

## Nautiloids of the Permian-Triassic Khuff Formation, central Saudi Arabia

Régis Chirat, Denis Vaslet and Yves-Michel Le Nindre

### ABSTRACT

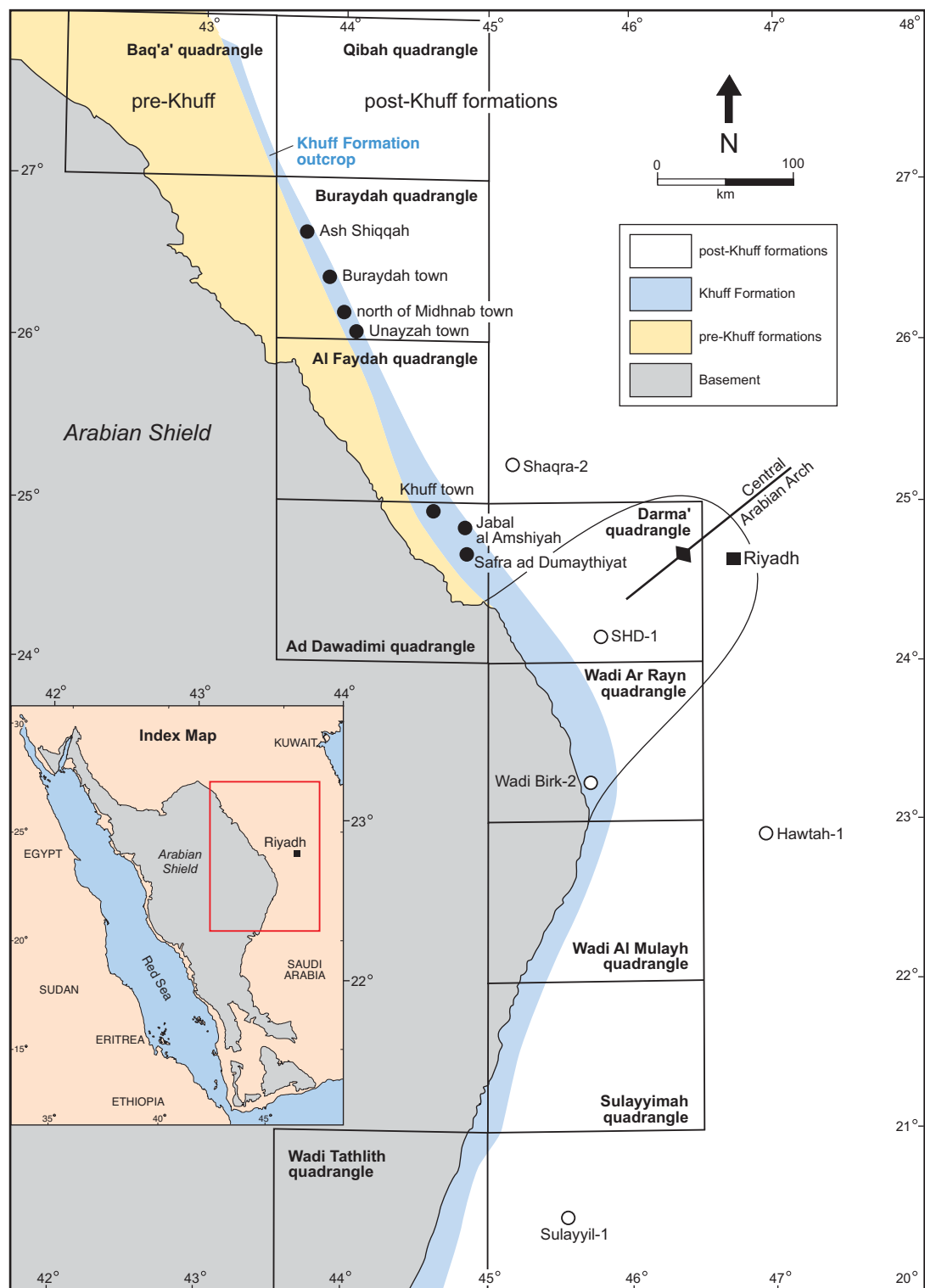
Nautiloids are described for the first time from the outcrops of the lower part of the Midhnab Member and the lower part of the Khartam Member of the Khuff Formation in central Saudi Arabia. The nautiloids from the lower Midhnab Member, including *Tirolonautilus* gr. *hoernesii*, were found at two localities, and are associated with conical shaped cephalopodes (bactritids), bivalves, brachiopods, foraminifers, algae and ostracods. The nautiloids were recovered from the most marine horizon of the Khuff Formation. The nautiloid fauna confirms the Late Permian (Changhsingian) age assigned to the Midhnab Member based on the foraminiferal assemblage. In the lower part of the Khartam Member, a single specimen of *Tirolonautilus feltgeni* n. sp. is described here. It occurs in association with other cephalopods (bactritids), bivalves, foraminifers, and ostracods. The specimen confirms the Late Permian age (late Changhsingian) assigned to the Lower Khartam Member based on foraminiferal and ostracod assemblages. This marine fauna is located within the latest Permian maximum flooding event of central Saudi Arabia. The Khuff Formation nautiloids are compared to other fauna in the Peri-Tethys, particularly the southern Alps, where similar forms are described. Their similarity confirms a Late Permian marine exchange between the Arabian platform and the Western Tethyan realm.

