Carnets Geol. 19 (5)

E-ISSN 1634-0744
DOI 10.4267/2042/70192

Le Dévonien supérieur du Sahara nord-occidental (Algérie) : Faciès, environnements et signification géodynamique des calcaires griottes

Abdelkader ABBACHE [1,2]

Abdelkader OUALI MEHADJI [2]

Catherine CRÔNIER [3,4]

Ahmed Hamza FELLAH [2,5]

Ninon ALLAIRE [3]

Claude MONNET [3]

Résumé : Sur la bordure nord-ouest du Sahara algérien, dans les bassins de Béchar (Ben-Zireg), de l'Ougarta (Marhouma) et du Gourara (Charouine), le Dévonien supérieur est marqué par les calcaires noduleux de type "griotte" qui s'échelonnent depuis le Frasnien jusqu'au Famennien (Dévonien). Il s'agit d'alternances argilo-gréso-calcaires riches en ammonoïdes. Des variations latérales de faciès et d'épaisseur sont observées dans ces trois bassins. Ces variations sont directement liées aux conditions de leur environnement de dépôts (hydrodynamisme, physiographie du bassin, arrêts sédimentaires). Dans les trois régions étudiées, les milieux de dépôt des faciès griottes correspondent à un environnement de type plateforme (hauts fonds) et bassin sous contrôle tectono-eustatique. À Ben-Zireg, les faciès correspondent à une plateforme. À Marhouma, les faciès correspondent d'abord à une rampe distale, puis à un environnement de talus à tablier à faciès allodapiques (Famennien II, VI et V) et de bassin (Famennien II et VI). À la fin du Famennien, on assiste à l'installation d'une sédimentation argilo-sableuse de talus (Membre inférieur des Grès de Ouarourout) rapidement relayée par la mise en place d'une plateforme (Membre supérieur des Grès de Ouarourout) avant émersion. À Charouine, les argiles du bassin (hémipélagites) dominent la sédimentation. La présence d'asphaltites sous forme d'imprégnation dans les faciès griottes, de galettes centimétriques et de blocs métriques dans les faciès postérieurs aux calcaires noduleux, suggère les effets d'une diagenèse précoce qui a dû également jouer un rôle important par la réduction des sulfates et l'oxydation anaérobique du méthane (biogénique et/ou thermique). La ségrégation d'aires sédimentaires à faciès griotte semble être calquée sur un morcellement du socle. En effet, les faciès griottes suivent de près la suture panafricaine. Dans l'Ougarta, l'accident "Sud Ougartien" ne serait que le prolongement du mégalinéament du Tibesti. La réactivation au Dévonien supérieur des fractures du socle précambrien serait responsable de ce contraste des faciès.

[1] *Université Mustapha Stambouli de Mascara, Faculté des Sciences de la Nature et de la Vie, BP 305, route de Mamounia, Mascara (Algérie)*
kader.abbache@gmail.com

[2] *Laboratoire de Paléontologie stratigraphique et paléoenvironments, Université Mohamed Ben Ahmed (Oran II), Bir El Djir, Oran (Algérie)*

[3] *Université de Lille, CNRS, UMR 8198 – Evo-Eco-Paleo, F-59000 Lille (France)*

[4] *catherine.cronier@univ-lille.fr*

[5] *Université Tahri Mohamed, Faculté des Sciences de la Nature et de la Vie, Béchar (Algérie)*

Manuscrit en ligne depuis le 31 mai 2019
[Éditeur : Bruno GRANIER ; éditeur pour la langue anglaise : Robert W. SCOTT]

Bulletin du Service Géologique de l'Algérie
Vol. **26**, n° **1-2**, pp. **3 - 21**, **7** fig., **2** pl., **2015**

LES INTERNALITES DU SILURO-DÉVONIEN DE LA SAOURA-OUGARTA (SAHARA, ALGÉRIE)

Abdelkader OUALI MEHADJI* et Boumediene BOUTERFA*

RÉSUMÉ

Les séquences de type internalites, récemment définies, permettent de compléter notre vision de la dynamique sédimentaire sur le profil marin hypsométrique classique. Fréquentes en position médiane (mid-ramp, mid-shelf) et distale (offshore) de la plateforme jusqu'au bassin, elles traduisent des moments de perturbations (eventites) au sein de phases à décantation boueuse (argiles ou marnes) en milieu calme à profond, en présence d'une pycnocline. Les faciès des internalites peuvent être confondus avec les tempestites à cause de certaines analogies de structures sédimentaires. Cependant, le contexte sédimentaire est différent (position distale). Des intercalations calcaires à orthocères isolées dans les argiles à graptolithes du Silurien de la Saoura-Ougarta (Formation de Oued Ali) ainsi que certains niveaux microconglomératiques et gréseux à laminations obliques en mamelons (HCS) et flaser bedding du Dévonien inférieur (Formation du Dkhissa et du Teferguenit) offrent de bons exemples de ces internalites.

Mots-clés - Internalites - Pycnocline - Faciès - Silurien - Dévonien - Saoura - Ougarta - Algérie.

SILURIAN-DEVONIAN INTERNALITES OF THE SAOURA-OUGARTA (SAHARA, ALGERIA).

