

MOSCOVIAN FUSULINIDS (FORAMINIFERA) FROM SE TUNISIA: THE CASE OF KR-1 KIRCHAOU BOREHOLE (TATAOUINE AREA)

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Abstract: Moscovian (Middle Pennsylvanian) deposits with mixed oolitic and fossil-rich carbonates have long been known from the Kirchaou KR-1 borehole in SE Tunisia. However, its biostratigraphy has never been investigated in detail. This study is mainly dedicated to reviewing the late Bashkirian and Moscovian successions, and characterizing the late Moscovian-early Kasimovian boundary interval. The important fusulinoid faunas of the Middle Pennsylvanian interval within the 315.5-meter-thick KR-1 borehole mainly include staffellines, eostaffellines, millerellines, pseudostaffellines, and Fusulinoidea, which are first illustrated here. The distribution of the main index taxa allows us to distinguish four foraminiferal biozones: (1) the *Tikhonovichiella tikhonovichi* - *Profusulinella* Zone of the Melekessian-Vereian (latest Bashkirian-earliest Moscovian), (2) the *Beedeina* - *Citronites* Zone of the Kashirian (late early Moscovian), (3) the *Taitzehoella prolibrovichi* - *Fusulina* of the Podolskian (early late Moscovian), (4) the *Protriticites* - *Quasifusulinoides* Zone of the Myachkovian - Krevyakinian (late late Moscovian - early Kasimovian). The Moscovian - Kasimovian transition is mainly characterized by *Protriticites*, *Quasifusulinoides*, *Montiparus*, *Topilinia*, *Beedeina*, *Fusiella*, *Profusulinella*, and *Fusulinella* taxa. The study of fusulinoid assemblages allows reliable correlations with coeval associations from the Russian Platform, Southern Urals, Western Europe, Spain, and Donbas (Ukraine).

Keywords : Carboniferous, Moscovian, Fusulinida, biostratigraphy, SE Tunisia.

1. INTRODUCTION

Apart from Permian works by Douvillé et al., (1933) in the Jebel Tebaga (Medenine area, SE Tunisia), Paleozoic marine outcrops are not exposed in Tunisia. However, investigations by oil companies since 1955 on the Paleozoic in southern Tunisia have led to the discovery of Carboniferous deposits in several boreholes drilled in the Jeffara basin and southernmost domains (Kirchaou oil license). This study aims to present updated biostratigraphic data on the Middle Pennsylvanian deposits of Southern Tunisia. These are dedicated to supplementing pioneer investigations of more than half a century ago (Glantzboeckel & Rabaté, 1964; Lys, 1988). The resulting regional biostratigraphic charts are based on the revision of rich assemblages of Pennsylvanian fusulinids first illustrated here. The studied Kirchaou-1 borehole (KR-1) is situated about 35 km to the east of Tataouine, 40 km to the west of Ben Gardane, and 200 m to the southwest of Kirchaou village. This

borehole ended at a depth of 2989 m revealing Ordovician formations. The interval analyzed here concerns successions reached between 2160 m and 2521.8 m (Figure 1).

2. PREVIOUS WORKS

In 1957, Carboniferous deposits were encountered by several boreholes in southern Tunisia. The Kirchaou KR-1 borehole was the first studied by Glantzboeckel & Rabaté (1964). These authors analyzed the sedimentological aspect and illustrated the microfauna. They described the Namurian based on the foraminifera *Millerella* and *Archaediscus*. The Moscovian is characterized by the presence of *Fusulina* and *Profusulinella*, and the Upper Carboniferous is marked by *Triticites* cf. *petschoricus* and *Quasifusulina eleganta*. Furthermore, the Carboniferous deposits of the Kirchaou borehole have been described by several authors.

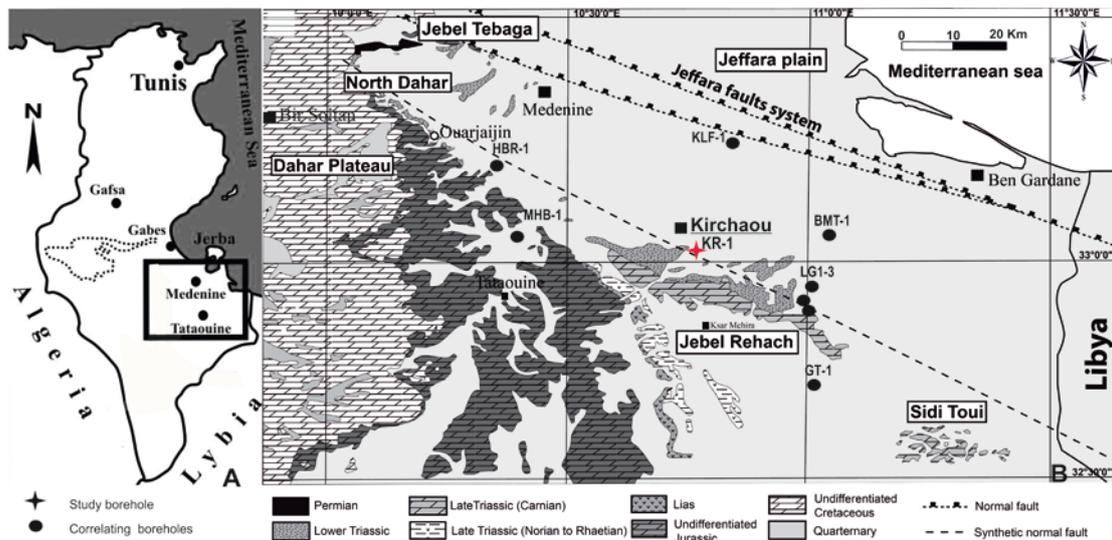


Figure 1. Geographical and geological context of the studied area. A. Location of B in Tunisia. B. Geological map showing Kirchaou borehole (KR-1) and nearby wells drilling (modified after Raulin et al., 2011).

In 1982, Boulouard and Viillard analyzed the Carboniferous palynological content of KR-1. They identified the Namurian and the Westphalian. Memmi et al., (1986), carried out a synthesis of the stratigraphic nomenclature of the Paleozoic boreholes in southern Tunisia. These authors attributed: (1) a late Viséan, Serpukhovian, and late Bashkirian age to the 2860-2569 m interval; (2) a Moscovian age to the 2569-2248 m interval; and (3) an Upper Carboniferous interval at 2248-2180 m.

Lys (1988) revised the Carboniferous deposits of KR-1 and identified the Moscovian (Kashirian-Myachkovian) considering the presence of *Fusulina distenta*; *Hemifusulina elliptica*; *Eofusulina triangula*; *Fusiella praecursor*; *Aljutovella*; *Eofusulina*; *Endothyranella gracilis*; *Schubertella obscura*; *Pseudostaffella gorskyi*; and *Hemifusulina kashirica*.

These authors identified the early Carboniferous (late Viséan-Serpukhovian), middle and late Carboniferous (Bashkirian-Kasimovian), with the uppermost part (Gzhelien) potentially lacking, at least in part.