### INTRODUCTION

Permian to Triassic sedimentary rocks of the Khuff Formation are exposed in central Saudi Arabia along a North-South belt, some 1,200 km long (Figure 1). The Khuff Formation rests everywhere unconformably (Pre-Khuff Unconformity - PKU) over Lower Palaeozoic or Proterozoic shield rocks (Powers et al., 1966; Powers, 1968). The Khuff Formation is conformably overlain by the clayey and evaporitic Early Triassic ('Scythian') Sudair Shale Formation. Le Nindre et al. (1990a, b) published the first synthesis of field work and extensive systematic geological mapping, conducted in the 1980s by the Saudi Arabian Deputy Ministry of Mineral Resources (DMMR) and the French Geological Survey (BRGM), including lithostratigraphy, biostratigraphy and palaeoenvironment reconstructions. More recent compilations from central Saudi Arabia, were interpreted in terms of sequence stratigraphy by Alsharhan and Nairn (1995), Al-Aswad (1997) and Sharland et al. (2001).

A complete revision, including new field acquisitions, and compilation of local studies for oil exploration (Senalp and Al-Duaiji, 1995, 2001), was prepared by Vaslet et al. (2005). It includes a reassessment of the biostratigraphy based on foraminifers and algae (Vachard et al., 2002, 2003, 2005), ostracods (Crasquin-Soleau et al., 2005, 2006) and palaeofloras (Broutin et al., 2002; Berthelin et al., 2006). Vaslet et al. (2005) divided the central Saudi Arabian outcrops of the Khuff Formation (some 200 m thick) into five members, from oldest to youngest: Ash Shiqqah, Huqayl, Duhaysan, Midhnab and Khartam members (Figure 2).

During the field campaigns for the systematic geological mapping of central Saudi Arabia, nautiloids were recorded from the Midhnab Member of the Khuff Formation. Accumulations of nautiloids and "nautiloid embryos" (the latter, probably misinterpreted, are probably small gastropods shells of *Bellerophon*-type) were recorded in the lower part of the Midhnab Member by: (1) Vaslet et al. (1983) in the Wadi ar Rayn quadrangle; (2) Manivit et al. (1985a) in the Wadi al Mulayh quadrangle; (3) Manivit et al. (1985b) in the Darma quadrangle; (4) Vaslet et al. (1985) in the Al Faydah quadrangle; and (5) Manivit et al. (1986) in the Buraydah quadrangle (Figure 1). All of these authors described thanatocoenoses ("littoral accumulations" of Vaslet et al., 1985) of cephalopods including bactritids, nautiloids, and of echinoderm, bryozoan, and brachiopod debris in platy fossiliferous limestone beds



**Figure 1: Simplified Khuff Formation outcrop, central Saudi Arabia (modified after Vaslet et al., 2005). Two nautiloid specimens were recovered from the Midhnaab Member: (1) east of Safra ad Dumaythiyat ( $24^{\circ}35'10''\text{N}$ ,  $44^{\circ}50'43''\text{E}$ ) in the Ad Dawadimi quadrangle (Delfour et al., 1982); and (2) a site ( $26^{\circ}07'01''\text{N}$ ,  $44^{\circ}02'26''\text{E}$ ) located some 20 km to the north of the Midhnaab town in the Buraydah quadrangle (Manivit et al., 1986). The nautiloid specimen from the Lower Khartam Member was recovered from Jabal al Amshiyah ( $24^{\circ}43'56''\text{N}$ ,  $44^{\circ}49'19''\text{E}$ ) in the Ad Dawadimi quadrangle (Delfour et al., 1982).**

rich in foraminifers in the lower part of the Midhnab Member. These records were summarised by Le Nindre et al. (1990b, p. 54) who cited, among the nautiloids, an assemblage composed of *Caelogastraceras* aff. *mexicanum* (Girty) and *Aphelaeceras* sp., but without great precision. This paper presents the first systematic description of the nautiloids from the Midhnab and Khartam members of the Khuff Formation in central Saudi Arabia. It proposes the biostratigraphic conclusions, as well as interpretations of palaeoecology and palaeogeography. The specimens that are described here are housed in the University of Lyon, France.

## LITHOSTRATIGRAPHY, BIOSTRATIGRAPHY AND SEQUENCE STRATIGRAPHY OF THE KHUFF FORMATION

The Ash Shiqqah Member (nearly equivalent to the obsolete Unayzah member of the Khuff Formation of Delfour et al., 1982) consists of terrigenous sediments with secondary clayey dolomite and local evaporite in the upper part of the unit. This member, as defined by Senalp and Al-Duaiji (1995, 2001), includes only the upper part of the now obsolete Unayzah Member. The palaeoenvironments range from transitional to continental and supratidal. The Unayzah Flora (Hill and El-Khayal, 1983; El-Khayal and Wagner, 1985; Broutin et al., 1995), formerly described in the lower part of the Khuff Formation, is now attributed to the underlying Unayzah Formation (Vaslet et al., 2005). Rare benthic smaller foraminifers occur locally in the upper part of the Ash Shiqqah Member, indicating a possible Middle Permian Capitanian (late Midian) age for this lowest unit of the Khuff Formation (Vachard et al., 2002; Vaslet et al., 2005).

The Huqayl Member is subdivided into two sequential units containing calcarenite, gypsiferous claystone, dolomite, and solution breccias related to subsurface evaporites. This marine transgressive unit is tentatively assigned a Late Permian ?Wuchiapingian (Dzhulfian) age according to its benthic foraminiferal content (Vachard et al., 2002, 2005; Vaslet et al., 2005). The Dhaysan Member is the first true calcareous subtidal to littoral unit of the Khuff Formation (Le Nindre et al., 1990b), and is interpreted as the transgressive unit of the overlying Midhnab Member (Vaslet et al., 2005). The Dhaysan Member has yielded benthic foraminifers, gastropods and abundant bacitritids. A Late Permian Wuchiapingian to Changhsingian age is tentatively assigned to the Dhaysan Member (Vaslet et al., 2005).