ABSTRACT

The internalites defined recently can complete our sedimentary dynamic vision along the classic marine hypsometric profile. This internalites are frequent in the mid-ramp / mid-shelf and offshore up to basin environments. They convey short-term perturbations moments (eventites) in muddy context sedimentation in quiet and deep environment with pycnocline. The internalites facies can easily be mis-interpreted with the tempestites regarding to many of their sedimentary structures analogies. Nevertheless, the sedimentation context is different (distal position). The limy beds intercalations bearing nautiloids isolated in graptolitic Silurian shales of the Saoura-Ougarta (Oued Ali Formation), and some Lower Devonian microconglomeratic and sandstones levels with HCS and flaser structures (Dkhissa and Teferguenit Formations) offer good examples of internalites.

Keywords - Internalites - Pycnocline - Facies - Silurian - Devonian - Saoura - Ougarta - Algeria.

*Laboratoire de Paléontologie Stratigraphique et Paléoenvironnements (LPSP), Département des Sciences de la Terre, Faculté des Sciences de la Terre et de l'Univers. Université d'Oran 2 Ahmed Ben Ahmed, BP. 1015, El-M'naouer, 31000 Oran, Algérie. E-mail : oualimeha@gmail.com
- Manuscrit déposé le 12 Novembre 2013, accepté après révision le 16 Décembre 2014.

Geol. Mag. **155** (*4*), *2018*, *pp. 811–840.* © *Cambridge University Press 2016*
doi:10.1017/S001675681600100X

Middle Devonian trilobites of the Saoura Valley, Algeria: insights into their biodiversity and Moroccan affinities

CATHERINE CRÔNIER*†‡, ABDELKADER ABBACHE§, AHMED YACINE KHALDI¶, MORGANE OUDOT†, SÉBASTIEN MAILLET* & ABDELKADER OUALI MEHADJI¶

*UMR8198, EvoEcoPaleo-CNRS, Université de Lille, UFR Sciences de la Terre, 59655 Villeneuve d'Ascq Cedex, France
†UMR6282, BIOGEOSCIENCES, Université Bourgogne Franche-Comté, 21000 Dijon, France
§Université de Mascara, Faculté SNV, Algérie
¶Laboratoire de Paléontologie stratigraphique et paléo-environnements, Université d'Oran, boîte postale 1524, El-M'naouer 31000 Oran, Algérie

(*Received* 25 March 2016; *accepted* 30 September 2016; *first published online* 12 December 2016)

Abstract – Trilobites are important elements of the Devonian macrobenthos; some of them were collected in the Chefar el Ahmar Formation, from two sections located near Béni Abbès in the Saoura Valley (Ougarta Basin, Saharan Algeria). This formation is characterized by alternations of claystones and limestones, and it is considered to be late Emsian to early Frasnian in age. Only the lower part of this formation has yielded trilobites so far; their presence has been known for a long time. Phacopines clearly dominate the trilobite assemblages, with *Austerops*, *Barrandeops*, *Chotecops* and *Phacops s.l.* as the main genera. Two new species are described (*Austerops salamandaroides* sp. nov. and *Phacops ouarouroutensis* sp. nov.), while some other taxa are presented in open nomenclature. Comparisons are made with closely allied species. These new trilobite occurrences have been analysed in terms of their intra- and interspecific variability and biodiversity. The occurrence of *Struveaspis maroccanica*, previously known from the Saoura Valley, provides an early Eifelian age, which is also confirmed by the presence of trilobites *Thysanopeltis* and *Koneprusites*, and ostracods *Bairdiocypris devonica* and *Bufina* ?*subovalis*.

Keywords: Trilobita, Eifelian, Ougarta, taxonomy, diversity, variability

1. Introduction

Trilobites are important elements of the Devonian macrobenthos. During Early Devonian time, the regressive Basal Pragian Event contributed to the development of shallow marine carbonate realms, which were favourable environments for trilobites. This led to an increase in their generic diversity and to a maintenance of their family diversity, with some minor changes, until early Eifelian time (Chlupáč, 1994; Crônier & VanViersen, 2007).

The publications of Alberti (1969, 1970, 1981, 1983), Chatterton *et al.* (2006) and McKellar & Chatterton (2009) have been major contributions to our current knowledge of North African Middle Devonian trilobites.

The present paper is a comprehensive contribution to the systematic study of the Middle Devonian phacopids and other trilobites from SW Algeria. Their discovery, including two new species assigned to *Austerops salamandaroides* sp. nov. and *Phacops ouarouroutensis* sp. nov., allows us to improve our understanding of Middle Devonian trilobite community structure and their palaeobiodiversity.

‡Author for correspondence: Catherine.Cronier@univ-lille1.fr

2. Geological setting and material

2.a. Local geological succession

The material described in the present study comes from two sections, designated as 'Ouarourout I' and 'Ouarourout II'. These sections are located in the Saoura Valley, in the eastern part of the Ougarta Basin (Algerian Sahara), about 250 km SSW of Béchar and 5 km SW of Béni Abbès (Fig. 1).

The mounts of Ougarta or the Ougarta Range extend over 400 km in length and 200 km in width. They are elongated according to a NW–SE direction. The Ougarta Range is a folded domain linking the Moroccan Anti-Atlas to the northwest with the hills of Bled El Mass and Tanezrouft to the southeast (Fig. 1). The Ougarta Range encompasses a northern unit, known as 'Saoura', which is constituted by anticlines with Cambro-Ordovician outcrops and synclines with Siluro-Devonian outcrops (Menchikoff, 1933; Donzeau, 1983; Fabre, 2005).

