2004

PROCEEDINGS OF THE 9TH TUNISIAN PETROLEUM EXPLORATION & PRODUCTION CONFERENCE

TUNIS, OCTOBER 4-8,2004

ETAP Memoir N° 25-2004

THE CENOMANIAN-TURONIAN BAHLOUL FORMATION IN CENTRAL-NORTH TUNISIA. BIOSEDIMENTARY EVENTS AND HYDROCARBON SIGNIFICATION

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ABSTRACT

The Cenomanian-Turonian Bahloul Formation constitutes, in Tunisia, a potential source rock (Layeb, 1990; Layeb et al., 2001). It is constituted of well bedded grey dark limestones, locally admitting frequent intercalations of marls and argillaceous limestones. In Oued Bahloul section, the Bahloul Formation (28m in thickness) directly overlies a massively bedded and lensoïd body (4m) which consists of conglomeratic sandy limestone showing a ravinating base. In terms of sequences, the Oued Bahloul section shows that the Bahloul Formation is constituted of deepening upward metric sequences comprising, each, three terms. Each sequence starts by laminated dark grey limestone, progressively changing to argillaceous limestone and terminates with bioturbated marls containing Whiteinella archaeocretacea biozone. Forthcoming studies will demonstrate that the deepening upward sequences package, constituting the Bahloul Formation, could be the expression of a transgressive interval. The latter ends with a maximum flooding surface (mfs) coinciding with the sudan apparition of "filaments" (the filament event). This mfs constitutes the summital boundary of the Bahloul Formation, which is directly overlain by the Annaba Member in which marls contain the Helvetoglobotruncana helvetica biozone, suggesting a Lower Turonian age. The "filament" event is one of four biosedimentary events identified within the Upper Cenomanian-Lower Turonian interval in Oued Bahloul section. From base to top, these four events correspond to (1) the extinction of Rotalipora genus, (2) the "Heterohelix shift", (3) the Whiteinella proliferation, (4) the "filament" event. These events were identified in other areas in Tunisia and abroad.

In terms of lateral facies changes, toward the SW, in Jebel Bireno, the Bahloul Formation which is clearly thinner (6m) and wholly carbonatic, is deposited in a relatively shallower conditions (probably in an outer platform environment). In fact, organic-rich facies constituting the Bahloul Formation change, to the South (in Sidi Bouzid, Gafsa areas), to open platform facies rich in rudists, algae and benthonic foraminifera (constituting the Gattar Member). However, toward the North, (in Bazina area, for example), the Bahloul facies change to basinal marls rich in ammonites and planktonic foraminifera.

Concerning hydrocarbon possibilities, the studied area shows that the maximum of development (in terms of thickness) of laminated organic-rich limestones, interests, in Central Tunisia, an intermediate position between platform and basin, such as in Oued Bahloul and Kalaat Senan areas.

As a consequence of lateral facies changes on the petroleum system, the lateral change of organic-rich facies (Bahloul Formation) to potential reservoirs (Gattar Member) and the sealing by impermeable Annaba marls could constitute an interesting play, especially in Central-South Tunisia.

INTRODUCTION

The Cenomanian-Turonian Bahloul Formation (Burollet, 1956) is mainly constituted of well bedded grey-dark limestones and argillaceous limestones rich in organic matter. Laminated limestones contain up to 5% total organic carbon and have a medium to high petroleum potential (Layeb, 1990; Layeb et al. 2001). The Bahloul Formation is considered as one of the best source rocks in Tunisia. However the stacking of these organic-rich facies is local (especially in Central-North Tunisia). These organic-rich facies laterally change to carbonates clearly poor in organic matter. Lateral changes of facies are closely related to changes of deposition environments and the paleogeography during Cenomanian-Turonian interval.
The main purpose of our paper will be to correlate at a regional scale, these organic rich facies. Two sections in which crop out organic-rich facies, were surveyed in Oued Bahloul area and in Jebel Bireno.

