The Wadi ad Dawasir “delta”, central Saudi Arabia: A relative sea-level fall of Early Bathonian age

Raymond Énay, Charles Mangold, Yves Alméras and Geraint Wyn ap Gwilym Hughes

ABSTRACT

The fluvial and deltaic deposits formerly described as the Wadi ad Dawasir “delta” have been reinterpreted on the basis of a new examination of biostratigraphic data, notably ammonites and brachiopods studied by the authors and nautilids studied by the late H. Tintant (the term “delta” as used in other documents is shown here in quotes because of insufficient evidence to confirm it as a true delta). Direct dating of the fluvial and deltaic deposits is not possible in the absence of age-indicative fossils, but the entire “delta” complex can be placed in the Lower Bathonian on the basis of Bathonian ammonite and brachiopod faunas found in underlying strata, and a Lower Bathonian nautilid found in the uppermost proximal beds. An Early Bathonian age of the “delta” revises the Middle Callovian age assumed by previous authors based on their admittedly lithostratigraphic correlation with marine strata of the Dhruma Formation. The Early Bathonian age is consistent with the alternative interpretation, which correlates the “delta” with the discontinuity in the marine sequence between units D5 and D6 of the Dhruma Formation, with a stratigraphic gap of Lower (in part) and Middle Bathonian. The nautilids and brachiopods from above and “apparently at the front” of the “delta” together with the ammonites, nautilids, brachiopods and calcareous nannoplankton from units D6 and D7, indicate a complete sequence from the Upper Bathonian (unit D6) to Upper Callovian (units T2 and T3 of the Tuwaiq Mountain Limestone) with transgressive overlap of the “delta” during Middle and Late Callovian. The Wadi ad Dawasir “delta” is here interpreted as resulting from a limited relative sea-level fall, causing progradation of a shelf deltaic wedge over the downlap surface associated with the D5–D6 discontinuity. Similar deltaic or/and paralic deposits have been described in the Lower Bathonian of northern Sinai, presumably of the same age, Negev and in the Bathonian of southern Tunisia, which indicate an event of wide extent (eustatic, climatic or tectonic) along the northern Gondwanan margin.

INTRODUCTION

Important stratigraphic understanding of the Jurassic rocks in central Saudi Arabia was achieved by the geological mapping at the scale of 1:250,000 along the eastern edge of the Proterozoic Arabian Shield by BRGM, the French Geological Survey (Figure 1). This study was part of the Phanerozoic Rocks Program by the Ministry of Petroleum and Mineral Resources of Saudi Arabia (Vaslet et al., 1983, 1985a, b; Manivit et al., 1985a, b, 1986) and was aimed at refining the 1:500,000 scale map produced by the United States Geological Survey (Bramkamp et al., 1956, 1963/1982; Bramkamp and Ramirez, 1958). During the BRGM mapping, a more detailed stratigraphical scheme was established using a set of informal sub-formational units that were chronostratigraphically constrained by extensive macropalaeontological and micropalaeontological biostratigraphy.

The Jurassic palaeogeography of central Saudi Arabia, together with a description of the deltaic deposits, which have been named the Wadi ad Dawasir “delta” by Le Nindre, Manivit and Vaslet (in Énay et al., 1986) was first briefly mentioned by Énay et al. (1986, 1987) with more comprehensive descriptions in subsequent papers by Le Nindre et al. (1987, 1990a) and Manivit et al. (1990). In this paper, the term “delta” is shown in quotes because of insufficient evidence to confirm it as a true delta. It was considered as Callovian in age by Énay et al. (1993) and in the Peri-Tethys Atlas (Thierry et al., 2000). The main, or upper, body of the deltaic sediments was previously considered to be of Middle Callovian age, but it is here revised in the light of recent studies of the Jurassic rocks of southern Tunisia that can be correlated to Saudi Arabia’s Jurassic by facies and faunas (e.g. Pachyerymnoceras)
Figure 1: Location map of Jurassic outcrops in central Saudi Arabia with the localities referenced in the text and index map of relevant 1:250,000 scale quadrangles. The lateral extent of the Wadi ad Dawasir “delta” is shown in Figure 3. Traverse line from outcrop number 9 to outcrop number 28 corresponding to Figures 4, 5, 7 and 9.
A revision of the earlier ammonite biofacies-based chronostratigraphy from Saudi Arabia and their chronostratigraphy (Énay and Mangold, 1985, 1994; Énay et al., 1986, 1987,) is now possible resulting in an improved age of the Wadi ad Dawasir “delta” (Le Nindre et al., 1987, 1990a; Manivit et al., 1990).

The following discussion highlights the recent progress of the Jurassic biostratigraphy in Saudi Arabia, followed by a detailed explanation leading to the revised chronostratigraphic placement of the Wadi ad Dawasir deltaic body and its palaeogeographic location on the Arabian Platform. This new interpretation presents implications for the sequence stratigraphy of the Arabian Plate and oil exploration.

**BIOSTRATIGRAPHY OF THE JURASSIC IN CENTRAL SAUDI ARABIA**

Arkell (1952) and Imlay (1970) laid the foundations of the biostratigraphy and proposed ages for the Jurassic rocks of central Saudi Arabia. Application of the ammonite stratigraphy to subsurface samples can only be performed through the use of micropalaeontological elements that are common to both.

**Palaeontological and Biostratigraphical Studies of the New Collected Faunas**

The two most useful biostratigraphic fossil groups for surface age determination and regional outcrop correlation in Saudi Arabia are ammonites (Énay and Mangold, 1982-1984, 1985, 1994; Énay et al., 1986, 1987) and brachiopods (Alméras, 1982–1984, 1987). A series of unpublished reports (Alméras, 1982–1984; Andréieff, 1985; Boullier, 1985; Clavel, 1982-1986; Énay and Mangold, 1982–1984; Tintant, 1982–1983) summarised the entire spectrum of available data and their stratigraphic, palaeoenvironmental and palaeogeographic implications. Extracts from these reports were summarised in the Geobios special volume (edited by Énay, 1987) where the biostratigraphy of ammonites (Énay et al., 1987), nautilids (Tintant, 1987), brachiopods from Lower and Middle Jurassic (Alméras, 1987), ostracods (Depêche et al., 1987), calcareous nannoflora (Manivit, 1987) and one new species of algae (Bernier, 1987) were presented. New information on Saudi Arabian Jurassic gastropods has been published (Fischer et al., 2001) but studies on the bivalvia (J. Roger), Upper Jurassic brachiopods (A. Boullier), echinids (B. Clavel), crinoids (M. Roux) and sponges (C. Gaillard) remain unpublished.

The doctoral thesis by Le Nindre, Manivit and Vaslet (1987) was published in BRGM Document no. 191-194 and includes four volumes of which two will be referred to in this paper (Le Nindre et al., 1990a, and Manivit et al., 1990). The lithostratigraphy of each formation by Vaslet (in Le Nindre et al., 1987, and Manivit et al., 1990), and the sedimentology by Le Nindre (in Le Nindre et al., 1987, 1990a) and biostratigraphy by Manivit (in Le Nindre et al., 1987, and Manivit et al., 1990) referred to ages and references to ammonite zones, which were not accepted by Énay and Mangold (1985) or Énay et al. (1986, 1987). The differences were already evident in the papers published in the Geobios special volume (e.g. Énay et al. and Alméras versus Depêche et al. and Manivit). New information (Figure 2) will enable an update of the reference to “the corresponding European zones” (Énay et al., 1986, 1987) and of the Arabian Province (Énay and Mangold, 1994), including some changes to the zonal scheme of Manivit (Manivit et al., 1990; Le Nindre et al., 1990a) together with those published by Énay et al. (2002). Fischer et al. (2001) adopted the ages already proposed by Enay and Mangold (1994) as well as the correlation between the new Arabian ammonite zonation and the European one, except the supposed Early Kimmeridgian age (?Hypselocyclum zone) of the uppermost Hanifa Formation based on echinids (Late Oxfordian according to Énay and Mangold).

**Biostratigraphy and Lithostratigraphy**

Jurassic formations of Saudi Arabia were formally defined by Brankamp and Steineke (in Arkell, 1952) and Steineke et al. (1958) (Table 1). Powers et al. (1966) and Powers (1968) supplemented the original definitions with more precise information on the facies and lateral thickness variations. Reference sections established by the BRGM synthesis are located close to the type sections of the Dhruma and Jubaila formations, but are at some distance from those of the Marrat, Tuwaiq Mountain and Hanifa formations.
Figure 2: Bathonian-Callovian Ammonite Zones and Brachiopod Assemblages used in central Saudi Arabia and correlation with the Submediterranean Province Zones.

Table 1

| Formation       | Original Type Locality (Brankamp and Steineke, in Arkell, 1952) | BRGM Reference Section (in Manivit, Le Nindre and Vaslet, 1990) |
|-----------------|------------------------------------------------------------------|-----------------------------------------------------------------|
| Marrat          | Near the town of Marrat (25°04'N)                                | Khashm ad Dhibi (24°14'N)                                       |
| Dhruma          | Between Khashm ad Dhibi (24°12'N) and Khashm Madhurd (24°19'N)  | Khashm ad Dhibi (24°14'N)                                       |
| Tuwaq Mountain  | “Haisyan Pass” (= Hisyan) (24°55'S)                              | Motorway Jeddah-Riyadh, near Khashm Qaddiyah (24°31'N)          |
| Hanifa          | Jabal al Abakkaya, north bank of the Wadi Hanifa (24°56'N)       | Ulayylah (23°54'N)                                              |
| Jubaila         | Near the locality of Jubaylah, along the Wadi Hanifa (24°54'N)   | Near the locality of Jubaylah, along the Wadi Hanifa (24°54'N)   |
The succession is thicker and the faunal record more complete in the central part of the Jurassic outcrops (Darma’ and Wadi ar Rayn quadrangles, Figure 1). Two formations concern this paper, the Dhurma and Tuwaiq Mountain Limestone.

The Dhurma Formation in the type section (Khashm ad Dhibi) is 450 m thick. It is subdivided into units D1 to D7 (Manivit et al., 1990) of which only the Middle Dhurma (units D3–D6, 193 m) and Upper Dhurma (unit D7, 111 m) are dealt with in this paper (Photos 1 and 2). Limestones and claystones are the major components of the formation in the central part of the outcrops area, which in the north and the south change to detrital rocks. The Dhurma Formation is dated by fossils as Early Bajocian to early Middle Callovian (Énay et al., 1987; Manivit et al., 1990; Énay and Mangold, 1994; Fischer et al., 2001).

The Tuwaiq Mountain Limestone Formation reaches 184 m thick in the type section near Riyadh and comprises three units, T1 (32 m), T2 (56 m) and T3 (96 m). Locally the basal part is clayey but the bulk of the formation is made of shallow-marine infra-littoral to reefal-related limestones (Photos 3 to 5). The cuesta of Jabal Tuwaiq, the main topographic feature in central Saudi Arabia, originated from these (Photo 6). The age of the Tuwaiq Mountain Limestone is Middle (Arabian Ogivalis or European Coronatum Zone) to Late Callovian (Arabian Solidum or European Athleta Zone) (same authors as above).

The new mapping program at a more precise scale (1:250,000 versus 1:500,000) required a more precise stratigraphy and it was necessary to divide the formations into informal mapping units. Some units were previously used by Manivit et al. (1990) as true formations, for example unit D7 was divided into two formal members previously defined by Powers et al. (1966), as the Atash and Hisyan members. Such lithosedimentological units are based both on sedimentological and palaeontological data from the more marine deposits of the central part of the Jurassic outcrops (between latitudes 23°50’N and 25°50’N), but their definition is based on the recognition of sequences, the latter being used to follow lateral facies. The same sequence basis was used to follow lateral facies changes north and south of the reference sections related to a few regionally extensive marker-beds (e.g. upper unit D2 or Dhibi Limestone, upper beds of unit D5) and also for the fluvi-deltaic deposits on the southern margin (e.g. Wadi ad Dawasir).

Subdivision of the formations into sequence-based units was used as the first reference for biostratigraphy, for which ammonite biostratigraphy was applied and permitted revision of the original lithostratigraphical assignment. For example, the D1–D2 boundary first placed above the sandstone body hence attributed to unit D1 has been lowered when a fauna with primitive *Ermoceras* was identified, an assemblage known northwards at the base of unit D2. Similarly, *Micromphalites* seemed apparently to be older (unit D4) southwards, in an area where environments are less suitable for ammonites, and younger (unit D6) northwards, therefore the limits and extent of unit D5 have been modified. Similar apparently diachronous relationships have subsequently been observed with the distribution of various species of nautilids and brachiopods.

**Changes to the Ammonite and Brachiopod Biostratigraphical Schemes**

References to localities and fossiliferous outcrops for each quadrangle follows the code used by BRGM geologists: first those responsible for mapping or visiting the quadrangle (VD = Vaslet Denis; JMA = Jacques Manivit), then the year of the mapping or exploratory (1980, 1981, 1982), followed by the sample number (not necessarily a serial number). From north to south, the more frequently quoted sites are on JMA 80 = Wadi al Mulay, VD 81= Sulayyimah, VD 82 = As Sulayyil, Al Faw and Al Mudafin (the last three ones were not mapped but superficially studied). More northerly quadrangles will be quoted occasionally VD 82.357 and 484 A and B in the Al Faydah quadrangle (Figure 1). The changes in this paper are limited to the time span corresponding to units D5 and from unit D7 (Hisyan Member) to unit T3. The unit D6 and the lower part (Atash Member) of unit D7 are devoid of ammonites (Figure 2).
Photo 1: North of Al Hamr, Wadi al Mulayh quadrangle. Middle and Upper Dhruma members. Grey slopes in the bottom correspond to the unit D5; slopes within unit D6 are covered by rust-coloured fragments from ferrugineous sandstone at top of the unit; in the background slopes in unit D7 and cliff of the Tuwaiq Mountain Limestone Formation (cliff height c. 100 m).

Photo 2: Khashm ad Turab, Shaqra quadrangle. Upper Dhruma (D7 unit) Member and Tuwaiq Mountain Limestone Formation.
Regarding unit D5, the only revised aspect is its correlation with the Submediterranean Europe zonation of Mangold and Rioult (1997). The *Micromphalites* fauna with Arabian affinities recently described from the Nièvre Département, France (Enay et al., 2001) supports the Arabian Clydocromphalus Zone as an equivalent of the upper part of the Zigzag Zone, Macrescens Subzone and the lower part of the Aurigerus Zone, Recinctus Subzone.

