

Kimmeridgian protoglobigerinids (Foraminifera) from Crussol (SE France)

Ágnes Görög · Roland Wernli

Received: 2 July 2009 / Accepted: 15 January 2010 / Published online: 5 June 2010
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Abstract A detailed investigation of the protoglobigerinids from the Kimmeridgian section of the Montagne de Crussol, SE France is presented. This monotonous succession of predominantly carbonate beds represents periplatform hemipelagic deposits, well dated by ammonites. Three species were determined in thin sections and in isolated forms after extraction by acetolysis. *Favusella? parva* (KUZNETSOVA) is the most common species occurring in almost the entire succession from the Orthosphinctes to the Beckeri zones. *Favusella hoterivica* (SUBBOTINA) has been retrieved less frequently from the Platynota to the Beckeri zones, and it is its oldest occurrence. The rare *Globuligerina bathoniana* (PAZDROWA) occurs only in the Late Kimmeridgian. Based on our study and the review of the literature a palaeogeographical map was plotted, showing that most of the protoglobigerinid occurrences are in deep water facies of the northern margin and central part of the Tethys. These records demonstrate the presence of *Globuligerina bathoniana*, *G. oxfordiana* (GRIGELIS), *Favusella hoterivica*, *F.? parva* and *Compactogerina stellapolaris* (GRIGELIS) in the Kimmeridgian.

Keywords Protoglobigerinids · Conoglobigerinidae · Favusellidae · Late Jurassic · Palaeogeography · SE-France

Introduction

Protoglobigerinids are tiny globigerina-like foraminifera known from the Jurassic sediments, especially from the Oxfordian for a long time. They are mentioned from the Late Triassic to the Early Cretaceous in rock thin sections as well as in isolated forms. However, the finds in isolated forms are very scarce, sporadic in space and time. Generally, they are poorly preserved because of their aragonite test wall. Despite the exhaustive synthesis of BouDagher-Fadel et al. (1997) their detailed morphology of these fossils, taxonomy and stratigraphic and palaeobiogeographic distributions, are still very lacunal. To understand the phylogenetic origin of these foraminifera, their evolution and their hypothetic relations with the Cretaceous planktonic species request to improve the field records as well as the laboratory analysis. While the Middle Jurassic–Oxfordian protoglobigerinid record is fairly good, there is a huge gap in the knowledge of this group from the Kimmeridgian up to the Hauterivian (e.g. Riegraf 1987a; BouDagher-Fadel et al. 1997; Görög and Wernli 2003, 2004). In these stages, some protoglobigerinids are reported in rock thin sections, while the descriptions of isolated forms are dramatically scarce.

Hence, the aim of this work is to review the Kimmeridgian records of protoglobigerinids in the literature and to add new discoveries in thin section as well as in isolated forms from the well-dated field section of Crussol, strato-type of the Crussolian stage, near Valence in the south-eastern France (Fig. 1).

Editorial handling: Silvia Spezzaferri & Daniel Marty.

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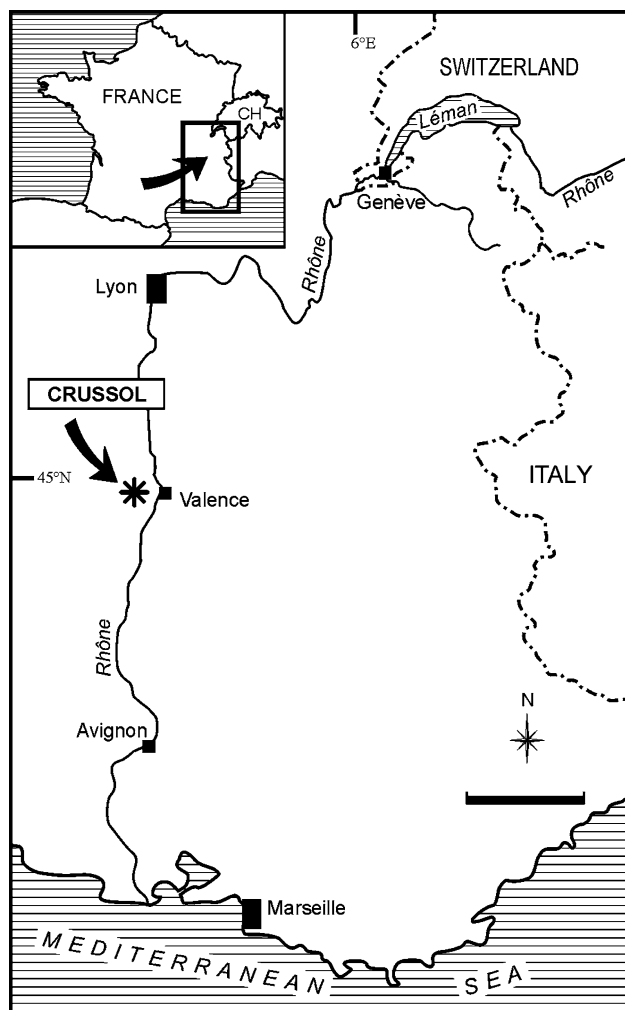