GEOGRAPHIC AND GEOLOGIC SETTING

The Oued Bahloul area is located in Central Tunisia, about 100km to the West of Kairouan city, about 10km to the South of Makthar city (fig.1). The Cenomanian-Turonian Bahloul facies well crop out on the North-Western flank of the Oued Bahloul anticline whose core is occupied by Cenomanian marls of Fahdene Formation (Burollet, 1956).
The Oued Bahloul section was correlated with the Jebel Bireno section located about 30km to the North of Kasserine city (fig.1). The Cenomanian-Turonian Bahloul limestones well crop out on the South Eastern flank of the asymmetric anticline of Jebel Bireno.
During the Cenomanian-Turonian interval, the paleogeography of Central Tunisia is mainly occupied by outer platform facies rich in planktonic foraminifera. This paleogeography is also dominated by the existence of islands (fig.1). The main island is located between Kairouan city and Oued Bahloul anticline. A smaller island is located immediately to the North of Oued Bahloul section. It will be demonstrated that these islands constitute a source of siliciclastic material resedimented in neighbouring basins.

THE BAHLOUL FORMATION IN OUED BAHLOUL : VERTICAL EVOLUTION OF FACIES

The Bahloul Formation includes the *Pseudaspidoceras pseudonodosoides* biozone (Caron et al., 1999) which suggests an Upper Cenomanian age. However, the *Watinoceras* sp. And Fagesia sp. Biozones (Maamouri et al., 1994; Caron et al., 1999) which are preferentially included within the summital part of the Bahloul Formation, suggests a Lower Turonian age. The *Whiteinella archaeocretacea* biozone (N. Belhaj Ali et al., 1994; Maamouri et al., 1994; Caron et al., 1999), which is identified in the whole Bahloul Formation, characterises the transition from the Upper Cenomanian to the Lower Turonian.
These Upper Cenomanian-Lower Turonian Bahloul laminated limestones and argillaceous limestones (28m in total thickness) directly overly a massively bedded and lensoid body (4m) which consists of a conglomeratic sandy limestone underlined by a ravinating base. This conglomeratic body constitutes the upper part of the Cenomanian Fahdene Formation. The Bahloul Formation is directly overlain by the marly Annaba Member (Burollet, 1956), Lower Turonian in age. The conglomeratic lensoid body which exhibits a clear graded bedding, contain, preferentially within its lower part, centimetric lithoclasts and quartz grains associated to bioclastic debris, benthonic and pelagic microfauna (essentially

Calcisphers and *Rotalipora*). Vertically, the massive conglomeratic sandy limestone abruptly changes to well bedded laminated limestones (plate,A) admitting marly intercalations (fig.2). Laminated limestones consist of wackestones rich in planktonic foraminifera mainly represented by Heterohelicidae species, Hedbergella and Wheitinella (fig.2). Laminations are expressed by the alternation of micritic dark millimetric beds and clear millimetric beds rich in allochems (plate,B). Dark beds consist of mudstones in which allochems are scarce and floating in a micritic-organic rich matrix. Clear beds consist of packstones rich in globular planktonic foraminifera. Marl intercalations which are highly bioturbated, show more diversified genus of planktonic foraminifera. Vertical transition from limestones to marls is progressive, by means of argillaceous limestones. However, transition from marls to limestones which is abrupt, clearly illustrates the existence of a lithological discontinuity on top of marls (that also means at the base of limestones). These discontinuities separate parasequences comprising each three terms. Each sequence (up to 5m in thickness) starts with laminated dark grey limestones which progressively changes to argillaceous limestones and terminates with marls.
The relative diversity of microfauna, in marls suggest relative open conditions probably in relation with a deepening of the deposition environment. The top of the Bahloul Formation corresponds to a centimetric limy bed highly bioturbated, rich in ammonite molds and showing frequent grains of glauconite and phosphate, illustrating a condensation phenomena and a sedimentation low rate.

In terms of environment deposition, the dominant limy lithology and the frequency of planktonic foraminifera suggest relative deep marine conditions probably dealing with the outer part of a ramp. However, the organic-rich facies preservation could be in relation with an episodic restriction of this environment.