The changes during the time span represented by units D7 (Hisyan Member) to T3 are of different value and concern the zonation and the correlation with the Submediterranean European zones. The Late Callovian age for unit T3 was recognised in 1994 (Enay and Mangold, 1994) and it was considered as a new Arabian Solidum Zone as more-or-less equivalent to the Submediterranean European Athleta Zone. Recent examination of the very few “Erymnoceras” previously quoted in units T2 and T3 has caused doubt on their identity. The genus is quite certain and numerous only
Photo 5: Vicinity of Darma’, Darma’ quadrangle. Tuwaq Mountain Limestone Formation. Top surface of unit T3 displaying silicified coral bioherms (e.g. black domes).

Photo 6: View from airplane in the vicinity of Shaqra, Shaqra quadrangle, shows cliff of the Tuwaq Mountain Limestone Formation in centre of photo (approximate width across the middle of the photo c. 10 km).
in unit D7 (Hisyan Member) and not present in unit T1 (Photo 7). Both units are dated as Middle Callovian, although the assignment of T1 is doubtful. The vertical range of *Kurnubiella* is longer, from unit D7 (Hisyan Member) upward to unit T2 and the range of the genus defines the Ogivalis Zone, with the Kuntzi horizon near the basis. Unit T2 is dated as early Late Callovian (Arabian Solidum vs European Athleta Zone).

**Brachiopod Assemblages**

The brachiopods biostratigraphic scale (Alméras, 1987, his figure 8) is a discontinuous scale of distinctive assemblages of species with a restricted vertical range between which there are transitional faunas whose species show a large vertical range. Improvements of the brachiopod scale only apply to Assemblage 4, which is now more restricted to units D6–D7. *Daghanirhynchia daghaniensis* Muir-Wood and *Eudesia cardioides* Douvillé are known everywhere in unit D6 and display an acme in D7 except at two localities (JMA.80.10 and 207) where they were attributed to the unit D5. These two sites did not yield ammonites and it is likely that they are to be placed within unit D6, instead of unit D5. It is of interest to note that *Kutchirhynchia gregoryi* Weir is known everywhere with numerous individuals of the species in the Hisyan Member of unit D7. The range up to unit T2 is based on a single specimen (VD.82.402) attributed to at Khashm Az Zifr (writing of locality or section names and latitudes are the same as those used in Manivit et al. (1990, figure 5, p. 24)) (19°30’N), even though the species is not detected in unit T1. These changes do not significantly modify the brachiopod scale, but will be useful for discussion and new interpretation of the Wadi ad Dawasir “delta”.

**WADI AD DAWASIR “DELTA” REVISITED**

The Wadi ad Dawasir “delta” was proposed as far back as the first paper by Énay et al. (1986, 1987), but it was fully described by Le Nindre, Manivit and Vaslet (1987), Manivit et al. (1990) and Le Nindre et al. (1990a). It refers to the clastic deposits of the upper (or main) body of the deltaic deposits developed in the southern part of the Jurassic outcrops, between latitudes 22° and 18°N. The name was established by Manivit et al. (1990) and Le Nindre et al. (1990a, b), but the use of “delta” (in...
quotes) is used in this paper because of insufficient evidence to confirm it as a true delta. Owing to the relatively poor extent of the outcrops, the sediments might be part of a larger detritic plain spreading north of the present outcrops where corresponding deposits have been eroded.

The figures of the “delta” by Manivit et al. (1990, their figures 38 and 46, and plates 10 and 11) and Le Nindre et al. (1990b, their figures 13, 14 and 23) as well as supporting field observations are limited by the outcrops extending as a long narrow and curved strip (between longitudes 45° and 47°E), first SSW-NNE, then SSE-NNW (Figures 1 and 3). The continental sediments disappear in the more easterly part of the Jurassic outcropping strip, which exhibits the more distal facies, and reappear at the northern end of the outcrops. Here, at the bottom as well as the top of the succession, continental characters are represented only by marsh deposits interfingered with marine beds, which are also known beyond and south of the Wadi ad Dawasir “delta”.

In the southern part of the outcrops, fluvio-deltaic supplies show a larger development and intermingling of various facies from which Manivit et al. (1990) and Le Nindre et al. (1990a, b) originated the name “delta”. However, the limits and extent of the “delta” depend on the outcrops and the palaeoenvironmental interpretation of facies in the passage zone to the marine deposits. According to Le Nindre, the main flow direction was towards NNE, oblique on the outcrops extension (Manivit et al., 1990, p. 283). The situation of the Wadi ad Dawasir “delta” with regard to the studied Jurassic outcrops is illustrated in figure 23 (Figure 3) of Le Nindre et al. (1990a, p. 108–109).

Previous Interpretations of the Wadi ad Dawasir “Delta”

Two interpretations were discussed by Manivit et al. (1990) and Le Nindre et al. (1990a, b) in regards to the setting of the “delta” and its relations with the marine deposits (Figure 4).

Interpretation 1

Although previously stating that the delta was deposited within the unit D7 and southwards ranged up the unit T1 (Énay et al., 1987, p. 50), Manivit et al. (1990, p. 223 and 304, their figure 38) and Le Nindre et al. (1990a) stated that the delta could correspond to the time separating the sedimentation of units D6 and D7, i.e. between the undifferentiated Middle and Upper Bathonian and lowermost Middle Callovian (Manivit et al., 1990, their figure 38). The corresponding time span exactly covers the gap placed by Manivit et al. (1990) and Le Nindre et al. (1990a, b) between units D6 and D7. This view was also expressed in the essay on the application of sequence stratigraphy to the Jurassic rocks of Saudi Arabia (Le Nindre et al., 1990b). The gap between units D6 and D7 is shown on all the faunal range charts (Manivit et al., 1990, their figures 21 to 29 and 31), but is in disagreement with the evidence provided by ammonites (Énay et al., 1986, 1987; Énay and Mangold, 1985, 1994) and brachiopods (Alméras, 1987), just below and above the discontinuity. This point will be discussed below (see section on “Biostratigraphic Data”).

Interpretation 2

The Wadi ad Dawasir “delta” was also interpreted by Manivit et al. (1990, p. 270–284; 1990a) as a lateral equivalent of unit D7 and dated as Middle Callovian and is displayed as such on the Middle Callovian palaeogeographical map by Le Nindre et al. (1990a, their figure 23), on the map and explanatory notes of the Tethys Atlas (Énay et al., 1993) and Peri-Tethys Atlas (Thierry et al., 2000). As discussed above, it is concluded the upper Dhruma (unit D7) displays a totally siliciclastic and argillaceous lithofacies in the south towards latitude 21°30’N with an increased thickness by more-or-less lenticular prograding bodies (Manivit et al., 1990, p. 130).

An inconsistency exists between these two interpretations (Manivit et al., 1990, p. 223 and 304), which remains in some more recent papers. In the explanatory notes of the Peri-Tethys Atlas for the Middle Callovian map, Thierry et al. (2000, map 9, p. 82) state a clear retrogradation of the deltaic facies and that they were not transgressed during the Callovian; thus they are considered as contemporaneous of the Callovian formations (e.g. unit D7). They further state that a sea-level fall and a decrease of tectonic effects in subsidence drove to a major unconformity and sedimentary gaps during late Middle Bathonian – Early Callovian interval, coeval with the setting of the huge Wadi ad Dawasir palaeodelta fan.
Figure 3: The Wadi ad Dawasir “delta” in the Middle Callovian (Upper Dhruma Member) palaeogeography according to Le Nindre et al. (1990a, figure 23), assuming the same age for the prograding siliciclastic supplies (“terrigenous supplies”) and the retrograding marine deposits of unit D7 (“build-up complex advance”). Outcrops are identified by solid drawing and the eroded parts or cancelled below overlapping Cretaceous by light drawing. 1, 2, 3: number of deltaic “lobes” following Le Nindre et al., 1990a.
**Siliciclastic Continental Deposits Attributed to Units D6 and T2 as Parts of the “Delta”**

The interpretation by Le Nindre, Manivit and Vaslet includes other points that are disputable. According to the interpretation, which acknowledges the Wadi ad Dawasir “delta” as a lateral equivalent of unit D7, units D6 (below) and T2 (above) are not considered as parts of the deltaic body, although the corresponding deposits show evidence of continental conditions. But the mapping program does not extend southwards beyond the 21°N and the outcrops south of 21°N “have been only the subject of exploratory sections”.

---

**Figure 4:** The Wadi ad Dawasir “delta” and the equivalent marine deposits according to Le Nindre, Manivit and Vaslet. The “delta” from Manivit et al. (1990), plate 10 (“Lias and Dogger environments”) and plate 11 (“Wadi ad Dawasir delta”) drawn on the unpublished document used for location of the samples, with lithostratigraphic units.
Wadi ad Dawasir “delta”, central Saudi Arabia

Relations between the Deltaic Wedge and the Marine Deposits

The clastic deltaic body and the partition into lithostratigraphic units are presented separately, and the same scheme was used in all the figures illustrating the range of the faunas in the special volume of Geobios (Énay ed., 1987) and Manivit et al. (1990). The lithosequential units based on the marine deposits were extended southwards beyond 22°N and the extent of the “delta” is always pictured independently of the formations and members. Two exceptions are the illustration of “The Liassic and Dogger environments” (Manivit et al., 1990, plate 10) and only north of latitude 21°30’N, then the one in Manivit et al. (1990, their figure 18) displaying the Dhruma and Tuwaiq Mountain formations south of 21°N.

Figure 4 presents a new and significantly different view of the relationship between the “delta” and the marine deposits. It is based on two original and separate documents: (1) an unpublished diagrammatic cross-section used for the location of the palaeontological samples, and (2) a figure illustrating palaeoenvironments (Manivit et al., 1990, their plates 10 and 11). The figure is also useful for comparing the fossil records below, above and “in front” of the deltaic body (Figure 7). It shows that the more distal lowermost expansion of the deltaic deposits appears to end relatively close to the bottom of unit D6, nearly at the D5–D6 boundary, as also drawn in the diagrams by Manivit et al. (1990, their figures 38 and 46) and Le Nindre et al. (1990b, their figure 4). In contrast, the relationships with the Tuwaiq Mountain Limestone, especially units T1 and T2, are not clear, except for the retrogradational signature.

The unit D6 south of the latitude 22°10’N

The unit D6 shows the same facies changes as those of the upper (Hisyan) member of unit D7 (the lower or Atash Member is unknown south of 22°10’N). From Jabal Shimrak (22°10’N) and southwards, the beds ascribed to unit D6 show a gradual supply of siliciclastic with rare plant fragments (Manivit et al., 1990, p. 114). Further south, the evidence for pedogenesis becomes evident where continental lithofacies and pedogenetic sediments become outstanding south of 22°N. South of 21°30’N, the entire D6 at the top of the Middle Dhruma Member consists of a soil profile. Its assignment to unit D6 is supported by the age of the underlying beds of unit D5, using ammonites and/or brachiopods as far as Khashm Mishlah (21°07’N). They lie on what would be the last evidence towards the south of the discontinuity of wide extent at the top of unit D5.

Beyond and towards the south, as far as about 20°18’N (Khashm Kumdah), the beds assigned to unit D6 increasingly become thinner downwards with root imprints (Manivit et al., 1990, their figure 18), but the assignment is no longer supported by faunas. The palaeo-soil with root at K. “861” (20°45’N) (Manivit et al., 1990) as well as the ferruginous crust at the top of sandstones observed at about 20°20’N (Énay et al., 1987) are supposed to be the same bed plane as the discontinuity known at the top of unit D5. From Khashm Mishlah southwards these beds (e.g. unit D6) are eroded by those ascribed to unit D7. That does not rule-out including them in the Wadi ad Dawasir deltaic body, which would start with the beds formerly ascribed to the unit D6 as suggested by the ending of the lowermost distal expansion within the unit according to Manivit et al. (1990, their figures 38 and 46).

The unit T2 south of 22°N and the marine overlapping of the deltaic body

South of 21°50’N, Tuwaiq units T1 and T2 show rapid changes. Unit T1 disappears south of Khashm Al Mukassar (21°36’N) and terrigenous supplies invaded the lower part of unit T2, the upper parts displaying more calcareous facies with a transgressive signature. Signs of continental environment (ferruginous bed-planes and crusts, plants remains, clays and sandstones with pedogenetic marks, etc.) become increasingly evident in the beds assigned to unit T2 from Khashm Mishlah (21°07’N) and as far as Khashm Gurab (18°52’N). Figure 6 is a new interpretation of the Manivit et al.’s original figure 18 (1990), illustrating the lateral changes of the Dhruma and Tuwaiq Mountain formations south of latitude 21°.

All the studied sections from Khashm Mishlah (21°07’N) to Khashm Khatmah (18°08’N) show one or two non-depositional surfaces within, or at the top of, the beds ascribed to the unit T2 as well as within unit T3. One of the more continuous surfaces is at the top of unit T2, whose uppermost beds are still carbonate-rich (limestone or dolomite) and sandy, locally with oolites, typical of transgressive
surfaces. They start the marine overlap of the deltaic body, well characterised above the discontinuity, corresponding to the limestones of unit T3, sometimes clayey, bioclastic or containing corals. These latter beds yielded the only faunas discovered south of the latitude 21°N, except for the above-mentioned nautilid from Khashm Sudayr (19°12'N), which offers the single evidence for dating the beds previously ascribed to the unit T2.

In summary, starting from south of 21°36'N (Khashm Al Mukassar), the siliciclastic deposits of continental origin, or with signs of continental influence, ascribed to units D6 (below) and T2 (above) respectively, belong to the siliciclastic deltaic wedge. But these assignments result from correlations based on lithosequential reference without biostratigraphic control and the single biostratigraphic evidence for dating the beds ascribed to unit T2 questions both the lithostratigraphic placement of the unit and the resulting age.

BIOSTRATIGRAPHIC DATA AND THE RELATIONS BETWEEN THE MARINE DEPOSITS (UNITS D6 TO T3) AND THE WADI AD DAWASIR “DELTA”

Biostratigraphic age determination of the deltaic body itself has not been achieved, and it is recommended that future work should focus on a study of palynomorphs and limnic ostracods. The “delta” according to Manivit et al. (1990, their plate 10) has been re-drawn on the unpublished document used for location of all the samples collected and the resulting Figure 7 was used for the purpose of displaying the available biostratigraphic data. Figure 7 shows that south of 21°30’N the palaeontological data are infrequent, just where the Wadi ad Dawasir deltaic deposits are developed, and are limited to the major marine expansion below and above the deltaic wedge.