The Devonian deposits were first identified in Saoura at the beginning of the twentieth century by Gautier (1906). Additional comprehensive studies were refined later by Flamand (1911), Menchikoff (1930, 1936), Alimen *et al.* (1952), Le Maître (1952) and Legrand (1967) among others and synthesized

Atif, K.F.T., Aretz, M., Legrand-Blain, M., Bouzid, A. and Aimouche,M., 2016. Brachiopods and rugose corals in an upper Serpukhovian (Mississippian) biostrome: preliminary results from the Djebel Arhlal (Béchar Basin, Algeria). *Boletín Geológico y Minero*, 127 (2/3): 345-360
ISSN: 0366-0176

Brachiopods and rugose corals in an upper Serpukhovian (Mississippian) biostrome: preliminary results from the Djebel Arhlal (Béchar Basin, Algeria)

K.F.T. Atif[1], M. Aretz[2], M. Legrand-Blain[3], A. Bouzid[4] and M. Aimouche[4]

(1) Laboratoire de Paléontologie Stratigraphique et Paléoenvironnement, Département des Sciences de la Terre et de l'Univers, Université Oran 2, BP 1524, El M'naouer, Oran, Algeria. kftatif@gmail.com
(2) Géosciences Environnement Toulouse (GET), Observatoire Midi Pyrénées, Université de Toulouse, CNRS, IRD, 14 Avenue E. Belin, F 31400 Toulouse, France. markus.aretz@get.omp.eu
(3) 216 Cours Général de Gaulle, F 33170 Gradignan, France.
legrandblain@wanadoo.fr
(4) Faculté des Sciences de la Terre, de Géographie et de l'Aménagement du Territoire, Département des Sciences de la Terre et de l'Univers, Université Oran 2, BP 1524, El M'naouer, Oran, Algeria.
aimouchmed@yahoo.com

ABSTRACT

The Djebel Arhlal is the southernmost outcrop of upper Serpukhovian strata in the Béchar Basin. Here the Djenien member of the Djenien Formation is three-folded and it contains a 10 m-thick coral biostrome in its middle unit formed by *Siphonodendron, Diphyphyllum* and *Lithostrotion*. Distances between in situ colonies are in the order of several decimetres and the space between them is filled with bioclastic limestone containing coral rubble. Few brachiopods and solitary corals are found as dwellers within the biostrome, but these groups are much more common in the strata below and above the coral biostrome. This is especially true for the brachiopods, which reach diversities of more than a dozen species in specific horizons. They mainly belong to the orders Productida, Spiriferida and Athyridida. Agitated open-marine platform interior or platform margin settings are the general facies encountered in the Djenien member at the Djebel Arhlal. The field data, including brachiopod coquinas and many fragmented brachiopods and corals, are confirmed by microfacies analysis. However, the coral biostrome records a quieter setting at the interface of middle and outer ramp settings, as seen in the co-existence of *in situ* coral growth, input of reworked material, deposition of carbonate mud, and sparitic textures. This autoparabiostrome at Djebel Arhlal is compared to other rather thick and of exceptional horizontal extension upper Serpukhovian biostromes (few kilometres).

Key words: Béchar Basin, Algeria, Serpukhovian, coral biostromes, brachiopods

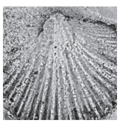
Braquiópodos y corales rugosos en un biostroma del Serpukhoviense superior (Misisípico): resultados preliminares del yacimiento de Djebel Arhlal (Cuenca Béchar, Argelia)

RESUMEN

Djebel Arhlal es el afloramiento más meridional de los estratos serpukovienses en la cuenca Béchar. En esta zona el Miembro Djenien de la Formación Djenien ha sufrido tres etapas de plegamiento y contiene en su unidad media un biostroma de coral de 10 m de espesor y formado por Siphonodendron, Diphyphyllum *y* Lithostrotion. *Las distancias in situ entre las colonias son del orden de varias decenas de decímetros y el espacio entre ellas está relleno de caliza bioclástica que contiene restos de coral. Se han encontrado pocos braquiópodos y corales solitarios como residentes dentro del biostroma, aunque sí son abundantes en los estratos por debajo y por encima del mismo. Esto es especialmente cierto para los braquiópodos, los cuales llegan a alcanzar una diversidad de más doce especies en horizontes específicos; y pertenecen a los*

Ordovician cold water brachiopods from the Ougarta Mountain Range, Algerian Sahara

Leonid E. Popov, Philippe Legrand, Boumedienne Bouterfa & Mansoureh Ghobadi Pour



In the Mid to Late Ordovician the area of the Ougarta Range in north-west Africa occupied a position in relative proximity to the South Pole. Eight successive low diversity brachiopod faunas, including the lingulide association dominated by unnamed species of *Lingulobolus*, the Darriwilian ?*Sivorthis fraterna* and *Tissintia convergens*, the Sandbian to early Katian *Drabovinella regia* and *Tafilaltia destombesi–Rostricellula ambigena* associations, the mid Katian *Drabovinella maxima* and *Svobodaina* cf. *havliceki* associations and the late Hirnantian *Plectothyrella crassicostis chauveli* Association are recognised. The brachiopod based correlation with the Middle to Upper Ordovician succession of the Anti-Atlas in Morocco, suggests the presence of some gaps in the Ougarta section. The occurrence of *Svobodaina* cf. *havliceki* in the Bou M'Haoud Formation Upper Member suggests its correlation with the upper part of the Lower Ktoua Formation of the Anti-Atlas. Among the other brachiopod taxa *Drabovinella regia*, *Orbiculothyris* cf. *costellata*, *Tafilaltia destombesi*, *Rostricellula ambigena*, together with the genera *Fehamya*, *Mezotreta* and *Leptaena* were previously unknown from Algerian Sahara. • Key words: Brachiopoda, Ordovician, taxonomy, biostratigraphy, Algeria, Gondwana.