THE BAHLOUL FORMATION IN JEBEL BIRENO AND IN BAZINA AREA : LATERAL EVOLUTION OF FACIES

In Jebel Bireno, the Bahloul laminated limestones (only 6m in total thickness) directly overly a limy massively bedded body (4m thick) which corresponds to the lateral equivalent of the conglomeratic sandy limestone identified in Oued Bahloul (fig.3). Limestones consist of packstones rich in Calcisphers (80%) and containing bioclastic debris and scarce benthonic foraminifera. The Bahloul formation which starts by lensoid intraformationnal conglomeratic limestones, is wholly carbonatic. It is represented by decimetric banks of laminated limestones admitting intercalations of argillaceous limestones. Laminated limestones consist of wackestones essentially containing planktonic foraminifera and Calcisphers.
The summital part of the Bahloul Formation is underlined by a condensed glauconitic and phosphatic bed; the equivalent of this bed was also identified in Oued Bahloul section (Zagrarni 1999). This glauconitic bed is directly overlain by marls and argillaceous limestones of the Annaba Member.
To the northern part of Tunisia, in Bazina area (fig.1), the Bahloul Formation which is relatively thick (40m), directly overlies marls of the Fahdene Formation. It is mainly represented by grey-dark marls admitting frequent intercalations of laminated limestones (fig.3). The latter which consist of wackestones rich in planktonic foraminifera, are comparable to those analysed in Oued Bahloul section.

THE MAIN EVENTS EXPRESSED BY THE BAHLOUL BLACK SHALES SEDIMENTATION

In Oued Bahloul and Jebel Bireno sections, the vertical succession of facies, from the summital part of Fahdene Formation to the Bahloul Formation, coincides with the succession of biosedimentary events (fig.4) regionally correlable.

The boundary between the top of the Fahdene Formation and the lower part of the Bahloul Formation is underlined by the extinction of the genus Rotalipora (such as *Rotalipora cushmani*) which are common and associated to Calcisphers within the Upper Fahdene carbonates (plate,C); in contrast, *Rotalipora* is completely absent within the Bahloul black shale.

A second event identified within the lower part of the Bahloul black shales corresponds to a massive occurrence of Heterohelicidae forms (*Heterohelix* shift) (plate,D). In Oued Bahloul and Jebel Bireno sections, entire forms and debris of Heterohelicidae represent about 80% of Bahloul limestone allochems. Only in Jebel Bireno sections, scarce entire forms of Heterohelicidae are also identified in the upper part of Fahdene Formation.

A third event identified within the middle part of the Bahloul Formation corresponds to the abundance of globular forms of planktonic foraminifera mainly represented by the genus *Wheitinella* and *Hedbergella* (plate,E). These genus which are identified in laminated limestones, argillaceous limestones and marls, constitute about 50% of allochems. These globular planktonic foraminifera are commonly associated to Heterohelicidae, rare Calcisphers (especially in Jebel Bireno section) and bioclastic debris.

A fourth event identified within the summital part of the Bahloul laminated limestones and argillaceous limestones, corresponds to the massive occurrence of filaments (the filament event) (plate,F). Filaments which consist of bioclastic debris, probably of lamellibranchs, constitute about 40% of allochems; in limestones, they are associated to planktonic foraminifera and bioclastic debris. Filaments are commonly characterized by a preferential orientation, parallel to bedding.

These fourth events will constitute a tool to correlate the Bahloul Formation and its equivalents at a regional scale.

THE CENOMANIAN-TURONIAN INTERVAL AS A GOOD PETROLEUM SYSTEM

In Tunisia, the Cenomanian-Turonian interval is characterised by frequent facies lateral changes. In fact, from North to South of Tunisia, this interval is associating several types of facies. This variety in facies justify the identification of several formations which have a similar age (fig.5). For example, the Bahloul Formation and the Gattar Member are equivalent in age. Its is also the case for the Annaba Member and the Beida Formation which have a similar age (Lower Turonian). This formations and members exhibit clearly different facies (fig.5). The Fahdene Formation which crops out in the northern part of Tunisia, is mainly constituted of basinal facies mainly represented by pelagic marls. From the latitude of el Kef area and toward the South, the Bahloul Formation, the Annaba and Bireno Members are individualised. To the South of the Kasserine area, the black shales Bahloul Formation laterally changes to porous carbonatic Gattar Member. In addition, the marly Annaba Member and the limy Bireno Member laterally changes to evaporatic Beida Member which is well represented in Gafsa area.

The Bahloul Formation which is mainly represented by well laminated black shales, is characterised by organic-rich facies. The latter contain up to 5% total organic carbone (Layeb et al., 1990; 2001) and have a good petroleum potential (a mean value of 17kg of hydrocarbon

compounds per tonne of rock in Oued Bahloul; up to 35kg of hydrocarbon compounds per tonne of rock in Jebel Kebbouch). The Bahloul Formation constitutes in Tunisia one of the best source rocks. Laterally, toward the South, this black shales progressively change to massively bedded carbonates, constituting the Gattar Member.