The Midhnab Member displays a succession ranging from marine fossiliferous limestones at the base, toward gypsiferous and dolomitic rocks deposited in restricted palaeoenvironments, in the upper part. The lower part of the Midhnab Member is dated by benthic foraminifers as Late Permian Changhsingian (Dorashamian) by Vachard et al. (2002, 2005). Locally, in northern central Saudi Arabia, the topmost part of the Midhnab Member presents continental facies including lacustrine limestone, sandstone channels and claystone in meandering river systems and swamps. These facies contain drifted wood and plant remains (Hill and El-Khayal, 1983; Vaslet et al., 1985; Le Nindre et al., 1990b; Vaslet et al., 2005). Recent descriptions of the Midhnab Flora indicate a Late Permian mixed flora including Cathaysian, Euramerian and Gondwanan plant remains (Broutin et al., 1995, 2002; Berthelin, 2002; Berthelin et al., 2006).

The Khartam Member, the uppermost mainly carbonate unit of the Khuff Formation, is subdivided into two marine units characterised by littoral to tidal and intertidal palaeoenvironments. The Lower Khartam Member consists of claystone, dolomite and sands, deposited in supratidal to tidal palaeoenvironments. The Upper Khartam Member is an oolitic, peloidal and bioclastic limestone, locally dolomitised, deposited in littoral to tidal and intertidal palaeoenvironments. The Lower Khartam Member yielded rare benthic foraminifers possibly dated as late Late Permian (late Changhsingian) by Vachard et al. (2002, 2005), as well as Late Permian ostracods (Crasquin-Soleau et al., 2005, 2006). The Upper Khartam Member, consisting principally of reworked dasycladacean algae ooids, is characterised by the appearance of *Spirorbis phlyctaena* Brönniman and Zaninetti, a serpulid that is particularly abundant in the Early Triassic rocks in Neo-Tethyan areas.

According to Vaslet et al. (2005), the Khuff Formation consists of four main depositional sequences (DS PKh, DS PKm, DS PKk and DS TrS, see Figure 2). The last depositional sequence starts with the Khuff Formation and continues in the overlying Sudair Shale Formation. The DS PKh (named after