Popov, L.E., Legrand, P., Bouterfa, B. & Ghobadi Pour, M. 2019. Ordovician cold water brachiopods from the Ougarta Mountain Range, Algerian Sahara. *Bulletin of Geosciences 94(1)*, 41–70 (11 figures, appendix). Czech Geological Survey, Prague. ISSN 1214-1119. Manuscript received September 27, 2018; accepted in revised form January 15, 2019; published online March 11, 2019; issued March 31, 2019.

Leonid E. Popov, Department of Natural Sciences, National Museum of Wales, CF10 3NP, United Kingdom • Philippe Legrand, Retired, 216, cours Général de Gaulle, 33170 Gradignan, France • Boumedienne Bouterfa, Département des Sciences de la Terre, Universté d'Oran 2 Mohamed Ben Ahmed, BP 1015, El M'Naouer, 31000 Oran, Algeria • Mansoureh Ghobadi Pour, Department of Geology, Faculty of Sciences, Golestan University, Gorgan 49138-15739, Iran; mghobadipour@yahoo.co.uk

The name Ougarta Mountain Range (or more simply Ougarta Range; Fig. 1) applies to a mountainous region trending NW–SE and extending for 330 km on the edge of the platform of the western Algerian Sahara. This range is the result of folding of a thick Palaeozoic succession during the Variscan compression. This range forms a link between the Anti-Atlas and the Saharan basins, thus justifying a comprehensive study.

Inferred reconstructions of the polar wander path suggest that the Ordovician South Pole drifted gradually across the north-west African sector of Gondwana (Torsvik & Cocks 2011, Torsvik *et al.* 2012), but without sedimentary evidence in the neighbourhood of the present Ougarta Range except for Hirnantian periglacial sediments. For most of the time this area was flooded by a shallow sea. However, a large part of the Ordovician succession is significantly affected by the fluvioglacial and glacial erosion which occurred during the Hirnantian time (Arbey 1968; Legrand 1974, 1985a; Ghienne *et al.* 2007). In the Mid to Late Ordovician, this shallow sea was inhabited by a low diversity fauna of which brachiopods form an important component; these brachiopods represented the major objective of the present study.

Although, together with the Anti-Atlas, the Ougarta Range is considered as an important source of the Ordovician macrofossils from the North African sector of Gondwana, the existing record of Ordovician brachiopods in the region is sparse. Roch (1933) was the first to report Ordovician brachiopods in the Ougarta Range. In a short paper he announced a presence of moulds assigned to "*Orthis* gr. *alternata* Sowerby – *retrostriata* M'Coy" in the vicinity of Hassi Chaamba, Daoura. Some months later Menchikoff (1933) reported, this time in the Ougarta Range *s.s.*, two fossiliferous horizons at Kheneg et Tlaïa, the lower one with unidentified brachiopods of presumed Llandeilo age, the upper one with orthides, identified as *Orthis redux* Barrande, 1848. The whereabouts of the specimens sampled during these pioneering works is presently unknown. Many years later, Poueyto (1951, 1952) cited the same species from Hassi Chamba (Daoura), from Tabelbala and from Kheneg et Tlaïa; also a little farther to the south-east, at Feidj ez Zeidiya,

Facies (2019) 65:17
https://doi.org/10.1007/s10347-019-0559-2

ORIGINAL ARTICLE

Carbonate concretions in Miocene mudrocks in NW Algeria: types, geochemistry, and origins

Abdelkrim Nemra[1] · Abdelkader Ouali Mehadji[1] · Axel Munnecke[2] · Salim Belkhedim[3] · Lahcen Belkebir[1]

Received: 28 August 2018 / Accepted: 25 February 2019

Abstract
Carbonate concretions have been recorded in many recent and ancient marine sediments around the world. The Middle Miocene marl of the Tenes area, situated in the northeast of the Lower Chelif Basin in NW-Algeria, contains such carbonate concretions but with a variety of different structures and morphologies. Three different basic types are distinguished: nodular (spheroidal, ellipsoidal, disc, and irregular), stratiform, and tubular concretions, the last locally have a central conduit. The close association between carbonate concretions and synsedimentary deformation structures (synsedimentary faults, slumps) and normal faults, pronounced in the Ounsour Anhas outcrop, indicates synsedimentary instability related to upward fluid movement. The concretions were formed by precipitation of micritic carbonate within the host marl at shallow burial depth, probably in the active microbial methanogenesis zone. Strongly varying δ^{13}C values (−9.82 to +5.85‰ PDB) are interpreted as the result of the balance between ^{13}C-enriched (residual CO_2 from methanogenesis) and ^{13}C-depleted (microbial organic matter decomposition) CO_2 added to the pore solutions. δ^{18}O values (−2.39 to + 1.71‰ PDB) indicate that carbonate concretion growth occurred during early diagenesis conditions, from marine-derived pore-water.