In fact, the Gattar Carbonates consist of porous bioclastic dolomitised limestones which could constitute potential reservoir rocks. The Bahloul-Gattar ensemble is commonly sealed by the Annaba marls or the Beida evaporites which constitute a cap rock.

On the whole, the Cenomanian-Turonian interval constitutes an interesting petroleum system, associating source rocks, potential reservoirs and cap rocks.

CONCLUSIONS

Detailed sedimentologic analyses of the Bahloul Formation shows that the black shales show variable facies from the basal part to the summital part. In fact, The first black shales, immediately overlying the Fahdene top, are rich in Heterohelicidae. However, the black shales of the summital part of the Bahloul Formation are rich in filaments.

This spectacular vertical evolution in facies could be related to biosedimentary events occurring during the black shales sedimentation. The biosedimentary events which are underlined by the extinction (of Rotalipora genus) and/or the abundance of certain organic compounds ("Heterohelix shift", Whiteinella proliferation and "filament event") are correlable at a regional scale.

In addition, we propose these events as a tool to recognise the summital and basal boundaries of the Bahloul Formation. In fact, the "filament" event announces the summital part of the Bahloul black-shales; however, the "Heterohelix shift" coincides with its lower part.

On the other hand, the Bahloul Formation is characterised by lateral changes of facies from the Oued Bahloul area to the South (Jebel Bireno, for example) and to the North (Bazina area, for example). In fact, to the South, the Bahloul Formation appears more limy and rather corresponds to outer platform facies. More to the South (in Gafsa area, for example) the Bahloul Formation changes to shallower facies corresponding to platform carbonates of the Gattar member. In contrast, to the North, the Bahloul black shales progressively change to marly facies rather dealing with a basinal environment.

In terms of hydrocarbon interest, the laminated organic-rich Bahloul facies are constituting one of the main source rocks in Tunisia. These black shales laterally change (to the South) to potential reservoir rocks (Gattar carbonates). The sealing of the source rock-reservoir rock ensemble is insured by the onlaping Annaba marls or Beida evaporites. On the whole, the Cenomanian-Turonian interval provides, in Tunisia, a complete petroleum system.

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CAPTIONS

PLATE

A : The Bahloul Formation black shales.
B : Laminated limestones of the Bahloul Formation, showing alternation of dark facies (mud-*wackestones*) and more clear facies (packstones rich in planktonic foraminifera).
C : Upper part of the Fahdene Formation corresponding to a packstone rich in quartz grains and Calcisphers and bioclasts and showing *Rotalipora Cushmani* (last occurrence).
D : The Lower part of the Bahloul Formation, formed of a wackestones exclusively containing *Heterohelix* genus.
E : The Bahloul limestones formed of a wackestones containing globular planktonic foraminifera (*Whiteinella*).
F : The Upper part of Bahloul Formation rich in oriented filaments and planktonic foraminifera.

