CHAPTER 4

A Palaeontological Review of the Devonian and Carboniferous Succession of the Murzuq Basin and the Djado Sub-Basin

MICHAL MERGL\(^1\) and DOMINIQUE MASSA\(^2\)

ABSTRACT

This chapter presents a synthesis of several palaeontological studies, mostly published in French, on the Devonian and Carboniferous faunas and biostratigraphy of the Murzuq Basin and its southerly extension, the Djado Sub-basin.

Lower Devonian formations outcrop extensively along the western flanks of the Murzuq Basin. The Tadrart Formation (Lochkovian/Pragian) shows a characteristic ichnofacies, but no diagnostic macrofaunas have yet been found. The more fossiliferous Ouan Kasa Formation (Emsian) was originally defined in the eastern parts of Jabal Akakus. Both formations are recognised over a distance of about 400 km as far south as the Djado Sub-basin.

The best and most fossiliferous Middle and Upper Devonian sections are located near Awaynat Wanin, on the western flanks of the Gargaf Uplift. Faunal and stratigraphical correlations of these sections with those in the nearby Wadi ash Shati area, on the northern flank of the Murzuq Basin, are good. The stratigraphic framework for this succession has been established in accordance with presently accepted stage divisions:viz. the Eifelian, Givetian, Frasnian and Famennian. The succession was mostly deposited in shallow water environments where brachiopods dominated the benthic communities; about 60 brachiopod species and several bivalves have been described from these communities. Some of the studies reported herein deal with the faunas collected in the Tahara and Ashkidah formations (Lower Touraisian).

Palaeontological studies have proved to be very useful for geological mapping and have given a better understanding of the major late Devonian transgression that occurred during the deposition of the Dabdab and Talagrouna formations, both of late Frasnian age. The consequent onlap is well documented in the Murzuq Basin and is now also demonstrated herein in the Djado area.

The Murzuq Basin and Djado Sub-basin show a subcontinuous belt of Carboniferous exposures along their flanks, but detailed knowledge of this succession is still uneven. For instance the Wadi ash Shati outcrops, located on the basin’s northern flank, are stratigraphically limited. The northwesternmost Murzuq Basin – the Zaghir area located west of the Awbari Sand Sea – shows the best Carboniferous exposures. The

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Carboniferous Illizi/Zaghir Basin covers an area of about 180,000 km². Several field studies carried out during the sixties were mainly devoted to the Carboniferous macrofaunas of this basin in eastern Algeria. In Libya, more recent papers have described the palaeontological and stratigraphical aspects of this succession. Three Carboniferous units – the Marar, Assedjefar and Dembaba formations show a maximum cumulative thickness of about 1000 to 1200 m. Macro- and microfaunas have been used to define thirteen biozones from the Upper Tournaisian to the Lower Moscovian in the Zaghir area.

The first major Carboniferous transgression is dated as late Tournaisian by a rich and diversified fauna including brachiopods and goniatites with Muensteroceras. The Upper Visčan is characterised by ammonoids such as Beyrichoceras hodderense and Goniatites striatus, together with ‘Collenia’ type stromatolitic build-ups. The Upper Marar contains several endemic brachiopods. The Namurian (Assedjefar Formation) is well defined by goniatites such as Neoglyphioceras, Cravenoceras and Anthracoceras, while many other macrofaunas have little stratigraphic significance. The carbonates of the Dembaba Formation mark the last marine Carboniferous transgression in this area. This episode is highlighted by the presence of large nautiloid cephalopods such as Metacoceras and Domatoceras together with cosmopolitan brachiopods known from America to China.

The Zaghir Carboniferous sections provide a biozonation that can be applied throughout the whole southwestern Libyan Province. There are gradual facies changes southwards towards the Djado Sub-basin, where the basal Marar Formation is the most fossiliferous part of the succession and represents the first marine Carboniferous transgression, as in the Murzuq Basin. The last marine transgression also reached the far south of the Djado Sub-basin, but the southern equivalent of the Dembaba Formation does not contain carbonates: these are replaced by sandstones alternating with green and red shales. The whole Carboniferous succession of the Djado area contains low diversity benthic communities with affinities to similar early Carboniferous platform faunas of North America, Russia and Australia.

INTRODUCTION

This chapter presents a regional review of the Devonian and the Carboniferous succession in the large area extending through western Libya and the Murzuq Basin to the northeastern Niger Djado Sub-basin.

The review takes into account several publications concerning the Carboniferous stratigraphy, macro- and micropalaeontology of the Algerian Illizi Basin and of the flanks of the Murzuq Basin in Libya. Stratigraphical field sections are also presented from the Djado Sub-basin for the first time. These are supplemented by an overview of the Carboniferous succession drilled in two old boreholes in the central Djado Sub-basin (KR1 and KO1). In this way the Devonian and Carboniferous succession extending over a large part of the central Sahara is now described and discussed in modern stratigraphic terms. Old collections from the first stages of exploration have also been restudied and revised.

In Western Libya, previous works have provided correlations in accordance with European stratigraphical standards (the Ardenno-Rhenish and Bohemian successions). Moreover, complementary studies of Devonian conodonts, present in the calcareous facies, have proved to give valuable biostratigraphic information. Studies of selected core chips established correlations between surface and subsurface developments of the Awaynat Wanin Group and the Ouan Kasa Formation (Weyant and Massa, 1985). Another interesting and useful microfossil group is
<table>
<thead>
<tr>
<th>AWAYNAT WANIN OUTCROPS</th>
<th>ASH SHATI OUTCROPS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARBONIFEROUS</strong></td>
<td></td>
</tr>
<tr>
<td>MASSA (1988)</td>
<td></td>
</tr>
<tr>
<td>Mrar Formation</td>
<td>Thickn. M.</td>
</tr>
<tr>
<td>679 m.</td>
<td>Visean</td>
</tr>
<tr>
<td>Tahara Formation</td>
<td>Age</td>
</tr>
<tr>
<td>60 m.</td>
<td>Upper Tournaisan</td>
</tr>
<tr>
<td><strong>UPP. DEVONIAN, LOW. Tournaisan</strong></td>
<td></td>
</tr>
<tr>
<td>Ouenine IV (A.O.IV)</td>
<td>Thickn. M.</td>
</tr>
<tr>
<td>42 m.</td>
<td>Famennian</td>
</tr>
<tr>
<td>Ouenine III (A.O.III)</td>
<td></td>
</tr>
<tr>
<td>68 m.</td>
<td>Upper Frasnian</td>
</tr>
<tr>
<td></td>
<td>Lower Frasnian</td>
</tr>
<tr>
<td>Ouenine II (A.O.II)</td>
<td></td>
</tr>
<tr>
<td>80 m.</td>
<td>Lowermost Givetian</td>
</tr>
<tr>
<td></td>
<td>Frasnian</td>
</tr>
<tr>
<td>Ouenine I (A.O.I)</td>
<td></td>
</tr>
<tr>
<td>46 m.</td>
<td>Eifelian</td>
</tr>
<tr>
<td><strong>LOWER - MIDDLE DEVONIAN</strong></td>
<td></td>
</tr>
<tr>
<td>Qurbanash Formation</td>
<td></td>
</tr>
<tr>
<td>22 m.</td>
<td>Emsian Pragien</td>
</tr>
<tr>
<td>Tadragat Formation</td>
<td></td>
</tr>
<tr>
<td>32 m.</td>
<td>Pragien Lochkov</td>
</tr>
</tbody>
</table>

**LOWER / MIDDLE SILURIAN**

Figure 1. Devonian correlation between the Awaynat Wanin and Wadi ash Shati areas (from Mergl and Massa, 1992).

represented by the tentaculitids, which are well represented in Devonian marine strata of western Libya, both in outcrop and the subsurface (Hajlasz et al., 1978).

More recent publications include the doctorate thesis by Massa (1988) that includes two chapters on the Devonian and the Carboniferous succession and a monograph on Devonian and lower Carboniferous brachiopods and bivalves from western Libya by Mergl and Massa (1992).

Field and drilling operations were carried out from 1957 to 1963 in the Djado Sub-basin by the Bureau de Recherches Pétrolières (BRP) and its subsidiary companies. A geological map on the scale 1:500 000 was one of the results of this work: this was edited and produced by B. Plauchut, BRP's geologist and Party Chief at the time (Plauchut and Faure, 1959). The present authors have revised and clarified the stratigraphical results obtained by the BRP teams, so new correlations can now be proposed between Libya and northern Niger. These new studies clearly demonstrate that the Djado Sub-basin is an extension of the Murzuq Basin.

**DEVONIAN**

Gargaf – Outcrops of the Awaynat Wanin Group and Wadi ash Shati ‘Series’

Figure 1 shows the stratigraphic correspondence between the two complementary charts used in our contribution. Both are important:
The Awaynat Wanin exposures in the type area on the southern margin of the Ghadames Basin can be applied to subsurface data from the northern part of the basin. The original Aouinet Ouenine Formation of Lelubre (1946) was revised and redefined by several workers until Massa and Moreau-Benoit (1976) suggested raising the unit to group level and introduced a series of informal units named Aouinet Ouenine I to IV. We will here refer to the Awaynat Wanin Group using Libyan orthography, but still term the informal subdivisions as AO I to IV. The whole Devonian succession thickens significantly northwards and in the Ghadames Basin there is a complete Lower Devonian development and all four mid/upper Devonian units (AO I, AO II, AO III and AO IV) can be recognised (Mergl and Massa, 1992). The outcrops around Awaynat Wanin are 330 m thick, while the succession in the centre of the Ghadames Basin is more than 900 m thick.

The second chart concerns the Wadi ash Shati area, from B‘ir-al-Qasr in the west to Brak in the east. A local nomenclature was established for geological mapping of the 1:250 000 sheets ‘Idri’ and ‘Sabha’ (Seidl and Röhlisch, 1984; Pařízek et al., 1984). As shown in Fig. 1, satisfactory regional stratigraphic correlations can be made between the outcrops to the west and south of the Gargas uplift.

Figure 2 is an up-to-date version of the Awaynat Wanin section, which was considered by Bellini and Massa (1980) as the best locality to serve as a Devonian reference section for the Libyan Ghadames Basin. The granulometric log is a valuable tool to trace the sedimentary evolution of successive Devonian units and the whole Devonian appears to be represented. The lower Devonian forms a single 54 m thick fossiliferous megasequence. Dating is based on correlations by Massa (1988) with subsurface data in the central Ghadames Basin. The 225 m thick middle and upper Devonian development is richly fossiliferous (Plates 1 and 2).

A reference section in the western part of Wadi ash Shati has been selected from near the town of Idri (Fig. 3). This location is most suitable for two reasons, as far as the northern Murzuq Basin is concerned: the mid and upper Devonian is complete and thick (175 m) and richly fossiliferous horizons in the basal B‘ir-al-Qasr Formation have a clear Eifelian age (Plates 3 and 4). It is important to note the absence of the lower Devonian in this area. The presence of the ‘Lower Bifungites Marker’ (L.B.M.), which is also present in the Awaynat Wanin area in the lower Frasnian, should also be noted (compare Figs. 2 and 3).

**Ghat Area**

The lower Devonian extends over the whole of the western Libyan Ghadames and Murzuq basins and is also developed in the Djado Sub-basin. It comprises two units that together form a single megasequence, viz. the sandstone-conglomerate Tadrart Formation and shales and siltstones of the Ouan Kasa Formation. This megasequence has been correlated to the Lochkovian/Pragian/Emmsian stratigraphic interval (Massa, 1988). It shows similar thicknesses of around 350 m throughout the western Murzuq and the northern Ghadames basins and subsidence of the two basins may have been roughly comparable during this time.

