite well coincide with the location of the footprint levels (discontinuities):

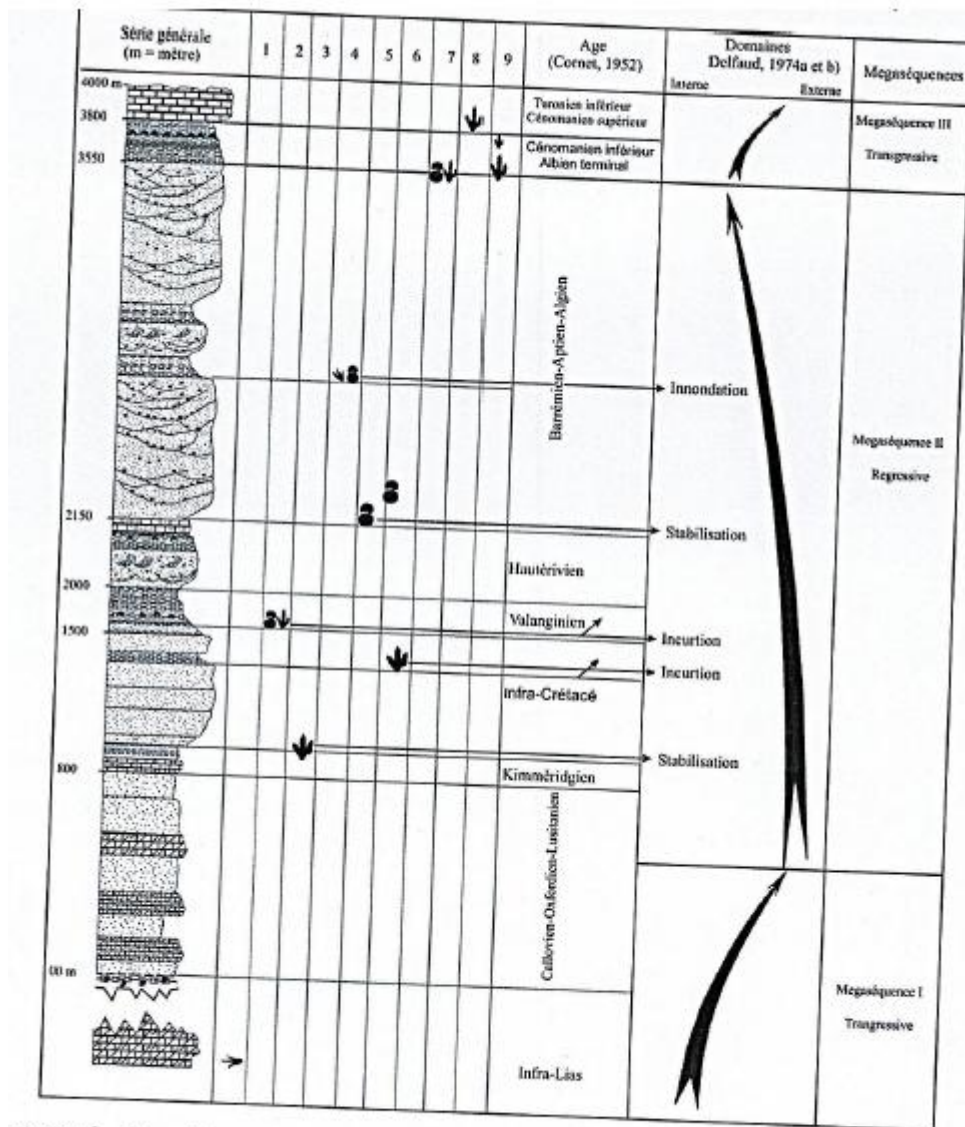


Fig. 81 : Évolution géodynamique de la série atlasique (Cornet, 1952 ; Bassoullet, 1973 ; Delfaud, 1974a et b) et position des niveaux à empreintes de dinosaures.

The location of dinosaur footprints within the Atlas series seems to coincide with phases of flooding or stabilization. These periods correspond to marine transgressions (recession of the Ksours delta) or phases of stabilization of marine and fluvio-deltaic domains.

V. Paleogeography:

This section discusses the paleogeography of dinosaurs based on their presence attested by their footprints and/or bones, the age of which is reported from the corresponding studies of the fossiliferous areas examined.

During the Lower Triassic-Lower Jurassic, the global paleogeography seems to have allowed the free movement of dinosaur faunas between North America, Europe, and Asia.