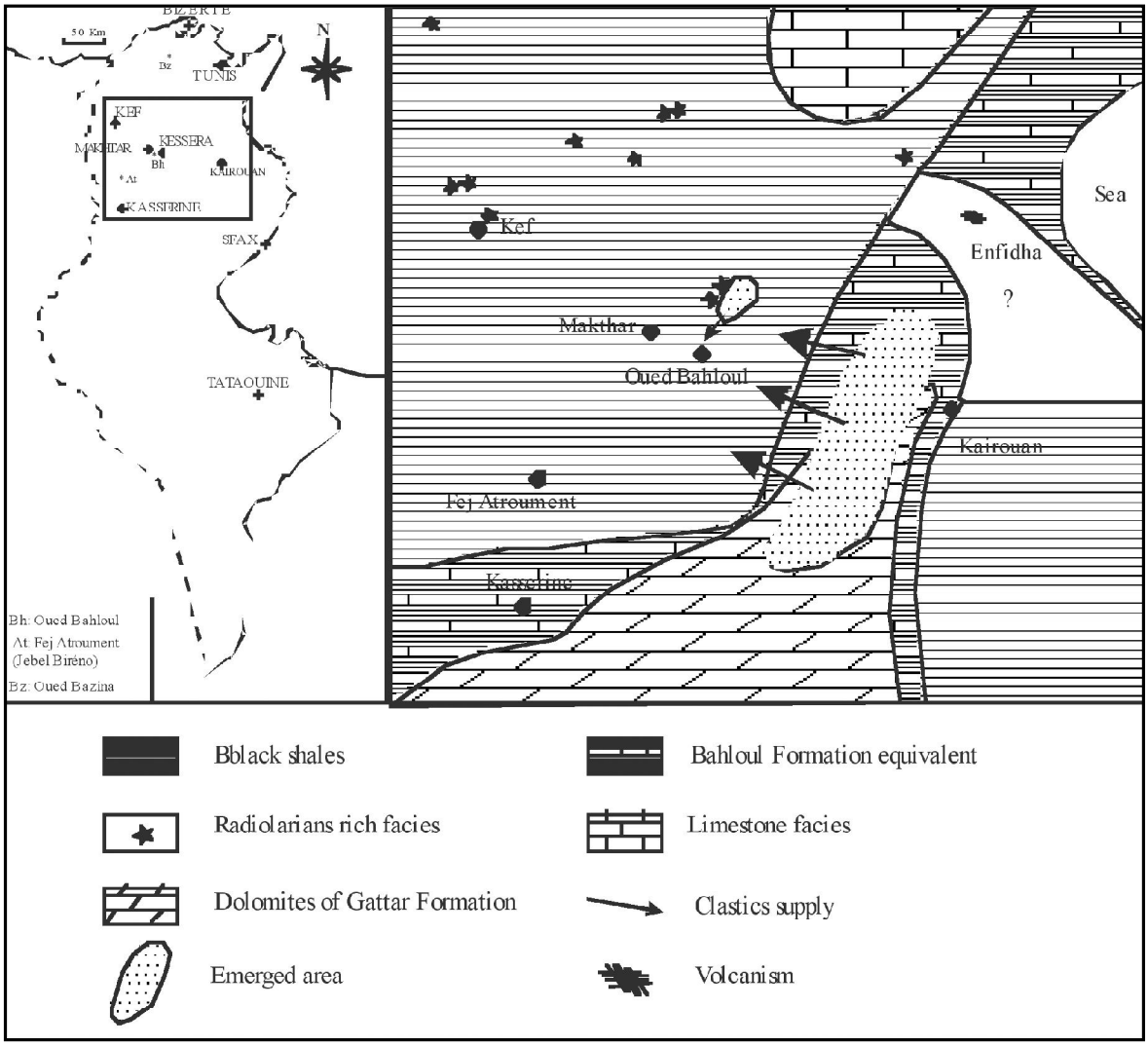

Fig.1 : Location map of the studied area and paleographic map of central Tunisia during the Cenomanian - Turonian interval (Ben Ferjani et al.; 1990, modified).