**Ghat–Tadrart Formation**

The Tadrart Formation outcrops in a continuous belt along the western flank of the Murzuq Basin and into its southern extension – the Djado Sub-basin of northern Niger. This is clearly shown in the map of Plauchut and Faure (1959). This Devonian exposure belt is also apparent on the simplified map shown in Fig. 4 that demonstrates the connection between southwestern Libya and northern Niger. On this western basinal flank, the Ouan Kasa Formation conformably
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#### DEВONIAN OF W. LIBYA

**TYPE SECTION**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>M'RAR Formation</td>
<td>UPP. Tournaisian</td>
</tr>
<tr>
<td></td>
<td>L.B.M.</td>
</tr>
<tr>
<td>TAHARA Formation</td>
<td>MID. Tournaisian</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>OUENINE IV Formation (AO IV)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L.B.M.</td>
</tr>
<tr>
<td>OUENINE III Formation (AO III)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frasnian L.I.</td>
</tr>
<tr>
<td>OUENINE II Formation (AO II)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Givetian L.I.</td>
</tr>
<tr>
<td></td>
<td>and Basal Frasnian</td>
</tr>
<tr>
<td>OUENINE I Formation (AO I)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eifelian L.I.</td>
</tr>
<tr>
<td>OUAN-KASA Formation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emsian L.I.</td>
</tr>
<tr>
<td>TADRART Formation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lochkovian / Pragian</td>
</tr>
<tr>
<td></td>
<td>Lower Silurian</td>
</tr>
</tbody>
</table>

#### AWAYNAT-WANIN OUTCROPS

**FAUNAS**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L.B.M.</td>
</tr>
<tr>
<td>Upper Bifungites Marker</td>
<td></td>
</tr>
<tr>
<td>Brach. Acanthatisa sp.</td>
<td></td>
</tr>
<tr>
<td>Cupularostrum sp.</td>
<td></td>
</tr>
<tr>
<td>Libyaerhynchus sp.</td>
<td></td>
</tr>
<tr>
<td>Blw. Nuculolidea, Posidonia</td>
<td></td>
</tr>
<tr>
<td>Ptychopteria</td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Bivalves Posidonia sp.</td>
<td></td>
</tr>
<tr>
<td>Brach. Schuchertella sp.</td>
<td></td>
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<tr>
<td>Cyphosarorhynchus talagounai</td>
<td></td>
</tr>
<tr>
<td>Cupularostrum sp.</td>
<td></td>
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<tr>
<td>Cyctaspirifer sp.</td>
<td></td>
</tr>
<tr>
<td>Septothyris boucoti</td>
<td></td>
</tr>
<tr>
<td>Brach. Rhyssochonetes 7 sp.</td>
<td></td>
</tr>
<tr>
<td>Eumetabolotoechia longiqua</td>
<td></td>
</tr>
<tr>
<td>Lower Bifungites Marker</td>
<td></td>
</tr>
<tr>
<td>Brach. Rhipidomella sp.</td>
<td></td>
</tr>
<tr>
<td>Leptaena, borghiana</td>
<td></td>
</tr>
<tr>
<td>Devonochonetes salemi</td>
<td></td>
</tr>
<tr>
<td>D. postremus,</td>
<td></td>
</tr>
<tr>
<td>Dichacoenia sp.</td>
<td></td>
</tr>
<tr>
<td>Cupularostrum sp.</td>
<td></td>
</tr>
<tr>
<td>Rhipidothyris barrois</td>
<td></td>
</tr>
<tr>
<td>Eumetabolotoechia longiqua</td>
<td></td>
</tr>
<tr>
<td>Libyaerhynchus fragosus</td>
<td></td>
</tr>
<tr>
<td>M. busrewii, M. mundus, M. hastatus,</td>
<td></td>
</tr>
<tr>
<td>Adolfa termicercae,</td>
<td></td>
</tr>
<tr>
<td>Cyctaspirifer precursor,</td>
<td></td>
</tr>
<tr>
<td>C. ratus Blw. Nuculites,</td>
<td></td>
</tr>
<tr>
<td>Leipteris, Leptocephala,</td>
<td></td>
</tr>
<tr>
<td>Actinodesma, Sphenatius,</td>
<td></td>
</tr>
<tr>
<td>Tropidoleptus sp. Cupularoskrahna,</td>
<td></td>
</tr>
<tr>
<td>Devonochonetes sp. Spinyctes magnus,</td>
<td></td>
</tr>
<tr>
<td>Spinyctes sp.</td>
<td></td>
</tr>
<tr>
<td>Brach. Rhipidomella sp.</td>
<td></td>
</tr>
<tr>
<td>Cupularostrum ruga,</td>
<td></td>
</tr>
<tr>
<td>Brachiopod Abyris sp.</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2.** Devonian succession in Awaynat Wanin, southern Ghadames Basin (from Massa, 1988).
overlies the Tadrart Formation’s sandstones (Fig. 5). The stratigraphic position of the Tadrart Formation has been mainly based on its ichnofacies and its relation to under- and overlying units. A notable regional sedimentological synthesis was carried out by Clark-Lowes (1985) on the Libyan western basinal flank, where the unit is about 300 to 350 m thick. Some

<table>
<thead>
<tr>
<th>MRAR FORMATION - UPPER TOURAISIAN</th>
<th>IDRI - TYPE SECTION</th>
<th>ASH SHATI</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHKIDAH FORMATION (= TAHARA FM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOURAISIAN</td>
<td>Brach. Rhipidomella maharuga, Saharotes saharensis, Semiprotodictys bulbosus, Schuchertella cf. globosa, Cupuladictyon cupulatum, Stenocoma crumenum, Composita cf. megalia, Unispirifer unicus, Syringothyris cf. texta, S. sp.</td>
<td></td>
</tr>
<tr>
<td>DABDAB FM. (= UPP. OUELINE III)</td>
<td>40 m.</td>
<td></td>
</tr>
<tr>
<td>FRASNIAN</td>
<td>56 m.</td>
<td></td>
</tr>
<tr>
<td>GIVETIAN + FRASNIAN</td>
<td>40 m.</td>
<td></td>
</tr>
<tr>
<td>BIR-AL-QASR FORMATION (= OUELINE I)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EIFELIAN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3.** Devonian succession around Idr, western Wadi ash Shati area. northern Murzuq Basin (from Mergl and Massa, 1992).
supplementary data, with a more stratigraphic and regional aspect, were later presented by Massa (1988).

Ghat–Ouan Kasa Formation

The important Gour Iduka section (Fig. 5 and Plate 5) is located east of Ghat (approximate coordinates 24°35' N, 10°55' E). This locality displays the type section of the Ouan Kasa Formation, and is located close to the type section of the Tadrart Formation. The section contains a rich fauna that provided the first stratigraphic correlation of this unit (Massa, 1988).

The Emsian age assigned to this formation in the nineteen-sixties (Burollet, 1960) was based on identifications of *Arduspirifer arduennensis* (Schnur) and other varieties of *Arduspirifer* known in the Ardenno-Rhenish basin. The association displays a pre-Eifelian character, and the correlation suggests a dating in the upper part of the early Devonian (uppermost Praghian or Emsian *sensu lato*).

The Ouan Kasa Formation comprises a 40 m development of shales and silty shales alternating with fine sandstones and calcareous siltstones; the percentage of primary carbonate beds varies from 15% to 25%. As far as the faunas are concerned, the commonest species is the acrospiriferid brachiopod *Spinella paulula*; the genus *Spinella* is well known in the Emsian of

![Figure 4. Location map of the Murzuq Basin and its extension into Niger (from Meister et al., 1991).](image-url)
Australia and Nevada. The trilobite *Homalanotus (Dipleura) simplex* also indicates a general Emsian age. Some of the siltstones and fine-grained sandstones yield a wealth of tentaculitid species (Hajlasz et al., 1978) known elsewhere from the early Devonian, viz. *Vlajovites cf. antarcticus, Styliolina uralica* and *S. glabra*, together with a microfauna of the arenaceous

![Gour-Iduka (Ouan-Kasa) Section](image)

**Figure 5.** Devonian succession of Gour Iduka, western flank of the Murzuq Basin (from Massa, 1988).
foraminifera *Parathurammina* and *Irregularina*, which are primitive forms reported from the lower Devonian of Siberia.

**Ghat–Awaynat Wanin Group**

The Gour Iduka section also shows good exposures of apparently conformably overlying Middle to Upper Devonian fossiliferous strata. The succession, as shown in Fig. 5, commences with Awaynat Wanin units I and II, which are about 80 m thick. Brachiopods have been collected from unconsolidated sandstones in the upper parts of this section: the occurrence of *Spionocyrtia ostiolata* confirms correlation to the Givetian. The upper parts of the Gour Iduka section are found on a flat plain with only scattered outcrops and AO III and possibly uppermost unit IV are difficult to study. The exact thickness is unknown, probably 75 m. The abundance of *Bifungites* suggests that the Frasnian (AO III) is represented: this is the classic 'L.B.M.' horizon, also known in the Awaynat Wanin and Idri sections and on the eastern flank of the Murzuq Basin, both in outcrop and subsurface. The *Bifungites* ichnofacies is a good regional Frasnian marker usually associated with ferruginous oolites, as in the Gour Iduka section. The uppermost part of the section is considered as a possible but unconfirmed ‘AO IV’ equivalent.

In conclusion, overlying a complete lower Devonian section of about 350 m, the total thickness of the middle to upper Devonian could be 150 to 170 m. The relationship between the Tadrart and Ouan Kasa formations has previously been interpreted incorrectly. Klitzsch (1969) for example assigned a middle Devonian age to the Ouan Kasa Formation as also did Clark-Lowes (1985). Along the western flanks of the Murzuq Basin and in western Djado, from NW to SE spanning a distance of some 500 km, the lower Devonian megacycle is complete. The basal Tadrart Formation appears to pass continuously up into the Ouan Kasa Formation, which is open marine and its richly fossiliferous strata give a reliable Emsian dating. These units are overlain by middle Devonian strata in an apparently continuous section.

These considerations are important, first to appreciate the correct local relationships between the lower and middle Devonian strata and second to correctly determine the ages of the Devonian succession in wells drilled in the central parts of these two basins. Sometimes, for example, lower and middle Devonian strata are missing altogether and the Devonian succession starts with Frasnian transgressive strata.

**East Tihemboka–Talagrouna Formation Type Section**

An Upper Devonian outcrop of limited extent occurs on the eastern flank of the ‘Tihemboka Arch’ – a major structural feature in the Libyan-Algerian boundary area. The approximate coordinates of the type section are 26°08’ N, 10°23’ E.

This section (Fig. 6) is only about 20 m thick. It starts with coarse sandstones overlying middle Llandovery fossiliferous shales, followed by alternating sandstones and silts. The Upper Devonian is unconformably overlain by fossiliferous upper Tournaisian strata. The Devonian sandstones have yielded a rich and well-preserved marine fauna assigned to the *Cyphotherorhynchos* Community. Besides *Cyphotherorhynchos* itself, other common taxa include various bivalves and the brachiopods *Leioproductus*, *Cyclotryster* and *Septothyris boucoti*. A late Frasnian age for the Talagrouna Formation is also clearly suggested by its common tentaculitids (*Dicriconus*, *Multiconus*) described by Mergl and Massa (1992). In this section, the Famennian is absent either because of non-deposition or by erosion and removal during the Upper Tournaisian transgression. It is important to emphasize the transgressive character of the late Frasnian, because it marks a major palaeogeographic event. The Famennian unconformity has been recognized in the Wadi as Shati area (Collomb, 1962), in several wells in the Murzuq Basin
(unpublished reports), and in the northeastern Djado Sub-basin, both in outcrop (Jacqué, 1962) and the subsurface.