The Wadi ad Dawasir: An Early Bathonian “delta”

The age of the Wadi ad Dawasir “delta” was interpreted by Manivit et al. (1990) and Le Nindre et al. (1990a) indirectly from the relations with the marine deposits. Manivit et al.’s figure 38 (1990, p. 116) is reproduced (Figure 5) and suggests a quite different interpretation. The figure displays the forestepping of the upper deltaic body upon the marine beds of unit D5 containing ammonites and/or brachiopods and the age is well constrained as Early Bathonian, Clydocromphalus Zone, as far as latitude 22°11’N (Khashm Munayyifiyah). On both sides of latitude 19°12’N (Khashm Sudayr), Lower Bathonian beds are also figured just above the “delta” leading to the interpretation that the entire delta is of Early Bathonian age (Figure 5).

Evidence for Lower Bathonian above the deltaic body from the so-called unit T2

The more southerly ammonites we have examined (VD.81.144) reach barely 21°37’N at Khashm Mukassar in unit T3; so on figure 38 the symbols “ammonite” beyond 21°37’N are erroneous. Nevertheless, Vaslet (in Manivit et al., 1990, p. 326) states that unit T2 contains the more southerly specimen of the Erminnoceras Assemblage at Khashm Gurab (18°52’N), which is the same as “the nautilid specimen, driven ashore by the winds” quoted at the same latitude by Le Nindre (in Manivit et al., 1990, p. 281). Le Nindre adds that the specimen “would be derived from the condensed and fossil-rich beds which underlines the renewal of the carbonate sedimentation and would be still of Bathonian age”, referring to the evidence provided by Manivit. However, Manivit described only undetermined ammonite likely ascribable to an Erminnoceras or Pachyceratidae at Khashm Gurab (18°52’N) (Manivit et al., 1990, p. 354). Le Nindre’s remark throws light on their figure 38 but the reference to the latitude 18°52’N and the symbol “ammonite” at the same place are erroneous as well as the one at latitude 19°30’N (Khashm Az Zifr) (Figure 5).

On the other hand, at latitude 19°12’N (Khashm Sudayr), two nautilids have been found (Figures 6 and 7) and one of them (VD.82.674) agrees perfectly with Le Nindre’s remark probably based on the comment by Tintant (1987, p. 88) concerning Ophionautus aff. zitelli (Gemm.), which it is worth quoting in extenso: “the studied specimen has been ascribed to the unit T2 (Callovian). Such age seems to be too late for an Ophionautus (species), especially because the species zitelli was described from Bajocian in Sicily and was found again recently from the Lower Bathonian (Zigzag Zone) in
Burgundy. The section where the Saudi sample was collected being at the southern distant end of the Jabal Tuwaiq Formation, very reduced at this place, it is allowed to wonder whether the stratigraphic placement is indisputable”. Tintant’s remark did not escape Le Nindre’s notice and we suppose that Le Nindre is the author of figure 38, but the inferences of the figure concerning the age and the interpretation of the Wadi ad Dawasir “delta” do not reflect this evidence. The “delta” should, therefore, be dated as Early Bathonian, but subject to the reliability and acceptance of the dating inferred from the nautilid from Khashm Sudayr.

The nautilid specimen in question was figured by Tintant (1987, p. 87–88, his plate 5 and figure 2). It is a single and incomplete specimen, of medium preservation, but the uncertainty of the determination is related as much to the previous supposed age of unit T2 as to the state of preservation. The hypothesis that the specimen was reworked from Bathonian beds and embedded in Middle-Upper Callovian deposits implies that Lower Bathonian deposits were spread-out southwards beyond latitude 18°N. Actually, within the marine facies area, Lower Bathonian beds were buried beneath the sedimentary stack of units D6 to T1, and we therefore accept as valid the independent comment by Tintant. The Wadi ad Dawasir “delta” is concluded to be Early Bathonian and this new interpretation has interesting implications for the age of unit D6 and the placing of the hiatus within D5–D7 interval in the marine deposits.
**Extent and dating of the marine beds below the deltaic body**

The marine deposits of unit D5, known as far as about 20°45’N and at Khashm Mishlah (21°07’N), have been identified as the last evidence southwards of one of the hiatuses occurring widely in the upper part of the unit, but it is not necessarily the one situated at the top of the unit (Manivit et al., 1990, their figure 18).

From north to south, at Khashm Munayyifiyah (22°11’N) and surrounding it, unit D5 is just below the more distal and lowermost expansion of the “delta”, well-dated by the ammonite *Micromphalites* sp. and the brachiopod *Daghanirhynchia subversabilis* (JMA.82.559). The dating is firmer southwards, near Khashm Mishlah, about 21°10’N (VD.81.246), where *D. subversabilis* was found together with *Micromphalites clydocromphalus*, Early Bathonian, Clydocromalus Zone (approximately equivalent to the Zigzag Zone, Macrescens Subzone and Aurigerus Zone, Recinclus Subzone of the Submediterranean Standard Scale; Énay and Mangold, 1994; Magold and Rioult, 1997). The more southern site (VD.81.201) at Khashm Mishlah (21°07’N) yielded only *D. subversabilis*, a species known from unit D5, but especially plentiful in the unit D4 [*D. daghaniensis* is quoted by Manivit (Manivit et al., 1990), but it is incorrect because the species is known only from the unit D6 upwards].

The wide extent of unit D5 (as well as unit D4 below) and the *Micromphalites* Assemblage are well-characterised also on the northern border. At about latitude 25°30’N, just south of Jurayfah, at the last occurrence, the *Micromphalites* Assemblage is abundant and diverse (VD.82.357, VD.82.484A and B). As far as the northern limit of the outcrops, unit D5 (and D4) occur between marsh deposits ascribed to units D3 (below) and D6 (above).

On the southern edge of the outcrops, a Middle Jurassic bivalve specimen, *Lopha solitaria* (fide J. Roger), is mentioned by Manivit et al. (1990, p. 120 and their figure 18; see Figure 7) and is a strange and totally isolated situation at latitude 18°43’N (Thulmat al Bayda). The specimen was collected from the first few meters of a 24-m-thick sequence (sandstones, sands and purple-coloured clays including sandstones) ascribed to Middle Dhurma Member; it would be the only proof of a marine on-lap as far as this latitude. The interpretation of the deposits by Le Nindre (Manivit et al., 1990, plate 11) as “bays, lagoons and sabkhas environments” lying on “levees and flooding plains” deposits is consistent with this hypothesis, though on the cross-section of plate 11, the marsh and/or alluvial channel deposits divide them from the marine edge of unit D5 ending at Khashm Mishlah. This apparent disposition depends on the location of the cross-section compared with the SW-NE direction of the “delta”, which in the outcropping strip extends between 22° and 20°N (Le Nindre et al., 1990a, their figure 23, p. 108–109) (Figures 1 and 3). The beds yielding *Lopha solitaria* at Thulmat al Bayda are situated beyond and on the south-eastern edge of the “delta”. We willingly would accept this evidence of a marine expansion as far as such a latitude in relation to the wide extent of unit D5 and the *Micromphalites* Assemblage, which was already interpreted as a maximum flooding surface, first by Le Nindre et al. (1990b) and more recently as MFS J30 by Sharland et al. (2001).

In conclusion, the establishment of the deltaic wedge occurred suddenly at the top of unit D5, which is dated as middle Early Bathonian, Clydocromalus Zone (equivalent to the Submediterranean Zigzag Zone, Macrescens Subzone and Aurigerus Zone, Recinclus Subzone). The ending of the deltaic deposits took place during Early Bathonian according to the dating by Tintant based on the nautilid from Khashm Sudayr. Le Nindre’s hypothesis of a drift specimen “driven ashore by the winds” agrees well with his sedimentological interpretation of the beds ascribed to unit T2 as “intertidal lobes, muddy tidal-flats, sandy tidal-flats”, which overlie the surface of the deltaic body between latitudes 22°45’N and 18°30’N (facies 7 in Manivit et al., 1990, plate 11).

The Early Bathonian age of the deltaic body we accept here calls into question its relations, both in age and geometry, with the marine deposits and the two previous interpretations (reviewed above) proposed by Manivit et al. (1990) and Le Nindre et al. (1990a, b).
Position and Age of the Hiatus within the D5 to D7 Interval

The location of the inter D5-D7 hiatus is considered to have two possible positions (see Figures 9a and b):

1. Top of unit D5 where the only non-deposition surfaces of wide extent in the marine deposits are observed, at least in the central part of the outcrops (Photo 8). Towards north and south, other surfaces of non-deposition become evident higher in the succession.

2. Top of unit D6 according to the interpretation by Manivit et al. (1990) and Le Nindre et al. (1990a, b) and previously used by Dépêche et al. (1987) or Manivit (1987), where the succession shows no sedimentological signs of a sustained break of the sedimentation.

The age of unit D5 is well-proven (Énay et al., 1986, 1987, 2001; Énay and Mangold, 1985, 1994) and the answer to this problem lies within the age determination of units D6 and D7.

Unit D6

It is probably Bathonian, although it yielded not very significant, impoverished and/or endemic faunas. The only one present, ammonite genus Drhumaites, is only known in Saudi Arabia; it is a clydoniceratid, which could equally be Middle or Late Bathonian. The Early Bathonian age assumed by Le Nindre, Manivit and Vaslet is based on two of the three nautilid species (the third is new) known in the underlying beds (Ophionautilus cf. catonis and Eutrephoceras cf. waageni). But in his unpublished 1983 report, Tintant was inclined to ascribe the level to Lower Bathonian beds because “any new form was missing”; but in describing the new species, Eutrephoceras globosum n. sp., only known from unit D6, Tintant did not firmly dismiss a Middle Bathonian age: “the persistence in that bed of Ophionautilus cf. catonis and Eutrephoceras cf. waageni seems to point out an Early or at the more a Middle Bathonian age” (Tintant, 1987, p. 124).
Brachiopods of unit D6 were neglected, probably because the unit does not yield any significant species, as the age of *Eudesia cardioides*, a species described and only known from Sinai, is not precisely defined. Unit D6, however, does show a renewal of the brachiopod fauna (first appearance of *Doghanitychia daghaniensis* M.-W. and *Burmitychia nazeri* Alm.) commencing in the acme of the Assemblage 4 in unit D7, where another species of the genus *Eudesia*, *E. multicostata*, becomes numerous; this latter species is known in northwest Europe in uppermost Upper Bathonian (Discus Zone) (Alméras et al., 1997), but no Middle Bathonian species were observed in unit D6.

**Unit D7**

Le Nindre, Manivit and Vaslet ascribed the entire D7 unit to Middle Callovian on the basis of calcareous nannofossils, especially on the first appearance of the two species *Wazneueria manivitae* and *Stephanolithion bigoti*, and their vertical range in the Levant (Moshkowitz and Ehrlich, 1976, 1980).

Calcareous nannofossils have been studied from a few sections and samples (cf. Manivit, 1987) and the first appearance datum (FAD) of two significant species has been studied: (1) *W. manivitae*, in two sections only, from the lower part of Atash Member at Khashm Turab (25°03'N), a few higher at Khashm Dhibi (24°14'N), and (2) for *S. bigoti*, in only one section in the upper part of the Atash Member at Khashm Turab. An increased abundance and diversity of calcareous nannofossils in the lower part of unit D7 (Atash Member) is coincident with the renewal and diversification of the macrofaunas, which are related to deepening and more open environments. The same fact was observed for the nannoflorae in the Levant in the upper part of the Zohar Formation (Moshkowitz and Ehrlich, 1976, 1980) and so, the first appearance datum of these two species was considered as significant of a Middle Callovian age in the Levant as did also Manivit et al. (1990) in Saudi Arabia.

The ranges of these species in northwest Europe, especially for *W. manivitae*, has caused reconsideration of their stratigraphic significance in the Saudi Arabian Jurassic. *W. manivitae* is known in marine sequences in southeast France from Lower Bajocian, Laeviuscula Zone upwards (Gardin, 1997) and the later first appearance in Saudi Arabia, as well as in the Levant, has only a regional value and it is not necessarily synchronous in these two areas. It results from a same environmental evolution, the more open condition controlling the first appearance of the species during its biochron.

*S. bigoti*, a well proved marker in western Europe, as well in Boreal as in Tethyan Realms, displays a first appearance in the uppermost Early Callovian, Calloviense Zone in northwest Europe, Gracilis Zone in southwest Europe and northwest Africa (Gardin, 1997; Kaenel et al., 1996). Moreover, although in Saudi Arabia the species is known for the first time in the upper part of Atash Member, Manivit (1987, p. 284) dated the whole unit D7 as Early Callovian (inconsistent with the Middle Callovian age in their table 1). Although only one locality yielded *S. bigoti*, there is reason to assume that the first appearance of the species in Saudi Arabia is very near to the beginning of its biozone (and biochron).

The first ammonites from the unit D7 occur slightly above the nannoflorae, in the basal part of the Hisyan Member. Among them, *Pseudomicromphalites kuntzi* Collignon is known from three localities, near the type-section at Khashm Mishraq (24°13'N) (JMA.82.425), at Khashm Aba al Hayyal (Qasab) (25°22'N) (VD.82.509) and at Khashm Furaythah (25°42'N) (VD.82.489). *P. kuntzi* described from Malagasy (Collignon, 1964, 1966) occurs here in the upper part of Lower Callovian (transitionals beds between *Macrocephalites chariensis* and *Nothocephalites semilaevis* Zone and *Indosphinctes patina* Zone). Westermann and Callomon (1988) set the boundary between these two zones approximately within the Calloviense Zone, Calloviense Subzone of northwest Europe or the Gracilis Zone, Michalskii Subzone of the Submediterranean Standard Scale.

Besides the *Grossouvria* from the type-section (JMA.82.207) and at Khashm Birk (23°18'N) (VD.80.520), previously mentioned by Imlay (1970), just at the boundary between the Atash and Hisyan members, several localities yielded numerous sufficiently young specimens of proplanulitids (cf. Énay et al., 1987, their plate 6 and figures 4 to 8). They probably represent spawns growing in these shallow-marine environments, e.g. at Khashm Turab (25°03'N) (VD.82.607/608), Khashm Aba al Hayyal (Qasab) (25°22'N) including *Pseudomicromphalites* sp. (VD.82.509) and the Al Liqa section (26°20’N)
(JMA.83.195). In the Indo-Malagasy area this ammonite group is especially present at the top of Lower Callovian and in Middle Callovian.