Fig. 1 Location of the studied Crussol section. Scale bar 50 km

Previous researches on the Kimmeridgian protoglobigerinids

Kimmeridgian protoglobigerinids were identified in 44 publications concerning 26 areas or lithologic units (Table 1; Fig. 2). The Kimmeridgian age of these fossils is questionable in 11 papers, and in 14 occurrences, the age is Kimmeridgian without any further specification. In most cases (17) the authors mentioned the forms from the Early Kimmeridgian and only three times from the Late Kimmeridgian. From 10 areas (21 papers) only citations without illustrations could be found. The protoglobigerinids are figured in thin sections of 10 areas (14 works) and as isolated specimens from 6 areas only (9 papers). Based on our experience (Görög and Wernli 2003) high and low trochospiral forms could be identified in the published illustrations and descriptions, suggesting that the low trochospiral forms are more frequent.

Ten species were cited, half of them from only one locality and we could not find any detailed systematic

description about *Globigerina* cf. *bulloides* D'ORBIGNY, 1826, *?Globuligerina lobata* (TERQUEM, 1883) and "*Globigerina (suprajurassica ?)*" (in Bergougnan 1971). In 27 publications, the determinations indicate only *Globigerina* or "*Protoglobigerina*".

In our detailed analysis, we disregard citations without illustration. For the morphological description of the shells, *H* is the height of the trochospire and *D* is the largest transverse diameter.

Records in rock thin sections in the literature

Our compilation shows that Kimmeridgian protoglobigerinids in thin sections are sparsely illustrated in the literature (Table 1). Apart from a single location in the North Atlantic (Luterbacher 1972), the palaeogeographical distribution of these occurrences covers essentially the Northern and the Central parts of the Tethyan realm (Fig. 2). Only one record is located in epicontinental sea (Southern Jura Mountains, Bernier 1984).

The determinations are usually on generic level. In general the sections are small, with *D* being in average around 180–200 µm, sometimes reaching up to 270 µm. In the majority of the areas the high and low trochospiral forms are associated. The walls appear thin, always recrystallised, and were probably originally aragonite. The building of the tests are not very clear, it may be consecutive or concurrent (Wernli 1988).

The most detailed studies are those of Giovagnoli and Schiavinotto (1986, 1987, 1990), who analysed a great number of sections from the Early Kimmeridgian of the Apennines (Umbria-Marche facies). Their statistical results show that the Kimmeridgian forms are small (up to 240 µm) with high trochospire, thin wall and concurrently built test. Hereinafter we will demonstrate that low trochospiral as well as high trochospiral forms exist in the Kimmeridgian.