**Djado Sub-Basin**

The lower Devonian lithofacies on the western flanks of the Djado Sub-basin are so similar to southwestern Libya that the standard Libyan nomenclature may be applied.

![Talagrouna Type Section Diagram](image)

*Figure 6. Upper Devonian of the Talagrouna area, northwestern Murzuq Basin.*
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**Djado Sub-Basin–Tadrart Formation**

As in the Ghat area, the contact between the Akakus Formation and the basal Tadrart Formation is clearly visible as a palaeosol rich in plant and root fragments, often silicified, with a haematite enriched interface between the two units. This contact was first described by Freulon (1964) and it represents the main Caledonian unconformity in the area. This often shows an angular discordance of 2° to 5° between underlying and overlying units, but in one locality (near In Ezzan), the angular unconformity is reported to reach 45°.

The Tadrart Formation here shows the typical facies of cross-bedded or cross-laminated sands, coarse sandstones and granular to conglomeratic sandstones. Thinly bedded siltstones in the middle of the section show ripple-marks and an ichnofacies with the trace fossils *Fraena, Palaeophycus, Skolithos*, diverse bilobate fucoids, and rare *Spirophyton*. It is important to note the absence of large *Arthrophycus*, which is characteristic of the underlying Akakus Formation. Common plant fragments, possibly belonging to the psilophyte taxa *Arthrostigma* and *Aneurophyton* were reported by Clark-Lowes (1985).

**Djado Sub-Basin–Ouan Kasa Formation and Awaynat Wanin Group**

The Ouan Kasa Formation has been traced far to the south of the Djado area. Its main fossiliferous horizon has been located 50 km east of the Chirfa Oasis (20° 55’ N, 12° 43’ E), a distance of approximately 400 km from the Gour Iduka section. Both localities show similar lithofacies, with predominant purple shales and fine-grained sandstones, about 30 to 40 m thick.

The middle and upper Devonian Awaynat Wanin Group equivalent is about 150 m thick and consists of roughly equal amounts of shales and siltstones and fine-grained sandstones with common *Spirophyton* and *Skolithos* (= *Tigillites*). Other fossils have little stratigraphic value (bivalves, crinoids and plant fragments).

Detailed study will probably show this Devonian succession to be more fossiliferous than present knowledge suggests. The ‘*Spirophyton* ichnofacies’ is a valuable Devonian stratigraphic marker known in both the Murzuq and Djado areas. This ichnofacies is not known in the Silurian and the Carboniferous but occurs in the middle of the lower Devonian and is also common in middle and upper Devonian strata.

In conclusion, the Awaynat Wanin Group seems to be complete in the western Djado area. The uppermost strata could possibly be assigned to the Tahara Formation, but this correlation cannot be confirmed biostratigraphically. Several wells in the central Murzuq Basin have encountered Tahara sandstones (Al Muzughri and Al Magtouf, 1981).

**East and South Djado–A Brief Review**

Extensive outcrop areas favour the study of Devonian sequences in this sub-basin. The existing geological map (Plauchut and Faure, 1959) allows correct location of the large Devonian exposure belt in northern Niger.

The Silurian Akakus Formation is developed in its characteristic fine-grained sandstone facies, rich in *Arthrophycus* (= *Harlania*). The erosive contact to the overlying Tadrart Formation shows an angular discordance of 2° to 4°. The Tadrart Formation’s lithofacies are similar in both the Murzuq and Djado basins (cross-stratified coarse sandstones, conglomerates and even breccias). Previous important observations (e.g. Jacqué, 1962) demonstrate early Devonian synsedimentational faulting activity in the Tadrart Formation; this may explain the frequent and rapid lateral changes in thickness – from 10–20 m to 150 m.
Detailed study of the middle/upper Devonian Awaynat Wanin Group equivalent has not been possible. The general lack of marine faunas in all sections, with only the common trace fossil Spirophyton indicating marine conditions, does not allow any precise datings or correlations. Lateral thickness variations are also rapid in this succession, passing from 10 to 100 m within a few kilometres. Overall thinning occurs southwards to near the probable maximum southern extension of the Djado Sub-basin. The Frasnian transgression (AO III) is suggested in several sections by Frasnian strata resting directly on the Tadrart Formation. The lithofacies is predominantly shaly, often with dark grey shales and ferruginous oolites.

An alternative interpretation is that the Awaynat Wanin Group is not developed and that the lower Carboniferous basal Marar Formation directly overlies the Tadrart sandstones. These two alternatives support the concept of polyphased early and late Caledonian structural events.

**CARBONIFEROUS**

A monograph of Carboniferous macrofaunas in Libya was published by Massa et al. (1974). In addition, micropalaeontological studies have helped to establish a detailed stratigraphical framework in these areas. Specimens are not very abundant but are sufficiently common in the Illizi-Zaghir basinal sections; the three main groups studied are ostracods, foraminifers and conodonts. Ostracod assemblages were shown to provide useful stratigraphical and palaeontological information by Bless and Massa (1982). Conodont determinations by Weyant and Massa (1985) were supplemented by additional studies of Weyant and Massa (1991). Two publications deal with the foraminifera of the Carboniferous of Libya (Massa and Vachard, 1979; Vachard and Massa, 1984), both giving descriptions of microfacies containing algae and foraminifera that allow correlation between Libya and the Illizi Basin. Finally, Massa (1988) presented a synthesis of the whole Palaeozoic succession, including the Carboniferous.

Several recent publications have dealt with the Carboniferous of western Libya, which is now relatively well known. However, it should be noted that most of the petroleum exploration has been carried out in the Illizi Basin of Algeria so that the majority of early stratigraphical studies were published in French (Dubois, 1960; Remack-Petitot, 1960; Lys, 1979, 1985; Legrand-Blain, 1980, 1985a, 1985b, 1986; etc.). Until now the Illizi and Ghadames basins have been considered separately. In our view, however, these two basins were parts of the same depositional complex during Carboniferous times. Hence we propose the term ‘Illizi-Zaghir’ Basin for this whole 180 000 to 200 000 km$^2$ region. The wide plateau covered by the Awbari sand sea represents the Zaghir area (often spelled Zegher on old maps), which extends in an E-W direction (Fig. 7). The Carboniferous largely outcrops in this area and includes the Marar, Assedjefar and Dembaba formations in the southeastern Tinghir Hammad (Bellini and Massa, 1980). In the present review, two composite reference sections have been selected, one representing the Illizi Basin and the other the Zaghir area (Figs 8 and 9).

The most valuable macro- and microfaunas (mainly foraminifera and conodonts) are discussed herein in order to augment the data described previously and to strengthen the proposed datings of successions located on the western and eastern sides of the Algerian-Libyan border (Fig. 10). The stratigraphical nomenclature used in this paper refers to the classical Dinantian succession of Belgium for the Lower Carboniferous and to the terminology proposed by the International Carboniferous Congress (1975) for the marine Upper Carboniferous of the Russian platform. The Carboniferous development of western Libya has been defined on the basis of both outcrop and subsurface data and the total thickness of the five formations described herein is about 1000 to 1200 m, including the Perm-Carboniferous Tiguentourine Formation. These units were first described by Bellini and Massa (1980), later supplemented by Massa (1988).
In a regional perspective, correlation between the southern part of the Ghadames Basin and the northern and central parts of the Murzuq Basin are possible in the sense that lateral facies changes are generally gradual, particularly in the Marar and Assedjefar formations. However, the correlations become more doubtful in the upper Dembaba Formation because the marine carbonates present in the northern areas disappear near the Niger-Libya frontier, passing laterally into red shales and sandstones.

**Zaghir–Marar Formation**

The lower parts of the formation consist of about 50 m of dark grey shales and marls containing several fossils, including goniatites (section in Fig. 8). A black phosphatic bed, with nodules rich in radiolarites, is developed at the base. Higher up the facies is mainly shaly (80% green and dark grey shales) with minor fine-grained sandstones and siltstones that may be ferruginous and/or dolomitic.

Near Al Awaynat, on the northwestern flanks of the Murzuq Basin, the basal Carboniferous rests directly on Lower Devonian or Silurian strata with a well-defined unconformity. The faunas found in this area have been described by Massa et al. (1974). Our dating of an Upper Tournaisian age is confirmed by the brachiopod genus *Fusella* (the 'Spirifer tornacensis' group).

![Figure 7. Simplified map of the Illizi-Zaghir Carboniferous Basin.](image)
In the Wadi ash Shati area, equivalent faunas are assigned to the Prospira Community. An upper Tournaisian age is also confirmed by the presence of Muensteroceras and other goniatites (Fig. 8) discovered at the base of the Awaynat Wanin section of the Marar Formation. This section contains a faunal assemblage with both endemic and cosmopolitan elements, including fish fragments, bivalves, nautiloid cephalopods (Orthoceratidae), corals and crinoids. Among endemic forms, the brachiopods Histosyrinx and Septacamera (= Paurogastroderhynchus) have been found in a sandy lithofacies of beach origin. Both these taxa are of regional interest as they

**Figure 8.** Zaghir Carboniferous section: lithology and faunas (modified after Coquel and Massa, 1993).
also occur in the Upper Tournaisian of the northern and southern Hoggar (Legrand-Blain, 1974). This indicates that the basal Carboniferous marine ingestion was synchronous throughout the central and eastern Sahara.

The upper Marar Formation displays a monotonous succession of shales and marls with few fossiliferous horizons. Two significant taxa are *Beyrichoceras* and *Fluctuaria undata*, because they characterise the Upper Viséan stage, more precisely termed 'V3C' in the Belgian nomenclature (Fig. 8). This age is also supported by the occurrence of *Goniatites striatus*.

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**Figure 9. Illizi Basin – Carboniferous section: lithology and faunas (modified from Coquel and Massa, 1993).**
The ‘Collenia Bed’ contains 4 to 5 stromatolitic levels (each 0.5 to 1.5 thick), which are used as lithologic markers. Associated with these are micrites, dolomicrites, breccias, oolites, dolomitic shales and anhydrite in the form of cement or as nodules. The stromatolites indicate an intertidal or supratidal environment corresponding to lagoonal mud flats that were periodically flooded. Among the fossils of the Collenia Bed, two characteristic Saharan taxa, Neospirifer fasciostatus and Saharopteria (Pachypteria) are worth mentioning.

**Zaghir-Asedjefar Formation**

Cross-bedded sandstones characterise most of this formation while the upper third consists mainly of carbonates (packstones) and marls. Only two biozones have been identified because most of the lithofacies do not favour the preservation of macrofaunas. The lower biozone is

![Carboniferous stratigraphy in eastern Algeria and western Libya.](image-url)
characterised by the alge *Calcifolium punctatum* and the upper by the two foraminifera *Eostafellina* and *Eosigmoilina*. These clearly establish a Serpukhovian age (Belgian E1 and E2). Correlation with the type sections of the upper Assekaifaf and Oubarakat formations in the Illizi Basin is excellent because diagnostic goniatites such as *Cravenoceras*, *Neoglyphioceras* and *Anthracoceras* (Fig. 11) have been found in these formations.

**Zaghir–Dembaba Formation**

The Lower Dembaba Formation begins with oolitic limestones and green to red dolomitic marls, but green gypsiferous shales dominate the unit. Macrofaunas are poor but foraminifera (Fig. 8) indicate a Bashkirian age.