In conclusion, the calcareous nannoflorae, especially the first appearance of *S. bigoti*, and the first known ammonites, especially *P. kuntzi* and proplanulitids, place the basis of the Middle Callovian within the unit D7 and not at its bottom, slightly above the boundary between the Atash and Hisyan members. Therefore, unit D6 and the lower part of unit D7 (Atash Member), which yielded the same brachiopod fauna (*Assemblage 4* in Alméras, 1987), are dated as Late Bathonian and Early Callovian, respectively. The Middle Bathonian and possibly also a part of the uppermost Lower Bathonian are missing just within the hiatus between the units D5 and D6, well characterised by the only non-deposition surfaces of regional extent at the top of unit D5.

**Faunas from Marine Deposits at the “Front” and at the Top of the “Delta”**

Manivit et al. (1990, their figures 38 and 46) and Le Nindre et al. (1990b, their figure 4) interpreted the clastic deltaic deposits as a lateral facies change equivalent to the marine deposits of Middle Callovian age (unit D7, Hisyan Member). This interpretation is inconsistent with the Early Bathonian age of the Wadi ad Dawasir “delta”. Evidence are discussed below.

**The faunas known at the “front” of the “delta”**

The Wadi ad Dawasir “delta” (Figure 7) from Manivit et al. (1990, plate 10) is the focus of the following discussion. The extent and limits of the deltaic body depend on the palaeoenvironmental interpretation of the facies and on the geometric relationships between sedimentary bodies. They are different in Manivit et al. (1990, their figure 38) or Le Nindre et al. (1990b, their figure 4) on one hand, and Manivit et al. (1990, plates 10 and 11) on the other, the “intertidal lobes, muddy tidal-flats and sandy tidal-flats” (symbol 7) being either included-with or excluded-from the delta. The poorly known faunas from such deposits, just at the border of the “delta”, are typically represented by a few number of individuals, only one nautilid species, more frequently brachiopods and no ammonite. The faunas are not of the same age in the muddy deposits at the “front” of the “delta” and in the sandy deposits at the top of the deltaic body between 21°42’N and 18°45’N, including the nautilid ascribed to the unit T2, but which would be Early Bathonian according to Tintant.

The fossiliferous localities yielding brachiopods from the marine facies at the “front” of the “delta” [VD.81.137 at Khasm Abu al Jiwar (21°53’N), JMA.80.430 at Khasm Shimrak (22°10’N) and JMA.80.561–562 isolated north of Fara’yid al Hamr (22°27’N)] were previously all ascribed to the upper part (Hisyan Member) of the unit D7. Except samples JMA.80.10 at As Sitarah (22°38’N) and JMA.80.207 at Khasm Mawan (22°50’N), situated in the continuation of the lower expansion of the “delta front” and ascribed to unit D5. They were previously replaced in unit D6, if not D7, because they share *D. daghaniensis* (4 specimens) and *Eudesia cardioides* (1 specimen). In the localities of the central part of the Jurassic outcrops where the specimens are numerous, these species show a range restricted to units D6 and D7 with the acme in the upper part of the unit D7 (Hisyan Member).

The two localities situated in the intertidal lobes, muddy tidal-flats, sandy tidal-flats, e.g. VD.81.136 at Khasm Abu al Jiwar (21°53’N) and JMA.80.348, isolated south of Khasm Shimrak (22°10’N), yielded also the fauna of unit D7. The nautilid from VD.81.136 is a new species *Paracenoceras (Metacenoceras) saoudense* Tintant known by this single specimen and cannot be used for dating (Tintant, 1987, p. 83).

To conclude, at the “front” of the “delta”, sometimes in the deposits assigned, as the case may be, to the distal part of the “delta” or to the marine deposits, all the discovered faunas are from unit D7 and from the upper part of the unit (Hisyan Member). Available data do not assist in determining whether unit D7 is a lateral counterpart of the deltaic deposits (as was assumed by Le Nindre, Manivit and Vaslet) or onlaps the latter; the Early Bathonian age of the deltaic body would favour the second interpretation and the matter will be examined further in the Discussion section.
Figure 6: The Wadi ad Dawasir "delta" south of latitude 21°N. New interpretation of the figure 18 in Manivit et al. (1990) with location of the rare known faunas, especially the Early Bathonian nautilid at Khashm Sudayr and Lopha solitaria at Thulmat al Bayda.
Wadi ad Dawasir “delta”, central Saudi Arabia

The faunas from beds overlapping the Wadi ad Dawasir “delta” between 21°42’N and 18°45’N (Figures 6 and 7)

Brachiopods are the more often collected fossil group, generally very few but from a large number of localities than the scarcer nautilids. From the same section, which yielded the nautilid ascribed to the unit T2 (Khashm Sudayr, 19°12’N) and assumed by Tintant to be older, another nautilid (VD.82.676), from unit T3, is the new species *Paracenoceras meridionale* Tintant (1987, p. 101, his plate 10, figures 1 and 2). This species is also known (VD.86.1) from the north (Khashm Aba al Hayyal, 25°22’N) from the beds yielding the *Pachyerymnoceras* fauna of the Solidum Zone (approximately Athleta Zone), Late Callovian (Manivit et al., 1990; Énay and Mangold, 1994).

Brachiopods collected south of 21°N were all ascribed to unit T3. At Khashm Kumah (20°15’N), *Bihenithyris* sp. (1 specimen) (VD.82.423) is not significant and *Kutchirhynchia cf. indica* (d’Orb.) (VD.82.420) is a species known both in units T2 and T3. Far towards the south in the Mudafin quadrangle, at Khashm al Fara’id (18°35’N), *Thadiqithyris thadiqiensis* Nazer (VD.82.410) is also a species from units T2 and T3. But just below in the same section *Bihenithyris barringtoni* M.W. (VD.82.407) was not found above unit T2 in the sites with numerous individuals from the central part of the Jurassic outcrops and this species is more indicative of unit T2 rather than unit T3. In an intermediate situation between the previous localities, at Khashm Az Zifr (19°30’N), VD.82.402 is a single site where *K. gregoryi* Weir (1 specimen) was found high in the succession, while in the Shaqra and Buraydah quadrangles the range of the species is restricted to unit D7 and especially to its upper member (Hisyan).

---

**Figure 7:** Location of the sites with ammonites, nautilids and brachiopods above, "at-the-front" and below the Wadi ad Dawasir “delta”. The same document as in Figure 4 but with a different interpretation of the relationships between the siliciclastic fluvial-deltaic body and the marine deposits.
To conclude, the sites VD.82.402 and 407 being considered apart, the rare faunas collected south of latitude 21°N allow one to assume that, in the same way as unit T1 vanishes southwards at the latitude of Khashm Abu Jiwar (21°53’N), unit T2 vanishes from Khashm Kumdah (20°15’N) southwards and unit T3 only overlaps the deltaic wedge. This relationship was also concluded by Manivit et al. (1990, p. 345), and contrasts with that by Vaslet (ibid., p. 325–327) who quotes unit T2 as far as the Khashm Khatmah (18°08’N). South of As Sulayyil (20°18’N), however, the beds ascribed to unit T2 are part of the deltaic body and also yield the nautilid (VD.82.674) of Early Bathonian age according to Tintant. Moreover, Le Nindre (in Manivit et al., 1990, p. 368) assumed that “southward the unit T3 alone is transgressive on the deltaic body”.

If we admit the ages supported by brachiopods, localities VD.82.402 and 407 underline the return of marine conditions above the deltaic body, then this would require a new detailed survey. Nevertheless, it seems that unit T3 corresponds to a renewal of marine depositional conditions of large extent southwards. If the rare fossils found from the units D7 and T2 are not reworked at the bottom of the unit T3, they would prove the local earlier re-establishment of marine conditions, possibly resulting from the unevenness of the upper surface of the Wadi ad Dawasir deposits.

DISCUSSION AND NEW INTERPRETATION OF THE WADI AD DAWASIR “DELTA”

The Wadi ad Dawasir deltaic body is dated as Early Bathonian, and although this determination could be considered to be based on possibly weak evidence, Early Bathonian deltaic deposits are known elsewhere in Middle East and southern Tunisia and a survey is justified before this new interpretation can be confirmed with certainty.

Deltaic or Paralic Deposits in Middle East and Southern Tunisia

Deltaic or paralic deposits dated as Bathonian have been described in northern Sinai (Egypt) and Negev (Levant) on the north margin of the Arabian-Nubian Shield as well as in southern Tunisia, on the northern margin of the Saharan Craton (Figure 8).

Safa Formation, northern Sinai (Al Far’s, 1966)

Al Far’s (1966, p. 31) distinguished cyclic alternations of sandstone and clay sequences with carbonaceous thin layers. In the lower part of the formation several coal-measures are intercalated, with lenticular bedding, some with enough extent to allow industrial working. The succession has been revised by Goldberg et al. (1971) and the more calcareous upper part of the unit was removed, without any indication on the corresponding beds in Al Far’s section, to be added to the upperlying Kehailia Formation [previously the lower member of the Masajid Formation (Al Far’s, 1966)]. Subsurface extension of the Safa Formation in the Western Desert of Egypt was redefined as a member of the Khatatba Formation, widely used in industry. Keeley et al. (1990) considered that the whole Khatatba Formation and in particular the Safa Member were deposited at a time of presumed low sea-levels.

The formation was dated globally as Bathonian by Al Far’s and Keeley et al. (1990), more precisely as Early-Middle Bathonian with reference to the ages previously assumed by Arkell concerning the Thambites and Micromphalites faunas in Saudi Arabia (Hirsch, 1976; Picard and Hirsch, 1987). The mention of ?Thambites sp. in the lower part of the unit (Al Far’s, 1966) was confirmed by the finding of Th. planus (Parnès, 1974; Picard and Hirsch, 1987). During our 1997 field-trip (R. Énay and C. Mangold), new specimens of Th. planus were collected at two different levels, first in the red hematitic limestone (probably Al Far’s bed 153, which is the lower boundary of the unit) and a few meters below in the uppermost beds of Bir Maghara Formation, Bir Maghara Member. Now, the Th. planus Assemblage (= Planus Zone) is correlated with the Parkinsoni Zone in the Submediterranean reference scale and dated as uppermost Late Bajocian (Énay and Mangold, 1994).
The lower part of the upperlying Kehailia Formation (or Member) is dated by \textit{Micromphalites} sp. (Al Far’s, 1966) and \textit{M. pustuliferus} (Parnès, 1974; Picard and Hirsch, 1987; Hirsch et al., 1998). The newly collected material does not bring any supplementary information, and referring to Saudi Arabia (Énay et al., 1986, 1987; Énay and Mangold, 1994), the fauna is dated as the middle part of Early Bathonian, Clydocromphalus Zone. Therefore, the Safa Formation is dated as earliest Bathonian, probably the Tuwaiqensis Zone in Saudi Arabia (Énay and Mangold, 1994; Énay et al., 1997), approximately the Zigzag Zone, Parvum Subzone in the Submediterranean reference scale.

\textbf{Sherif Formation, central Negev (Eliezri in Coates et al., 1963)}

The formation was observed and studied only from borings in central Negev, in the eastern extension of the Gebel Maghara outcrops, with a progressive thickening from east to west (Goldberg and Friedmann, 1974). The dominant facies are alternating sandstones and shales, with occasional limestones. Concurrently to the thickening, the formation changes towards the northwest (coastal plain of the Levant) to carbonate platform limestones (Haifa facies), 300–400 m thick.

The paralic facies are developed in the lower member, 100 m thick, for the most part represented by sands or sandstones, including a lens of brown coal, 5 to 60 centimetres thick. The extent of these paralic beds in the lower part of the formation is limited towards the northwest. They change to marl deposits until they are replaced by carbonate platform limestones with nerineids and corals (Hirsch, 1976, his figure 2).
The lower member of the Sherif Formation has been compared with the paralic facies of Safa Formation with which they are considered to be an eastern extension of the same age (Goldberg and Friedman, 1974; Hirsch, 1976; Picard and Hirsch, 1987; Hirsch et al., 1998). Ammonites being absent, the ages are based on ostracods and calcareous nannoplankton and not very constrained. The palynomorphs from the upper member characterise a Middle-Late Bathonian faunal assemblage that agrees with the Early Bathonian age resulting from the correlation with the Safa Formation in Gebel Maghara.

**“Grès du Techout” Formation, Jeffara, southern Tunisia (Busson in Freinex and Busson, 1963)**

Compared to homologous deposits of Saudi Arabia and the Middle East (northern Sinai), deposits on the margin of the Saharan Craton outcropping in Jeffara (southern Tunisia) show more clearly proximal facies. The “Grès du Techout” Formation is a regressive event in-between the weak transgressive pulse of the Bajocian “Calcaires de Krachoua” Formation below and the widespread Callovian transgression of marls and limestones of the “Foum Tataouine” Formation above.

The unit displays alternations of thin and rare marine beds with bivalves and brachiopods, gypsiferous clays of lagoonal condition and beds with continental indications and very abundant wood remains. Busson (1967) used the word deltaic “to account with the mixture, the superposition and alternation, many times repeated” of such facies. Clays and carbonates decrease southwards to the advantage of anhydrite and sandstones towards the continent, which provided the supplies. This facies change is parallel to the coarsening of the grain size and increasing coal layers.

According to Bouaziz (unpublished report and thesis, 1986, 1987), the formation is divided into two members (Barale et al., 2000). The lower Zahra Member is dominated by clays and gypsum interfingered with dolomites and limestones, and wood remains; the overlying Maned Member includes yellow greenish clays, often sandy or gypsiferous, the middle part of which contains numerous plant remains (conifers, ferns). Rare macrofaunas linked to the thin marine beds occur in the outcrops of north Jeffara, near Tataouine, mostly bivalves that are not very characteristic (*Eomiodon, Modiolus, Liostrea, Trigonia*).