3. MATERIALS AND METHODS

The revision of the Carboniferous of the KR-1 borehole is based on the analysis of thin sections with the permission of the oil company Tunisian Petroleum Research and Exploitation (SEREPT). Our results are limited here to the biostratigraphic analysis of the Moscovian interval. A total of 200 thin sections were observed under a polarized Zeiss microscope and photographed with a Canon incorporated camera. Relatively well-preserved fusulinid specimens are

matched with their content in Figure 3, illustrating the fusulinid distribution for the study borehole. Fusulinid specimens were measured according to traditional parameters (Diameter (D); Width (W); W/D; Number of whorls (N); Proloculus diameter (P); Height of the last whorl (H); and wall thickness (S)), into essentially axial sections, subaxial, and subtransverse sections of fusulinids, and classified according to the taxonomic hierarchy of Loeblich & Tappan (1992) and Ueno (2022). Once taxonomic interpretations are established and corresponding zones delimited, biostratigraphic results are then cross-checked among co-authors, and an agreement was made on the exact bed under which a given limit can be traced. Fusulinid biozones are considered as "interval" biostratigraphic units, the base of each is placed considering the first appearance (FO) of index species, cross-checked by characteristic associations, and/or complemented by the abundance of marker taxa.

4. RESULTS

4.1. Lithological description of KR-1 Borehole

In the KR-1 borehole, the total thickness is circa 2989 m. The Carboniferous is underlain by folded Cambro-Ordovician sediments at the base and overlain by Permian deposits, with a total thickness of about 860 m (2000–2860 m). The entire Carboniferous interval is subdivided into eleven lithological units (units 1–11). The descriptions of the different levels are presented in reverse stratigraphic order (from top to base) (Figure 2).

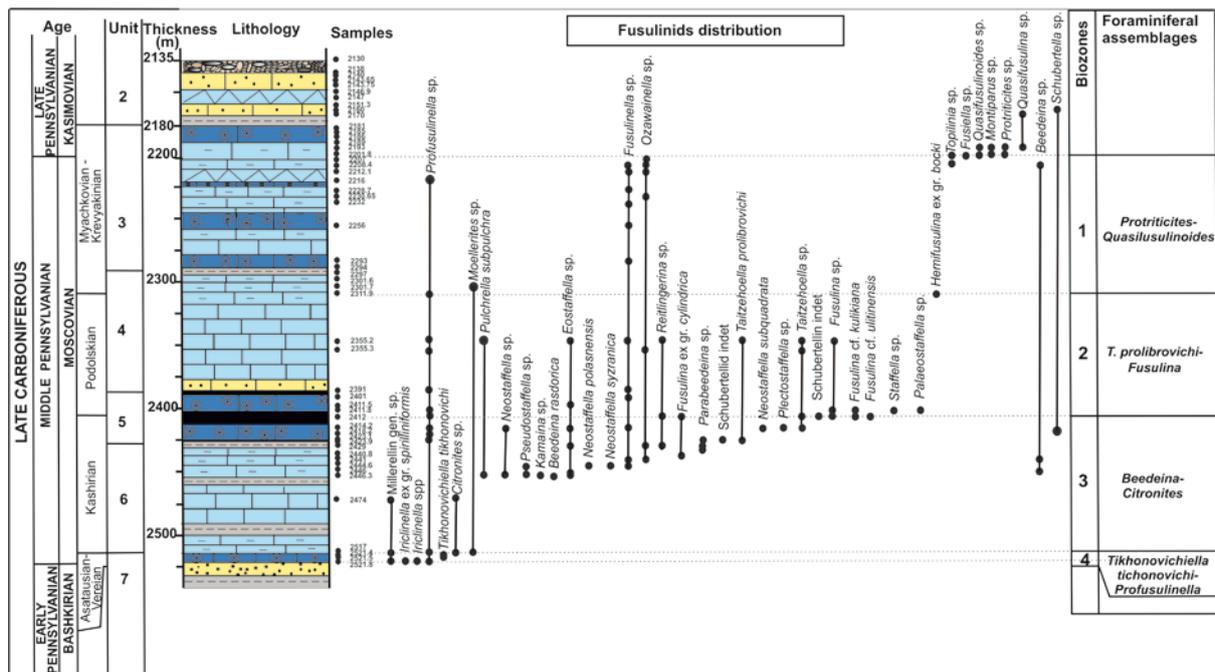


Figure 3. Stratigraphic occurrences of the Moscovian fusulinids in Kirchaou (KR-1) borehole.

Fusulinella sp. (Figure 7C), and *Profusulinella* sp. (Figure 9D). According to index fossils *Protriticites*, *Quasifusulinoides*, *Hemifusulina* ex gr. *bocki*, *Topilinia*, and *Fusiella*, the *Protriticites-Quasifusulinoides* Zone corresponds to the transitional Myachkovian-Krevyakinian boundary interval (late Myachkovian or the early Kasimovian), in Timan-Pechora Basin (Remizova, 1995, 2004; Ueno, 2022), Donets Basin (Putrya, 1940; Makhlina et al., 2001a, b), Central Asia, and Cantabrian Mountains (van Ginkel & Villa, 1999; Villa et al., 2015; Ueno, 2022).

4.2.2. *Taitzehoella prolibrovichi-Fusulina* Zone

The top of this zone is marked by the FOD (first occurrence datum) of the index fossil *Taitzehoella prolibrovichi* (Rauzer-Chernousova, 1951) (Figure 6I), *Hemifusulina* ex gr. *bocki* associated to *Moellerites* sp. (Figure 6K), *Profusulinella* sp. (Figure 6F-H), *Fusulinella* sp. (Figure 8E-F). Collected at levels 2355.2 m to 2412 m. This zone, which comprises a rich fusulinid assemblage mainly belonging to the genus *Fusulina* (*Fusulina* cf. *kulikiana* (Rauzer-Chernousova, 1951) (Figure 7A), *F. ultinensis* (Rauzer-Chernousova, 1951) (Figure 7D), *F. ex gr. cylindrica* (Figure 6L), *F. sp.* (Figure 7B)). This zone is traditionally attributed to the upper Moscovian (Podolskian); (Lucas et al., 2021; Ueno, 2022).

4.2.3. *Beedeina-Citronites* Zone

Rich records of fusuline fauna, mainly

belonging to the Beedeininae (Solovieva in Rauzer-Chernousova et al., 1996), are determined by the FOD of *Neostaffella subquadrata* (Grozdilova & Lebedeva, 1950) (Figure 6D), *N. sp.* (Figure 6E), and the LOD (last occurrence datum) of *Citronites* sp., (Figure 8I). The abundant and diverse fusulinid assemblage of this zone includes *Neostaffella* sp., *Pseudostaffella* sp. (Figure 9C), *Kamaina* sp. (Figure 7F), *Beedeina rasdorica* (Figure 7G-H), *B. sp.* (Figure 7I-L), *Neostaffella polasmensis* (Rauzer-Chernousova & Safonova in Rauzer-Chernousova et al., 1951) (Figure 6B), *N. subquadrata* (Grozdilova & Lebedeva, 1950) (Figure 6D), *N. syzranica* (Rauzer-Chernousova & Safonova in Rauzer-Chernousova et al., 1951) (Figure 6C), *Fusulinella* sp., *Ozawainella* sp. (Figure 8J), *Parabeedeina* sp. (Figure 8C), *Taitzehoella prolibrovichi* (Figure 6I), *T. sp.* (Figure 6J), and *Moellerites* sp. (Figure 6K). Traditionally *Beedeina* and *Citronites* suggest a Kashirian (late early Moscovian; Vachard et al., 2013; Lucas et al., 2021; Ueno, 2022).