The lithology of the Upper Dembaba Formation is rather monotonous, with about 80% carbonates, but the microfacies developed are highly diversified (biopelmicrites, oolitic grainstones, wackestones, mudstones with several pyritised plant fragments, etc.). Macrofaunas are abundant, diversified and well preserved. The rich macrofaunal associations (Massa et al., 1974) and the microfauna shown in Fig. 8 clearly demonstrate a Moscovian age.

**The Illizi Basin**

The Carboniferous succession oversteps several levels of the Silurian and/or the Devonian from the west to the east in the Illizi Basin (Dubois, 1960). This basal unconformity is well defined in outcrops in the northern Tassili-n-Ajjer. Different formations were defined within the Carboniferous during the nineteen-sixties and the major stratigraphic units are now well established.

**Illizi–Issendjel Formation**

This formation is made up of marls, silty shales and sandy limestones, with sedimentological features resembling those described by Whitbread and Kelling (1982) in the deltaic Marar complex of the southern part of the Ghadames Basin. In the Illizi area, the base of the formation is dated as Upper Tournaisian and this is well constrained by the brachiopod association. Higher strata containing species of *Beyrichoceras* suggest a Middle Viséan age. Uppermost strata have been referred to as the ‘Mushroom sandstones’ because weathering and erosion have produced characteristic mushroom shaped outcrops.

**Illizi–Assekaifaf Formation**

The lower parts of this unit consist of marls and limestones including a *Collenia* stromatolitic horizon. In its upper parts a second ‘Mushroom sandstone’ horizon forms a good local marker. Both horizons are laterally extensive. Foraminifera discovered in the middle part of the formation, such as *Eostafella pseudostruvei*, indicate a Late Viséan to Early Serpukhovian age, which is also supported by a rich fauna of ammonoids and brachiopods (Fig. 9).

**Illizi–Oubarakat Formation**

The lower and middle members consist of silty shales with frequent limestone interbeds. Among the foraminifera, *Neoarchaediscus angulatus* indicates a late Serpukhovian age.
Figure 11. Typical Carboniferous succession, log from well A1–59, eastern Illizi-Zaghir Sub-basin (from Massa, 1988).
**Illizi–El Adeb Larache Formation**

The lower part of the formation is a thick shaly unit with several gypsum interbeds: it is dated to the Bashkirian from an association of foraminifera including *Pseudostafella antiqua* and *Eostafella chomatifera*. Carbonate facies dominate the upper part of the unit, with limestones and dolomites. An early Moscovian dating is based on foraminifer and conodont associations as well as large nautiloid cephalopods (*Domatoceras, Metacoceras* etc.).

Three biozones have been defined from the foraminiferal assemblages in the upper part of the Al Adeb Larache Formation (Massa and Vachard, 1979):

The *Aljutovella* Biozone of the Lower Moscovian,

The *Profusulinella* Biozone (also with the ammonoid *Eoparalegoceras*, dated as Kashirian,

The *Glomospirella* Biozone dated post-Kashirian and possibly Podolskian.

The uppermost biozone, containing *Hemigordus discoideus*, indicates a nearshore facies of Myatchkovian age. Following this last marine episode, the Carboniferous sea definitively retreated from eastern Algeria and western Libya.

**Illizi–Tiguentourine Formation**

The total thickness of this formation is about 200 m: its dating must be considered as tentative due the scarcity of fossils in the sediments. The following description is mainly based on the works of Fabre (1970) and Bertrand-Sarfati and Fabre (1972).

The lower part is made up of red and green shales with primary dolomites indicating a fluvial or lagoonal environment. The lower half contains thin layers of stromatolitic limestones rich in *Euestheria* (*E. simoni* and *E. tenella*) associated with palaeoniscid and selachian fish fragments. In the upper part, there is a massive gypsum bed (2 to 4 m thick) and reddish cross-bedded sandstones indicate a fluviaval environment with evidence of aeolian influence.

The lower part of the formation is assigned to the continental upper Carboniferous interval, while the upper part is given a general pre-Triassic (perhaps Permian) assignation. This correlation is partly based on the occurrence of unstable heavy minerals (disthene, hornblende, hypersthene) in the upper part of the formation: these might be related to the erosion of pre-Permian volcanics and are unknown in the lower part of the formation.

The lithofacies and thickness of the Tiguentourine Formation in the Zaghir area are very similar to those described in the Illizi Basin.

**Outcrops in Eastern Fezzan**

The Carboniferous succession largely outcrops in the eastern Murzuq Basin between 24° and 22° N in the Dor El Gussa area: the Carboniferous was first studied in this area by Lelubre (1948, 1952) and Jacqué (1962). The facies displayed here are comparable to those described in the Zaghir area (Massa, 1988) and lateral equivalents of the Marar, Assedjefar and Dembuba Formation are well developed.

**Eastern Fezzan–Marar Formation**

The base of this 450 m to 500 m thick development contains a ferruginous oolite with Carboniferous fossils (chonetids and *Septacamera*). The basal Marar Formation comprises about
60 m of shales with several dolomitic limestones and fine-grained calcareous sandstone interbeds. This horizon, which is an excellent marker southwards into the Djado Sub-basin, is dated to the late Tournaissian. Upsection there are coarse-grained yellow sandstones and green shales with some interbeds of fine-grained calcareous sandstones and ferruginous oolites; the ‘Mushroom facies’, already noted, has been found in some places. Despite the lack of faunas, the Marar Formation is considered as Viséan except for its base, which could be late Tournaissian in age.

*Eastern Fezzan–Assedjefar Formation*

This formation comprises a 60 m to 120 m succession of green shales and calcareous interbeds with brachiopods and bryozoans. Foraminifera and conodonts indicate a Serpukhovian (early Namurian) age.

*Eastern Fezzan–Upper Dembaba Formation*

This 70 m to 90 m thick unit comprises green to red-brown shales, sometimes gypsiferous, with lenses of sand- and siltstones. Two thick calcareous cliff-forming beds, slightly dolomitic, are highly fossiliferous. Conodonts indicate a Moscovian age (Weyant and Massa, 1985). Macrofaunas are represented by large nautiloid cephalopods such as *Domatoceras*, *Paradomatoceras* and *Ephippioceras*.

*Eastern Fezzan–Tiguentourine Formation equivalent*

This is represented by about 50 m of sandy red shales associated with barren red sandstones. These sediments are considered as equivalents of Unit JC-6/7 defined in the subsurface and outcrops of the central Djado Sub-basin.

*Outcrops of Eastern Djado*

To the south, towards border areas to northeastern Niger, thicknesses remain similar but there are some facies changes relative to the formations described from eastern Fezzan: limestones decrease in the Assedjefar and Dembaba formations and diagenetic cone-in-cone structures become more common, as also do sand and gypsum interbeds. All these features indicate that environments became less marine-influenced and more lagoonal in this direction.

We will now present a composite section for the eastern Djado Sub-basin of northern Niger, based on outcrops between 23° 30' and 23° N (Fig. 4).

*Djado Sub-Basin faunas*

In the late nineteen-fifties, French geological teams were assigned to a large-scale reconnaissance of the Djado area. Fossils collected in the course of this fieldwork were deposited in the Natural History Museum in Paris for palaeontological investigation. This original collection has now been partially retrieved, together with both geographic locations and measured field sections. Three main fossiliferous horizons were sampled during the field
reconnaissance (Fig. 12), viz. the Upper Tournaisian, Upper Viséan and the basal and middle parts of the Serpukhovian. All these samples, mostly associated with calcareous sandstones or limestones, have been restudied and these new palaeontological results are presented in the last part of this chapter.

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**COMPOSITE SECTION JADU (=DJADO) SUB-BASIN**

Figure 12. Composite section of Carboniferous outcrops in the Eastern Djado Sub-basin: lithology and faunas.
Eastern Djado–Marar Formation

The formation is about 450 m thick in this area. Its base, resting unconformably upon Devonian strata, is represented by conglomeratic sandstones and cone-in-cone limestones with various fossils. Brachiopods (mainly chonetids), bivalves, crinoids, gastropods and orthocone nautiloids are preserved in overlying green shales. Conodonts are also present. These fossiliferous strata are about 40 m thick. Fine-grained beige sandstones alternating with silty and more or less gypsiferous shales represent the upper part of the formation.

Eastern Djado–Assedjefar Formation

Marine influence is more apparent in this 160 m thick formation; oolitic limestones and *Collenia* (stromatolites) are common and the associated green shales contain primary gypsum. The formation can be dated to the Serpukhovian from two beds containing foraminifera.

Eastern Djado–Dembaba Formation

The base of this 80 m to 120 m thick development contains a marker horizon that is well known both from outcrops in eastern and southern Djado and in the subsurface from wells drilled in the centre of the sub-basin. This is called the ‘Blue Limestone Marker’ in the BRP reports but its lithological characteristics may differ from one area to another (*Collenia* beds or organic-rich limestones or gypsiferous limestone). In our composite section, it has not been possible to confirm the Moscovian age of this marker, although it is assigned to the Dembaba Formation. The dating of this formation in the area is essentially based upon foraminifers and conodonts discovered in another limestone in the same succession (Fig. 12).

The formation otherwise comprises red and white shales with a few blue to black limestone beds. It is thought to represent a lagoonal facies of Moscovian age. This assessment is essentially based on lithological correlation as no diagnostic fossils (only gastropods) have been found.

Eastern Djado–Tiguentourine Formation

This 100 m thick formation is assigned to the continental Upper Carboniferous. The sediments become increasingly sandy (fine red micaceous sandstones) upwards, with shaly interbeds. This unit may be a lateral equivalent of the Madama sandstone and is represented by unit JC-6 in the subsurface of the basin (see below).

The Subsurface of the Djado Sub-Basin

The most accurate data on the Carboniferous development in the subsurface of this area come from two boreholes:

‘Kourneida, (KR1)’, coordinates 22°40’50” N, 13°36’10” E, and
‘Kouana, (KO1)’, coordinates 22°40’04” N, 13°31’18” E.

These two wells are close to each other and can be easily correlated, so that lateral variations in the succession can be documented. Correlations with an outcrop in the south-central part of the sub-basin are also proposed (Fig. 13). A local lithostratigraphic scheme is proposed for the
Chapter 4

Djado Sub-basin, although the terminology for the interval between the Upper Tournaisian and the base Triassic (units ‘JC-1 to 7’ in ascending order, ‘J’ for Djado and ‘C’ for Carboniferous), is informal and based on well KR1.

Unit JC-1 (26 m from 1,337 m to 1,363 m): Upper Tournaisian

Micaceous black shales and siltstones are very fossiliferous, with chonetids and goniatites. This unit has locally been called the ‘Dada Shale’ based on an outcrop at 20°15’ N and 14°05’ E.

Unit JC-2 (463 m from 900 m to 1,337 m): Viséan

This unit consists of dark grey and black shales, often silty (90% of the unit), with some fine-grained sandstones. Some thick calcareous sandstones are well developed in the unit. A 2 m

Figure 13. Regional correlation of the southern Djado Sub-basin Carboniferous succession from subsurface and outcrop data.
thick carbonate bed containing gastropods (bellerophontids) found uppermost correlates approximately to the Viséan to Serpukhovian transition (Fig. 12).

*Unit JC-3 (247 m from 653 m to 900 m): Serpukhovian*

Unit JC-3 shows a similar general shale facies to the underlying unit, but with frequent interbeds of gypsiferous shales, fine-grained calcareous sandstones and siltstones. Some lignite and black plant fragments occur.

*Unit JC-4 (13 m from 640 m to 653 m): uppermost Serpukhovian to base Moscovian*

A white massive anhydrite bed that is a good regional marker and is tentatively dated to the Bashkirian overlies bluish limestones and shales. This unit has also been found on the eastern flank of the sub-basin. It should be noted that definite Bashkirian age strata have been confirmed only in the northwestern Murzuq Basin (Massa and Vachard, 1979).