Records in isolated forms in the literature

Grigelis et al. in (1977, p. 927, fig. 1) described by means of drawings a new, low trochospiral species, *Globuligerina stellapolaris* (GRIGELIS, 1977) from the Kimmeridgian and the Volgian (Tithonian) of the Timan-Pechora region in northern Russia. Later, Grigelis and Gorbachik (1980a, pl. 2, fig. 1, republished in 1980b, pl. 1, fig. 5) and Gorbachik and Kuznetsova (1998, pl. 1, figs. 1–3) gave SEM pictures of topotypes. This species is also cited from the Early Kimmeridgian of Crimea (Kuznetsova and Uspenskaya 1980; Gorbachik and Kuznetsova 1998). The diameter is 250–260 µm and the wall surface shows pseudomuricae in discontinuous ridges. Simmons et al. (1997) have chosen *G. stellapolaris* as type species of their new monotypic

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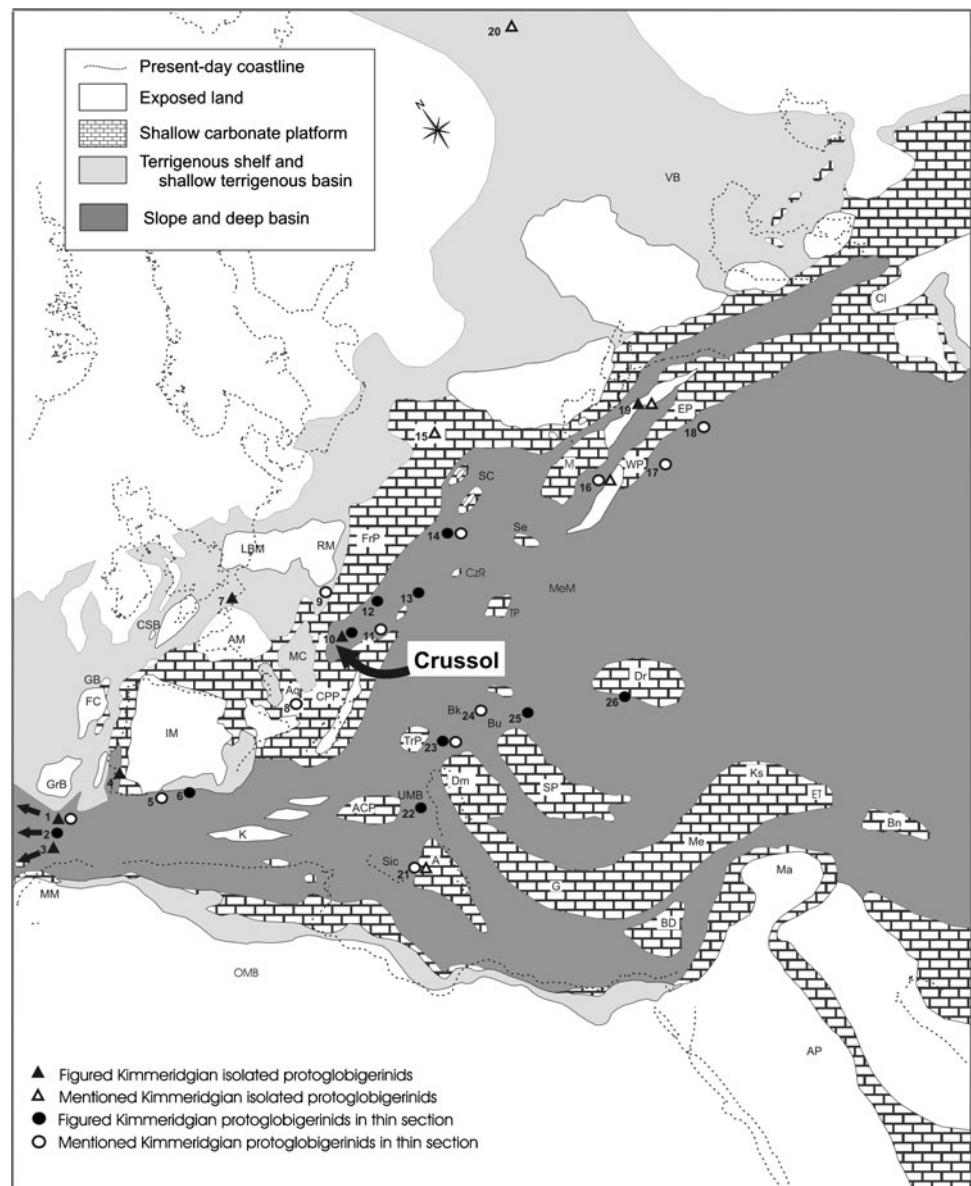
Table 1 continued