4.2.4. *Tikhonovichiella tikhonovichi-Profusulinella* Zone

The top is characterised by the FOD of *Tikhonovichiella tikhonovichi* (Rauzer-Chernousova, 1951) (Figure 8L) and *Citronites*. The base is characterised by the FOD of *Profusulinella* (Figure 6F), *Ircelinella* ex gr. *spirilliniformis* (Brazhnikova & Potievskaya, 1948), and *Ircelinella* spp. The assemblage is formed by *Tikhonovichiella tikhonovichi*, *Profusulinella*, *Millerellin* gen. sp., and *Moellerites* sp., which are characteristic of the

Melekessian–Vereian boundary interval in sections of the central Iran, Turkey, East European Platform and Urals.

5. DISCUSSION

5.1. Foraminiferal assemblages

The biostratigraphic information from the Late Carboniferous (Moscovian–Kasimovian) suggests that fusulinid assemblages from several boreholes in southern Tunisia exhibit certain similarities to those from the Russian Platform, Urals, Western Europe, Spain (Cantabrian Mountains), Donets Basin (Ukraine), and Turkey (Figure 4). In regions such as the Moscow Syncline, Urals, Donets Basin, and Spain (Cantabrian Mountains), as well as in Turkey, the middle and early Late Pennsylvanian periods are the most complete, ranging from the Kashirian to the Kasimovian. The sedimentary deposits in these areas are predominantly carbonates and host a diversity of genera such as *Montiparus*, *Protriticites*, *Quasifusulinoides*, *Fusiella*, *Topilinia*, *Fusulinella*, *Profusulinella*, *Kamaina*, *Parabeedeina*, and *Moellerites*. Additionally, species like *Hemifusulina bocki*, *Taitzehoella prolibrovichi*, *Fusulina kulikiana*, and *F. cylindrica* are found both at KR-1 and in other boreholes in southern Tunisia.

However, the genera *Citronites* and *Tikhonovichiella* index markers zone of Kashirian and late Asatauian-early Vereian have not been reported in the Moscow Syncline, Urals or Cantabrian Cordillera. These genera have been identified in Iran, Turkey and Central Asia over the same period.

5.2. Comparison with nearby boreholes

In southern Tunisia, the most complete Moscovian is found in the Kirchaou-1 borehole (Figure 5). In other wells, it is either absent or incomplete. At the KR-1 borehole, the early Vereian was not characterized, and was only found by Lys (1988) at LG-2 and BMT-1, where Vereian was identified, marked by *Aljutovella aljutovica* (Figure 1) biozone, associated to *Profusulinella rhombiformis* (Figure 15), *Profusulinella priscatimanica* (Figure 14). Glintzboekel and Rabaté (1964) have reported the presence of *Profusulinella cf. simplex* Safonova, which indicates the late Vereian (Vilesov, 2002; Leven & Gorgij, 2008, 2011). Later, Ghazzay-Souli et al., (2015) investigated samples from the Bir Mastoura BMT-1 borehole and recognized a

Profusulinella Zone, a lateral equivalent of the *Aljutovella* Zone from early Vereian (Figure 11, Photo 6). The identified fusulinids in this borehole are from the early Vereian, according to several researchers (Leven & Gorgij (2008, 2011), Vilesov (2002), and Ivanova (2008)).

The Melekessian–Vereian transition (latest Bashkirian–earliest Moscovian) is marked by the *Tikhonovichiella tikhonovichi* - *Profusulinella* biozone. The *Tikhonovichiella tikhonovichi* species is reported for the first time from the KR-1 borehole. In various regions such as the European part of Russia, southern Turkey, Iran (Anarak), Darvaz, Central Asia, and China, the appearance of *Tikhonovichiella tikhonovichi* characterizes the late Melekessian – Vereian, Bashkirian–Moscovian transition (Rauzer-Chernousova et al., 1996; Dzhenchuraeva & Okuyucu, 2007; Ivanova, 2008; Leven, 2009; Leven & Gorgij, 2011, Fassihi et al., 2017).

The Kashirian corresponds to the *Beedeina-Citronites* Zone. In the KR-1 borehole, it is characterized by the occurrence of the genus *Citronites*, mentioned for the first time in southern Tunisia, and identified at the base of this biozone associated to *Moellerites*, which, in the other boreholes, has been defined as early Kashirian zone. In fact, Ghazzay-Souli et al., (2015) characterized the early Kashirian by the presence of the *Moellerite* Zone (Figure 9, Photo 11) overlain by the *Trinodella* and *Schubertella* Zone of the Kasimovian–Gzhelian transition. In the LG-2 and LG-1 boreholes, Lys (1988) identified the following species: *Eofusulina triangula* (Putrya) (Figures. 3–4) and *Aljutovella postaljutovica* (Figure 1), *Hemifusulina cf. pulchella*, and attributed this assemblage to the early Kashirian, overlain directly by the Permian or Triassic deposits.

The Podolskian - Myachkovian - Kasimovian ages are represented by oolitic limestones very zoogenic, which include fusulinids and rare smaller foraminifera. The genera or species of these intervals are *Taitzehoella*, *Fusulina*, *Hemifusulina*, *Fusiella*, *Quasifusulinoides*, and *Protriticites*. The Kasimovian corresponds to the *Montiparus* Zone. Although Lys (1988) recognised late Kasimovian assemblage, *Triticites* aff. *irregularis*, *T. aff. plummeri* (Figure 8), *T. petschoricus* (Figure 7), *Quasifusulina eleganta*, indicate another age. In the same limestone levels, he reported the presence of the algae *Dvinella* aff. *comata*, to the late Myachkovian-early Kasimovian transition. We did not identify these species at KR-1. We note that only at the KR-1 borehole there is continuity of marine deposits from the Bashkirian to the Gzhelian.