According to Bouaziz (unpublished report and thesis, 1986, 1987), all the succeeding authors agreed with the Bathonian age of the formation (Soussi et al., 2000). Ostracods (Mette, 1997) and floral impressions recently discovered in the upper member of the formation (Barale et al., 2000) confirm the Bathonian age but do not add any precision. More precise ages are assumed by Peybernès et al. (1985) and Kamoun et al. (1992). They refer to sequence stratigraphy and identification of “the sequences as planned in the Haq et al. eustatic chart” to assume a Late Bajocian to Middle-Late Bathonian age. The other dating evidence is the same brachiopods as those previously mentioned by Peybernès et al. (1985). They were found at two different levels: the first below the hard-ground ending the underlying “Calcaires de Krachoua” Formation (fauna F2); the second in the condensed interval at mid-height of the Zahra Member of the “Grès du Techout” Formation (fauna F3). Both levels yielded the same species studied by Alméras, e.g. *Burmihrynchia termeriae* Rousselle (= *B. athiensis* Rousselle) and *Formosarynchia dumortieri* (Szajnocha) [= *Cymatorynchia regnesi* (Oppel)] (see Almeras et al., 2007, fig. 2), both especially known from Upper Bajocian (Europe and northern Africa), more scarcely from Lower Bathonian (Morocco and western Algeria). The overlying Beni Oussid I Member (Foum Tatouine Formation) would be Middle-Upper Bajocian or uppermost Bathonian, according to benthic foraminifers (Peybernès et al., 1985) and sequence stratigraphy (Kamoun et al., 1992), but already Callovian according to echinids (Clavel in Ben Ismail et al., 1989) and ostracods (Mette, 1997). Although the dating is uncertain, the Grès du Techout Formation gives evidence for a regressive event during Bathonian time resulting in the progradation of siliciclastic continental facies on the northern margin of the Saharan Craton. Barale et al. (2000) mentioned “sedimentological results displaying a regressive tendency within the Techout Formation clearly expressed at the bottom and less and less pronounced upwards”.

In Sinai and Levant on the northern margin of the Arabian-Nubian Shield and its eastern margin, in central Saudi Arabia, as well as in Tunisia on the northern margin of the Saharan Craton, the siliciclastic deposits of the paralic and/or deltaic suite became widely expanded during Bathonian. Although dating is sometimes uncertain, the event seems to reach its maximum development during Early Bathonian.
Previous Interpretations of the Jurassic Successions on the Arabian Platform

Previous interpretations either refer exclusively to the concepts of sequence stratigraphy (Le Nindre et al., 1990 b; Al-Husseini, 1997) or also accept a parallel role by tectonic control (Sharland et al., 2001; Le Nindre et al., 2003). Among these interpretations we only examine the relevant interval of the present paper and the Wadi ad Dawasir “delta” (Figure 10).

Le Nindre et al. (1990b, 2003) presented two successive interpretations. In the first (Le Nindre et al., 1990b) the time interval studied here corresponds to the end of their sequence 2 and the beginning of sequence 3 (Figure 5). The boundary between the two sequences is drawn at the D6–D7 discontinuity, which is correlated with the second-order sequence boundary ZA-2 and ZA-3 in Haq et al. (1988). The unit D5 is identified with the maximum flooding surface and unit D6 would be the highstand followed by the regression resulting in the *prograding platform deltaic wedge* (e.g. Wadi ad Dawasir “delta”). But unit D7, assumed by Manivit et al. (1990) and Le Nindre et al. (1990a, b) to be coeval with the siliciclastic deltaic body, together with the Tuwaiq Mountain Limestone, are identified as a *transgressive reef sequence* and correlated with Haq et al. sequence ZA-3.2. The maximal flooding surface is placed at the boundary between units T2 and T3. So, the proposed sequential interpretation preserves the ambiguity we underlined previously: the platform deltaic wedge identified with unit D7 (Manivit et al., 1990 and Le Nindre et al., 1990a) is first placed at the top of sequence 2, but the same unit D7 starts sequence 3.

In the second interpretation based on subsidence modelling, Le Nindre et al. (2003) reduced the importance of eustatic control and added associated tectonic activity. Specifically, up to Early Bathonian (units D5 and D6), depositional control resulted from active tectonic subsidence connected with tectonic inversion. Deposition during the D7–T3 interval, still dated as Middle-Late Callovian, was related to accelerated subsidence with prograding deltaic deposits on the southern margin of the sedimentary area.

Al-Husseini (1997) adopted Le Nindre et al.’s interpretation (1990b) and compared it to the ones by McGuire (1993) and Grabowski and Norton (1995), and used it as a reference for correlations with other areas of the Arabian Plate (Kuwait, Bahrain, Qatar, United Arab Emirates and Oman). The Wadi ad Dawasir event was never mentioned except on the Callovian palaeoenvironmental map (Al-Husseini, 1997, his figure 2), which follows the map in Manivit et al. (1990) and Le Nindre et al. (1990a, b).

Sharland et al. (2001) completed a large survey on “Arabian Plate Sequence Stratigraphy” from Late Precambrian to Recent, using mainly subsurface data from the greater oil-producing countries around the Arabian Gulf (from Syria to Oman). They made use of biostratigraphic data at outcrops, especially the Jurassic of central Saudi Arabia, to support their interpretations of maximum flooding surface (MFS). They adopted the concepts of genetic stratigraphy by Galloway (1989) rather than the ones by the Exxon group (Vail et al., 1977; Haq et al., 1987, 1988). The Bathonian – Callovian interval is a part of their Tectonic Megasequence (TMS AP7) from uppermost Toarcian up to uppermost Tithonian. In the environments on unstructured Jurassic ramp, as in the case of the Arabian Platform, eustacy is considered as the major factor controlling the sedimentary architecture of carbonates, sometimes exaggerated by subsidence. Megasequence AP7 includes two second-order T/R cycles *sensu* Vail et al. (1977).

The first T/R cycle (from Aalenian up to Bathonian) starts with a transgressive interval ending with the Early Bajocian maximum flooding surface (MFS J20). The ensuing highstand includes the Early Bathonian transgressive event and the maximum flooding surface MFS J30. But the MFS surface is placed within the calcareous clays in the middle part of unit D5 and not in the non-deposition surfaces at the top of the unit as did Manivit et al. (1990) and Le Nindre et al. (1990a, b).

The second T/R cycle (from Callovian up to basal Tithonian) is also a complex one including a first transgressive systems tract corresponding to the Upper Dhruma Member (unit D7) and Tuwaiq Limestone and Hanifa formations, and two successive maximum flooding surfaces. The first (MFS
J40) occurs within the thick green clays in the upper part (Hisyan Member) of unit D7 (the basis of their sequence 3, in Manivit et al., 1990 and Le Nindre et al., 1990a, b), the second (MFS J50) occurs near the top of the Hawtah Member (unit H1 of the Hanifa Formation).

Neither the siliciclastic sediments nor the Wadi ad Dawasir “delta” are mentioned. Sharland et al. (2001) only mention, within the (genetic) sequence GSS 30, the weak clastic supplies previously quoted by Murris (1980) in the southwest, south and southeast, arriving from the Arabian highlands (Hadramaut Arch). And, referring to G. Grabowski about signs of emersion and erosion at the top of Araej Formation in the central Gulf area (Qatar, Bahrain), a general maximum regression surface (MRS) is assumed within the interval between the MFS J30 and J40 (= GSS 30) as well as a probable Late Bathonian-Callovian gap (Sharland et al., 2001, p. 101 and enclosure 2b).

The Wadi ad Dawasir “delta”: An Early Bathonian Relative Sea-level Fall

Palaeogeographic framework of the Wadi ad Dawasir “delta”

In the Arabian Platform, located between the Arabian-Nubian Shield and the continental passive margin in the Oman-Zagros-Eastern Taurus regions, a carbonate ramp developed, almost horizontal or with a very gentle slope, deepening towards north-northeast (Sharland et al., 2001). The basin aspect shown on the figures by Énay et al. (1986, 1987), Manivit et al. (1990) and Le Nindre et al. (1990a, b) is misleading, and results from the trend of Jurassic outcrops around the Arabian-Nubian Shield which crop out obliquely. The Wadi ad Dawasir “delta” compared with the studied Jurassic outcrops (Figure 3), which is taken up again from Le Nindre et al. (1990a, their figure 23, p. 108–109) (disregarding the marine deposits assumed to be of the same age and the resulting Callovian age of the “delta”). The SSE-NNW trend of the facies distribution is well-exemplified in Figure 3 as well as the SW-NE direction of the prograding siliciclastic supplies, in the same direction as the deepening of the platform. The latter was occupied by epeiric very shallow seas often just beyond emersion and the facies of marine deposits prove the deepest environments were in distal infratidal conditions. Ecological endemism of Arabian faunas, especially ammonites, implies that they adapted to such peculiar environments on very shallow platforms. Therefore, accommodation was never very important and subsidence cannot alone be considered as a controlling factor of sedimentary infilling as Le Nindre et al. (2003) have shown in their new interpretation of the Jurassic in Saudi Arabia.

Following Sharland et al. (2001), sedimentary load alone was probably sufficient to cause slow subsidence of the Arabian Plate owing to its weakened crustal strength resulting from the multiple-rift events during most of the Phanerozoic. No rifts are identified during the Jurassic (and a part of the Cretaceous), between the Late Triassic Carnian extension and the Late Cretaceous Turonian obduction. It seems out of the question that a tectonic origin of erosional conditions would have resulted in the extent of the Wadi ad Dawasir deltaic deposits. Similarly, assuming that Jurassic climate was not so equable (uniformly temperate) than it is often asserted, a relative stability during Jurassic is well evidenced (see survey by Hallam, 1993). The most prominent change occurred between the Middle and Late Jurassic, when the arid conditions already developed at the low latitudes during Early and Middle Jurassic extended towards the high latitudes. Such conditions prevailed during the Bathonian in the studied area. The sedimentological study of the “delta” by Le Nindre (Le Nindre et al., 1990) concerns in fact its stratal architecture. He does not bring data on the process concerning the derivation of the siliciclastic material, especially on a possibly more humid period. Therefore, owing to the lack of evidence to identify and acknowledge what is the possible part of tectonics and climate in the origin of the Wadi ad Dawasir “delta, the proposed interpretation rests mainly with eustacy.

What is the place of the Wadi ad Dawasir “delta” facing the marine deposits?

The uncertainty regarding the age determination of unit D6 led to two interpretations (Figure 9a and b).

The first would be to connect the siliciclastic body to unit D6 (Figure 9a). On one hand, as it is shown in Manivit et al. (1990, their figures 38, 40 and plate 10) the lower distal expansion of the “delta” ends in the lowermost beds of unit D6. On the other hand, unit D6 yielded not very characteristic impoverished and/or endemic faunas, which are difficult to place between the Lower-Middle Bathonian and Upper Bathonian. Therefore unit D6 could be identifiable with the maximum regression, which accompanied
the setting of the prograding Wadi ad Dawasir siliciclastic deltaic wedge. Unit D6 would also be the first unit from which the marine suite D7–T3 developed (sequence 3 of Manivit et al., 1990; Le Nindre et al., 1990b), but it is not assumed here as the equivalent of the Wadi ad Dawasir “delta”. Such a choice involves an Early Bathonian age for the unit D6 and fits-in with the choice previously made by Manivit et al. (1990) and Le Nindre et al. (1990a, b), but it disagrees with the authors’ interpretation assuming a Late Bathonian age for unit D6, which is also the first unit of the D6–T3 suite. On the contrary, basinward extension of the “delta” by perideltaic deposits corresponding to the unit D6 would be a consideration.

The second possibility is to correlate the setting of the siliciclastic deltaic body with the discontinuity at the top of unit D5 (Figure 9b). Moreover, localities JMA.80.10 and JMA.80.207, formerly attributed to the unit D5, are replaced here in the unit D6 (if not D7); therefore the more distal lowermost expansion of the deltaic body is closer to the units D5 and D6. The lack of perideltaic deposits is the weak point of this interpretation, which could to be explained by the removal of the finest sediments by marine perideltaic currents (coastal drift current). But, this explanation requires additional field work. An alternative explanation would be a sequence boundary causing a facies dislocation. This second interpretation is one of the previously proposed interpretations by Manivit et al. (1990) and Le Nindre et al. (1990a, b), except that the gap is now placed between units D5 and D6, not between units D6 and D7 as did Le Nindre, Manivit and Vaslet, and its age would be Early (in part) - Middle Bathonian, not Early-Middle Bathonian to Middle Callovian. Later, in their attempt to apply sequence stratigraphy to Saudi Arabia’s Jurassic rocks, Le Nindre et al. (1990b) identified the uppermost unit D5 with the maximum flooding surface. The unit D6 was the higstand followed by the regression that caused progradation on the Wadi ad Dawasir deltaic wedge. Hence, probably, the need for placing the gap between units D6 and D7 as well as the interpretation as a type 2 sequence boundary, despite certain reservation by Énay et al. (1987).

The transgressive sequence D7–T3 and the relations with the Wadi ad Dawasir “delta”

Contrasting with the impoverished and/or endemic not very characteristic faunas of unit D6, unit D7 shows a progressive trend towards open-marine environments. The resulting renewal and diversification of faunas occur earlier for brachiopods, as soon as unit D6 (Assemblage 4) and nannoplancton, at the bottom of unit D7 (Atash Member), and later for ammonites, in the upper part (Hisyan Member) of D7. The above examination of ammonite faunas favours a complete and unbroken record from unit D7 up to unit T3. The Early Bathonian age we accepted for the Wadi ad Dawasir “delta” does not allow its equivalence to units D6 to T2 in the marine deposits as Manivit et al. (1990) and Le Nindre et al. (1990a, b) proposed, on the basis of only lithological and very hypothetical correlations. The only coherent relationship is that the different units of the succession D7 to T3 were transgressive and onlap the clastic deltaic body. The inconsistencies concerning the southward extent of unit T2, between Vaslet [assuming the unit is known as Khashm Khattma (18°08’N)], and Manivit [assuming the unit vanishes as soon as 20°18’N (Khashm Kumda)], disappear because we place within the “delta” the beds previously assigned to unit T2 south of 20°N. They yielded the Early Bathonian nautilid at Khashm Sudayr.