*Unit JC-5 (245 m from 395 m to 640 m): Moscovian*

Red, brown, purple and yellow shales with a high sand content also have frequent interbeds of fine-grained calcareous sandstone and siltstone. Some silicification (chalcedony) takes the form of nodules or thin interbeds. Two carbonate grainstones (between 472 and 492 m) have yielded porcellaneous foraminifers including *Cornuspira turbulenta*, *Cornuspira parva* and *Globovalvulina minima*. This bed represents the last marine episode on the southern margins of the Murzuq Basin.

*Unit JC-6 (55 m from 345 m to 395 m): Lower Tiguentourine equivalent – probably upper Carboniferous*

White fine-grained sandstones, with interbeds of red plastic shales and sandstones with carbonate cement, are locally called the ‘Madama sandstones’ because they are exposed near and around Madama, a military fort in the central part of the basin. This facies is unfossiliferous and probably represents a continental environment.

*Unit JC-7 (74 m from 278 m to 345 m): Upper Tiguentourine equivalent – probably uppermost Carboniferous*

Red or violet plastic clays are often silty and contain black carbonate ooids rich in manganese oxide. A thin volcanic microbreccia was observed at 304 m in KR1. The age of this unit is unconfirmed, although it can probably be correlated to the uppermost Carboniferous or basal Permian Tiguentourine beds.

*Zarzaitine equivalent (77 m from 201 m to 278 m): Triassic*

Haematitic red shales and coarse sand and gravels (7 m) mark the unconformable contact with JC–7; the remainder of the unit comprises monotonous unconsolidated sands with quartzitic
gravels. In well KO1 (Fig. 6), a 315 m thick sandy shale succession overlies this unit. This is not dated but could be an equivalent of the Upper Zarzaitine and – in part – the Taouratine Formation of Jurassic age, both these units being well known in the Illizi Basin and in the subsurface of the central Murzuq Basin.

DEVONIAN AND CARBONIFEROUS PALAEOGEOGRAPHY OF W LIBYA AND NW NIGER

The regional stratigraphy of this enormous area, extending from southeastern Algeria to northeastern Niger and including two flanks of the Murzuq Basin, highlights the main palaeogeographic changes in the area during Devonian and Carboniferous times. Considering the size and nature of the study area, the brief summary below is necessarily tentative. We should also note that palaeobotanical and palynological studies, which have provided excellent results in the Palaeozoic of other North African basins, have not been included in this review.

The regional late Frasnian transgression represents one of the most important Devonian events in the region. This marine invasion of large areas has already been recognised by geologists working in Libya such as Collomb (1962) who described the ‘Chatti Formation’, Jacqué (1962) who described the ‘Meerschema Formation’ in the eastern Murzuq Basin and Massa (1988) who described the ‘Talagrouna Formation’ in western Murzuq. This late Frasnian transgression is now seen to have extended southwards into the Djado Sub-basin.

Structuring of present-day uplifts and arches was possibly initiated during the early to middle Devonian because sediments of this age are relatively thin or missing over these palaeostructures – although condensed deposits of mainly black radioactive shales do occur during major highstand periods, such as in the late Frasnian. The regional Famennian regression is more important in the Murzuq-Djado area than in the Ghadames Basin: this regression, well known over the whole African platform, was followed by renewed transgression in the Early Carboniferous (Conrad et al., 1986).

During the Upper Tournaisian a new transgression occurred in the central Fezzan region and it is worthwhile to note some differences between the flanks of the Murzuq-Djado area: the eastern Tibesti coast formed a large sandy flat and euxinic marine conditions were quickly established over the entire area. The basin’s western coast was different and morphologically varied, with embayments, islands and capes. This explains why the first Carboniferous sediments in this area may be palaeosoils, continental sands rich in plant fragments or ferruginous oolites (Chauvel and Massa, 1981).

The environments that prevailed southwards during the Viséan are increasingly continental in aspect, with monotonous sequences of sandstones, siltstones and shales in which alluvial conditions are indicated by carbonaceous shales with lignites and lycophyte fragments. These sediments were called ‘Viséen à Plantes’ by the first field geologists working in the Djado and are characterised by a lack of marine fossils and a high frequency of plant fragments such as lycophytes, lycopods and psilophytes.

Certain facies that are encountered only in the Viséan/Lower Namurian of the Djado Sub-basin highlight the continental character of this succession. These include concretionary limestones of travertine type indicating a lacustrine environment and caliche beds typical of soils in arid climates. Collenia stromatolitic beds have already been mentioned; these are laminated columnar structures resulting from periodic algal growth. They are known in the Illizi Basin (uppermost Viséan), in the Murzuq Basin (lower Serpukhovian) and in the Djado Sub-basin and cannot be considered as synchronous markers as they reflect purely local conditions in an overall generally tropical and humid environment; they may also be reworked and redeposited in different units of late Viséan to Moscovian age.
The sea retreated from the region in the latest Carboniferous. A widespread continental horizon containing calcitised wood without any internal structure contains fragmented trunks up to 6 m long and 15 cm in maximum diameter; this may represent a regionally extensive palaeosol.

**PALAEONTOLOGY**

*Faunas of the Ghadames Basin: Awaynat Wanin Area*

The mid- to upper Devonian sequence in the Awaynat Wanin area, ranging from the Eifelian to the Famennian, is richly fossiliferous – particularly in the Givetian to Frasnian interval (Fig. 2 and Plates 1, 2). Faunas consist of brachiopods and bivalves and several other less common invertebrates. Several authors have described elements of this fauna, the most comprehensive data being provided by Boucot et al. (1983) and Mergl and Massa (1992).

**Awaynat Wanin Area—AO I**

The oldest fossiliferous beds at the top of AO I contain a low-diversity fauna, including poorly preserved *Athyris* sp. and unidentifiable bivalves. The community is referred to a shallow subtidal environment.

**Awaynat Wanin Area—AO II**

AO II is highly fossiliferous, with distinct benthic communities being concentrated in sandstones at the tops of three sedimentary cycles (Van Houten and Karasek, 1981; Vos, 1981).

The sandstones in the lower part (cycle I) have yielded a low-diversity *Rhipidothyris* Community, with a dominance of the coarsely costate terebratulid *Rhipidothyris africana* and rare rhynochonellids (*Eumetabolotoechia* and *Cupularostrum*). Their preservation, with a markedly high percentage of articulated shells, indicates a calm but shallow marine environment.

Sandy levels in the upper part of cycle I contain the *Eumetabolotoechia* Community. The large rhynochonellid *Eumetabolotoechia* sp. is associated with coarsely ribbed, medium-sized rhynochonellids (*Cupularostrum* sp.), an orthid (*Rhipidomella* sp.) and abundant bivalves (*Leiopteria* sp.). Disarticulation of the shells and traces of abrasion indicate an agitated shallow subtidal environment.

Siltstones in the lower part of the overlying cycle IIa (Vos, 1981) have yielded the more diverse *Spinocyrtia* assemblage, characterised by the large spiriferid *Spinocyrtia magna*, together with minute rhynochonellids (*Cupularostrum* sp.), an orthid (*Rhipidomella* sp.) and abundant bivalves (*Myalinella* as well as encrusting and ramose bryozoans, rugose corals and trilobites (*Greenops, Phacops*), are common. This fauna indicates a deeper, calmer subtidal environment and a latest Givetian age.

A different, taxonomically distinct fossil association is present in the uppermost part of cycle IIa and in cycle IIb. This is characterised by spiriferid genera (*Cyrtospirifer* and *Macrospirifer*), indicating an early Frasnian age. The rapid succession of different brachiopod associations suggests generally low rates of sedimentation.
Plate 1. (for description of plates see end of chapter)
Plate 2.
Particular sandstone levels may be distinguished by characteristic, ‘marker’ species belonging to rapidly evolving lineages (e.g. the murospiriferid lineage *Murospirifer mundus* – *M. busrewilli* – *M. hastatus* – *M. fezzanensis* and the cyrtospiriferid lineage *Cyrtospirifer praecursor* – *C. ratus*). Spiriferids are associated with abundant, generally weakly costate rhynchonellids of which *Libyaerhynchus fragosus* is dominant. Less common rhynchonellids are *Eumetabolotoechia longiqua* and *Ripidothyris* cf. *barroisi*. Other brachiopods (*Rhipidomella, Leptaena, Dichaceaenia, Devonochonetes* and *Adolfia*) are even less common. The absence of *Tropidoleptus* is significant. Bivalves are abundantly represented (*Nuculites, Leiopteria, Leptodesma, Actinodesma, Sphenotus* and *Lyriopecten*) while other benthic invertebrates (e.g. loxonematid and mourlonid gastropods, encrusting bryozoans, crinoids, and the trilobite *Greenops*) are rare. Tentaculites are not common (*Tentaculites lardeuxi*; Hajlasz et al., 1978). The *Murospirifer* and *Libyaerhynchus* assemblages are interpreted as shallow subtidal communities that occupied sandy bottoms affected by moderate to strong currents. There is evidence of taphonomic size sorting, disarticulation, fragmentation and accumulation of the shells. These communities mark an episode of maximum benthic diversity in the Devonian succession of this area.

The rapid changes between different fossil assemblages in AO II may be explained by the model of deltaic sedimentation presented by Vos (1981). Terebratulid and rhynchonellid communities (*Rhipidothyris, Eumetabolotoechia* and *Libyaerhynchus* communities) at the tops of sedimentary cycles correspond to the progradational, shoaling phases of the deltaic complex, while the associations with abundant spiriferids and chonetids (middle part of cycle IIa, Vos, 1981) indicate somewhat deeper environments developed during transgressive phases. The taxonomic composition indicates close affinities to coeval communities on the eastern margin of Laurentia (Bowen et al., 1974; McGhee, 1976; McGhee and Sutton, 1981; Brett, 1986). It is noteworthy that the sandstones with the *Libyaerhynchus* Community were known to Beyrich (1852) almost 150 years ago.

**Awaynat Wanin Area—AO III**

In contrast to AO II, this unit is quite poor in body fossils. The lower part is rich in *Bifungites* (Fig. 2), a typical ichnofossil of nearshore environments (Gutschick and Lamborn, 1975). Shelly fossils are uncommon in most of the unit but claystones have yielded a chonetid (*Rhyssochonetes*), a rhynchonellid (*Eumetabolotoechia*), bivalves and remains of lingulid brachiopods. A quite different brachiopod association occurs in a ferruginous sandstone in the middle of the unit, where brachiopods are represented by a large rhynchonellid (*Cyphoterorhynchus talagrouni*), a terebratulid (*Septothyris boucoitii*) and rare *Cyrtospirifer, Cupularostrum* and *Schuchertella*. The fragmentation of the shells indicates that they were reworked before fossilization. The association is identical with the *Cyphoterorhynchus* Community of the Talagrouna Formation on the NW flank of the Murzuq Basin. Sedimentology indicates a deeper, prodeltaic to shelf environment. The age of AO III is probably upper Frasnian.

**Awaynat Wanin Area—AO IV**

This unit has yielded an uncommon and low diversity assemblage dominated by *Posidonia* sp. This bivalve indicates reduced oxygen levels but offers no clue to the age of this unit.
Awaynat Wanium Area–Tahara Formation

This Devonian–Carboniferous boundary unit is generally poor in fossils, but a rich brachiopod-bivalve assemblage is known in the middle part of the unit. This comprises rhynchonellids (Cupularostrum and Libyea rhynchus) and the productid Acanthadia. Bivalves are small and less numerous (Nuculoidea and Psychopteria). The association is of shallow water origin, as indicated by heavy haematisation, the position of the fossil-bearing beds, and the low diversity levels. A Famennian age is suggested.