Keywords Carbonate concretions · Nodular limestone · Synsedimentary instability · Methanogenesis · Tenes · Algeria · Lower Chelif Basin

Introduction

Selectively lithified parts of sediment with roundish to ovoid or tube-like structures are often referred to as "concretions" or "nodules". In the literature, the distinction between these two terms is not straight forward. Usually, "nodules" form a major part of a specific rock (e.g., in "nodular limestone") but a single nodule commonly does not show a nucleus. They usually form early in the shallow subsurface by precipitation of minerals (commonly calcite or quartz), within the sediment, as, for example, chert nodules in limestone. In contrast, "concretions" tend to form some sort of more erratic "components" within sediment (e.g., Campbell et al. 2002; Conti et al. 2004; Pierre and Rouchy 2004; De Boever et al. 2006; Campbell et al. 2008; Nyman et al. 2010; Oppo et al. 2015; Viola et al. 2017). Concretions can be assigned to a specific origin because they either show a distinct nucleus in the center such as a fossil, or they are somehow related to specific pathways of fluid, e.g., seep-related carbonate concretions, well documented from many recent marine settings (e.g., Stakes et al. 1999; Dìaz-del-Rìo et al. 2003; Campbell et al. 2010; Roberts et al. 2010; Wehrmann et al. 2011; Nehza et al. 2012; Pierre et al. 2014). In cold seep provinces, the precipitation of authigenic carbonate responsible for the growth of the concretions usually occurs within the sediment at shallow burial depths. Precipitation of authigenic carbonate may be related to microbially mediated anaerobic oxidation of methane (AOM) and sulfate reduction (SR) at or near the seafloor (Peckmann et al. 1999; Campbell 2006). Strongly ^{13}C-depleted signatures indicate the influence of thermogenic (−30 to −50‰ PDB) or biological (−50 to

Abdelkrim Nemra
nemra.a14@gmail.com

Salim Belkhedim
saligeol@gmail.com

1 Laboratoire de Paléontologie Stratigraphique et Paléoenvironnements, Université Mohamed Ben Ahmed Oran 2, El-M'naouer, BP 1524, 31000 Oran, Algeria

2 GeoZentrum Nordbayern, FG Paläoumwelt, Loewenichstr. 28, 91054 Erlangen, Germany

3 Laboratoire de Géodynamique des Bassins et Bilan Sédimentaire, Université Mohamed Ben Ahmed Oran 2, Bir El Djir, BP 1524, 31000 Oran, Algeria

Published online: 13 March 2019

Geol. Mag. **153** (*3*), *2016, pp. 357–387.* © *Cambridge University Press 2015*

doi:10.1017/S0016756815000345

A trilobite faunule from the Lower Devonian of the Saoura Valley, Algeria: biodiversity, morphological variability and palaeobiogeographical affinities

AHMED YACINE KHALDI*, CATHERINE CRÔNIER‡†, GAUTIER HAINAUT‡, ABDELKADER ABBACHE§ & ABDELKADER OUALI MEHADJI*

*Laboratoire de Paléontologie stratigraphique et paléo-environnements, Université d'Oran, boîte postale 1524, El-M'naouer 31000 Oran, Algérie
‡UMR8198, EvoEcoPaleo-CNRS, Université Lille 1, UFR Sciences de la Terre, 59655 Villeneuve d'Ascq Cedex, France
§Université de Mascara, Faculté SNV, Algérie

(*Received* 13 January 2015; *accepted* 1 May 2015; *first published online* 21 July 2015)

Abstract – Trilobites are widespread in Lower Devonian deposits of north Gondwana, and some have been collected from two known sections of the Saoura Valley in SW Algeria, from the 'Chefar el Ahmar' Formation. This formation is considered to be from late Emsian to Frasnian in age, but only the lower parts of this formation have yielded trilobites. Nevertheless, no detailed studies have focused on their biodiversity and their morphological variability. New occurrences of phacopids including *Barrandeops chattertoni* sp. nov., *Geesops fabrei* sp. nov., *Austerops legrandi* sp. nov. and *Phacops boudjemaai* sp. nov. are described from this area and comparisons are made with closely allied species. These new occurrences have been integrated into analyses of intra- and inter-specific variability and biodiversity.

Keywords: Phacopida, Proetida, Chefar el Ahmar Formation, Emsian, Ougarta, diversity, palaeogeography.

1. Introduction

Throughout the lowermost Devonian, trilobite diversity is relatively poor. The Basal Pragian Event of regressive character contributed to the installation of shallow marine realms with carbonate sedimentation favourable for trilobites. This led to an increase in the generic diversity and, at least, to a preservation of the family diversity, which lasted with some changes until early Eifelian time (Chlupáč, 1994; Crônier & Van Viersen, 2007).

The publications of Alberti (1969, 1970, 1981), Morzadec (1997, 2001), Chatterton *et al.* (2006), McKellar & Chatterton (2009) and Gibb & Chatterton (2010) have been major contributions to our current knowledge of North African Lower Devonian trilobites.