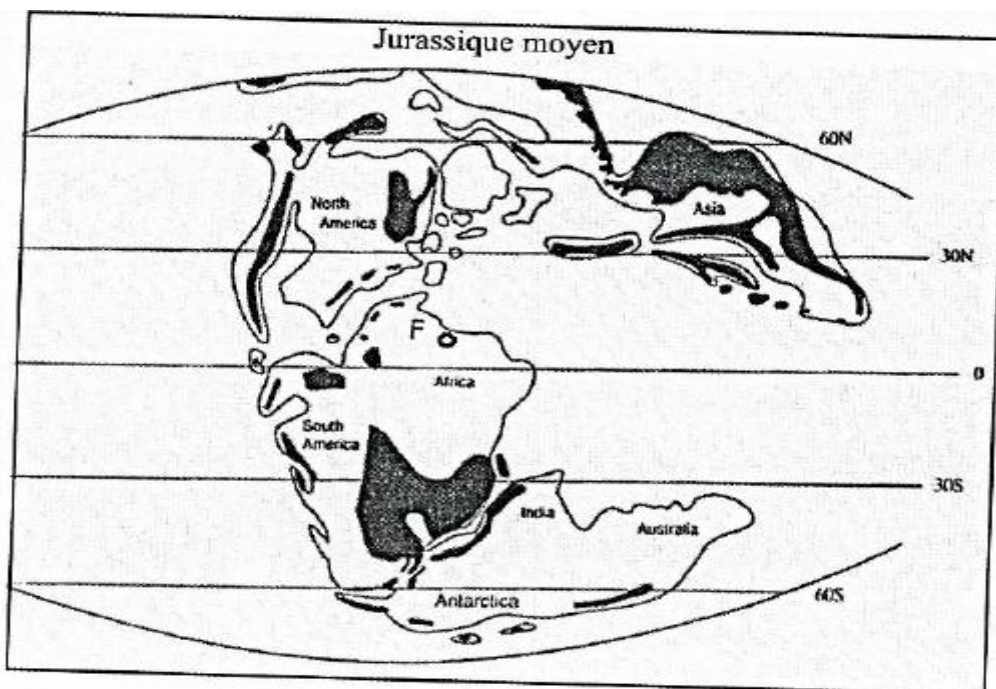


Trias

The existence of *Grallator* in Site 17 from the Rhetian-Hettangian age suggests faunal exchanges between Africa, Europe, and America, regions where the ichnogenus *Grallator* is very widespread. Other more recent footprints (*Carrixian*) have been reported in Morocco.

In the Middle Jurassic, vast emerged paleogeographic areas could allow the circulation of continental faunas within the African continent (fig.).

This explains the presence of dinosaur footprints during the Bathonian, particularly in Morocco, and the bone remains of the same age in Morocco and Algeria. This paleogeography, however, does not seem to allow for faunal exchanges between North America-Europe and Africa.



During the Late Jurassic (Oxfordian-Kimmeridgian, fig.), the transgressive episode is marked by the presence of trace fossil levels in America, Europe, Asia, and North Africa.

It seems that the transgressive episode that led to the flooding of lands on these continents allowed for the establishment of these footprints.

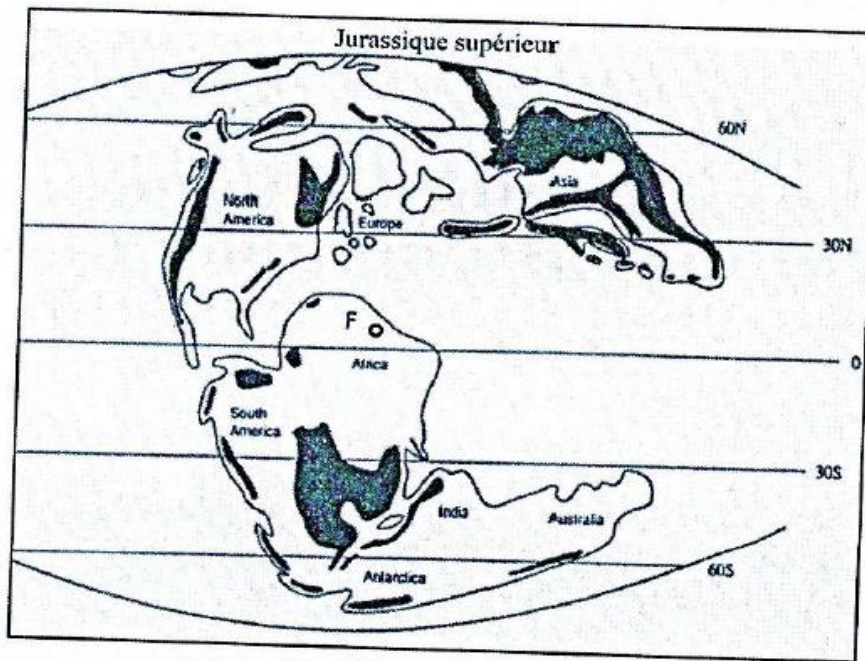
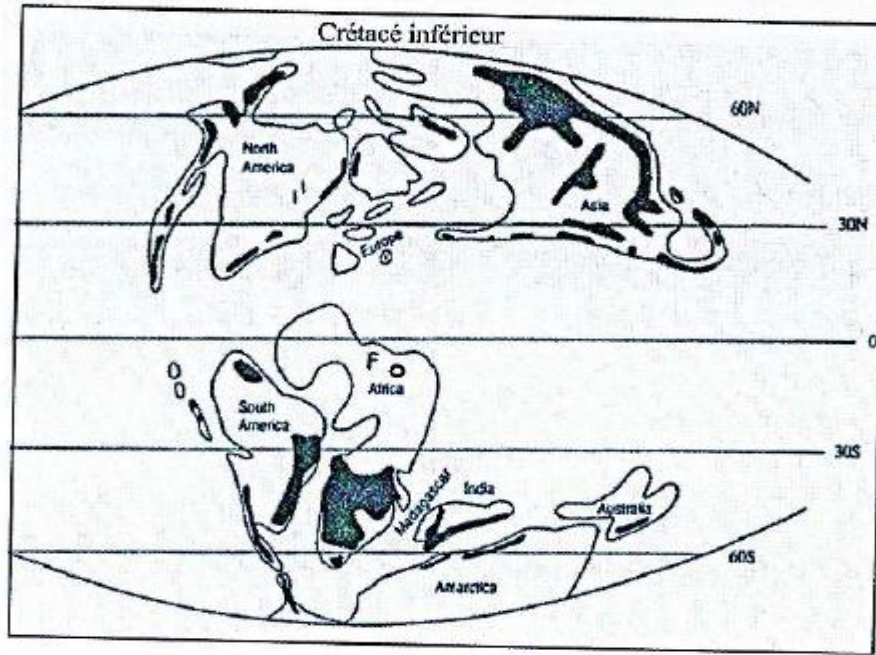