Khuff Formation type section, Ad Dawadimi quadrangle, Saudi Arabia

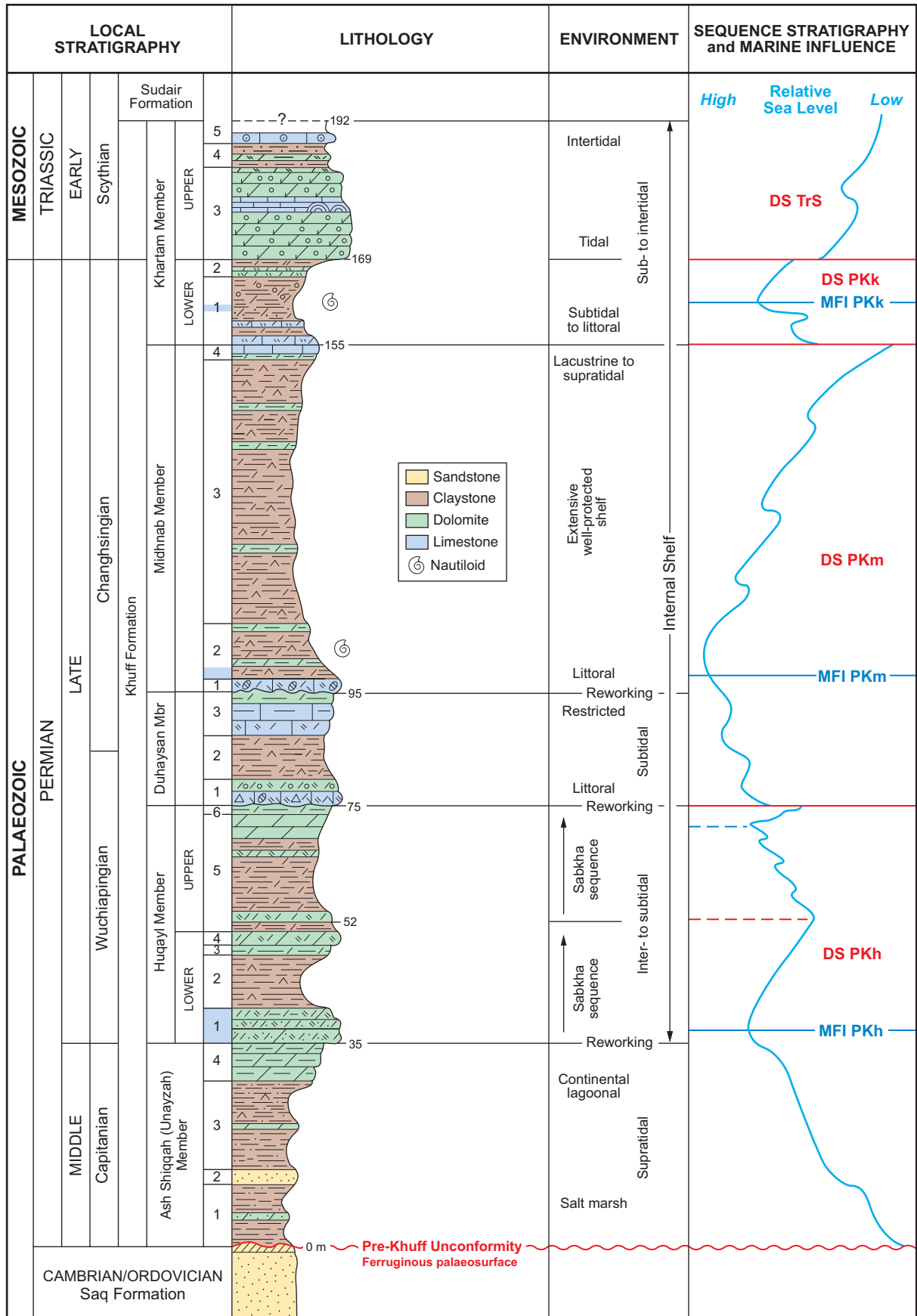


Figure 2: Type section of the Khuff Formation in northern central Saudi Arabia, Ad Dawadimi quadrangle (modified after Delfour et al., 1982; Vaslet et al., 2005). A single specimen of nautiloid,

Permian-Khuff-Huqayl) includes the Ash Shiqqah and the Huqayl members. Its basal sequence boundary (SB) corresponds to the Pre-Khuff Unconformity (PKU) and it contains the maximum flooding interval MFI PKh that represents the first Late Permian flooding event over central Saudi Arabian outcrop areas. This flooding interval is located in the basal part of the Huqayl Member and is followed by the regressive evaporitic palaeoenvironments of the Huqayl Member (Le Nindre et al., 1990b; Vaslet et al., 2005).

The DS PKm (named after Permian-Khuff-Midhnab) started with subtidal to littoral deposits of the Duhaysan Member above an erosive surface at the top of DS PKh, and ended with the regressive supratidal to continental deposits of the upper part of the Midhnab Member. A maximum flooding interval (MFI PKm) is clearly located in the outcrops at the base of the Midhnab Member, with abundant marine fauna including cephalopods, brachiopods (Vaslet et al., 2005; Angiolini et al., 2006; this paper) associated with the ostracod fauna (Crasquin-Soleau et al., 2006).

The DS PKk corresponds to the Lower Khartam Member (Permian-Khuff-Khartam), and represents the terminal Late Permian Depositional Sequence in the outcrops of central Saudi Arabia. The basal SB is marked by a return to marine subtidal conditions after the continental break at the end of DS PKm. It contains a maximum flooding interval (MFI PKk) that contains the remains of marine fauna, including abundant ostracods (Crasquin-Soleau et al., 2005, 2006), bactritids and locally cephalopods (this paper).

The DS TrS (named after the Sudair Shale Formation) starts with the littoral, tidal to intertidal deposits of the Early Triassic Upper Khartam Member of the Khuff Formation, and ends with the closed-basin, clayey to evaporitic rocks of the Lower Triassic Sudair Shale Formation (Le Nindre et al., 1990b; Vaslet et al., 2005).

## NAUTILOIDS

### Midhnab Member Nautiloids

Nautiloids were collected in two localities from the lower part of the Midhnab Member (MFI Pkm) along the outcrops in central Saudi Arabia (Figures 1 and 2). The first fossiliferous locality (24°35'10" N, 44°50'43" E) was discovered in 1979, east of Safra ad Dumaythiyat, while mapping the Ad Dawadimi quadrangle by D. Vaslet, J.M. Brosse, and Y.-M. Le Nindre (Delfour et al., 1982). A single specimen of nautiloid, hereafter described as *Tirolonautilus* gr. *hoernesii*, was recovered from bluish-grey clayey platy bioclastic limestone of the lowest part of subunit 2 of the Midhnab Member (Vaslet et al., 2005). Besides the nautiloid specimen, the limestone contains a rich marine fauna including cephalopods (bactritids), bryozoans, bivalves (Myophoridae), gastropods, and a microfauna of dasycladacean algae, benthic foraminifers and ostracods.

The second fossiliferous site (26°07'01"N, 44°02'26"E) is located in the Buraydah quadrangle (Manivit et al., 1986), some 5 km to the north of the Midhnab town. A single specimen of nautiloid occurs at the lowest part in the subunit 2, bluish bioclastic platy fossiliferous limestone and yellow clayey limestone of the Midhnab Member (Vaslet et al., 2005). The nautiloid was found together with other marine fauna including brachiopods (Angiolini et al., 2006), bactritids, and gastropods (*Bellerophon*). The nautiloid specimen collected in this second Midhnab Member location is identified as a Nautilida belonging to the Tainoceratidae without more precision. This nautilid family ranges from Carboniferous to Triassic in age.

---

**Figure 2 (continued):** *Tirolonautilus* gr. *hoernesii* was recovered from bluish-grey clayey bioclastic limestone in the lowest part of subunit 2 of the Midhnab Member in the Ad Dawadimi quadrangle. The second nautiloid specimen was also collected from subunit 2 of the Midhnab Member in the Buraydah quadrangle (see Figure 1). It is identified as a Nautilida belonging to the Tainoceratidae without more precision. This nautilid family ranges from Carboniferous to Triassic in age. The specimen of *Tirolonautilus feltgeni* n. sp. was found in the lower part of the Khartam Member (Ad Dawadimi quadrangle).



**Figure 3: Nautiloid, bactritids and gastropod association, in the Lower Khartam Member. Fossil locality at Jabal al Amshiyah (24°43'56"N, 44°49'19"E), Ad Dawadimi quadrangle, Saudi Arabia.**

The nautiloid specimen from the first locality is attributed to the genus *Tirolonautilus* (Mojsisovics, 1902), known from the Late Permian "Bellerophon Limestone" in the Southern Alps, and recorded from Dzhulfian (Wuchiapingian) to Dorashamian (Changhsingian) strata in the Tethyan areas (Granier and Grgasovic, 2000).