The present paper is a contribution to the systematic study of the Lower Devonian trilobites and especially phacopid trilobites from SW Algeria. The discovery of new taxa assigned to *Barrandeops*, *Geesops*, *Austerops* and *Phacops sensu lato* gives us the opportunity to understand these forms more fully and to explore their palaeobiodiversity.

2. Geological setting and material

2.a. Local geological succession

In southwestern Algeria, beyond the Saharan Atlas and the High Zousfana, a mountain range of Palaeozoic age called the Mountains of Ougarta or the Ougarta Range appears. This folded domain links the Moroccan Anti-Atlas to the northwest and the hills of Bled El Mass and Tanezrouft to the southeast (Fig. 1). The Mountains of Ougarta, which extend over 400 km in length and 200 km in width, are elongated in a NW–SE direction and subdivided into two structural units consisting of folds with the same long axis, i.e. two 'beams', separated by the Erg Er Raoui: (1) a northern unit, i.e. 'beam of Saoura', constituted by anticlines that expose Cambro-Ordovician outcrops and synclines that expose Siluro-Devonian outcrops; and (2) a southernmost unit, i.e. 'beam of Daoura' also called Kahal Tabelbala, located to the east of the Pan-African sutures that exposes only Cambro-Ordovician outcrops (Menchikoff, 1933; Donzeau, 1983; Fabre, 2005).

The sampled material in the present study has been collected from two sections located in the beam of Saoura: (1) the 'Erg el Djemel' section located 70 km to the south of Beni-Abbès city and 7 km to the south of Ougarta village, and (2) the 'Marhouma' section called 'km 30', which is located 30 km to the SE of Beni-Abbès city and 5 km from the Marhouma oasis (Fig. 1). This 'km 30' section is used as reference for the lithostratigraphic correlations of the Devonian in North Africa (Le Maître, 1952; Boumendjel *et al.* 1997).

The Palaeozoic deposits of Saoura have been known since the beginning of the twentieth century (Gautier, 1902). However, the stratigraphy and the fauna of the Devonian only began to be described later (Menchikoff, 1930, 1932, 1933, 1936; Le Maître, 1952). Former

†Author for correspondence: catherine.cronier@univ-lille1.fr

Facies (2019) 65:12
https://doi.org/10.1007/s10347-019-0554-7

ORIGINAL ARTICLE

Challenging asymmetric cements as indicators of vadose diagenesis: "pseudo-gravitational" cements from the lower Pliensbachian of the Traras Mountains in NW Algeria

Salim Belkhedim[1,2] · Axel Munnecke[2] · Miloud Benhamou[1] · Abdelkrim Nemra[3] · Radouane Sadji[1]

Received: 18 August 2018 / Accepted: 17 January 2019

Abstract
Asymmetric, pendant cements are considered good indicators for early lithification in the vadose zone. In the present study, asymmetric cements are recorded in thin-sections of a Lower Jurassic limestone from the Traras Mountains (northwest Algeria). Geopetal fabrics, however, indicate that these seemingly "pendant cements" are, in some places, oriented upwards, i.e., they have grown in the opposite direction from that expected, or they grew from grains towards the pore centers. These observations disprove their origin as gravitational cements precipitated from pendant water droplets on the undersides of grains as in the vadose zone. In contrast, a formation in the marine phreatic zone seems more probable. Under high-energy conditions, and after an early lithification stage with isopachous cements in the subtidal zone, strong tidally driven horizontal pore-water flow allowed sufficient seawater to pass through the slightly cemented but still highly permeable rock. Those grain sides, which were oriented towards the pore center, where faster flowing water prevailed, were more exposed to $CaCO_3$-supersaturated percolating seawater and therefore the cements precipitated here show their greatest thickness. In relatively more protected areas around the margins of the pores, asymmetric cements are rarely developed. The resulting rock exhibits an unusual, heterogeneous cementation with preferential centripetal nucleation areas.

Keywords Geopetal fabrics · Horizontal permeability · Phreatic zone · Early lithification · Centripetal nucleation

Introduction

Microscopic studies of carbonate cements provide visual information with respect to the diagenetic environments in which the rocks have been lithified or altered (Schneidermann and Harris 1985). Isopachous needle-shaped (acicular or fibrous) cements distributed around sedimentary components with more or less equal thickness are interpreted as precipitated when the pores were completely filled with seawater, thereby indicating formation in subtidal conditions (e.g., Flügel 2010). Reliable indicators for an early diagenetic lithification in a vadose setting are meniscus cements and pendant cements, the latter also called gravitational, microstalactitic or dripstone cements (e.g., Scholle and Ulmer-Scholle 2003; Flügel 2010). In such environments, pores are only periodically and partially water-filled (e.g., Hood and Wallace 2012; Andrieu et al. 2018; Christ et al. 2018), and the selective collection of water on the undersides of grains as pendant droplets is driven principally by gravitational drainage (Tucker and Wright 1990; Collin et al. 2009). After multiple phases of drainage and precipitation, visible asymmetric cements will develop beneath the grains, in the same positions as occupied by the water droplets (Scholle and Ulmer-Scholle 2003; Moore 2004). Thus, the thickest part of the cements is directed downward, and they thin towards the upper sides of the grains. The mineralogy and thus the shape of the pendant cement crystals depends on the Mg/Ca ratio of the fluid from which they have been precipitated (Molenaar and Venmans 1993; Flügel 2010). In view of the high Mg/Ca ratio of seawater, pendent cements in the