On the basis of the palaeontological data based on nautilids and brachiopods, after the Atash Member vanishes at about 22°20’N, the upper part of unit D7 (Hisyan Member) also vanishes progressively supported by the “front” of the “delta” between 22°30’N and 22°N, as does the unit T1 which extends hardly beyond southwards (about 21°50’). Unit T2 extends widely on the top surface of the “delta” as far as 20°N and is widely overlaapped by unit T3 towards the south until it lies on the Palaeozoic beds at and beyond Khashm Khattma (18°08’N). Below unit T3, local occurrence of beds with brachiopods from unit T2 (VD.82.407) at Khashm Far’a’id (18°35’N) or even from unit D7 (VD.82.402) at Khashm Az Zifr (19°70’N) are probably related to the irregular surface topography of the clastic deltaic body. The surface is furrowed by channels due to tidal action.

Onlapping the Wadi ad Dawasir “delta” implies one or more transgressive surfaces were overlapped by the transgressive deposits, which are identifiable with the discontinuities or ferruginous surfaces at the top of the Wadi ad Dawasir “delta”, approximately between the latitudes 20°N and 18°N. This surface supports the deposits of unit T3 and/or locally those assigned to units D7 and T2. But the
surface remains to be identified at the so called “front” of the “delta”, just where Manivit et al. (1990, their figures 38 and 46) drew a lateral change with indentations in the marine deposits of units D6 (in part), D7 and T2. Moreover, we emphasised previously that Manivit et al. (1990, their figures 38 and 46, plate 10 and 11) and Le Nindre et al. (1990b, their figure 4) gave different drawings of the relationships, including or not in the “delta” the facies interpreted as “intertidal lobes, muddy tidal flats, sandy tidal flats” and “coastal sandy bodies” (or marine clastics). Specifically, these facies yielded the rare and only known faunas at the “front” or at the top of the “delta” that justify placing them in the “post-delta” overlapping beds.

Figure 9: Two possible interpretations of the Wadi ad Dawasir “delta” and its relationships with the marine deposits.
(a) The "delta" is synchronous with unit D6.
(b) the "delta" developed during the discontinuity between units D5–D6.

---

Downloaded from http://pubs.geoscienceworld.org/geoarabia/article-pdf/14/1/17/5444227/enay.pdf by guest on 01 November 2021
It remains unclear as to whether the interpretation of Manivit et al. (1990) is really the result of the relationships between the “delta” and the marine facies illustrated by the figure, or whether, on the contrary, the accepted interpretation reflected the drawings. The answer requires new fieldwork accounting for the interpretation proposed here, assuming that the “delta” was initiated during the Early Bathonian and transgressively overlapped during Late Bathonian and during Callovian.

The new proposed interpretation of the Wadi ad Dawasir (Figure 10)
The Wadi ad Dawasir clastic deltaic deposits illustrate a regressive event. The siliciclastic deposits, with deltaic or paralic features, in Sinai, also dated as Early Bathonian, and the ones in southern Tunisia not so precisely dated, prove that it is not an isolated event on the Gondwanan margin of the Tethys.

Where data are available for dating (Saudi Arabia, Egypt) the ages are not exactly the same within Early Bathonian. In Sinai and Levant, it is possible that the Safa and Sherif formations dated as Early Bathonian (Tuwaigensis Zone) could range up the *Micromphalites* beds of the Clydocromphalus Zone. In Saudi Arabia, where only the distal part of the deltaic body (north 21°16’N) overlies the *Micromphalites* beds of unit D5, the proximal part could start earlier, reducing the time difference with the homologous paralic deposits in Sinai. Nevertheless, the latter are older than the Wadi ad Dawasir “delta”. In Oman (Rousseau et al., 2006, 2007), the clastic supplies of the Terrigenous Member of the Sahtan Group are older and compare with those that in central Saudi Arabia were transgressed during Bajocian time. Moreover, too few and uncertain evidences support the comparison between the sequence identified in the Oman carbonate platform deposits (?Bajocian to ?Callovian) with those by Sharland et al. (2001).

In northwest Europe, the coastal onlap curves by Haq et al. (1987) and Hardenbol et al. (1998) show several similar events and the stratigraphic cycles chart for NW Europe and Tethys by Jacquin et al. (1998, their figure 2) agrees well with data for Saudi Arabia and nearby areas. A detailed study on the beds corresponding to the T/R7 cycle in Normandy was given by Riout et al. (1991) and Dugué et al. (1998). The transgressive phase links several parasequences up to the maximum flooding surface that is reached in the upper Zigzag Zone, Yeovilensis Subzone (= Aurigerus Zone, Recinctus Subzone in the Submediterranean zonal scale). The regressive phase also includes several parasequences and starts with latest Early Bathonian (Tenuiplicatus Zone/Subzone) and continues up to the middle part of Middle Bathonian (Morrisi Zone), which fits with the maximum of regression. The Late Bathonian commences the transgressive phase of the following cycle, which proceeds by steps during Late Bathonian and Callovian up to the end of Early Oxfordian.

In Saudi Arabia, the setting of the Wadi ad Dawasir “delta” fits with the regressive half-cycle of the T/R7 cycle, which would start during Early Bathonian, Macrescens Subzone and ends with Middle Bathonian and the Morrisi Zone (Figure 10). In the Arabian Province, the Macrescens Subzone is correlated with the *Micromphalites* beds and unit D5, which widely extended southwards. It is interpreted as a maximum flooding surface placed by Le Nindre et al. (1990b) at the top of unit D5 and by Sharland et al. (2001) in the middle part of unit D5. Until now there is no known equivalent of the Morrisi Zone in Saudi Arabia (lack of faunas or/and corresponding beds).

In their survey of the Jurassic second-order T/R cycles in northwest Europe, Jacquin et al. (1998) emphasised that several regressive events, and especially the T/R7 event, are synchronous in all the northwestern European basins, at least within the limits of the available biostratigraphic data. They suggested that local tectonics had limited effects on the evolution of the long-term stratigraphic cycles (first-order). So the first-order long-term tectonic subsidence controlled most of the accommodation and the overall stratal pattern as well as stratal stacking pattern, to which is superimposed a possible second-order eustatic signal. But more detailed comparison with Saudi Arabia is not possible because a true and complete sequence analysis at the scale of the units below second-order remains to be realised.

Another weakness in the available data is the inadequate knowledge of precise geometrical relationships of sedimentary units within the “delta” and its proximal part. First, outcrops south of 20°N have not been mapped, and were only studied from far-apart exploratory sections without continuous geometric control. More significantly, south of 20°N (Figure 3; Le Nindre et al., 1990 their
the cross section built from the outcrops (Manivit et al., 1990, plate 10 and 11) is geometrically ambiguous because the proximal part of the deltaic body is eroded in outcrop. The regressive features of the deltaic wedge and its relationships with marine deposits lead us to assume a possible limited emersion of the inner platform correlative with a slow relative sea-level fall, i.e. at a lower rate than the platform subsidence. Hence, the coastal onlap shifted basinward but remained on the platform.

Figure 10: The Wadi ad Dawasir ‘‘delta’’ and the Bathonian-Callovian T/R cycles in Saudi Arabia. Previous interpretations by Le Nindre et al. (1990b, 2003), Sharland et al. (2001), and the one proposed here. * Location of the Wadi ad Dawasir ‘‘delta’’ according to Le Nindre et al. (1990b, figure 3). ** Cf. Sharland et al., 2001, figures 3.25 and tab. 3.19: TMS 7, Tectonostratiographic Megasequence 7; GSS, Genetic Stratigraphic Sequence. *** Concerning correlations with the Submediterranean Province Zones, see Figure 2.

---

| Ages | Lithostratigraphy | T/R Cycles | Zones and Ages *** |
|------|-------------------|------------|-------------------|
|      | 1990 b *          |            |                   |
| Upper |                   |            |                   |
|      | T3                | HST        |                   |
|      |                   | Increase in sedimentation rate and tectonic subsidence |                   |
| Callovian | T2      | HST        |                   |
| Middle | T1                | HST        |                   |
|      | Atash Mb          | MFS        |                   |
|      |                   | (IT)       |                   |
|      |                   | Wadi ad Dawasir delta-shelf margin wedge |                   |
|      |                   |            |                   |
|      |                   |            |                   |
| Lower | D7                | HST        |                   |
|      |                   | MFS        |                   |
|      |                   | J30        |                   |
|      |                   | IT         |                   |
|      |                   | 100 m      |                   |
| Bathonian | D6            | HST        |                   |
|      |                   | MFS        |                   |
|      |                   | J40        |                   |
|      |                   | IT         |                   |
|      |                   | 100 m      |                   |
|      |                   |            |                   |
|      |                   |            |                   |
|      |                   |            |                   |
| Bajocian | D5            | HST        |                   |
|      |                   | MFS        |                   |
|      |                   | J30        |                   |
|      |                   | IT         |                   |
|      |                   | 100 m      |                   |
|      |                   |            |                   |
|      |                   |            |                   |
|      |                   |            |                   |

Figure 13, p. 108–109, the cross section built from the outcrops (Manivit et al., 1990, plate 10 and 11) is geometrically ambiguous because the proximal part of the deltaic body is eroded in outcrop. The regressive features of the deltaic wedge and its relationships with marine deposits lead us to assume a possible limited emersion of the inner platform correlative with a slow relative sea-level fall, i.e. at a lower rate than the platform subsidence. Hence, the coastal onlap shifted basinward but remained on the platform.
In this manner, the Wadi ad Dawasir “delta” represents a platform deltaic wedge, whose setting matches a basinward shift of the regressive deposits (Haq et al., 1987; Vail et al., 1977, 1984, 1987). Le Nindre (Manivit et al., 1990) emphasised occurrence of prograding bodies as well as the prograding pattern of the bedding and Le Nindre et al. (1990a) acknowledged a platform deltaic wedge. But, it would be (as well as unit D6) related to the highstand and following regression (sequence 2) and it would correlate to unit D7 of the overlying transgressive systems tract (sequence 3) (see IV.2.1). In our interpretation the maximum regression surface correlates to the upper surface of the siliciclastic wedge. At the top of the “delta”, it coincides with the wide extent of the facies interpreted by Le Nindre (Manivit et al., 1990, plate 10) as “intertidal lobes, muddy tidal flats, sandy tidal flats” assigned to unit T2. These beds yielded the nautilid (VD.82.674) on which is based the new Early Bathonian age.

Between the two previously discussed interpretations of the relationships between the Wadi ad Dawasir “delta” and marine deposits we retain here the one which connects the prograding siliciclastic body to the discontinuity between units D5–D6 (Figure 9b) and assume the “delta” is a platform deltaic wedge. The discontinuity between units D5–D6 is interpreted as a downlap surface (Vail et al., 1984, 1987) at the top of uppermost limestones of unit D5, intersected with several surfaces of non-deposition and it is compared with a condensed interval truncated by the topmost discontinuity. Uppermost limestones of unit D5 represent the highstand systems tract above the maximum flooding surface (MFS J30 in Sharland et al., 2001) within unit D5, which follows the transgressive systems tract D2–D5 (lower part).

Onlapping the deltaic wedge, the D6–D7 suite corresponds to the transgressive systems tract up to the maximum flooding surface within the Hisyan Member of unit D7 (MFS J40 in Sharland et al., 2001), which is followed by the highstand systems tract D7 (in part)–T3 units. Surely the deposition of the sequence D6–T3 is associated with a rise of the relative sea level during the Late Bathonian – Callovian transgression, well-known in numerous areas around the Tethys, and beyond, but also with subsidence acceleration well-evidenced by subsidence modelling (Le Nindre et al., 2003).

**Implications for Oil Exploration**

The Shaqra Group (Vaslet, 1987; Manivit et al., 1990) consists mostly of carbonate sediments that were deposited during the Jurassic as a succession of well-defined sequences. The Group hosts important hydrocarbon reservoirs within grainstones that were deposited during the late highstands of each sequence. Although the presence of clastic sediments within the Group was described by Powers (1968), they were considered to represent the nearshore equivalents of the shelfal carbonates with gradational facies relationships. Sandstones within the Dhruma Formation were originally described by Vaslet (1987), Manivit et al. (1990) and Le Nindre et al. (1990), and considered to be related to the hiatus they located between the D6 and D7 units of the Dhruma as well as a lateral equivalent of the unit D7 and attributed a Middle Callovian age. In the present paper, the stratigraphic position has been reassigned to between the D5 and D6 units of the Dhruma and dated as Early Bathonian. These sandstones have been informally considered to constitute the Wadi ad Dawasir “delta”.

As sandstones are typically present within carbonates due to the basinwards migration of the clastic source, it is not unreasonable to attribute their presence within the Dhruma Formation as being indicative of the result of a sea-level fall, incision of the platform deposition of the delta and gradual backfill during the following transgression. The Wadi ad Dawasir “delta” should therefore be examined in greater detail as it provides a potential clastic exploration play within a province normally considered to be characterised by carbonate sediments and their reservoirs. Clastic deltaic deposits can extend deep within the basin, dependant upon the basin margin gradient, and this location could be considered as a point source of reservoir sands in the subsurface, east of Wadi ad Dawasir.

**CONCLUSIONS**

Our interpretation concludes an Early Bathonian age to the Wadi ad Dawasir fluviodeltaic siliciclastic body. Its setting would be synchronous of the uppermost discontinuity of unit D5, of which the upper beds are characterised by several non-depositional surfaces that are interpreted to represent a condensed interval. Within the marine deposits, the D5–D6 discontinuity fills a previously interpreted
hiatus between the Early (in part) (?) and Middle Bathonian. Unit D6 and the lower part (Atash Member) of unit D7 yielded the same brachiopod fauna (Assemblage 4 of Alméras, 1987) and are indirectly dated by ammonites and calcareous nannofossils as Late Bathonian and Early Callovian, respectively. The Middle Callovian begins approximately at the boundary between Atash and Hisyan members of unit D7 and includes the first unit (T1) of the Tuwaiq Mountain Limestone. Units T2 and T3 were previously dated as Late Callovian (Enay et al., 2002). Units D7 (Dhruma Formation) and T1–T3 (Tuwaiq Mountain Limestone), as a whole, are transgressive and onlap the Wadi ad Dawasir siliciclastic deltaic wedge, of which only unit T3 overlaps the deltaic wedge southwards from 20°15'N (Khashm Kumdah). The Wadi ad Dawasir “delta” resulted from a relative sea-level fall during the Early Bathonian and is interpreted as a prograding platform deltaic wedge connected to the uppermost discontinuity of unit D5. Similar deposits are also known in the Lower Bathonian in northern Sinai and central Negev and the Bathonian in southern Tunisia.