### **Khartam Member Nautiloid**

An isolated specimen of nautiloid was found *in situ* in the Lower Khartam Member outcrops of central Saudi Arabia during a field trip led by D. Vaslet and Y.-M. Le Nindre to the Khuff Formation outcrop, in 2002 (Figures 1 and 2). The nautiloid was found in the bioclastic coquina (Figure 3), pelletoidal limestone and the blue laminated dolomitic clay of subunit 1 (Vaslet et al., 2005), at a locality south of Jabal al Amshiyah (24°43'56"N, 44°49'19"E) in the Ad Dawadimi quadrangle (Delfour et al., 1982). This Lower Khartam Member specimen is attributed to the genus *Tirolonautilus* (Mojsisovics, 1902), known from the Late Permian "Bellerophon Limestone" in the Southern Alps, and recorded from Dzhulfian to Dorashamian strata in the Tethyan areas (Granier and Grgasovic, 2000).

### **SYSTEMATIC PALAEOLOGY (Régis Chirat)**

**Class:** Cephalopoda Cuvier, 1797

**Order:** Nautilida Agassiz, 1847

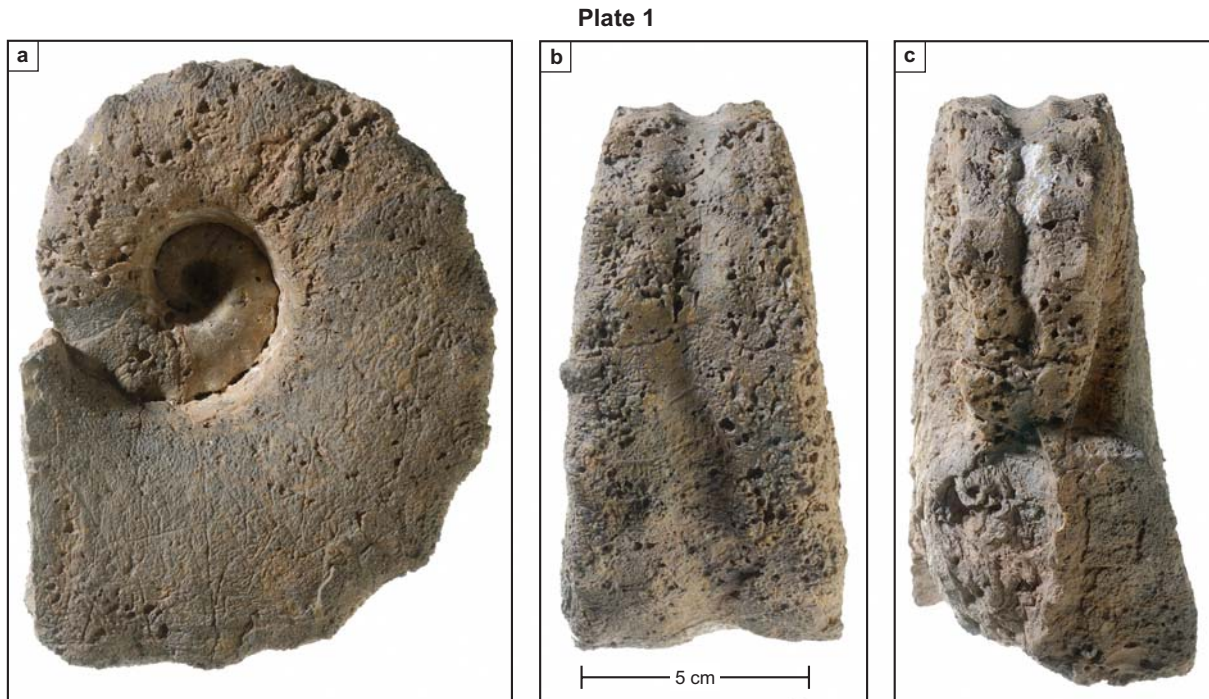
**Family:** Tainoceratidae Hyatt, 1883

**Genus:** *Tirolonautilus* Mojsisovics, 1902

**Type species:** *Nautilus crux* Stache 1877, Kummel 1953 by subsequent designation

***Tirolonautilus* gr. *hoernes* (Stache, 1877) (Plate 1.a to 1.c)**

1877 *Nautilus hoernes* Stache, p. 286-289, pl. V, fig. 2a-b.

**Plate 1:**

**1a–c:** *Tirolonautilus* gr. *hoernesii* (Stache, 1877). (FSL 391801). Lower part of the Midh nab Member of the Khuff Formation (Late Permian, Changhsingian), east of Safra ad Dumaythiyat, central Saudi Arabia. (a) Lateral view. (b) Ventral view. (c) Oral view.

**Material:** An internal mould of adult specimen, 130 mm in diameter, with an almost completely preserved body chamber (reposit as no. FSL 391801, at the palaeontological collections of the Claude Bernard University, Lyon 1, France).

**Stratigraphy and Locality:** Lower part of the Midh nab Member (subunit 2) of the Khuff Formation (Late Permian, Changhsingian), east of Safra ad Dumaythiyat (24°35'10"N, 44°50'43"E), Ad Dawadimi quadrangle, central Saudi Arabia.