A different fossil assemblage is known from the top of the unit. Sandstones contain the brachiopods Rhipidomella maharuga, Saharonetes saharensis, Spinocarinifera (?) bulbosa, Composita cf. megala, Syringothyris sp., Unispirifer unicus and others. Bivalves are numerous, but are represented mainly by small forms. Moderate diversity, together with a high level of shell fragmentation and current-generated accumulations, indicates a high-energy environment. The association is early Tourmaisian (Hastarian) in age and identical with fossil associations from the uppermost part of the Ashkidim Formation in the Wadi ash Shati area.

Awaynat Wanium Area–Marar Formation

This unit consists of shales and siltstones interbedded with sandstones. Its lower part has yielded a low-diversity assemblage with the productid Acanthadia placita associated with a rhynchonellid (Cupularostrum cupulousum), a chonetid (Saharonetes saharensis), a strophomenid (Schuchertella sp.), and a lingulid (Wadiglossa sp.). This assemblage is definitely of very shallow water origin, with some elements living intertidally. The age is probably early Tourmaisian (Hastarian).

A different assemblage from higher in the Marar Formation consists mainly of a small, coarsely costate rhynchonellid (Cupularostrum minutum). Less common are spiriferids (Apousiella, Prospira and Syringothyris), as well as other brachiopods (Oehlertella, Schuchertella, Saharonetes, Martinothyris, Composita and Acanthocosta). Bivalves are represented by Spathella. The higher diversity indicates a more favourable marine environment. The assemblage’s composition is remarkable: apart from the chonetid Saharonetes saharensis, none of the taxa have been found elsewhere in the Ghadames and Murzuq basins.

Faunas of the Northern Margin of the Murzuq Basin (Wadi Ash Shati)

The benthic fossils of the Wadi ash Shati area were described in detail by Havlíček and Röhlich (1987), and some new data on the Devonian faunas were later presented by Mergl and Massa (1992). The most significant taxa are shown in Fig. 3 and Plates 3, 4 and 6.

Northern Murzuq–B’ir Al Qasr Formation

Sandstones of the B’ir al Qasr Formation contain an imperfectly known and mostly fragmented fauna, in which the brachiopods Schizophoria, Cupularostrum, Iridistrophe and Rhyachophrider, along with remains of spinocyrtiid, fenestellid bryozoans, bivalves, the trilobite Kayserops and tentaculoids are important. The assemblage is probably of Eifelian age. Fossils from the upper part are less diverse and contain only calcitic remains such as the brachiopods Rhipidothyris, Cupularostrum, Mediophrider and pectinid bivalves suggesting a Givetian age.
Plate 3.
Plate 4.
Plate 5.
Plate 6.
Northern Murzuq–Idri Formation

This unit contains distinct, brachiopod-dominated assemblages that are very similar to those in AO II of the Awaynat Wanin section. In the *Rhipidothyris* Community in the lower part of the formation, the coarsely costate terebratulid *Rhipidothyris africana* is associated with a less common rhyonconellid (*Cupularostrum idriense*) and the bivalve *Leptodesma*.

The middle part of the Idri Formation contains the *Tropidoleptus* Community. Significant elements are the brachiopods *Tropidoleptus*, *Mucrospirifer*, *Cupularostrum* and *Eumetaboletoechia*. Other fossils are represented by a trilobite (*Dipleura*), gastropods, and diverse bivalves (*Goniophora*, *Spathella*, *Leptodesma* and *Lyriopecten*). Disarticulation and fragmentation of the valves together with a high amount of coarsely costate rhyonconellids indicate shallow-water with current and wave agitated sandy bottoms. A second brachiopod-dominated assemblage contains the chonetid *Devonochoenetes postremius* and the rhyonconellid *Cupularostrum arenosum*. Both genera also occur in the upper part of the Idri Formation, where they are associated with the spiriferid *Mucrospirifer hastatus*, the productid *Spinulicosta hamata*, remains of a spinocyrtiid and the trilobite *Greenops*. The age of this assemblage is probably latest Givetian. The formation of the top of the Idri Formation contains a quite different assemblage with *Cyrtospirifer*, locally abundant *Cupularostrum arenosum* and pectinid bivalves. The presence of *Cyrtospirifer* indicates a Frasnian age. Along with AO II, the Idri Formation has yielded the most diverse and richest shelly associations and these permit a good correlation between the two areas. *Cyrtospiriferids* in the upper beds are probably equivalent to the *Libyaerhynchus* Community of the Awaynat Wanin section, but the species *Libyaerhynchus fragosus* itself is unknown in the Wadi ash Shati area.

As noted by Seidl and Röhlich (1984) and Havlíček and Röhlich (1987), the assemblage with *Tropidoleptus* is certainly of Givetian age, while the brachiopod assemblage at the top of the Idri Formation is better referred to the early Frasnian.

Northern Murzuq–Quttah Formation

The Quttah Formation contains low diversity shelly assemblages. Sandstones in the lower part are rich in the ichnofossil *Bifungites fezzanensis* (Fig. 3), while shale interbeds contain remains of the lingulid *Wadiglossa*. Sandstones in the upper part of the formation have yielded many spiriferids close to *Cyrtospirifer verneulli*, the rhyconellids *Cupularostrum opulentum* and *Cassidirostrum* cf. *pedderi* and various bivalves (*Pteriopecten*, *Lyriopecten*, *Leptodesma*, *Modiomorpha*, *Grammysia*, *Grammatodon*, *Paracyclas*, and *Sphenotus*). Sandstones at some levels have also yielded remains of a large terebratulid (*Neoglobothyris timisanensis*) associated with fish remains (bone beds). A shallow subtidal environment with extensive sandy bottoms is suggested; these offered a favourable habitat for burrowing bivalves, but were generally less appropriate for epibenthic brachiopods. Fragmentation, size sorting and abrasion also suggest high-energy conditions. The silty and shale horizons, sometimes with remains of lingulids, probably mark a transgression with calm, perhaps oxygen-deficient conditions and restricted communication with open marine conditions (Seidl and Röhlich, 1984).

Northern Murzuq–Dabdab Formation

The Dabdab Formation is generally poor in fossils. Common lingulid brachiopods and placoderm debris indicate a low-diversity, very shallow lagoonal environment. Fragments of articulate brachiopods are rare, but shells of the atrypid *Spinatryptina* indicate a pre-Famennian age for the upper part of the formation.
Northern Murzuq–Tarut Formation

The Tarut Formation is characterised by a low diversity brachiopod and bivalve fauna. Shales in the lower part of the formation contain organophosphatic brachiopods (Tarutiglossa, Wadiglossa and Orbiculoidea), while numerous bivalves (Leptodesma, Lyriopecten, Myalina, Nuculopsis and Sphenotus) are found in sandy beds. Articulate brachiopods occur in ferruginous oolites and in siltstone interbeds in the upper part of the formation. Together with abundant lingulids (Wadiglossa supramarginalis and Oehlertella tarutaensis), there is the coarsely ribbed rhynchonellid Cupularostrum arenosum and the bivalve Myalina, both with calcitic shells. Placoderm and cladoselachid bones are also common. Lithofacies and fauna indicate near-shore, lagoonal and swamp environments. The base of the Tarut Formation probably corresponds to the basal AO IV beds of the Awaynat Wanin area. A Famennian age is suggested.

Northern Murzuq–Ashkidah Formation

The Ashkidah Formation is generally poor in fossils, which are mostly represented by the organophosphatic brachiopods of the genera Oehlertella and Wadiglossa. A richer faunal assemblage is present only in the upper part of the formation (the ‘brachiopod sandstone marker’ of Seidl and Röhlisch, 1984). This assemblage is dominated by articulate brachiopods, whose shells are densely packed at some horizons. Characteristic taxa include the spiriferids Unispirifer unicus, Syringothyris cf. texta, and Syringothyris sp., the productid Spinocarinifera (?) bulbosa, and the chonetid Saharonetes saharenisi, together with Schuchertella globosa, Rhipidomella maharuga, Composita cf. megala, Stenosictoma crumenum, Cupularostrum cupulosum and fragments of the crinoid Platychacrinus. This association indicates a shallow but fully marine environment.

The age of the formation is poorly constrained, but the upper part with the ‘brachiopod sandstone marker’ is definitely of early Tournaisian age, while microfossils from the lower parts of the formation have a late Famennian–early Tournaisian transitional character (Seidl and Röhlisch, 1984).

Northern Murzuq–Marar Formation

Fossils in the Marar Formation cluster into several distinct associations. The sandstones in the lower part of the formation often contain the chonetid Saharonetes saharenensis, the lingulid Wadiglossa and the productid Dictyoclostus sp. A quite different association in the middle of the formation is characterised by the dominance of the large spiriferid Prospira platycosta, associated with the terebratulid Balanoconcha micropuncta, spiriferids (Brachythryis sp., Tylothyris sp., Syringothyris cf. texta) and other brachiopods (Antinoconchus lamellosa, Pleuropugnoides cf. pleurodon, Marginatia sp., Pustula sp. Schuchertella sp.), gastropods, bivalves and crinoids. The Prospira Community is restricted to a pebbly greywacke in the Ashkidah area. This association is notable because of its low percentage of rhynchonellids and the complete absence of chonetids, which are common elsewhere in the Marar Formation.

A different benthic association in coquinoïd limestones in the upper part of the formation is dominated by the large productid Dictyoclostus cf. semireticulatus. Other brachiopods are represented by the spiriferid Phricodothyris sp. and a small undeterminable chonetid (Havliček and Röhlisch, 1987).

Fossils in the lower part of the Marar Formation are diagnostic of the late Tournaisian, while the upper part of the formation is likely to be early Viséan in age (Seidl and Röhlisch, 1984).

Younger Carboniferous units do not outcrop in the Wadi ash Shati area.
Fauna of the Western Murzuku Basin

Western Murzuku–Ouan Kasa Formation

The first fossiliferous units in the Devonian on the western margin of the basin (Fig. 4 and Plate 5) comprise sandstones with poorly preserved spiriferids (Acrospirifer), undeterminable atrypid and chonetid brachiopods, an early Devonian trilobite (Dipleura) and crinoid columnals. This association reflects a shallow subtidal habitat, as shown by low species diversity and the disarticulation and sorting of the valves into coquina beds.

Better-preserved fossils occur in siltstones. The generally small-sized brachiopod fauna is characterised by a small spiriferid (Spinella), chonetids, poorly preserved rhychonellids and dalmanellids. Of particular interest is the presence of Tropidoleptus, which generally indicates a pre-Frasnian age. Associated tentaculitids (Stylolina, Vjalovites) indicate an Emsian age for the assemblage (Hajlasz et al., 1978), which is widespread along the western margin of the Murzuku Basin and also extends farther to the SE: the same horizon with Spinella and Tropidoleptus is also known from the Djado Sub-basin in northern Niger.

Western Murzuku–Talagrouna Formation

The Talagrouna Formation comprises siltstones interbedded with quartzitic sandstones. Fossils are common throughout the unit (Fig. 5 and Plate 5), and are mainly represented by large bivalves (Goniophora, Grammysia, Sphenus, Lyriopecten, Leiopteris, Eoschizodus) and smaller undeterminable nuculids. Brachiopods are also abundant, with the large rhychonellid Cyphoterorhynchus talagrouna, the spiriferid Cyrtospirifer, the productid Leiotrochus, the orthotetacean Schuchertella and the minute terebratulid Septothyris boucoti. Among the common large tentaculitids, Dicricoconus libyensis prevails. Brachiopod and bivalve shells are only slightly reworked and thus reflect the original benthic community. The Cyphoterorhynchus Community resembles the shallow-subtidal benthic communities of the Upper Devonian in the Central Appalachians (Bowen et al., 1974; McGhee, 1976; McGhee and Sutton, 1981; Brett, 1986). Their age is probably late Frasnian, roughly coeval with the middle part of AO III in the Awaynat Wanin area and the top of the Dabdab Formation in Wadi ash Shati.