✉ Salim Belkhedim
saligeol@gmail.com

1 Laboratoire de Géodynamique des Bassins et Bilan Sédimentaire, Université Mohamed Ben Ahmed Oran 2, 1524 El M'naouer, 31000 Oran, Algeria

2 GeoZentrumNordbayern, FachgruppePaläoumwelt, University of Erlangen-Nuremberg, Loewenichstr. 28, 91054 Erlangen, Germany

3 Laboratoire de Paléontologie Stratigraphie et Paléoenvironnement, Université Mohamed Ben Ahmed Oran 2, 1524 El M'naouer, 31000 Oran, Algeria

Published online: 04 February 2019

Journal of Sedimentary Research

Journal of Sedimentary Research, 2019, v. 89, 784–807
Perspectives
DOI: http://dx.doi.org/10.2110/jsr.2019.33

INTERPLAY OF AUTOGENIC AND ALLOGENIC PROCESSES ON THE FORMATION OF SHALLOW CARBONATE CYCLES IN A SYNRIFT SETTING (LOWER PLIENSBACHIAN, TRARAS MOUNTAINS, NW ALGERIA)

SALIM BELKHEDIM,[1,2] EMILIA JAROCHOWSKA,[2] MILOUD BENHAMOU,[1] ABDELKRIM NEMRA,[3] RADOUANE SADJI,[1] AND AXEL MUNNECKE[2]

[1]Laboratoire de Géodynamique des Bassins et Bilan Sédimentaire, Université Mohamed Ben Ahmed Oran 2, 1524 El M'naouer, 31000 Oran, Algeria
[2]GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, University Erlangen–Nuremberg, Loewenichstrasse 28, 91054 Erlangen, Germany
[3]Laboratoire de Paléontologie Stratigraphie et Paléoenvironnement, Université Mohamed Ben Ahmed Oran 2, 1524 El M'naouer, 31000 Oran, Algeria
e-mail: saligeol@gmail.com

ABSTRACT: **Meter-scale shallowing-upward cycles are recorded in many carbonate successions around the world. It is often difficult to recognize whether they represent autocycles, formed through intrinsic controls, or allocycles, resulting from orbital forcing or tectonic movements, or both. Here, we review the criteria used in the identification of the two types of cyclicity and apply them to two newly described lower Pliensbachian outcrops in the Traras Mountains, northwestern Algeria. Throughout the investigation of six sections, the deposits are suggested to have formed in intertidal–supratidal to shallow subtidal environments on a tropical ramp in the Western Tethys. In this area, shallowing-upward small-scale peritidal and subtidal cycles have been shown to be, and are assumed to be, ordered. The carbon isotope data mirror the recorded cycles and indicate different lengths of subaerial exposures. These cycles, in a developed within synrift setting, have been interpreted as produced mainly by autocyclic processes, but interacting with allocyclic factors. Peritidal cycles are thought to be generated by progradation of intertidal and supratidal flats into lagoonal sediments, while subtidal cycles are interpreted to have been controlled by lateral migration of shoals. The impact of the minor fluctuations of eustatic sea level is weakly marked, and only long subaerial exposure can reveal the contribution of these fluctuations to the formation of the recorded cycles. Tectonic movements resulting from spreading of the Tethys are interpreted to have controlled cycle distribution and thickness at a regional scale. However, synsedimentary tectonic features are rare in the studied area; this suggests that sediment transport would control the thickness and duration of cycles instead of the rate at which accommodation was created.**

INTRODUCTION

The formation of meter-scale shallowing-upward cycles can result either from allocyclic processes exerting external control or from autocyclic processes, which depend on the conditions controlling the depositional realm (Miall 1997; Schlager 2005; Catuneanu et al. 2011), or both. In shallow areas, where the distribution of facies is controlled mainly by topography, autocyclic factors seem to have been the dominant control on the formation of shallowing-upwards cycles (Strasser et al. 1999; Hillgärtner 1999). Such autocycles are typical of greenhouse periods. They could be generated through progradation of shorelines and islands (Ginsburg 1971; Hardie 1986; Demicco 1998; Burgess 2001, 2006; Burgess et al. 2001; Burgess and Wright 2003; Burgess and Emery 2004), by lateral migration of shoals, delta lobes, and tidal channels (Satterley 1996), or by changes in carbonate production (Burgess 2001; Yang and Lehrmann, 2014). They are sensitive to rates of subsidence, carbonate productivity, and sediment transport (Burgess 2001), but they are assumed to generate only peritidal shallowing-upward discontinuous cycles, which lack long subaerial exposure in the subtidal zone (Osleger 1991; Strasser et al. 1999). Allocyclic processes generate changes in accommodation space, driven by Milanković orbital forcing or by repeated synsedimentary faults, giving rise to cycles most readily recorded in shallow subtidal and peritidal facies. Orbitally controlled cycles reflect high-amplitude sea-level changes due to glacio-eustatic fluctuations. They are well expressed, especially during icehouse periods (Goldhammer et al. 1990; Lehrmann and Goldhammer 1999; Strasser et al. 1999), and are often characterized by high lateral continuity, correlatable at the regional scale. They also display the superimposition of supratidal facies upon subtidal facies (Miall 1997; Tresch and Strasser 2011). In contrast, discontinuous cycles are thought to be controlled by tectonic factors. Because tectonic movements can generate subsidence and uplift, and thereby control changes in the accommodation space at the local scale, the number of cycles, as well as their type and thickness, should change from one section to another (De Benedictis et al. 2007). Besides their nature (autogenic and/or allogenic), the identification of cycles should be carefully processed by qualitative analysis (Fisher plots and facies analysis), accompanied by quantitative analysis (bundle testing, runs testing, and time-series analysis), to see whether the strata are ordered or disordered (e.g., Wilkinson et al. 1997; Burgess 2016a, 2016b).