**Description:** Shell moderately evolute (umbilical diameter/shell diameter ratio = 0.3), with whorls only just in contact. Rapidly expanding outer whorl. Whorl section varied greatly during ontogeny between the phragmocone and the body chamber, as the animal approached and reached maturity. Whorl section slightly depressed (whorl width/whorl height ratio = 1.2), subrectangular on the phragmocone, becomes trapezoidal on the mature body chamber. Parallel plano-convex flanks on phragmocone, become slightly convex on the body chamber, diverging towards the ventral area. Maximum width on the mid-flank on the phragmocone, at the level of ventrolateral shoulders on the mature body chamber. Wide plano-concave venter with median "gutter", bordered with slightly oblique flattened areas. Angular ventrolateral shoulders. Wide umbilicus with steep wall and broadly rounded umbilical shoulder. Elongated and oblique nodes on the ventrolateral shoulders, projecting adapically in line with elongated and oblique ventral nodes. Suture line slightly sinuous, with shallow ventral and lateral lobe, and small saddle on the latero-ventral and umbilical shoulders. Position of the siphuncle unknown.

**Comparison:** The specimen from Saudi Arabia is an almost completely preserved adult, displaying strong ontogenetic allometries in whorl section on the body chamber, while the holotype of *Tirolonautilus hoernesii* (Stache, 1877), from the Late Permian Bellerophon Limestone of the southern Alps, is a small internal mold of the phragmocone. If allowances are made for adult morphology, the specimen from Saudi Arabia differs only from the Alpine form in its more prominent ventral nodes. Both of these forms could be conspecific.

Plate 2

**Plate 2:**

2a–c: *Tirolonautilus feltgeni* n. sp. (FSL 391800). Lower part of the Khartam Member of the Khuff Formation (Late Permian, late Changhsingian), south Jabal al Amshiyah, central Saudi Arabia. (a) Lateral view. (b) Ventral view. (c) Oral view.

*Tirolonautilus feltgeni* n. sp. (Plates 2.a to 2.c)

**Derivation of name:** In honour of Ludovic Feltgen.

**Material:** The holotype is an internal mould of the phragmocone, 115 mm in diameter (FSL 391800, repositated at the palaeontological collections of the Claude Bernard University, Lyon 1, France).

**Stratigraphy and Locality:** Lower part (subunit 1) of the Khartam Member of the Khuff Formation (Late Permian, late Changhsingian), south of Jabal al Amshiyah (24°43'56"N, 44°49'19"E) in the Ad Dawadimi quadrangle, central Saudi Arabia.

**Diagnosis:** Shell moderately evolute ( $U/D = 0.21$ ) with whorls only just in contact. Whorl section compressed ( $W/H = 0.75$ ), trapezoidal in outline. Rapidly expanding outer whorl. Flanks flattened to slightly plano-concave, converging toward the ventral area. Maximum width just above the umbilical margin. Narrow concave venter with median "gutter", bordered with oblique flattened areas. Subangular ventro-lateral shoulders. Narrow umbilicus with steep wall and broadly rounded umbilical shoulder. Elongated and oblique nodes on the ventro-lateral shoulders, projecting adapically over the ventral area with tongue-shaped hyponomic sinus. One row of rounded nodes on the umbilical shoulder and one on the mid-flank, radially arranged. Suture line slightly sinuous, with shallow ventral and lateral lobe, and small saddle on the latero-ventral shoulder. Large centro-ventral siphuncle.

**Comparison:** The species from Saudi Arabia differs from other cogeneric species, mainly in the presence of two rows of nodes on the flank and umbilical shoulder. This species is probably phylogenetically more closely related to *Tirolonautilus sebedinus* than other species in the genus.



## PALAEO GEOGRAPHIC IMPLICATIONS

Nautilida seem to have had a nektonic mode of life throughout their post-embryonic development. Various aspects of their reproduction also made them highly dependent on palaeoenvironmental characteristics of the sea bottom; a hard and hollow substrate in shallow and warm waters appears to have been required for their egg-laying and successful embryonic development (Chirat and Rioult, 1998). Factors controlling their palaeobiogeographic dispersion were partly linked to the depth limits of resistance of their shell to implosion and explosion of the siphuncle, and partly to the osmotic emptying capacity of the siphuncular epithelium. The physiography of the sea bottom thus constituted one of the most important factors controlling the dispersion of fossil Nautilida. Epicontinental shelves and continental slopes represented suitable and preferential dispersion pathways, while the great oceanic areas constituted palaeobiogeographic barriers.

The four named species of *Tirolonautilus* [*T. crux* (Stache), *T. sebedinus* (Stache), *T. hoernesii* (Stache), and *T. bicristatus* Caneva)], and all specimens so far assigned to this genus, all come from the Late Permian Bellerophon Limestone of the southern Alps (Stache, 1877; Mojsisovics, 1902; Merla, 1930). The presence of this genus in central Saudi Arabia thus confirms a Late Permian marine exchange between the Arabian Platform and the Western Tethyan realm.

## ACKNOWLEDGEMENTS

The authors thank G. Wyn Hughes (Saudi Aramco) and Michael Stephenson (British Geological Survey) for their constructive remarks. Special thanks to Noël Podelvigne for the photographs of the specimens. The authors also thank GeoArabia for assisting with editing and designing the manuscript.