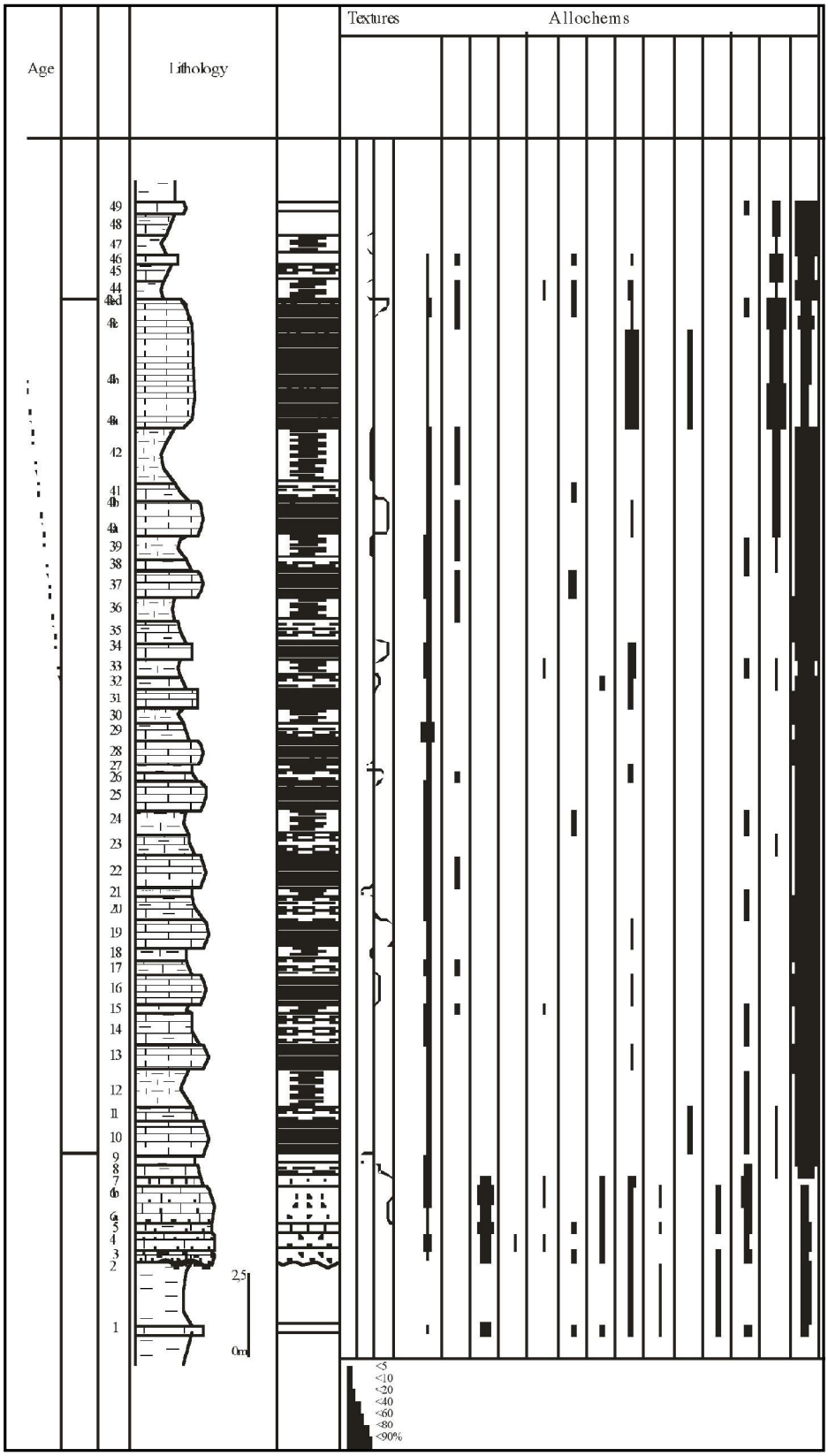

Fig.2 - Sedimentary characters of Bahloul Formation in Oued Bahloul.