Many studies have been undertaken on Sinemurian platforms in Western Tethys, either on a regional scale (Bosence et al. 2009) or on a local scale (Hamon and Merzeraud 2008; Bádenas et al. 2010), and tectonic factors were used to explain the occurrence of discontinuous shallowing-upwards

Published Online: August 2019
 1527-1404/19/089-784

doi:10.1017/S0016756814000715

Frasnian (Late Devonian) conodonts and environment at the northern margin of the Algerian Sahara platform: the Ben Zireg section

ABDESSAMED MAHBOUBI*, RAIMUND FEIST*, JEAN-JACQUES CORNÉE†, ABDELKADER OUALI MEHADJI‡ & CATHERINE GIRARD*§

*Institut des Sciences de l'Evolution, Université Montpellier 2, CNRS, IRD, CC064, Place Eugène Bataillon, Montpellier Cedex 05 (France)

†UMR 5243 CNRS, Université Montpellier 2, Geosciences Montpellier, Place Eugène Bataillon, 34095 Montpellier Cedex 05 (France)

‡Département des Sciences de la Terre, Université d'Oran, Es Sénia, Oran (Algérie)

(*Received* 10 April 2014; *accepted* 5 November 2014)

Abstract – The Ben Zireg anticline NW of Bechar yields the currently most-important Frasnian succession on the northern margin of the Algerian Sahara. It represents 26.5 m of calcilutites which are attributed to the middle–late Frasnian. As the early Frasnian is not represented, the succession rests conformably on undifferentiated, probably late Givetian, substrate. Fine-scaled conodont biostratigraphy reveals a continuous sequence of Montagne Noire Zones 5–13, superseded by the earliest Famennian Lower *triangularis* Zone. The deposits are organized into 15 sedimentary cycles that are initially condensed and become dilated upwards. Conodont biofacies indicate an overall deepening towards the top of the section with an episode of slight shallowing at the MN11/12 transition marked by an increase of ancyrodellids, which is also seen in the Marhouma section of the Ougarta region (SW Algeria). Homogeneous calcareous microfacies with only a few shaly intercalations determine a predominantly oxygenated depositional environment on an outer platform, submarine rise or ramp setting. This is also indicated by relatively low sedimentation rates which are similar in selected sections from the Tafilalt platform, and contrast with those from the Marhouma trough and the Maider basin. Unlike other Frasnian successions south of the Atlas Fault, but similar to the Moroccan Meseta, the Upper Kellwasser horizon is clearly discriminated at Ben Zireg by an outstanding occurrence of black shales on top of the oxygenated latest Frasnian deposits.

Keywords: Frasnian, conodont biostratigraphy, biofacies, depositional environment, NW Algerian Sahara.

1. Introduction

The Ben Zireg area at 50 km NE of Bechar township constitutes the north-easternmost exposure of Saharan Palaeozoic deposits adjacent to the Main Atlas Fault. They differ from all neighbouring outcrops of the Bechar basin, such as Soltane el Betoum and Maider el Mhadjib to the north and west of Djebel Antar (Weyant, 1988) (Fig. 1a), in comprising a well-exposed, almost complete, succession of Cambro-Ordovician – early Carboniferous marine sediments. As such, the Ben Zireg section is a reference for the northern margin of epi-continental Sahara in SW Algeria, at 200 km from the Palaeozoic sediments of the Ougarta region further to the south (Fig. 1a). A major description of the structure and stratigraphy by Pareyn (1961) was mainly devoted to Carboniferous sediments; apart from a few other scattered Devonian (Frasnian in particular) stratigraphic data, this area has remained largely unstudied in terms of biostratigraphical subdivision and sedimentary development.

§Author for correspondence: catherine.girard@univ-montp2.fr

After the first recognition of Devonian fossils at Ben Zireg by G.B.M. Flamand (unpub. thesis, University of Lyon, 1911), Menchikoff (1936) established the existence of Late Devonian series based on cephalopods. Among them, *Pharciceras* was considered at that time representative of the early Frasnian period. However, this taxon is now restricted to the latest Givetian period since the definition of Frasnian stage boundaries by SDS/IUGS (Klapper, Feist & House, 1987; Klapper *et al*. 1993). The presence of Frasnian strata was definitely established when Massa, Combaz & Manderschied (1965) recovered the first conodonts, notably *Ancyrognathus asymmetricus* and *Ancyrodella curvata*.

Since then, and in contrast to numerous conodont-based biostratigraphical investigations in the neighbouring Tafilalt area (e.g. Belka *et al*. 1999), no more work has been carried out to evaluate the extent and completeness of the lower Upper Devonian sediments in the Algerian part of northern Sahara.

This study aims to provide fine-scaled conodont biostratigraphy and biofacies. The sedimentary dynamics of the Ben Zireg section emphasizes the importance of its pivotal position between Frasnian sections on