## REFERENCES

- Agassiz, L. 1847. An Introduction to the Study of Natural History. In, a series of lectures delivered at the Hall of the College of Physicians and Surgeons, New York. 58 p.
- Al-Aswad, A.A. 1997. Stratigraphy, sedimentary environment and depositional evolution of the Khuff Formation in south-central Saudi Arabia. *Journal of Petroleum Geology*, v. 20, p. 307-326.
- Alsharhan, A.S. and A.E.M. Nairn 1995. Tertiary of the Arabian Gulf: sedimentology and hydrocarbon potential. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 114, p. 369-384.
- Angiolini, L., D. Vaslet and Y.-M. Le Nindre 2006. Brachiopods of the Khuff Formation, Midhnab Member, Late Permian, central Saudi Arabia. *GeoArabia* (in preparation).
- Berthelin, M. 2002. Flore mixte du Permien de l'Oman et Pangées permiennes: dynamique de mise en place et signification paléocéologique, paléoclimatique et paléogéographique. Thèse de Doctorat, Université de Paris VI, Paris, 263 p.
- Berthelin, M., J. Broutin, D. Vaslet, Y.-M. Le Nindre and M. Halawani 2006. Mixed Late Permian floras and related paleoenvironments in the upper Khuff Formation of central Saudi Arabia. *GeoArabia* (in preparation).
- Broutin, J., M. Berthelin, M. Halawani, D. Vaslet and Y.-M. Le Nindre 2002. Mixed Late Permian floras and related paleoenvironments in the upper Khuff Formation of central Saudi Arabia. *GeoArabia*, v. 7, no. 2, p. 219.
- Broutin, J., J. Roger, J.-P. Platel, L. Angiolini, A. Baud, H. Bucher, J. Marcoux and H. Al-Hashmi 1995. The Permian Pangea. Phytogeographic implications of the new paleontological discoveries in Oman (Arabian Peninsula). *Comptes Rendus Académie Sciences, Paris*, v. 321, p. 1069-1086.
- Chirat, R. and M. Rioult 1998. Occurrence of early post-hatching Jurassic Nautilida in Normandy, France: palaeobiologic, palaeoecologic and palaeobiogeographic implications. *Lethaia*, v. 31, p. 137-148.
- Crasquin-Soleau, S., D. Vaslet, and Y.-M. Le Nindre 2005. Ostracods as markers of the Permian-Triassic boundary in the Khuff Formation of Saudi Arabia. *Palaeontology*, v. 48, no. 4, p. 853-868.
- Crasquin-Soleau, S., D. Vaslet and Y.-M. Le Nindre 2006. Ostracods of the Permian-Triassic Khuff Formation (Saudi Arabia): paleoecology and paleobiogeography. *GeoArabia*, v. 11, no. 1, p. 55-76.

- Cuvier, G. 1797. Tableau élémentaire de l'histoire naturelle des animaux. Paris, 710 p., 14 plates.
- Delfour, J., R. Dhellemmes, P. Elbass, D. Vaslet, J.M. Brosse, Y.-M. Le Nindre and O. Dottin 1982. Geologic map of the Ad Dawadimi quadrangle, sheet 24G, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resources, Geoscience Map GM60, Scale 1:250,000.
- El-Khayal, A.A. and R.H. Wagner 1985. Upper Permian stratigraphy and megafloras of Saudi Arabia; paleogeographic and climatic implications. 10 Congreso Internacional de estratigrafica y geologia del Carbonifero. Instituto Geologico y Minero de España, Madrid, p. 17-26.
- Granier, R.C. and T. Grgasovic 2000. Les Algues Dasycladales du Permien et du Trias: nouvelle tentative d'inventaire bibliographique, géographique et stratigraphique. *Geologia Croatica*, Zagreb, v. 53, no. 1, p. 1-197.
- Hyatt, A. 1883. Genera of fossil cephalopods. *Proceedings of the Boston Society of Natural History*, v. 22, p. 253-338.
- Hill, C.R. and A.A. El-Khayal 1983. Late Permian plants including Charophytes from the Khuff Formation of Saudi Arabia. *Bulletin of the British Museum of Natural History, Geology Series*, v. 37, p. 105-112.
- Kummel, B. 1953. American Triassic coiled Nautiloids. *United States Geological Survey, Professional Paper 259*, p. 1-104.
- Le Nindre, Y.-M., J. Manivit and D. Vaslet 1990a. Histoire Géologique de la Bordure Occidentale de la Plate-forme Arabe, vol. 2: Géodynamique et Paléogéographie de la Plate-forme Arabe du Permien au Jurassique. Bureau de Recherches Géologiques et Minières, Orléans, Document 192, 278 p.
- Le Nindre, Y.-M., D. Vaslet and J. Manivit 1990b. Histoire Géologique de la Bordure Occidentale de la Plate-forme Arabe, vol. 3: Le Permo-Trias d'Arabie Centrale. Bureau de Recherches Géologiques et Minières, Orléans, Document 193, 262 p.
- Manivit, J., C. Pellaton, D. Vaslet, Y.-M. Le Nindre, J.M. Brosse and J. Fourniguet 1985a. Geologic map of the Wadi al Mulayh quadrangle, sheet 22H, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resources, Geoscience Map, GM92, Scale 1:250,000.
- Manivit, J., C. Pellaton, D. Vaslet, Y.-M. Le Nindre, J.M. Brosse, J.P. Breton and J. Fourniguet 1985b. Geologic map of the Darma quadrangle, sheet 24H, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resources, Geoscience Map, GM101, Scale 1:250,000.
- Manivit, J., D. Vaslet, A. Berthiaux, P. Le Strat and J. Fourniguet 1986. Geologic map of the Buraydah quadrangle, sheet 26G, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resources, Geoscience Map, GM114, Scale 1:250,000.
- Merla, G. 1930. La fauna del Calcare a Bellerophon della regione dolomitica. *Memorie dell' Istituto Geologico della reale Università di Padova*, v. 9, no. 2, p. 1-221.
- Mojsisovics, E. von 1902. Nachtrag zu den Cephalopoden der Hallstätter Kalke. *Abhandlungen der Geologischen Reichsanstalt Wien 1 (Supplement-Heft)*, p. 175-356.
- Powers, R.W. 1968. Saudi Arabia. *Lexique stratigraphique international*, III, fasc.10b 1. Centre National de la Recherche Scientifique, Paris, 177 p.
- Powers, R.W., L.F. Ramirez, C.D. Redmond and E.L.J. Elberg 1966. Geology of the Arabian Peninsula: Sedimentary Geology of Saudi Arabia. *United States Geological Survey, Professional Paper 560 D*, 147 p.
- Stache, G. 1877. Beiträge zur Fauna der Bellerophonkalke Südtirols; Nr.1, Cephalopoden und Gastropoden. *Jahrbuch der kaiserlich-königlichen Geologischen Reichsanstalt, Vienna*, v. 27, p. 271-318.
- Senalp, M. and A. Al-Duaiji 1995. Stratigraphy and sedimentation of the Unayzah reservoir, central Saudi Arabia. In, M.I. Al-Husseini (Ed.), *Middle East Petroleum Geosciences Conference, GEO'94. Gulf PetroLink, Bahrain*, v. 2, p. 837-847.
- Senalp, M. and A. Al-Duaiji 2001. Sequence stratigraphy of the 'Unayzah reservoir' in Central Saudi Arabia. *The Saudi Aramco Journal of Technology*, Summer 2001, p. 20-43.
- Sharland, 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*, 371 p.