Western Murzuku–Marar Formation

Overlying the late Devonian hiatus, the Marar's haematitic basal beds contain a rich fauna typical of the Prospira Community. There are abundant spiriferids (Prospira platycosta and Syringothyris sp.), associated with other brachiopods (Balanoconcha micropuncta, Antinoconchus lamellosus, Pleuropunoids cf. pleurodon, Cleiothyridina sp., Marginatia sp., Pustula sp., Schuchertella sp.), rare bivalves and rugose corals. Low levels of shell fragmentation and numerous articulated whole shells in this diverse community indicate calm and fully marine conditions.

Another distinct assemblage (Fig. 5) consists of the large, subglobose rhychonellid Paurogastroderhynchus serdelesensis (= Septacamera), the syringothyrid Septosyringothyris vautrini (= Histosyrinx), the productid Setigerites, and a poorly preserved chonetid. This assemblage is known throughout the basin and has also been documented on the opposite eastern flank of the Murzuku Basin. It is late Tournaisian in age.

The upper part of the formation (Fig. 10) yields faunas with abundant productids, characteristically with Fluctuaria, Argentioproductus, Libys, the rhychonellid Cupularostrum, the syringothyrid Syringothyris cf. hannibalensis, athyrids and diverse other benthic invertebrates (bryozoans, bivalves and corals). The fauna is probably of late early Viséan age. A
different benthic assemblage, known from stromatolitic beds ('Collenia Unit', Upper Viséan), is characterized mainly by productid brachiopods (Dictyoclostus, Libys, Linoproductus) associated with Protoniella, Pleuropugnoides, spiriferids (Neospirifer, Syringothyris), bivalves and corals (Massa et al., 1974).

**Western Murzuq–Assedjefar Formation**

The fauna of this unit was described by Massa et al. (1974). The lower fossiliferous horizons contain productids (Echinoconchus, Flexaria, Juresiana, Linoproductus, Stratiforma, Productus and Gigantoproductus). Other brachiopods include Schellwienella, Rugosochonetes, Pleuropugnoides and Syringothyris journyi. The latter species is of great stratigraphical significance as it is a marker for the early Namurian throughout the whole Sahara (Legrand-Blain, 1970), and has also been reported from the Al Awaynat area (Rossi, 1939). The associated fauna is remarkably rich, with diverse gastropods, bivalves, bryozoans and the rare trilobite Lingaphillipsia. These lower Assedjefar beds have a clear early Namurian aspect.

A similarly rich benthic fauna from the upper fossil-bearing horizon of the Assedjefar Formation. Along with some elements already common in the lower part of the unit (e.g. the genera Linoproductus, Productus and Syringothyris), there are new elements, of which the productids Ovatia and Antiquatonia are significant.

**Western Murzuq–Dembaba Formation**

The fauna of the Dembaba Formation (Fig. 10) consists mainly of brachiopods of the genera Schizophoria, Enteletes, Linoproductus, Conocardium etc. These faunas suggest a Moscovian age.

**Faunas of the Djado Sub-basin**

The limited Devonian faunas known from this area have not been restudied in the present work. As may be expected, fossiliferous sites and levels in the Carboniferous (Fig. 12 and Plate 7) are generally scattered in this area. Moreover, available samples are limited, which makes determinations and the reconstruction of the original taxonomic spectrum difficult. Thus, the data presented below will certainly be improved by further studies.

**Djado–Marar Formation**

The sandstones in the lower part of the Marar Formation contain a brachiopod-dominated community with abundant, medium-sized specimens of the coarsely costate syringothyrid Syringothyris cf. ahnetensis, locally associated with a large new rhyonchonellid taxon (Rhyonchopora magnifica). Less abundant brachiopods at more or less the same level near the base of the Carboniferous sequence are Saharaeites saharenus and Schuchertella sp. The brachiopods occur in densely and often chaotically, packed beds, commonly as isolated or broken valves, although some complete shells are also present. Bivalves are rare.

The basal sandstones of the Marar Formation, resting unconformably on Devonian strata, contain the taxa Schuchertella sp. and Syringothyris sp., although in very restricted numbers. These resemble the association of the 'brachiopod sandstone marker' in the Ashkidah Formation.
of the Wadi ash Shati area. Another distinct, but low-diversity, association at the base of the Carboniferous is characterised by the rhynchonellid *Paurogastroderhynchus serdelesensis*. The age of both associations is latest Tournaisian.

Sandstones in the upper Marar Formation contain the characteristic late Viséan productid *Fluctuaria undata*.

**Djado-Assedjefar Formation**

The Upper Viséan and Lower Namurian are generally poor in fossils but a calcareous sandstone has yielded shells of a large *Schellwienella*, associated with less common productids. A second brachiopod association is early Namurian in age; sandy limestones contain mainly productids (*Flexaria, Antiquatonia* and *Ovatia*), but other brachiopods are also represented by the widespread genera *Rhipidomella, Composita, Syringothyris* and small rhynchonellids. Another association of early to middle Namurian age is characterised by the large syringothyrid *Syringothyris jordyi*, and the rare terebratulid *Beecheria*. An early Namurian age is also documented by the presence of *Anthracospirifer* gr. *curvilateralis*. Other poorly preserved brachiopods include the productid *Ovatia*.

**Djado-Dembaba Formation**

The upper part of the marine Carboniferous (Moscovian) in the Djado Sub-basin has yielded an assemblage consisting exclusively of the chonetid *Rugosochonetes* cf. *chesterensis* (Fig. 12), which is commonly articulated, but with abraded external surfaces. This assemblage is probably Moscovian in age.

In conclusion, the lower and mid-Carboniferous shelly assemblages of the Djado Sub-basin show low diversities and represent shallow marine environments. The assemblages are dominated by productids, coarsely ribbed rhynchonellids and spiriferids, with a few terebratulids or strophomenids. As stated by previous authors (e.g. Legrand-Blain et al., 1987), there are taxonomic affinities with Carboniferous faunas of North America (e.g. *Flexaria, Anthracospirifer, Rugosochonetes*), while most of the recorded faunal elements have a worldwide distribution (*Schellwienella, Ovatia, Cupularostrum, Syringothyris, Beecheria*). Only a few elements may be considered as endemic to the Murzuq Basin, such as the rhynchonellid *Paurogastroderhynchus serdelesensis* and the syringothyrid *Septosyringothyris vautrini*, both from the Upper Tournaisian. *Saharonetes*, which is widespread in the Murzuq Basin, is also known from Ghana (Racheboeuf et al., 1989).

**INTRABASINAL AND EXTRABASINAL RELATIONS OF FAUNAS**

The southeastern margin of the Ghadames Basin (Awaynat Wanin area) and the northern margin of the Murzuq Basin (Wadi ash Shati area) provide the most complete, most fossiliferous and best-documented Devonian sections. Although now belonging to different basins, these two areas show a very similar distribution of characteristic shelly faunas, permitting a reliable correlation between these two areas. Carboniferous fossiliferous strata are well known in the southern Ghadames and northern and northwestern parts of the Murzuq Basin, but become sparse along the basin’s southwestern margin and into the Djado Sub-basin.

The following well-documented and stratigraphically restricted benthic communities are important for intrabasinal correlation (in ascending order):
Chapter 4

- **Tropidoleptus Community.** Characterised by dominance of the orthid *Tropidoleptus carinatus freuloni*, this low- to medium-diversity community is present in AO II of the Awaynhat Wanin area and in the Idri Formation of Wadi ash Shati. A latest Givetian age is highly probable: although the genus *Tropidoleptus* ranges into the Frasnian (Cooper and Dutro, 1982), its acme is in the Givetian (Isaacson and Perry, 1977). The typical environment of the *Tropidoleptus* Community is shallow subtidal.

- **Libyaerhynchus Community and related communities.** Typically developed in the Awaynhat Wanin area, with the spiriferids *Mucrospirifer* and *Cyrtospirifer* and the rhyncholeds *Libyaerhynchus*, *Ripidiorhynchus* and *Eumetabolotoechia*. The community is also known from the western part of the Wadi ash Shati area. The presence of several species of *Mucrospirifer* has a great significance for detailed correlation between both areas. The association of *Cyrtospirifer* and *Eumetabolotoechia* indicates an early Frasnian age for the *Libyaerhynchus* and related communities.

- **Neoglobithyris and Cyphoterorhynchus communities.** Despite differences and limited data, both communities appear to be good stratigraphic markers of the mid-upper Frasnian. *Neoglobithyris tmisanensis* (upper part of the Dabdb Formation in Wadi Ash Shati) or a closely related species (*Septothyris boucoti*: Mergl and Massa, 1992) is probably also present on the western flank (Talgrouna Formation) of the Murzuq Basin, as well as in the Awaynhat Wanin area (AO III). Obviously this terebratulid has a wide areal extent.

- **Saharonetes Community.** A rich brachiopod assemblage (‘brachiopod sandstone marker’ of Seidl and Röhlch, 1984) in the top of the Ashkidah Formation (Wadi ash Shati area) has its counterpart in the top of the Tahara Formation (Awaynhat Wanin area). This community is characterized by *Unispirifer unicus*, *Rhipidomella maharuga* and other brachiopods, while associated species (e.g. *Saharonetes saharenisis*) have a wider stratigraphic range. The typical *Saharonetes* Community is early Tournaisian (Hastarian) in age.

- **Prospira Community.** This community was originally described from the lower part of the Marar Formation in Wadi ash Shati (Havlicek and Röhlch, 1987), but it has also been found in the Marar Formation on the western flank of the Murzuq Basin in the basal Carboniferous transgressive beds (*Fusella Community* in original diagnosis of Massa et al., 1974). The community is unknown, however, in the Awaynhat Wanin area. The *Prospira* Community includes many elements unknown at other levels in the Murzuq Basin (e.g. the genera *Antinoconchus*, *Brachythyris*, *Tylothyris*, *Balanoconcha* etc.), although they otherwise have a worldwide distribution in this period. This community indicates a favourable, thoroughly marine environment and may be used as a good stratigraphical marker for the late Tournaisian in different parts of the Murzuq Basin.

- **Septosyringothyris Assemblage.** This assemblage is named after the syringothyrid *S. vautrini*, which is locally associated with the large rhyncholed *Paurogastroderhynchus*. It has not yet been found in the Wadi ash Shati, but is present near the base of the Marar Formation both on the western and eastern margins of the Murzuq Basin and also in the Djado Sub-basin. The age of this association is probably late Tournaisian.

- **Syringothyris jourdyi Assemblage.** This assemblage is characterized by the large syringothyrid *S. jourdyi*, some productids and the terebratulid *Beecheria*. It is known from the western margin of the Murzuq Basin and from the lower Namurian of the Djado Sub-basin. *S. jourdyi* is a characteristic species for the western Sahara (Legrand-Blain, 1970).