Fig. 86 : Paléogéographie du Jurassique supérieur (d'après Farlow, 1992, redessinée de Scotese et Golonka 1992).
En noir : régions montagneuses ; en Blanc : limite des terres émergées ; F : Fossile de dinosaures ; cercle noir : empreintes.

Indeed, vast lands in North Africa have alternately been emerged and submerged from the High Atlas (Morocco) to the central Saharan Atlas.

The paleogeography of the Early Cretaceous seems to preclude any land connection between North America, Europe, and Asia (Laurasia) on one side and Africa and South America (Gondwana) on the other (fig. 87).

In the El Bayadh region, the footprints appear in facies dated to the Valanginian and Barremian. -Aptian-Albian



Dinosaur bones are numerous in Algeria, both in the Sahara (Timimoun, Tiherte) and in the Saharan Atlas (Brezina).

The new development in the region is the discovery of dinosaur footprints near Brezina, at the top of the Continental Intercalary, which dates to the late Albian (Vraconnian). This region (El Kohol site) has also yielded a Charcarodontosaurus.

At that time (fig.), the American continents (North and South), European, and Asian were already separated from Africa, which suggests that the dinosaur ichn populations of the Saharan Atlas seem to be typically African.

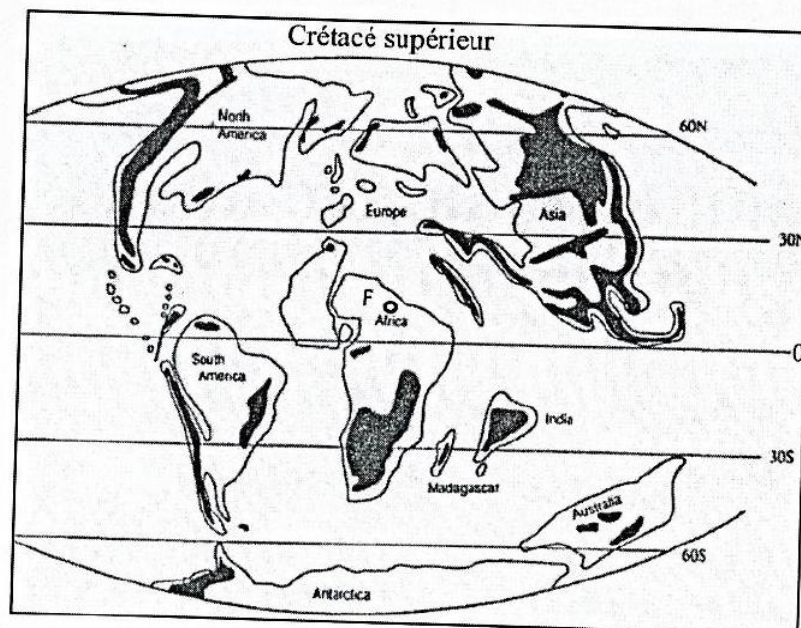


Fig. 88 : Paléogéographie du Crétacé supérieur (d'après Farlow, 1992, redessinée de Scotese et Golonka 1992).
 En noir : régions montagneuses ; en Blanc : limite des terres émergées ; F : Fossile de dinosaures ; cercle noir : empreintes.