ACKNOWLEDGEMENTS

The new interpretation of the Wadi ad Dawasir “delta” here exposed has been possible because we were allowed to study the Arabian invertebrate faunas collected by the French BRGM field teams, and also for two of us to visit the Saudi Arabia Jurassic outcrops. We are indebted to the BRGM and especially C. Cavelier who gave us the opportunity to work on the samples from such an interesting and normally inaccessible region. We are sincerely grateful to the Committee of the Deputy Minister of Mineral Resources of Saudi Arabia for facilitating the fieldwork that led to the results of this contribution. During fulfilment of the paper, we received the friendly help of Professors P. Cotillon and P. Hantzpergue (Lyons University) who accepted to read a first version of the paper and brought constructive remarks and criticisms. The French draft has been reviewed by C. Durlet (Dijon University) who contributed to improve the final version. The English version was checked by Geraint W. Hughes (Saudi Aramco). The authors thank the two anonymous reviewers and Moujahed I. Al-Husseini for their constructive comments. The initial drawings were prepared by Arlette Armand (Lyons University) and designed for final printing by GeoArabia’s Arnold Egdane deserves our warm thanks.

REFERENCES

Al Far’s, D.M. 1966. Geology and coal deposits of Gabal El-Maghara (Northern Sinai). Geological Survey of Egypt, Cairo, v. 38, 59 p.
Al-Husseini, M.I. 1997. Jurassic sequence stratigraphy of the western and southern Arabian Gulf. GeoArabia, v. 2, no. 4, p. 361-382.
Alméras, Y. 1982-1984. Inventaire des brachiopodes du Dogger d’Arabie par cartes, par gisements et par niveaux de récoltes. Rapports inédits, 21 p.
Alméras, Y. 1987. Les brachiopodes du Lias-Dogger: Paléontologie et biostratigraphie. Geobios, Mémoire Spécial 9, p. 161-219.
Alméras, Y., A. Boullier and B. Laurin 1997. Brachiopodes. In Groupe Français d’Etude du Jurassique. Biostratigraphie du Jurassique ouest-européen et méditerranéen: Zonations parallèles et distribution des invertébrés et microfossiles. E. Cariou and P. Hantzpergue (Coord.), Bulletin du Centre de Recherche Elf Exploration-Production, Pau, v. 17, p. 169-195.
Alméras, Y., P. Fauré, S. Elmi. R. Énay and C. Mangold 2007. Zonation des brachiopodes du Jurassique moyen sur la marge sud de la Tethys occidentale (Maroc, Algérie Occidentale). Comparaison avec la marge nord tétysienne française. Geobios, v. 40, no. 1, p. 1-19.
Andriei, P. 1985. Étude micropaléontologique. Rapport Bureau de Recherches Géologiques et Minières, unpublished report no. 85 GEO. SED 25.
Arkell, W.J. 1952. Jurassic ammonites from Jebel Tuwaiq, central Arabia. With a stratigraphic introduction by R.A. Bramkamp and M. Steineke. Philosophical Transactions of the Royal Society of London, Series B, no. 634, v. 247, p. 252-324.
Barale, G., M. Ouaja and M. Philippe 2000. Une flore bathonienne dans la formation Techout du Sud-Est tunisien. Neues Jahrbuch für Geologie und Paläontologie. Stuttgart, no. 11, p. 681-697.
Ben Ismail, M., S. Bouaziz, Y. Alméras, B. Clavel, P. Donze, R. Énay, M. Ghenni and H. Tintant 1989. Nouvelles données biostratigraphiques sur le Callovien et les faciès “purbecko-wealdiens” (Oxfordien à Vraconien) dans la région de Tataouine (Sud-tunisien). Bulletin de la Société Géologique de France, v. 8, 5/2, p. 353-360.
Bernier, P. 1987. Petrascula arabica nov. sp.: Nouvelle espèce d’algue dasycladale du Bathonien d’Arabie saudite. Geobios, Mémoire Spécial 9, p. 293-303.
Boullier, A. 1985. Les brachiopodes du Jurassique supérieur d’Arabie centrale. Rapport inédit, 5 p.
Bramkamp, R.A., R.D. Gierhart, G.F. Brown and R.O. Jackson 1958. Geological map of the Southern Tuwayq Quadrangle, Kingdom of Saudi Arabia. Map I-212 A. United States Geological Survey.
Bramkamp, R.A. and L.F. Ramirez 1958. Geological map of the Northern Tuwayq Quadrangle, Kingdom of Saudi Arabia. Map I-207 A. United States Geological Survey.

Bramkamp, R.A., L.F. Ramirez, G.F. Brown and A.E. Pocock 1963. Geological map of the Wadi ar Rimah Quadrangle, Kingdom of Saudi Arabia. Map I-206 A. Jiddah, Saudi Arabia.

Bramkamp, R.A., L.F. Ramirez, G.F. Brown and A.E. Pocock 1982-1986. Geological map of the Wadi ar Rimah Quadrangle, Kingdom of Saudi Arabia. Map GM-206 A. Jiddah, Saudi Arabia (reprint of map I-206 A).

Busson, G. 1967. Le Mésozoïque saharien. 1ère partie: l’Extrême sud tunisien. Centre National de la Recherche Scientifique, Paris, Géologie, v. 8, 204 p.

Clavel, B. 1982-1986. Echinides du Jurassique d’Arabie Saoudite. Rapports inédits, 61 p.

Coates, J., E. Gottesman, M. Jacobs and E. Rosenberg 1963. Gas discoveries in the western Dead Sea region. Proceedings of the 6th World Petroleum Congress/Main.

Collignon, M. 1964. La série Dogger-Malm dans la région est d’Ankishtita (NW Madagascar) et ses faunes successives. Comptes Rendus. Sém. Géol. Comité Malgache de Géologie, Tananarive, p. 43-48.

Collignon, M. 1966. Sur quelques ammonites remarquables nouvelles ou peu connues du Jurassique de Madagaskara. Comptes Rendus. Sém. Malgache de Géologie, Tananarive, p. 21-27.

Dépêche, F., Y. Le Nindre, J. Manivit and D. Vaslet 1987. Les Ostracodes du Jurassique d’Arabie Saoudite centrale: Systématique, répartition stratigraphique et paléogéographique. Geobios, Mémoire Spécial 9, p. 231-275.

Dugué, O., G. Fily and M. Rioult 1998. Le Jurassique des côtes du Calvados. Biostratigraphie, Sédimentologie, paléocéologie, paléogéographie et stratigraphie séquentielle. Bulletin, Société de Normandie et Amis, Museum du Havre, v. 85, no. 2, p. 1-132.

Énay, R. 1987. Le Jurassique d’Arabie Soudite centrale. Geobios, Lyon, Mémoire Spécial 9, 316 p.

Énay, R. and C. Mangold 1982-1984. Document de synthèse sur les faunes d’ammonites et les datations du Jurassique d’Arabie. Rapports inédits, 46 p.

Énay, R. and C. Mangold 1985. L’ammonite succession from Toarcian to Kimmeridgian in Saudi Arabia, correlation with the European faunas. International Symposium on Jurassic Stratigraphy, Erlangen, September 1-8, 1984. Geological Survey of Denmark, Copenhagen, v. 3, p. 642-651.

Énay, R. and C. Mangold 1994. Première zonation par ammonites du Jurassique d’Arabie Saoudite, une référence pour la province arabe. Geobios, Mémoire Spécial 19, p. 161-194.

Énay, R., Y.-M. Le Nindre, C. Mangold, J. Manivit and D. Vaslet 1986. The Jurassic of central Saudi Arabia: New data on lithostratigraphic units, palaeoenvironments, amonite faunas, ages and correlations. Deputy Ministry of Mineral Resources, Jiddah, Technical Report BRGM-TRO6-3, 65 p.

Énay, R., Y.-M. Le Nindre, C. Mangold, J. Manivit and D. Vaslet 1987. Le Jurassique d’Arabie Saoudite centrale: Nouvelles données sur la lithostratigraphie, les paléoenvironnements, les faunes d’Ammonites , les âges et les corrélations. Geobios, Mémoire Spécial 9, p. 13-65.

Énay, R. (Coord.), E. Cariou, C. Mangold, J. Thierry, R. Guiraud and Y. Bellion 1993. Callovian (162-158 Ma). In J. Dercourt, Énay, R., Y.-M. Le Nindre, C. Mangold, J. Manivit and D. Vaslet 1987. Le Jurassique d’Arabie Saoudite centrale: Nouvelles données sur la lithostratigraphie, les paléoenvironnements, les faunes d’Ammonites , les âges et les corrélations. Comptes Rendus. Géosciences, Paris, v. 334, p. 1157-1167.

Énay, R., C. Mangold, Y.M. Abu Kammam and A.M. Kassab 1997. The Jurassic of G. Maghara (N. Sinai, Egypt). Preliminary results. Peri-Tethys Program, Annual Meeting, Rabat, Abstracts, 2 p.

Énay, R., H. Gauthier, M. Trevisan, J.-B. Berton, J.-L. Brodbeck, J.-F. Demaizières, P. Donie, F. Fourel and M. Trehoub 2001. Les Microenammites (Ammonites) du Bathonien inférieur de la Nièvre (France): Installation sur la marge européenne de la Tethys de formes sud-téthysiennes d’origine araboïde et description d’un néotype de M. busqueti (de Gross.). Revue de Paléobiologie, Genève, v. 20, no. 2, p. 503-524, 4 figure, 2 plates.

Énay, R., E.L. Asmi, K. Soussi, C. Mangold and P. Hantzpergue 2002. Un Pachyerymnoceras arabe dans le Callovien supérieur du Dahar (Sud tunisien), nouvel élément de datation du membre Ghozazzine (formation Tataouine); corrélation avec l’Arabie Saoudite et le Moyen-Orient. Comptes Rendus. Géosciences, Paris, v. 334, p. 307-334.

Fischer, J.-C., Y.-M. Le Nindre, J. Manivit and D. Vaslet 2001. Jurassic gas field in the central Saudi Arabia. GeoArabia, v. 6, no. 1, p. 63-100.

Frenel, S. and G. Busson 1963. Sur les faunes de bivalves du Jurassique moyen et supérieur du Sahara Tunisien. Comptes Rendus de l’Académie des Sciences, v. 267, p. 1632-1634.

Galloway, W.E. 1989. Genetic stratigraphic sequences in basin analysis I: Architecture and genesis of flooding Surface Bounded Depositional Units. American Association of Petroleum Geologists Bulletin, Tulsa, v. 73, p. 125-142.

Gardin, S. 1997. Les bioévénements à nano fossiles calcaires. In E. Cariou and P. Hantzpergue (Coord.), Biostratigraphie du Jurassique ouest-europén et méditerranéen: Zonations parallèles et distribution des invertébrés et microfossiles. Bulletin du Centre de Recherche Elf Exploration Production, Mémoire 17, p. 305-329.

Goldberg, M. and G.M. Friedman 1974. Paleoenvironnements et paleogeographic evolution of the Jurassic System in Southern Israel. Geological Survey of Israel Bulletin, v. 61, p. 1-44.

Goldberg, M., A. Barzel, P. Cook and Y. Mimran 1971. Preliminary columnar section of the Jurassic of Gebel Maghara. Geological Survey of Israel, Report MM/1/71.

Grabowski, Jr. G.J. and I.O. Norton 1995. Tectonic controls on the stratigraphic architecture and hydrocarbon Systems of the Arabian Plate. In M.I. Al-Husseini (Ed.), Middle East Petroleum Geosciences, GEO’94, Gulf Petrolink, Bahrain, v. 1, p. 413-430.

Groupe Français d’études du Jurassique (G.F.E.J.) 1997. Biostratigraphie du Jurassique Ouest-Europén et Méditerranéen: Zonations parallèles et distribution des invertébrés et microfossiles. In E. Cariou and P. Hantzpergue (Coord.), Bulletin du Centre de Recherche Elf Exploration Production, Mémoire 17, 440 p.

Hallam, A. 1993. Jurassic climates as inferred from the sedimentary and fossil record. Philosophical Transactions of the Royal Society of London, v. 341, p. 287-293.
Haq, B.U., J. Hardenbol and P.R. Vail 1987. The chronology of fluctuating sea-level since the Triassic. Science, Washington, v. 235, p. 1156-1167.

Haq, B.U., J. Hardenbol and P.R. Vail 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In C.K. Wilgus, B.S. Hastings, C.G.St.C. Kendall, H. Posementier, J. Van Wagoner and C.A. Ross (Eds.), Sea-level Changes: An Integrated Approach. Society of Economic Paleontologists and Mineralogists, Special Publication no. 42, p. 71-108.

Hardenbol, T., J. Thierry, M.B. Farley, T. Jacquin, P-C. de Graciansky and P.R. Vail 1998. The Mesozoic and Cenozoic chronostratigraphic framework of European Basins. In P-C. de Graciansky, J. Hardenbol, T. Jacquin and P.R. Vail (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. Society of Economic Paleontologists and Mineralogists, Special Publication no. 60, p. 1-13 and Appendix: 763-781, Charts 1-8.

Hirsch, F. 1976. Sur l’origine des particularismes de la faune du Trias et du Jurassique de la plate-forme Africo-Arabe. Bulletin de la Société Géologique de France, v. 7, 19/2, p. 544-552.

Hirsch, F., J.-P. Bassoullet, E. Cariou, B. Conway, H.R. Feldman, L. Grossowicz, A. Honigstein, E. Owen and A. Rosenfeld 1974. The Jurassic of the southern Levant. Biostatigraphy, palaeogeography and cyclic events. In S. Crasquin-Soéleau and E. Barrier (Eds.), Peri-Tethys Memoir 4: Epicratonic Basins of Peri-Tethyan Platforms. Mémoires du Muséum National d’Histoire Naturelle, Paris, Peri-Tethys Mémoire 199, p. 223-236.

Imlay, R. 1970. Some Jurassic ammonites from central Saudi Arabia. United States Geological Survey, Professional Paper 644-D, 19 p.

Jacquin, T., G. Dardeau, C. Durlet, P-C. de Graciansky and P. Hantzpergue 1998. The North Sea cycle: An overview of 2nd-order Transgressive/Regressive facies cycle in Western Europe. In P-C. de Graciansky, J. Hardenbol, T. Jacquin and P.R. Vail (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. Society of Sedimentary Geology, Special Publication 60, p. 445-476.