INTERNAT. SCALE	REGIONAL SUBDIVISIONS	Moscow Syncline Aretz et al., 2020; Lucas et al., 2021; Makina et al., 2001a, b.	Urals Enor, 1975; Chuvaikov et al., 1984; 1991; Ivanova, 2008.	Donets Basin Putrya and Leontovich, 1948; Fohrer et al., 2007; Khojanzizova and Davitov, 2013.	Cantabrian Mountains Vila, 1995; Vila et al., 2010, 2015, 2018; Merino-Tomé et al., 2020; Vila et al., 2021.	Turkey Akbaş and Okuyucu, 2022 a, b.	Kirchaou borehole This study
SYSTEM-SUBSYSTEM-STAGE	RUSSIAN PLATFORM	Fusulinid Zones	Fusulinid Zones	Fusulinid Zones	Fusulinid Zones	Fusulinid Zones	Fusulinid Zones
LATE PENNSYLVANIAN-KASIMOVIAN	Kreyvakinian	<i>Protriticites subswagerinoides</i> - <i>Obsoletes obsoletus</i> <i>Obsoletes</i> - <i>Fusella lancetiformis</i>	<i>Protriticites pseudomontiparus</i> - <i>Obsoletes obsoletus</i>	<i>Protriticites plicatus</i> , <i>P. parvus</i> <i>Obsoletes cf. lamellosus</i> <i>Pseudostaffella</i> sp., <i>Fusella spatiosa</i> .	<i>Protriticites grajalensis</i> , <i>P. ex gr. subswagerinoides</i> <i>Quasifusulinoides parafusiformis</i> <i>Pseudotrinitites cantabricus</i>	<i>Quasifusulinoides</i> - <i>Protriticites-Montiparus</i>	<i>Protriticites</i> - <i>Quasifusulinoides</i>
LATE PENNSYLVANIAN-KASIMOVIAN	Myachkovian	<i>Protriticites ovatus</i> <i>Fusulina cylindrica</i> <i>Fusulinella bocki</i>	<i>Obsoletes burkenensis</i> <i>Fusulina cylindrica</i> <i>Fusulinella bocki</i>	<i>Protriticites parvus</i> , <i>Quasifusulinoides fusulinoides</i> <i>Fusulinella bocki</i> , <i>Fusulinella rara</i> <i>Fusulina rossoschanka</i> , <i>Hf. stabilis</i>	« <i>eximius</i> » <i>Protriticites</i> : <i>Protriticites ovatus</i> <i>Beedeina elegans</i> , <i>Fusulinella alvaradoi</i> <i>Fusulinella broncaeae</i> , <i>Putrella</i> <i>Tatzehoella perseverata</i> , <i>Pseudostaffella</i>	<i>Fusulinella bocki bocki</i>	
MIDDLE PENNSYLVANIAN-MOSCOWIAN	Podolskian	<i>Fusulina chernovi</i> <i>Fusulinella colaniae</i> - <i>Beedeina ulinensis</i> <i>Putrella brazhnikovae</i> <i>Dukkevichella vozgalka</i>	<i>Fusulina kamensis</i> - <i>Putrella brazhnikovae</i> <i>Fusulinella vozgalkensis</i> <i>Fusulinella colaniae</i>	<i>Beedeina samarica</i> , <i>Fusulinella colaniae</i> , <i>Fusulinella pseudocolaniae</i> <i>Putrella brazhnikovae</i>	<i>Beedeina truyoloi</i> , <i>Fusulina agujasensis</i> , <i>Fusulinella girieffi</i> <i>F. ex gr. colaniae</i> <i>Putrella brazhnikovae</i>	<i>Fusulinella vozgalkensis devexa</i> <i>Beedeina schellwieni</i>	<i>Tatzehoella prolbrovichi</i> - <i>Fusulina</i>
MIDDLE PENNSYLVANIAN-MOSCOWIAN	Kashirian	<i>Fusulinella priscooides</i> - <i>Kanmeria subpulchra</i> <i>Fusulinella schubertellinoides</i> <i>Beedeina pseudoelegans</i> <i>Ajutovella? priscoidea</i>	<i>Kanmeria subpulchra</i> - <i>Beedeina schellwieni</i> - <i>Fusulinella schubertellinoides</i> <i>Ajutovella? priscoidea</i>	<i>Beedeina schellwieni</i> <i>Fusulinella schubertellinoides</i> <i>Kanmeria subpulchra</i>	<i>Beedeina bona</i> , <i>Fusulinella delepini</i> , <i>Kanmeria subpulchra</i> <i>Profusulinella ovata</i> <i>Dukkevichella ex gr. moelleri</i>	<i>Eofusulina triangula</i> - <i>Ajutovella priscoidea</i>	<i>Beedeina</i> - <i>Citronites</i>
MIDDLE PENNSYLVANIAN-MOSCOWIAN	Vereian	<i>Profusulinella arta</i> <i>Ajutovella ajutovica</i>	<i>Profusulinella prisca</i> - <i>Ajutovella ajutovica</i>	<i>Eofusulina triangula</i> <i>Ajutovella postajutovica</i> <i>Profusulinella pseudorhomboides</i>	<i>Profusulinella prisca</i> <i>Ajutovella arificata</i> <i>Eofusulina cf. triangula</i>	<i>Ajutovella ajutovica</i> - <i>Solovievaia ovata</i>	
EARLY PENNSYLVANIAN-BASHKIRIAN	Melekessian		<i>Verella spicata</i> - <i>Ajutovella tickonovichi</i>	<i>Verella cf. transiens</i> , <i>Ajutovella skeinavatica</i> <i>Profusulinella pseudorhomboides</i> <i>Neostaffella subquadrata</i>	<i>V. spicata</i> and <i>V. transiens</i> <i>Eowadokindalina solovievae</i> <i>Profusulinella siltteri</i> <i>P. martinezi</i>	<i>Tikhonovichiella tikhonovichi</i> - <i>Verella spicata</i>	<i>Tikhonovichiella tikhonovichi</i> - <i>Profusulinella</i>

Figure 4. Correlation of the fusulinid zones established in this study with the fusulinid zones of the adjacent regions (Ueno, 2022 modified).

6. LITHOSTRATIGRAPHIC CORRELATION

Lithostratigraphic correlation in southern Tunisia, oriented NW-SE, considering the seven petroleum wells KJD-1, BMT-1, KR-1, GT-1, LG-3, HBR-1 and MER-1, is useful to interpret the variations in the Moscovian deposits along the Jeffara Basin. Only a limited number of boreholes have crossed through Carboniferous deposits, over the permit Kirchaou eight boreholes have accessed the Moscovian (Kilani et al., 2015; Ghazzay- Souli et al., 2015).

The Carboniferous deposits overlay different terms of the Lower Paleozoic (Figure 5). During the late Viséan, the sea transgressed from north to south of the Saharan platform. By the Moscovian period, at the KR-1 borehole, the sea advanced over the folded Cambro-Ordovician, along LG-2 and LG-1, reaching Ordovician sediment, and over Silurian deposits along LG-3 and GT-1.

The Carboniferous was deposited in its entirety at Kirchaou-1 (Viséan-Gzhelian) or partially (incomplete Carboniferous). Early Moscovian strata were encountered only in KR-1, LG-2, LG-1, LG-3, and BMT-1. The Vereian is missing along all the boreholes, except for LG-2 (Lys, 1988). The gap at the base of the Moscovian is probably due to regression or detrital deposition, indicated by the occurrence of sandy or sandstone intervals, or vacuolated dolomites. In LG-1 and LG-2 boreholes, the Podolskian is the most recent marine deposit, while ecological conditions in KR-1 are still favorable, allowing for the definition of the Myachkovian and Kasimovian. In the other boreholes, the Carboniferous is missing, and the

Permian rests directly on the Silurian or Ordovician layers.

7. SYSTEMATIC PALEONTOLOGY

Order Fusulinida Fursenko, 1959

Family Pseudostaffellidae Putrya, 1956

(nom. transl. Rauzer-Chernousova et al., 1996

ex Pseudostaffellinae Putrya, 1956)

Genus *Topilinia* Ivanova, 2008

Type species. *Staffella ozawai* var. *topilini* Putrya, 1939, by original designation.

Description. Test large, subglobular to subquadratic, with a rounded periphery; proloculus are faint or absent. The number of whorls is big, with 6-7 and occasionally 7-8 whorls. The spire is more tight in the initial whorls, and more loose in the outer whorls, especially in the penultimate and last whorls. Chomata are massive, low, ribbon-shaped. The wall is moderately thick, with three layers, and four layers in the outer whorls, with a diaphanotheca. Aperture simple, small, crescentic.

Occurrence. From late Bashkirian to Myachkovian; Russia (Moscow basin, Saratov-Volga area, Volga-Urals area, Urals (eastern slope of the southern Urals, along the rivers Mugodzhar, Ural and Uly-Taldyk), Bashkortostan, Kama area, Timan-Pechora area); Central Asia; Donbas (Ukraine); northern Spain (see Rauzer-Chernousova et al., 1996); Tunisia (this study).