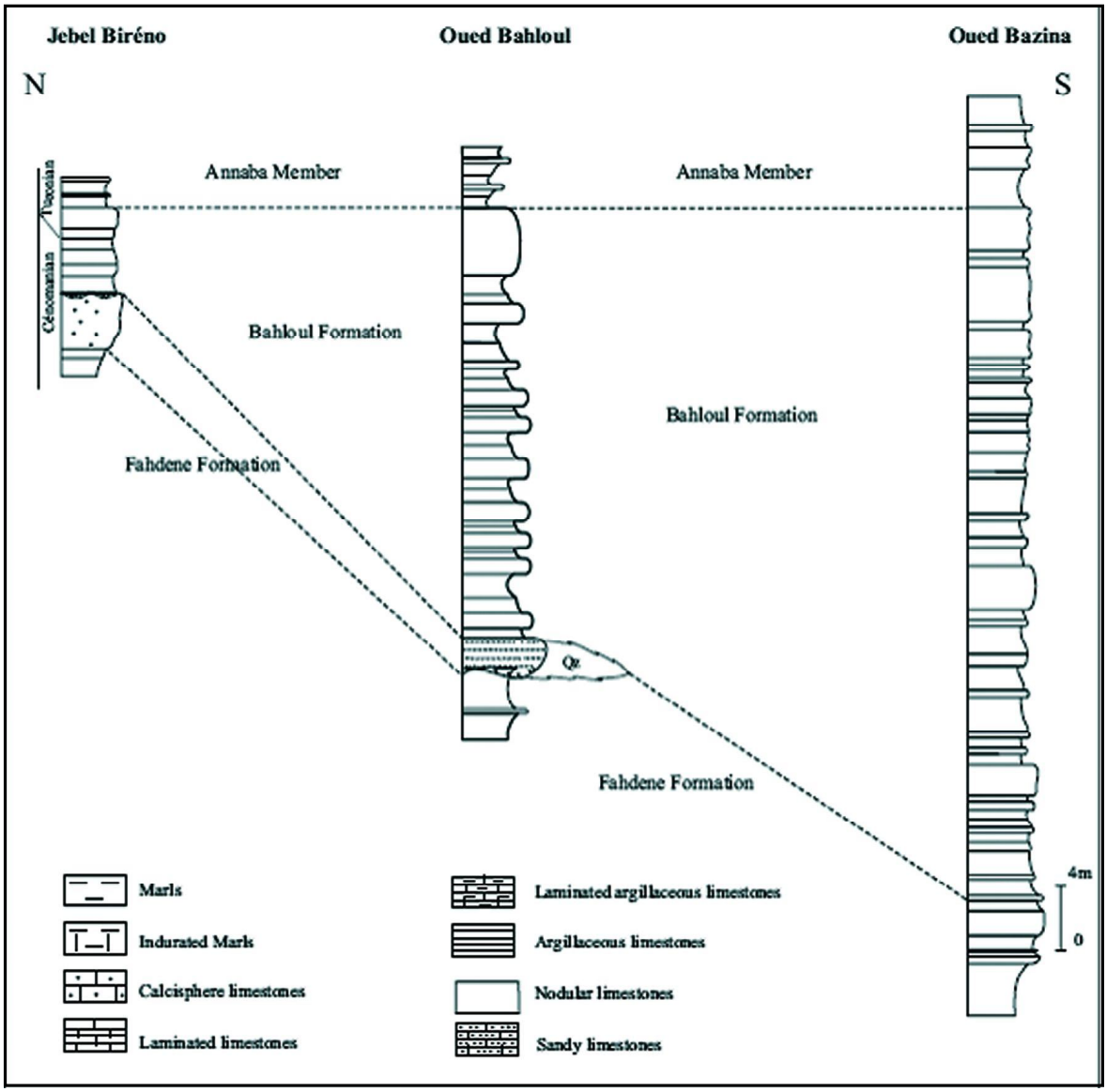

Fig.3 - Lithostratigraphic correlation of the Bahloul Formation in North and Central Tunisia.