Kaelin, E. de, J.A. Bergen and K. von Salis Perch-Nielsen, 1996. Jurassic calcareous nannofossils biostratigraphy of western Europe. Compilation of recent studies and calibration bioevents. Bulletin de la Société Géologique de France, v. 167, no. 1, p. 15-28.

Kamoun, F., M. Ben Youssef and B. Peybernès 1992. Stratigraphie séquentielle du Dogger et de la base du Malm (intervalle Ablénien-Kimmeridgien) de l’Extrême-Sud de la Tunisie. Comptes Rendus de l’Académie des Sciences, Paris, v. 315, p. 1373-1379.

Keely, M.L., G. Dungworth, C.S. Floyd, G.A. Forbes, C. King, R.M. McGarva and D. Shaw 1990. The Jurassic system in northern Egypt. 1. Regional stratigraphy and implications for hydrocarbon prospectivity. Journal of Petroleum Geology, v. 13, no. 4, p. 397-420.

Le Nindre, Y.-M., J. Manivit and D. Vastel 1987. Histoire géologique de la Bordure occidentale de la Pléistocène inférieur au Jurassique supérieur. Thèse de Doctorat de l’Université de Paris 6, 4 vol., 1113 p. dactyl. + Annexes.

Le Nindre, Y.-M. and D. Vastel 1990a. Le Jurassique d’Arabie centrale, Histoire géologique de la bordure occidentale de la plate-forme Arabe, vol. 2. Document du Bureau de Recherches Géologiques et Minières, v. 192, 290 p.

Le Nindre, Y.-M. and D. Vastel 1990b. Stratigraphie séquentielle du Jurassique et du Crétacé en Arabie Saoudite. Bulletin de la Société Géologique de France, Paris, sér. 8, v. 6, p. 1025-1034.

McGuire, M.D., R.B. Koepnick, J.R. Markello, M.L. Stockton, G.S. Kompanik, M.J. Al-Shammery and M.O. Al-Amoudi 1993. Importance of sequence stratigraphy concepts in development of reservoir architecture in Upper Jurassic grainstone, Hadriya and Hanifa Reservoirs, Saudi Arabia. Proceedings of the 8th Middle East Oil Show, SPE 25578, p. 489-499.

Mangold, C. and M. Riotull 1997. Bathonien. In E. Cariou and P. Hantzpergue (Coord.), Biostratigraphie du Jurassique du Paléozoïque inférieur au Jurassique supérieur. Thèse de Doctorat de l’Université de Paris 6, 4 vol., 1113 p. dactyl. + Annexes.

Manivit, H. 1987. Distribution des nannofossiles calcaires du Jurassique moyen et supérieur en Arabie Saoudite centrale. Geobios, Mémoire Spécial 9, p. 277-301.

Manivit, J., Y.-M. Le Nindre and D. Vastel 1990. Le Jurassique d’Arabie centrale, Histoire géologique de la bordure occidentale de la plate-forme Arabe, vol. 4. Document du Bureau de Recherches Géologiques et Minières, v. 194, 559 p.

Manivit, J., D. Vastel, A. Berthiaux, P. Le Strat and J. Fourniquet 1985a. Geological map of the Buraydah quadrangle, sheet 26 G. Kingdom of Saudi Arabia (with text). Saudi Arabia Deputy Ministry of Mineral Resources, Geoscience Map GM-114, Scale 1:250,000.

Manivit, J., C. Pellaton, D. Vastel, Y.-M. Le Nindre, J.-M. Brosse and J. Fourniquet 1985b. Geological map of the Wadi al Mulayh quadrangle, sheet 22 H. Kingdom of Saudi Arabia (with text). Saudi Arabia Deputy Ministry of Mineral Resources, Geoscience Map GM-92, Scale 1:250,000.

Manivit, J., C. Pellaton, D. Vastel, Y.-M. Le Nindre, J.-M. Brosse and J. Fourniquet 1986. Geological map of the Darma’ quadrangle, sheet 24 H. Kingdom of Saudi Arabia (with text). Saudi Arabia Deputy Ministry of Mineral Resources, Geoscience Map GM-101, Scale 1:250,000.

Mette, W. 1997. Palaeoecology and palaeobiogeography of the Middle Jurassic ostracods of southern Tunisia. Palaeoecology, Palaeoclimatology, Palaeoecology, Elsevier Science, Amsterdam, v. 132, p. 65-111.

Moshkovitz, S. and A. Ehrlich 1976. Distribution of Middle and Upper Jurassic calcareous nannofossils in the northeastern Negev, Israel and in Gebel Maghara, northern Sinai. Geological Survey of Israel Bulletin, v. 69, p. 1-47.

Moshkovitz, S. and A. Ehrlich 1980. Late Jurassic calcareous nannofossils in Israel’s offshore and onland areas. Geological Survey of Israel, Current Research, p. 65-72.

Murray, R.J. 1980. Middle East stratigraphic evolution and oil habitat. American Association of Petroleum Geologists Bulletin, v. 64, no. 5, p. 597-618.

Parnes, A. 1974. Biostratigraphic correlation of the Middle Jurassic in Makhtesh Ramon, Gebel Maghara and in Morocco.
Abstract of Lectures. Israel Geological Society, Proceedings of the Annual Meeting, Jerusalem.

Peybernès, B., Y. Alméra, M. Ben Youssef, F. Karmoun, J. Mello, J. Rey and F. Zargouni 1985. Nouveaux éléments de datation dans le Jurassique du Sud-Tunisien (Plate-forme Saharienne). Comptes Rendus de l’Académie des Sciences, Série 310, Paris, v. 2, no. 3, p. 113-119.

Picard, L. and F. Hirsch 1987. The Jurassic stratigraphy in Israil and the adjacents countries. Israel Academy of Sciences and Humanities, Jerusalem, 106 p.

Powers, R.W. 1968. Saudi Arabia. Lexique stratigraphique international. Volume III, Asie, Fas. 10 b1, Arabia Saudite. Centre National de la Recherche Scientifique, Paris, 177 p.

Powers, R.W., L.F. Ramirez, C.D. Redmon and E.L. Elberg Jr. 1966. Geology of the Arabian Peninsula: Sedimentary geology of Saudi Arabia. United States Geological Survey, Professional Paper, 560-D, 147 p.

Rioul, M., O. Dugué, R. Jan Du Chêne, C. Ponsot, G. Fily, J.-M. Mojon and P.R. Vail 1991. Outcrop sequence stratigraphy of the Anglo-Paris basin, Middle to Upper Jurassic (Normandy, Maine, Dorset). Bulletin du Centre de Recherche Elf Exploration Production, Mémoire 15, p. 101-194.

Rousseau, M., G. Dromart, H. Droste and F. Homewood 2006. Stratigraphic organisation of the Jurassic sequence in interior Oman, Arabian Peninsula. GeoArabia, v. 11, no. 1, p. 17-30.

Rousseau, M., G. Dromart, J.-P. García, F. Atrops and F. Guillocheau 2007. Jurassic evolution of the Arabia carbonate platform edge in the central Oman Mountains. Journal of the Geological Society of London, v. 162, p. 349-362.

Sharland, P.R., R. Archer, D.M. Casey, R.B. Davies, S.H. Hall, A.P. Heward, A.D. Horbury and M.D. Simmons 2001. Arabian Plate Sequence Stratigraphy. GeoArabia Special Publication 2, Gulf PetroLink, Bahrain, 371 p., with 3 charts.

Soussi, M., R. Enay, C. Mangold and M. Turki 2000. The Jurassic events and their sedimentary and stratigraphic records on the Southern Tethyan margin in Central Tunisia. In S. Crasquin-Soleau and E. Barrier (Eds.), Peri-Tethys Memoir 5: New Data on Peri-Tethys Sedimentary Basins. Mémoires du Muséum National d’Histoire Naturelle, v. 182, p. 57-92.

Steinke, M., R.A. Brankamp and N.J. Sander 1958. Stratigraphic relations of Arabian Jurassic oil. American Association of Petroleum Geologists, Symposium, Tulsa, p. 1294-1329.

Thierry, J. et al. (42 co-authors) 2000. Middle Callovian (157-155 Ma). In J. Dercourt, M. Gaetani, B. Vrielynck, B. Biju-Duval, M.F. Brunet, J.P. Cadet, S. Crasquin and M. Sandulescu (Eds.), Atlas Peri-Tethys. Palaeogeographical Maps. CGGM/CGWM, Paris, Map 10.

Tintant, H. 1982-1983. Nautilides du Jurassique d’Arabie Saoudite. Rapport inédit, 13 p.

Tintant, H. 1987. Les nautilides du Jurassique d’Arabie Saoudite. Geobios, Mémoire Spécial 9, p. 67-159.

Vail, P.R., R.M. Mitchum Jr., R. Todd, J.W. Widmer, S. Thompson, J.B. Sangree, J.N. Bubb and W. Hatelid 1977. Seismic stratigraphy and global changes of sea level. In Seismic Stratigraphy. Application to Hydrocarbon Exploitation. American Association of Petroleum Geologists, Memoir 26, p. 49-212.

Vail, P.R., J. Hardenbol and R.G. Todd 1984. Jurassic unconformities, chronostratigraphy and sea level changes from seismic stratigraphy and biostratigraphy. American Association of Petroleum Geologists, Memoir 36, p. 129-144.

Vail, P.R., J.-P. Colin, J. Jan du Chêne, J. Kuchly, F. Mediavilla and V. Trifilieff 1987. La stratigraphie séquentielle et son application aux corrélations chronostratigraphiques dans le Jurassique du Bassin de Paris. Bulletin de la Société Géologique de France, série 8, tome 3, fasc. 7, p. 1301-1321.

Vasel, D., J. Delfour, J. Manivit, J.-M. Le Nindre, J.-M. Brosse and J. Fourniguet 1983. Geological map of the Wadi ar Rayn quadrangle, sheet 23 H, Kingdom of Saudi Arabia (with text). Saudi Arabia Deputy Ministry of Mineral Resources, Géosciences Map GM-63, Scale 1:250,000.

Vasel, D., C. Pellaton, J. Manivit, J.-M. Le Nindre, J.-M. Brosse and J. Fourniguet 1985a. Geological map of the Sulayyimah quadrangle, sheet 21 H, Kingdom of Saudi Arabia (with text). Saudi Arabia Deputy Ministry of Mineral Resources, Géosciences Map GM-100, Scale 1:250,000.

Vasel, D., M. Beurrier, M. Villey, P. Le Strat, A. Berthiaux, J.-M. Brosse and J. Fourniguet 1985b. Geological map of the Al Faydah quadrangle, sheet 25 G, Kingdom of Saudi Arabia (with text). Saudi Arabia Deputy Ministry of Mineral Resources, Géosciences Map GM-102, Scale 1:250,000.

Westernmann, G.E.G. and J.H. Callomon 1988. The Macrocephalitinae and associated Bathonian and Early Callovian (Jurassic) ammonoids of the Sula Islands and New Guinea. Palaeontographica, Stuttgart, A, v. 203, p. 1-90.

ABOUT THE AUTHORS

Raymond Énay is presently retired and Emeritus Professor in Earth Sciences at Claude-Bernard-Lyon 1 University, which he entered in 1956. He received his Natural Science “Agregation” in 1957 and his DSc in 1967. His scientific work focused on Jurassic ammonite palaeontology, biostratigraphy and palaeobiogeography. He has published more than one hundred and eighty papers, and has contributed extensively to applied geology in the French Jura Mountains. The studied areas are Jura and SE France to Spain and northern Africa (Morocco, western Algeria, Tunisia), Turkey, Egypt ( Sinai), Saudi Arabia, Yemen, Nepal and India, most of them along the Jurassic South Tethyan margin. Since his retirement, Raymond continues to be involved in publishing data and faunas collected during his time of active employment.

raymond.enay@univ-lyon1.fr
Charles Mangold is Emeritus Professor in Earth Sciences at the Claude-Bernard-Lyon 1 University, France. He first joined the University as Demonstrator. Then as Senior Lecturer he presented the defence of his thesis, in 1970, based on the Southern Jura Mountains. He became Professor in 1971 successively at Oran (Algeria), Nancy and Lyon Universities, managing PhD and doctoral students. His research is devoted to Middle Jurassic stratigraphy and ammonite palaeontology in France, Switzerland, Spain, Portugal, Morocco, Algeria, Tunisia, Egypt and Saudi Arabia. Charles retired in 1997, but continues his investigations on faunas collected before his retirement.

Yves Alméras is Emeritus Senior Lecturer in Earth Sciences at the University Claude-Bernard-Lyon 1. He received his Natural Science “Aggregation” in 1961 and his DSc in 1971. His palaeontological investigations (more than 150 papers and memoirs) deal with Early and Middle Jurassic brachiopods. The studied areas are located in France, French-Spanish Pyrenees, Portugal, Morocco, Western Algeria, Tunisia and also in Central Saudi Arabia (the brachiopods study was published in 1987). Yves is now retired, but he is still involved in the realization of brachiopod Zonal Scheme suitable for Northern and Southern margins of the Western Tethys and correlated to the Standard Chronostratigraphies based on ammonites.

Geraint Wyn ap Gwilym Hughes is Senior Geological Consultant in the Carbonate Systems and Micropalaeontology Unit in Saudi Aramco’s Geological Technical Services Division. He gained BSc, MSc, PhD and DSc degrees from Prifysgol Cymru (University of Wales) Aberystwyth and in 2000 he received the Saudi Aramco Exploration Professional Contribution award, in 2004 the best paper award, and in 2006 the GEO 2006 best poster award. His biostratigraphic experience, prior to joining Saudi Aramco in 1991, includes 10 years with the Solomon Islands Geological Survey, and 10 years as Unit Head of the North Africa-Middle East-India region for Robertson Research International. Wyn’s professional activities are focused on integrating micropaleontology with sedimentology to enhance the sequence stratigraphically-influenced understanding of Saudi Arabian hydrocarbon intra-reservoir bio- and lithofacies distribution. He maintains links with academic research as an Adjunct Professor of the King Fahd University of Petroleum and Minerals, Dhahran. He is an editor for the AAPG, GeoArabia reviewer, and a member of the British Micropalaeontological Society, the Grzybowski Agglutinated Foraminiferal Society, the Dhahran Geoscience Society, the International Fossil Alga Association and the Cushman Foundation for Foraminiferal Research.

Manuscript received December 12, 2007
Revised May 27, 2008
Accepted June 3, 2008
Press version proofread by authors December 09, 2008