Topilinia sp.

Figure 6A

Diameter (D): 0.29 mm; Width (W): 0.23 mm; W/D: 0.8; Number of whorls (N): 5; Proloculus diameter (P): 0.02 mm; Height of last whorl (H): 0.06 mm; Wall thickness (S): 0.016 mm.

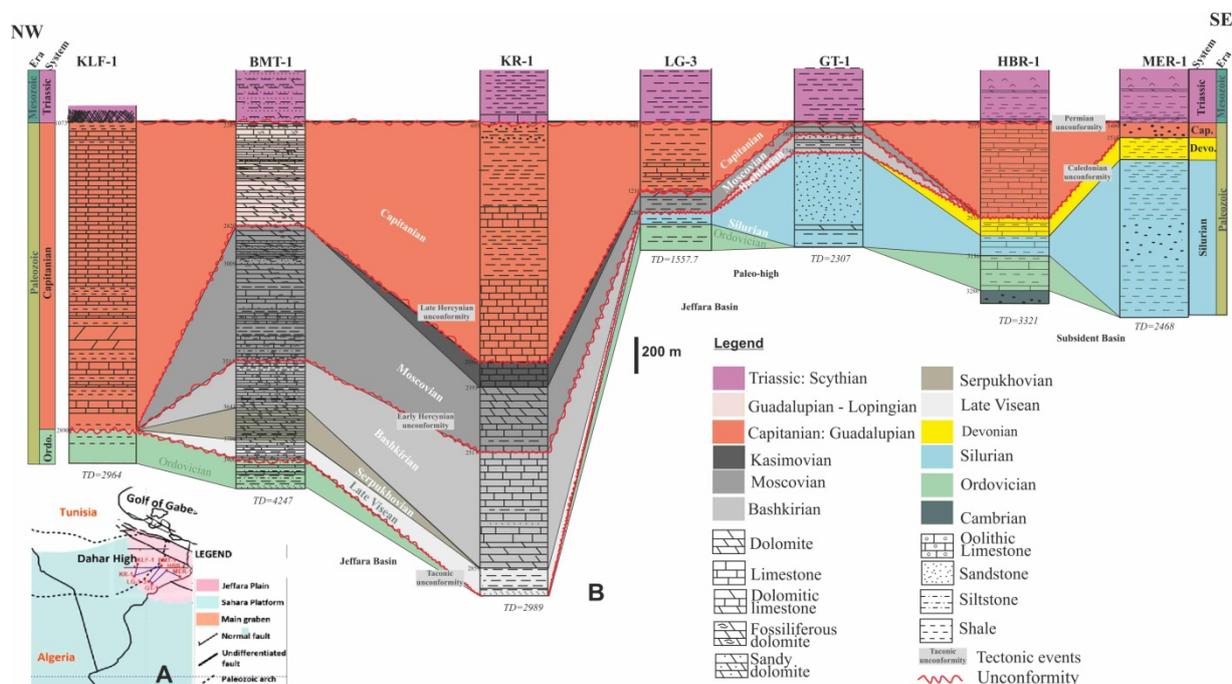


Figure 5. Lithostratigraphic correlation of the Moscovian deposits along the Jeffara basin, southern Tunisia. A. Location of seven boreholes (KLF-1, BMT-1, KR-1, LG-3, GT-1, HBR-1 and MER-1) in structural map of the central Mediterranean, showing the Jeffara basin (modified from Raulin et al., 2011 and Ghalgaoui et al., 2023). B. Lithostratigraphic correlation, directed NW-SE, flattened on the Permian unconformity.

Genus *Neostaffella* Miklukho-Maklay, 1959
emend. Miklukho-Maklay 1963

Type species. "*Pseudostaffella sphaeroidea* Ehrenberg" in the sense of Rauzer-Chernousova 1951 = *Neostaffella sphaeroidea* in the sense of Miklukho-Maklay, (1959); by original designation.

Description. Tests medium-sized to broad, spherical, drum-shaped, occasionally with concave umbilical areas, involute, rarely slightly evolute in the terminal whorl. The initial stage is sometimes deviated. The height of the whorl increases progressively. Up to 7 volutions. Well-developed, broad chomata, ribbon-shaped, up to the umbilici. The wall is poorly differentiated in the initial whorl, but the adult wall exhibits four layers, including a diaphanotheca. Aperture terminal simple.

Occurrence. Moscovian of Eurasia, Indochina, and Japan (see Rauzer-Chernousova et al., 1996).

Neostaffella polasnensis (Rauzer-Chernousova & Safonova in Rauzer-Chernousova et al., 1951)

Figure 6B

D: 0.30 mm; W: 0.24 mm; W/D: 0.7; N: 6; P: 0.01 mm; H: 0.05 mm; S: 0.016 mm.

Neostaffella syzranica (Rauzer-Chernousova & Safonova in Rauzer-Chernousova et al., 1951)

Figure 6C

D: 0.76 mm; W: 0.58 mm; W/D: 0.7; N: 9; P: 0.05 mm; H: 0.09 mm; S: 0.016 mm.

Neostaffella subquadrata (Grozdilova & Lebedeva,

1950)

Figure 6D

D: 0.4 mm; W: 0.38 mm; W/D: 0.9; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Neostaffella sp.

Figure 6E

D: 0.59 mm; W: 0.27 mm; W/D: 0.46; N: 6; P: 0.02 mm; H: 0.04 mm; S: 0.016 mm.

Family Profusulinellidae Solovieva in Rauzer-Chernousova et al., 1996

Genus *Profusulinella* Rauzer-Chernousova & Belyaev in Rauzer-Chernousova et al., 1936

Type species. *Profusulinella pararhomboides* Rauzer-Chernousova & Belyaev in Rauzer-Chernousova et al., 1936; by original designation.

Description. Test minute small to medium sized, inflated fusiform to subellipsoidal, with bluntly rounded poles. First whorl subdiscoidal to spherical and occasionally coiled at large angles to the coiling axis. Coiling uniform but rather loose. Septa are thin. Septal fluting absent or poorly developed in polar regions. Proloculus spherical. Tunnel rather narrow. Chomata massive and wide. Wall unilayered, dark microgranular. Aperture terminal simple.

Occurrence. Late Bashkirian-early Moscovian; probably cosmopolitan (see Kobayashi and Vachard, 2022).

Profusulinella sp.

Figure 6F-H

D: 0.20 mm; W: 0.18 mm; W/D: 0.9; N: 3; P: 0.03 mm; H: 0.03 mm; S: 0.016 mm.