- **Lingulid Community.** By comparison with modern *Lingula*, this community is generally thought to represent intertidal, brackish and warm conditions. However, as suggested by Emig (1997), fossil lingulids tend to occur during periods of drastic or catastrophic ecological change. Recent lingulids live in compact and stable sediments under the influence of moderate currents and normal salinity. None of the recent species is adapted to brackish-water conditions, although they can survive strong salinity variations. Thus low salinity and brackish
conditions cannot be inferred from the mere presence of fossil lingulids. In the Murzuq Basin, the lingulid-bearing beds, often with ferruginous cement, probably represent intertidal but wholly marine, sandy environments. Marine swamps (similar to modern mangroves) provide the best models for the lingulid-bearing beds. Their appearance near the Devonian-Carboniferous boundary probably reflects extreme eustatic fluctuations at this time, while their stratigraphic significance is very low.

- **Bivalve Communities.** Along with the brachiopods, bivalves are the most common and often the only, macrofossils in some beds. Their diversity is rather high and more detailed study would certainly permit the discrimination of discrete assemblages. Burrowing bivalves, with diagnostic morphologies (elongate outline, burrowing sculptures), indicate bottoms inhabited by infaunal or semi-infaunal filter feeders. However, there are also epiphiyseal forms, largely pectinids. It is only our insufficient taxonomic knowledge that makes this group stratigraphically useless while their mere presence is sufficient to recognize fully marine environments.

**BIOGEOGRAPHIC AFFINITIES OF DEVONIAN AND CARBONIFEROUS FAUNAS**

The biogeography of the Saharan intracratonic basins has been summarized by Boucot et al. (1983) for Devonian brachiopod faunas in general, by Racheboeuf (1990) for Devonian chonetid brachiopods, by Mergl and Massa (1992) for Devonian-Tournaisian brachiopod faunas, by Legrand-Blain (1986, 1995) for Carboniferous productids and spiriferids and by Legrand-Blain et al. (1987) for other Carboniferous invertebrates. Generally, Early to Middle Devonian faunas of the eastern Saharan domain have close affinities to the Old World Realm, although there are occasional influxes of elements from the Eastern American Realm. In contrast, late Givetian and Frasnian faunas contain many elements with Eastern American Realm affinities, such as *Mucrospirifer*, *Spinocyrtia*, *Eumetabolotoechia* and *Devonochonetes*. Carboniferous biogeographic relationships are less evident, except for the occurrence of some North American elements (e.g. *Anthracospirifer*) in the Namurian. The late Devonian to early Carboniferous productids of North Africa (Legrand-Blain, 1995) include *Acanthatia*, a characteristic genus of North America.

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Note that fossils figured in Plates 1 to 7 are stored in the following depositories according to the abbreviations given in the plate texts: **FSL**: material housed in the collections of Centre National de la Recherche Scientifique, Lyon University, Lyon, France; **IRCT**: material housed in the Industrial Research Centre, Tripoli, Libya; **VH**: material housed in the Museum of Dr. B. Horák, Rokycany, Czech Republic.
REFERENCES


DESCRIPTION OF PLATES (BAR = 5 mm IN ALL PLATES)


1. Athyris sp., dorsal valve, FSL 413.125.
2. Eumetabolotoechia sp., dorsal valve, FSL 413.098.
3, 4. Cupularostrum rudis Mergl and Massa, dorsal and ventral valves, FSL 413.074.
5, 6. Rhipidothyris africana Boucot, Massa and Perry, dorsal and ventral valves, FSL 413.218.
7. Variatrypa sp., dorsal valve, FSL 413.119.
8. Eumetabolotoechia perryi Boucot, Massa and Perry, dorsal valve, FSL 413.101.
9. Spinocyrtia magna Mergl and Massa, ventral valve, FSL 413.168.
10, 11. Mucrospirifer mundus Mergl and Massa, ventral and dorsal valves, FSL 413.142, FSL 413.143a.
12, 13. Cyrtospirifer praecursor Mergl-Massa, ventral valves, FSL 413.184.
14. Strophoeodonta sp., dorsal valve, FSL 413.034.
15, 16. Mucrospirifer hastatus Mergl-Massa, ventral and dorsal valves, FSL 413.146a, FSL 413.149.

PLATE 2. (p. 68). Ghadames Basin: Fossils from the Awaynat Wanin area (AO II).
2. *Leptaena borghiana* Mergl and Massa, ventral valve, FSL 413.018.
3. *Devonochochonetes salemi* Mergl and Massa, ventral valve, FSL 413.035g.
4. *Spinulicosta hamata* Mergl and Massa, ventral valve, FSL 413.049.
5. *Eumetabolotheria longiqua* (Beyrich), ventral valve, no number.
6–8. *Libyaerhynchus fragosus* Mergl and Massa, two ventral and dorsal valves, VH 7631, VH 7620.
9, 10. *Ripidiorhynchus cf. barroisi* (Riaux), two ventral valves, FSL 413.085, FSL 413.087.
11, 12. *Mucrospirifer fezzanensis* (Mathieu), dorsal and ventral valves, VH 7607a, VH 7608.
13. *Leptodesma* sp., left valve, VH 7607b.
15. *Actinodesma erectum* Conrad, right valve, VH 7632.
17. *Sphenotus* sp., left valve, FSL 413.266.
18. *Mucrospirifer busreewili* Mergl and Massa, ventral valve, FSL 413.035j.
20, 21. *Cyrtospirifer ratus* Mergl and Massa, dorsal and ventral valves, FSL 413.196, FSL 413.197.

**PLATE 3.** (p. 71). Murzuq Basin: Fossils from the Middle to Upper Devonian, Wadi ash Shati.
1. *Schizophoria* sp., ventral valve, IRCT, B’ir al Qasr Formation.
2. *Iridistrophia* sp., ventral valve, IRCT, B’ir al Qasr Formation.
4. *Spinulicosta hamata* Mergl and Massa, dorsal valve, FSL 413.050, Idri Formation.
5–7. *Tropidoleptus carinatus freuloni* Boucot, Massa and Perry, dorsal, ventral and dorsal valves, VH 7611, VH 7612, VH 7612, Idri Formation.
8, 9. *Capularostrum idriense* Havlíček, ventral and dorsal valves, VH 7629, Idri Formation.
10, 11. *Devonochochonetes postremus* Havlíček, ventral and dorsal valves, FSL 413.025, FSL 413.145, Idri Formation.
12, 13. *Mucrospirifer hastatus* Mergl and Massa, ventral and dorsal valves, FSL 413.025a, FSL 413.050, Idri Formation.
15. *Cassidirostrum cf. pedderi* McLaren, dorsal valve, IRCT, Quttah Formation.
17. *Cyrtospirifer* sp., dorsal valve, FSL 413.204, Quttah Formation.
18. *Capularostrum opulentum* Havlíček, ventral valve, FSL 413.070, Quttah Formation.
19. *Neoglobithyris tmisanensis* Havlíček, ventral valve, IRCT, Quttah Formation.

**PLATE 4.** (p. 72). Ghadames and Murzuq Basins: Fossils from the Upper Devonian to Lower Carboniferous, Wadi ash Shati (11–19).
1. *Rhipidomella maharuga* Havlíček, ventral valve, VH 7614, Ashkidah Formation.
2. *Spinocarinifera (?) bulbosa* (Havlíček), dorsal valve, VH 7618, Ashkidah Forma-
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3, 4. *Unispirifer unicus* Havlíček, ventral valve, FSL 413.122c, FSL 413.122b, Ashkidah Formation.


7, 8. *Stenoscsisma crumenum* (Martin), ventral and dorsal valves, IRCT, Ashkidah Formation.


11. *Acanthocosta* sp., ventral valve, FSL 413.213, Marar Formation.

12. *Martinothyrs* sp., ventral valve, FSL 413.058a, Marar Formation.

13, 14. *Saharonetes saharensis* Havlíček, ventral and dorsal valves, IRCT, VH 7603, Marar Formation.

15, 16. *Cupularostrum minutum* Mergl-Massa, ventral and dorsal valves, FSL 413.081, FSL 413.084, Marar Formation.

17. *Sphenotus libyaensis* Mergl and Massa, right valve, FSL 413.263, Talagrouna Formation.

18. *Eoschizodus* sp., left valve, FSL 413.271, Talagrouna Formation.

19. *Syringothyris* sp., ventral valve, FSL 413.039, Talagrouna Formation.

20. *Septothyris boucoti* Mergl and Massa, ventral and dorsal valves, FSL 413.226, FSL 413.230, Talagrouna Formation.

**PLATE 5.** (p. 73). Murzuq Basin: fossils from the Ouan Kasa and Talagrouna formations.

1. *Tropidoleptus* sp., dorsal valve, FSL 413.016, Ouan Kasa Formation.

2, 5. *Spinella paulula* Mergl and Massa, dorsal and ventral valve, FSL 413.139, FSL 413.137b, Ouan Kasa Formation.

3. *Acrospirifer* sp., two dorsal valves, FSL 413.132, Ouan Kasa Formation.

5. *Aseptonetes* ? sp., ventral valve, FSL 413.041, Ouan Kasa Formation.

6, 7. *Cyphoterorhynchus talagrounaensis* Mergl and Massa, complete shells, FSL 413.114, FSL 413.041, Talagrouna Formation.


9, 10. *Leioproductus* sp., dorsal and ventral valves, FSL 413.063, FSL 413.061, Talagrouna Formation.

11. *Sphenotus libyaensis* Mergl and Massa, right valve, FSL 413.263, Talagrouna Formation.


13. *Eoschizodus* sp., left valve, FSL 413.271, Talagrouna Formation.

14. *Schuchertella* sp., ventral valve, FSL 413.039, Talagrouna Formation.

15, 16. *Septothyris boucoti* Mergl and Massa, ventral and dorsal valves, FSL 413.226, FSL 413.230, Talagrouna Formation.

17. *Dicricoconus libyensis* Hajlasz, Massa and Bonnefous, two shells, Talagrouna Formation.


1, 3. *Pustula* sp., ventral and dorsal valves, IRCT.

2, 5. *Marginatia* sp., ventral valve, IRCT.


6. *Syringothyris* cf. *texta* (Hall), dorsal valves, IRCT.

7. *Brachythyris* sp., ventral valve, IRCT.
8. Tylothyris sp., ventral valve, IRCT.
9. Prospira platycosta Havlíček, dorsal valve, IRCT.
10. Balanoconcha micropuncta Havlíček, complete shell, IRCT.
11. Antinoconchus lamellosus (Leveille), ventral valve, IRCT.
12. Cleiothyridina aff. tomiensis Besnossova, ventral valve, FSL 413.126.
13, 14. Paurogastroderhynchus (= Septacamera) serdelesensis Massa, Termier and Termier, ventral and dorsal valves, FSL 413.117, FSL 413.118.
15. Septosyringothyris vautrini Massa, Termier and Termier (Histosyrinx), dorsal valve, FSL 413.209.

PLATE 7. (p. 79) Djado Sub-basin: Carboniferous fossils.
1, 2. Flexaria arkansana (Girty), ventral valve, Assedjefar Formation.
3, 4. Ovatia sp., ventral valve, Assedjefar Formation.
5, 6. Cupularostrum sp., complete shell, Assedjefar Formation.
7, 8. Antiquatonia insculpta (Muir-Wood), ventral valve, Assedjefar Formation.
9, 10. Rhynchopora sp., ventral and dorsal valves, Marar Formation.
11. Chonetes cf. chesterensis (Weller), complete shell, Dembaba Formation.
12. Syringothyris sp., dorsal valve, Marar Formation.
13. Anthracospirifer gr. curvilateralis (Easton), ventral valve, Assedjefar Formation.
14, 16, 17. Syringothyris jourdyi jourdyi Douvillé, ventral valve and side view to complete shell, Assedjefar Formation.
15. pectinid bivalve, left valve, Dembaba Formation.