- Vachard, D., M. Hauser, R. Martini, L. Zaninetti, A. Matter and T. Peters 2002. Middle Permian (Midian) foraminiferal assemblages from the Batain Plain (Eastern Oman): their significance to Neotethyan paleogeography. *Journal of Foraminiferal Research*, v. 32, no. 2, p. 155-172.
- Vachard, D., A. Zambettakis-Lekas, E. Skourtsos, R. Martini and L. Zaninetti 2003. Foraminifera, algae and carbonate microproblematica from the late Wuchiapingian/Dzhulfian (late Permian) of Peloponnesus (Greece). *Rivista Italiana di Paleontologia e Stratigrafia*, v. 109, no. 2, p. 339-358.
- Vachard, D., J. Gaillot, D. Vaslet and Y.-M. Le Nindre 2005. Foraminifers and algae from the Khuff Formation (late Middle Permian-Early Triassic) of central Saudi Arabia *GeoArabia*, v. 10, no. 4, p. 137-186.
- Vaslet, D., M. Beurrier, M. Villey, J. Manivit, P. Le Strat, Y.-M. Le Nindre, J.M. Brosse, A. Berthiaux and J. Fourniguet 1985. Geologic map of the Al Faydah quadrangle, sheet 25G, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resources, Geoscience Map, GM102, Scale 1:250,000.
- Vaslet, D., Y.-M. Le Nindre, D. Vachard, J. Broutin, S. Crasquin-Soleau, J. Gaillot, M. Berthelin, M. Halawani and M.I. Al-Husseini 2005. The Permian-Triassic Khuff Formation of central Saudi Arabia. *GeoArabia*, v. 10, no. 4, p. 77-134.
- Vaslet, D., J. Manivit, Y.-M. Le Nindre, J.M. Brosse, J. Fourniguet and J. Delfour 1983. Geologic map of the Wadi ar Rayn quadrangle, sheet 23H, Kingdom of Saudi Arabia (with explanatory notes). Saudi Arabian Deputy Ministry for Mineral Resources, Geoscience Map, GM63, Scale 1:250,000.

## ABOUT THE AUTHORS

*Régis Chirat is a Palaeontologist at the University of Lyon, France. He received a PhD in Palaeontology from Caen University in 1997 where his research focused on the palaeobiology, systematic and phylogeny of Mesozoic nautiloids. His work also focuses on theoretical studies of molluscan shells - morphogenesis and their systematic and evolutionary implications.*

*Regis.Chirat@univ-lyon1.fr*



*Denis Vaslet is Head of the Geology and Geoinformation Division at the Bureau de Recherches Géologiques et Minières (BRGM), the French Geological Survey. He has 30 years of experience in the geology of the Middle East. From 1977 to 1979 Denis was involved in geological mapping and phosphate prospecting in Iran for the Geological Survey of Iran and the National Iranian Oil Company. From 1979 to 1991, he was responsible for the Cover Rocks mapping program in Saudi Arabia for the Saudi Arabian Deputy Ministry for Mineral Resources. Denis has been involved in the complete lithostratigraphic revision of the Phanerozoic rocks of central Saudi Arabia, for which he received his Doctorate of Sciences from the University of Paris in 1987. He is currently in charge of geological and geophysical mapping both in France and overseas, and for the production and distribution of digital geological information at BRGM. Denis remains involved in several research projects in the sedimentary geology and stratigraphy fields within the Arabian Peninsula.*



*d.vaslet@brgm.fr*

*Yves-Michel Le Nindre has more than 10 years of experience in the geological mapping of the Phanerozoic rocks of Saudi Arabia. He received his Doctorate of Sciences from the University of Paris in 1987. Yves-Michel's dissertation was on the sedimentation and geodynamics of Central Arabia from the Permian to the Cretaceous. He is currently working with the Bureau de Recherches Géologiques et Minières on sedimentary basin analysis and modelling, particularly in hydrogeology, and is also involved in present-day littoral modelling.*

*ym.lenindre@brgm.fr*



---

Manuscript received August 15, 2004

Revised November 20, 2004

Accepted January 20, 2005

Press version proofread by Authors September 12, 2005