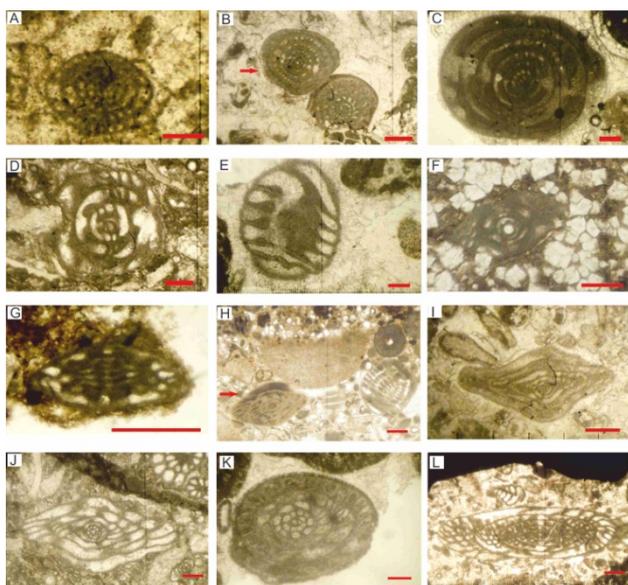


Figure 6. Selected representative fusulinids from the Kirchaou borehole (KR-1). A. *Topilinia* sp., oblique section, sample 2208.4 m; B. *Neostaffella polasniensis* Rauzer-Chernousova and Safonova in Rauzer-Chernousova et al., 1951, oblique axial section, sample 2444.6 m; C. *Neostaffella syzranica* Rauzer-Chernousova and Safonova in Rauzer-Chernousova et al., 1951, subaxial section, sample 2444.6 m; D. *Neostaffella* cf. *subquadrata* Grozdilova and Lebedeva, 1950, subaxial section, sample 2414.2 m; E. *Neostaffella* sp., oblique tangential section, sample 2446 m; F-H. *Profusulinella* sp., (F) axial section, sample 2228.7 m, (G) sample 2311.9 m, (H) subaxial section, sample 2521.4 m; I. *Taitzehoella prolibrovichi* Rauzer-Chernousova, 1951, axial section, sample 2423.9 m; J. *Taitzehoella* sp., axial section, sample 2414.2 m; K. *Moellerites* sp., subaxial section, sample 2517 m; L. *Fusulina* ex gr. *cylindrica* Fischer de Waldheim, 1830, axial section, sample 2440.8 m. Scale bar: 0.1 mm.

Genus *Taitzehoella* Sheng, 1951

Type Species. *Fusulinella librovitchi* Dutkevich, 1934 (= *Taitzehoella taitzehoensis* Sheng, 1951), by original designation.

Description. Test fusiform with median region inflated and narrow polar regions of reduced diameter. Early whorls deviated; W/D commonly 1.7 to 2.0; number of whorls 6-9. Wall unilayered microgranular; occasionally with two or three layers. Chomata high and asymmetrical. Tunnel regular and gradually widening. Aperture terminal simple.

Occurrence. Moscovian; especially Kashirian and early Podolskian. European part of Russia, Central Asia, Spain, Algeria, Tunisia, Iran, Greenland, and China (see Rauzer-Chernousova et al., 1996; Leven & Gorgij, 2011).

Taitzehoella prolibrovichi (Rauzer-Chernousova,

1951)

Figure 6I

D: 0.24 mm; W: 0.17 mm; W/D: 0.7; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Taitzehoella sp.

Figure 6J

D: 0.35 mm; W: 0.28 mm; W/D: 0.8; N: 4; P: 0.03 mm; H: 0.08 mm; S: 0.016 mm.

Genus *Moellerites* Solovieva, 1986

Type Species. *Moellerites lopasniensis* Solovieva, 1986, by original designation.

Description. Test inflated-fusiform to elongate-fusiform, ovoid, with rectilinear or slightly convex flanks, W/D up to 3.9; number of whorls up to 6. Wall thin or more rarely moderate in thickness, with a diaphanotheca sporadically developed. Chomata irregular in inner whorls. Ribbon-shaped in the outer whorls. Aperture narrow in the inner whorls, becoming broad in the outer whorls.

Occurrence. Moscovian (Kashirian-early Podolskian); European part of Russia, Urals, Turkey, Iran, Tien Shan (see Rauzer-Chernousova et al., 1996; Okuyucu, 2009; Leven & Gorgij, 2011; and Orlov-Labkovsky & Bensch, 2015).

Moellerites sp.

Figure 6K

D: 0.56 mm; W: 0.32 mm; W/D: 0.57; N: 6; P: 0.03 mm; H: 0.07 mm; S: 0.016 mm.

Family Fusulinidae von Möller, 1878

Subfamily Fusulininae Staff & Wedekind, 1910

Genus *Fusulina* Fischer de Waldheim, 1829

Type species. *Fusulina cylindrica* Fischer de Waldheim, 1830; by subsequent designation by Meek and Hayden, 1865, according to Thompson, 1967.

Description. Test elongate fusiform to subcylindrical, with bluntly pointed poles. Proloculus spherical, small to moderate. Septal folding strong to very strong. Chomata massive, symmetrical to asymmetrical. Tunnel straight to relatively irregular. Aperture terminal, simple, basal. Wall typically fusulinoid; i. e. with tectum, diaphanotheca and two tectoria.

Fusulina ex gr. *cylindrica* Fischer de Waldheim, 1830

Figure 6L

D: 0.95 mm; W: 0.29 mm; W/D: 0.31; N: 6; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Fusulina cf. *kulikiana* Rauzer-Chernousova, 1951

Figure 7A

D: 0.24 mm; W: 0.17 mm; W/D: 0.7; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Fusulina cf. *ulitnensis* Rauzer-Chernousova, 1951

Figure 7D

D: 0.24 mm; W: 0.17 mm; W/D: 0.7; N: 4; P: 0.03

mm; H: 0.09 mm; S: 0.016 mm.

Fusulina sp.

Figure 7B, E

D: 1.08 mm; W: 0.41 mm; W/D: 0.4; N: 5; P: 0.04 mm; H: 0.09 mm; S: 0.016 mm.

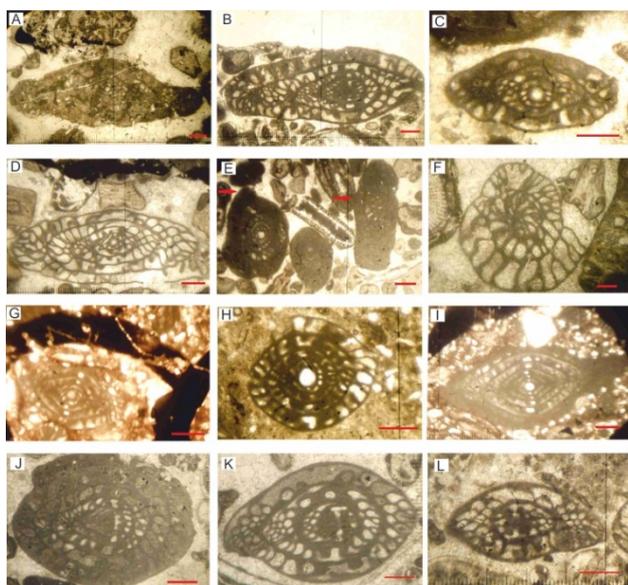


Figure 7. Selected representative fusulinids from the Kirchaou borehole (KR-1). A. *Fusulina* cf. *kulikiana* Rauzer-Chernousova in Rauzer-Chernousova et al., 1951., axial section, sample 2412 m; B, E. *Fusulina* sp., (B) subaxial section, sample 2429.15 m, (E) axial section and oblique subaxial section, sample 2411.8 m; C. *Fusulinella* sp., axial section, sample 2412 m; D. *Fusulina* cf. *ulitensis* Rauzer-Chernousova in Rauzer-Chernousova et al., 1951, axial section, sample 2412 m; F. *Kamaina* sp., subtransverse section, sample 2446 m; G-H. *Beedeina rasdorica* Putrya, 1938, (G) axial section, sample 2446.3 m, (H) oblique axial section, sample 2446.3 m; I-L. *Beedeina* sp., (I) subaxial section, sample 2446.3 m, (J), (K) oblique section, sample 2446 m, (L) subaxial section, sample 2440.8 m. Scale bar: 0.1 mm.