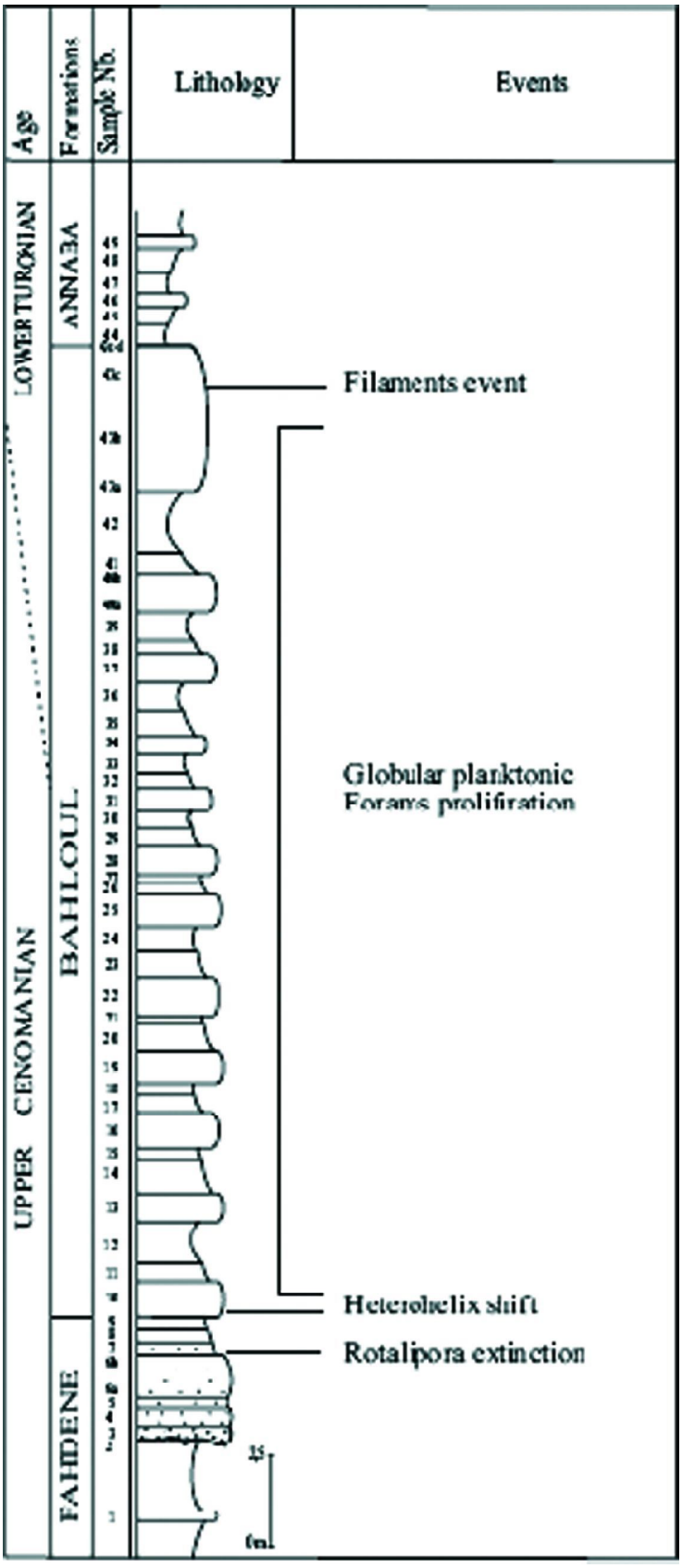

Fig.4 - Main events within the Bahloul Formation in Oued Bahloul

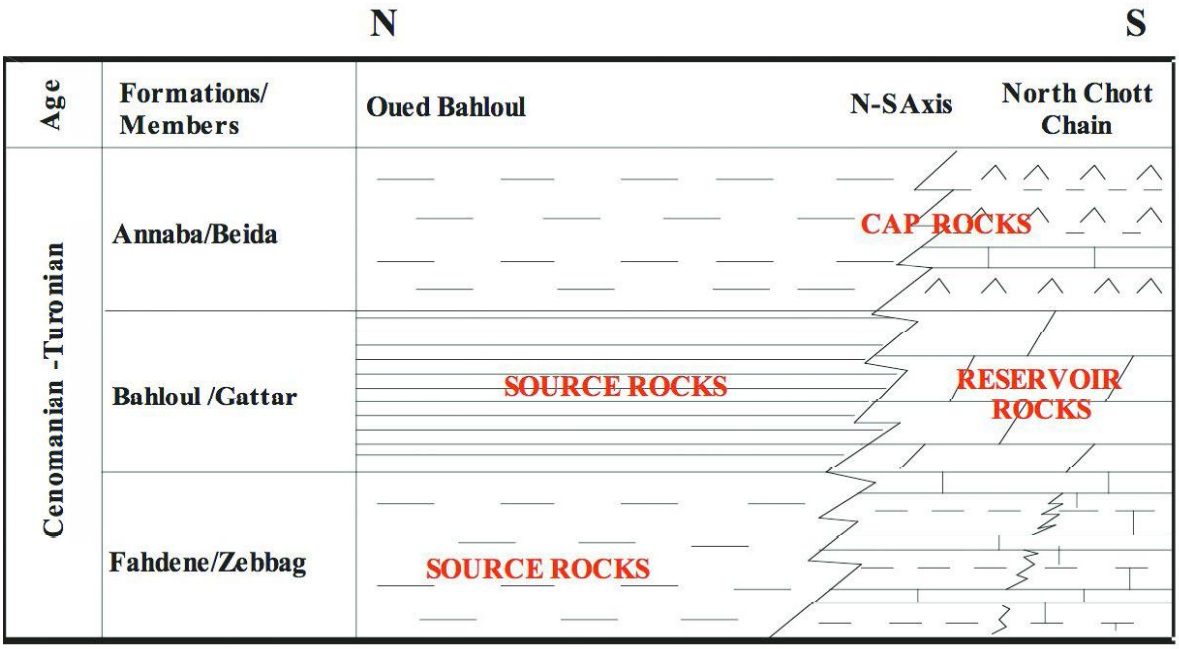

Fig.5 - Main events within the Bahloul Formation in Oued Bahloul

Plate