Genus *Kamaina* Solovieva in Rauzer-Chernousova et al., 1996

Type species. *Fusulina kamensis* Safonova in Rauzer-Chernousova et al., 1951; by original designation.

Description. Test large, elongate or subcylindrical (W/D up to 5.5). The septal folding is high and irregular. Chomata are weak. Aperture simple, very narrow.

Occurrence. Moscovian, generally Podolskian. European part of Russia, Svalbard, Spain, Hungary, Iran, central Asia (see Rauzer-Chernousova et al., 1996; Ivanova, 2008; Leven & Gorgij, 2011).

Kamaina sp.

Figure 7F

D: 0.24 mm; W: 0.17 mm; W/D: 0.7; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Subfamily Beedeininae Solovieva in Rauzer-Chernousova et al., 1996

Genus *Beedeina* Galloway, 1933 emend. Ishii, 1957

Type species. *Fusulinella girtyi* Dunbar and Condra, 1927, by original designation.

Description. Test inflated fusiform to subrhombic, with bluntly pointed poles. Proloculus spherical, small to moderate. Septal folding strong to very strong. Chomata massive, symmetrical to asymmetrical. Tunnel straight to relatively irregular basal. Wall typically fusulinoid; i. e. with tectum, diaphanotheca and two tectoria. Aperture terminal simple.

Beedeina rasdorica (Putrya, 1938)

Figure 7G-H

D: 0.24 mm; W: 0.17 mm; W/D: 0.7; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Beedeina sp.

Figure 7I-L

D: 0.24 mm; W: 0.17 mm; W/D: 0.7; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Genus *Parabeedeina* Solovieva in Rauzer-Chernousova et al., 1996

Type species. *Fusulina elegans* Rauzer-Chernousova and Belyaev, 1936; by original designation.

Description. Test subrhomboidal, elongate, with a rounded central part. Generally, there are 6-7 whorls, rarely 8, exceptionally 9. Septal folding relatively strong. Chomata generally strong up to the penultimate whorl. Aperture terminal simple.

Occurrence. Late Moscovian. European part of Russia, Central Asia, Primorye, Spain, Greenland, China, Japan, U.S.A. (see Rauzer-Chernousova et al., 1996).

Parabeedeina sp. 1

Figure 8B-C

D: 0.24 mm; W: 0.17 mm; W/D: 0.7; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Family Hemifusulinidae Putrya, 1956

Genus *Hemifusulina* von Möller, 1877

Type species. *Hemifusulina bocki* von Möller, 1878; by original designation.

Description. Test ellipsoidal, ovoid, subcylindrical short. One or two initial whorls are subspherical; then the adult shape appears. Up to 6-7 whorls, rarely 8. Septa almost planar in the center; more strongly folded near the poles. Wall thin (20-30 microns), bilayered (tectum and porous layer), occasionally with a median diaphanotheca. Chomata distinctive. Aperture terminal simple.

Occurrence. Moscovian (Kashirian-Myachkovian); European part of Russia, Central Asia, Kazakhstan, China, Thailand, Europe (Spain, former Yugoslavia, Hungary), northern Africa (Egypt, Tunisia) (see

Rauzer-Chernousova et al., 1996).

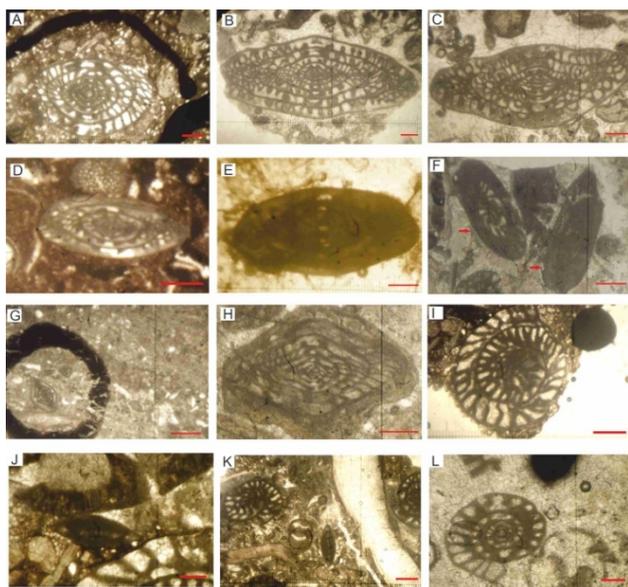


Figure 8. Selected representative fusulinids from the Kirchaou borehole (KR-1). A. *Beedeina* sp., subaxial section, sample 2446.3 m; B-C. *Parabeedeina* sp., (B) axial section, sample 2429.1 m, (C) subaxial section, sample 2423.9 m; D. *Hemifusulina* ex gr. *bocki* von Möller, 1878, axial section, sample 2311.9 m; E-F. *Fusulinella* sp., (E) axial section, sample 2301.6 m, (F) axial section, sample 2293 m; G-H. *Pulchrella subpulchra* Putrya, 1938, (G) axial section, sample 2446.3 m, (H) axial section, sample 2355.2 m; I, K. *Citronites* sp., (I) subtransverse section, (K) subtransverse section, sample 2517 m.; J. *Ozawainella* sp., axial section, sample 2517 m; L. *Tikhonovichiella tikhonovichi* Rauzer-Chernousova, 1951, axial section, sample 2521.5 m. Scale bar: 0.1 mm.

Hemifusulina ex gr. *bocki* von Möller, 1878

Figure 8D

D: 0.24 mm; W: 0.17 mm; W/D: 0.7; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Family Fusulinellidae Staff & Wedekind, 1910

Subfamily Fusulinellinae Staff & Wedekind, 1910

Genus *Fusulinella* von Möller, 1877

Type species. *Fusulinella bocki* von Möller, 1878; by subsequent designation.

Description. Test minute to medium sized, inflated fusiform to subellipsoidal, with bluntly rounded poles. First whorl subdiscoidal to spherical and occasionally coiled at large angles to the coiling axis. Coiling uniform but rather loose. Septa are thin. Septal fluting absent or poorly developed in polar regions. Proloculus spherical. Tunnel rather narrow. Chomata massive and wide. Wall plurilayered, with dark microgranular tectum, diaphanotheca and tectoria. Aperture terminal simple.

Occurrence. Moscovian-Kasimovian; European part of Russia, Urals, Central Asia, Kazakhstan, Primorye, Europe, China, Indochina, Japan, northern America

(Rauzer-Chernousova et al., 1996).

Fusulinella sp.

Figure 8E-F

D: 0.26 mm; W: 0.19 mm; W/D: 0.7; N: 4; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

Genus *Citronites* Solovieva in Rauzer-Chernousova et al., 1996

Type species. *Fusulina citronoides* Manukalova, 1948, by original designation.

Description. Test ovoid or rounded-subrhomboidal, with smooth extremities, and an ovate first whorl, a few whorls number, generally 5; coiling with a progressive increasing of the spire height; wall with three layers: tectum, outer tectoria, with a diaphanotheca poorly differentiated in the last whorls; outer tectorium can be absent; septal folding is moderate with rounded or angular solid archs. Septal number moderate: 28-30 in the last whorl; chomata are well developed, angular or subquadratic; they are weaker or absent in the last whorl. Aperture terminal simple.

Occurrence. Early Moscovian (Tsin Mountains, Donbas, Volga northern area, Darvaz, Tien Shan; Central Asia) (Rauzer-Chernousova et al., 1996; Leven, 2009).

Citronites sp.

Figure 8I-K

D: 0.43 mm; W: 0.36 mm; W/D: 0.85; N: 3; P: 0.04 mm; H: 0.09 mm; S: 0.005 mm.

Genus *Tikhonovichiella* Solovieva in Rauzer-Chernousova et al., 1996

Type species. *Aljutovella tikhonovichi* Rauzer-Chernousova, 1951; by original designation.

Description. Test minute, inflated fusiform to subrhombic, with bluntly rounded poles. First whorl subdiscoidal to spherical and occasionally coiled at large angles to the coiling axis. Coiling uniform but rather loose. Septa are thin. Septal fluting absent or poorly developed in polar regions. Proloculus spherical. Tunnel rather large. Chomata massive and wide. Wall unilayered, dark microgranular. Aperture terminal, simple.

Occurrence. Late Bashkirian and rare in early Moscovian (Vereian); European part of Russia, southern Turkey, Iran (Anarak), Darvaz, Central Asia, and China (Rauzer-Chernousova et al., 1996; Dzhenchuraeva and Okuyucu, 2007; Ivanova, 2008; Leven, 2009; Isakova, 2012).

Tikhonovichiella tikhonovichi Rauzer-Chernousova, 1951

Figure 8L, Figure 9A

D: 0.43 mm; W: 0.39 mm; W/D: 0.91; N: 3; P: 0.04 mm; H: 0.12 mm; S: 0.005 mm.

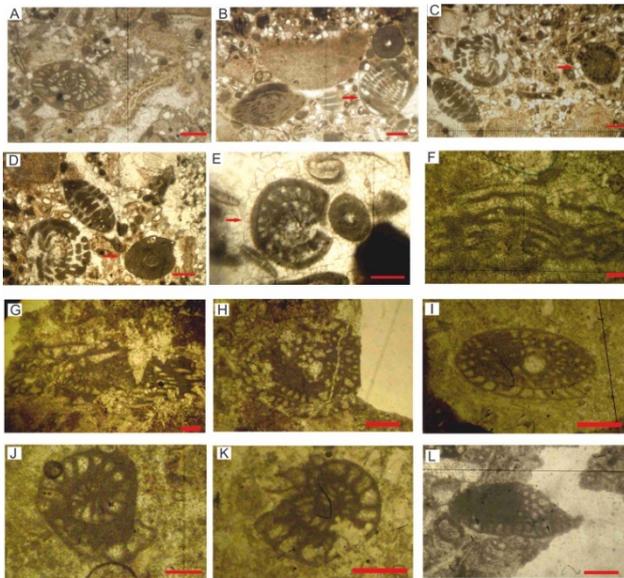


Figure 9. Selected representative fusulinids from the Kirchaou borehole (KR-1). A. *Tikhonovichiella tikhonovichi* Rauzer-Chernousova in Rauzer-Chernousova et al., 1951, axial section, sample 2517 m; B,E. *Parastaffelloides?* or *Staffella?* sp., (B) subtransverse section, sample 2521.5 m, (E) subaxial section, 2521.5 m; C. *Pseudostaffella* sp., subtransverse section, sample 2521.5 m; D. *Profusulinella* sp., axial section, sample 2521.4 m; F. *Fusiella* sp., subaxial section, sample 2201.8 m; G. *Montiparus* sp., subaxial section, sample 2193 m; H. *Quasifusulinoides* sp., oblique axial section, sample 2201.8 m; I, L. *Quasifusulina* sp., (I) oblique axial section, sample 2193 m, (L) subaxial section, sample 2170 m; J-K. *Protriticitis* sp., (J) subtransverse section, sample 2201.8 m, (K) subaxial section, sample 2193 m. Scale bar: 0.1 mm.

Subfamily Pulchrellinae Solovieva, 1983

Genus *Pulchrella* Solovieva, 1983

Type species. *Fusulinella pulchra* Rauzer-Chernousova & Belyaev in Rauzer-Chernousova et al., 1936; by original designation.

Description. Test medium-sized, rhomboidal, inflated fusiform, with gradually enlarging whorls. Septa similar to *Fusulinella*. Wall with four layers. Chomata relatively high and asymmetrical. Aperture terminal simple.

Occurrence. Moscovian-earliest Permian, European part of Russia, Greenland, Tien Shan, rare in the U.S.A. (see Rauzer-Chernousova et al., 1996 and Orlov-Labkovsky & Bensch, 2015).

Pulchrella subpulchra (Putrya, 1938)

Figure 8G-H

D: 0.49 mm; W: 0.29 mm; W/D: 0.6; N: 7; P: 0.03 mm; H: 0.09 mm; S: 0.016 mm.

8. CONCLUSIONS

The biostratigraphic results on the KR-1 borehole of SE Tunisia can be summarized as

follows:

-- The late Bashkirian - early Moscovian is marked by *Tikhonovichiella tikhonovichi*. The Vereian is probably absent due to a slight regression.

-- Moscovian is completely represented by all these zones: Kashirian is characterised by the *Beedeina-Citronites* Zone; Podolskian by *Taitzeoella prolibrovichi-Fusulina* Zone; Myachkovian is recognised by the index fossils *Topilinia*, *Quasifusulinoides*, and *Protriticitis*, and Kasimovian corresponds to the first occurrence of *Montiparus* Zone marker.

-- Several genera or species were not found in other boreholes in southern Tunisia; *Tikhonovichiella tikhonovichi*, *Citronites*, *Parabeedeina*, *Kamaina*, *Topilinia*, *Pulchrella subpulchra*, *Neostaffella polasnensis*, *N. syzranica*, *N. subquadrata*, *Taitzeoella prolibrovichi*, *Fusulina kulikiana*, *F. ulitinensis*, *Hemifusulina bocki*, *Fusiella*, *Quasifusulinoides*, *Montiparus*.

-- We have identified 35 genera and 50 species. The fusulinids are principally: staffellins, eostaffellins, millerellins, pseudostaffellins, and fusulinoidea like *Beedeina*, *Fusulina*, *Fusulinella*, *Hemifusulina* and *Taitzeoella*.

-- The comparison of the genera *Topilinia*, *Taitzeoella*, *Kamaina*, *Beedeina*, *Parabeedeina* and species *Taitzeoella prolibrovichi*, *Beedeina rasdorica*, *Hemifusulina* ex gr. *bocki*, *Pulchrella subpulchra*, *Fusulinella* sp., *Fusulina* cf. *kulikiana*, *Neostaffella subquadrata* identified in KR-1 as well as European parts of Russia, Spain, Iran, Greenland, Central Asia, Urals, and Donbas (Ukraine).

-- In Tunisia, the early Moscovian, which is highly zoogenic and contains the richest fusulinid assemblages, was recorded at Kasbah Leguine 1 (LG-1) (see Lys, 1988).

-- The paleoecology of the different fusulines and characters of deposit environments, in comparison with Baranova & Kabanov (2003); Vachard et al., (2010); and Khodjanyazova & Davydov (2013), permit to reconstruct a shelf transect which includes from west to east: LG (deeper); KR-1 (transitional), and BMT-1 (shallower), and to speculate that the Tunisian Jeffara is a semi-graben.

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