Indication on the map of Figure 2	Locality	References	Age	Isolated Thin section Mention	Trochospire		Determinations in the literature										
					High	Low											
17	Tinaz Tepe, W Taurus, Turkey	Farinacci et al. 1997, p. 22	E Kim	M		+											○
17	Tinaz Tepe, W Taurus, Turkey	Farinacci 2002, fig. 11 (on p. 18)	E Kim	M		+											
18	Berdiga Dag, NE Anatolia, Turkey	Nébert 1964, p. 47	Kim-Tit	M													○
19	Crimea, Ukraine	Kuznetsova & Gorbachik 1985, p. 113 = Simmons et al. 1997, p. 29, metatype	E Kim	I		+											▲
19	Crimea, Ukraine	Gorbachik & Kuznetsova 1998, p. 556	E Kim	I		+											
19	Crimea, Ukraine	Kuznetsova & Uspenskaya 1980, p. 749 on fig. 1.	E Kim	M		+											
19	Aj-Petri Yaila, Crimea Mts, Crimea, Ukraine	Krajewski & Olszewska, 2007 fig. 8c	Kim-Tit	T		+											
20	Pechora Basin, Russia	Grigelis et al. 1977, p. 927 Grigelis & Gorbachik 1980a, pl: II, fig. 1, 1980b, pl: II, fig. 1	Kim	I		+											
21	Sicily, Italy	Gianotti 1958, p. 41, 46	Kim-Tit	M													△ ○
22	Umbria-Marches Basin, Appenines, Italy	Giovagnoli & Scianotto 1986, p. 132; 1987, p. 191; 1990, p. 115	E Kim	T		+											●
23	Tölgyhát, Gerecse Mts, Hungary	Papp & Turnovsky 1970, p. 28	Kim	T		+	+										●
23	Kálvária Hill, Tata, Gerecse Mts, Hungary	Fülöp 1975, p. 64, figs. 39- 40	Kim	M													○
24	Sümege, Bakony Mts, Hungary	Haas et al. 1984, p. 60	Kim	M													○
25	Zumberak, NW Croatia	Gusić & Babić 1970, p. 45	Kim?	T		+	+										●
26	W Greece	Bernoulli & Renz 1970, p. 584	Kim?	T													●

Ox Oxfordian, Kim Kimmeridgian, Tit Tithonian, E early, L late

▲, Figured isolated forms; △, mentioned isolated forms; ●, figured forms in thin section; ○, mentioned forms in thin section

Fig. 2 Palaeogeographical distribution of the Kimmeridgian protoglobigerinids. The palaeogeographical map is modified after Thierry (2000). Numbers refer to the Table 1. *ACP* Apennine Carbonate Platform, *AM* Armorican Massif, *Aq* Aquitaine, *BK* Bakony, *Bu* Bükk, *CPP* Corbières-Provence Platform, *Dm* Dalmatia, *Dr* Drama, *EP* Eastern Pontids, *FC* Flemish Cap, *GrB* Great Bank, *H* Hochstegen, *IM* Iberian Meseta, *LBM* London Brabant Massif, *M* Moesia, *Ma* Mardin, *MC* Massif Central, *Mg* Magura, *MM* Moroccan Meseta, *OMB* Oued Mya Basin, *RM* Rhenish Massif, *SC* Silesian Cordillera, *Sic* Sicanids, *SP* Serbo Pelagonian, *TrP* Trento Plateau, *UMB* Umbria-Marches Basin, *VoB* Vocontian Basin, *VB* Volgian Basin, *WP* Western Pontids



genus *Compactogerina*, and they only recorded it from the Tithonian.

In northwestern Atlantic at DSDP site 534A, the poorly preserved *Globuligerina* aff. *oxfordiana* (GRIGELIS, 1958) (Gradstein, 1983, p. 552, pl. 2, figs. 1–10, low trochospiral small forms, $D = 70\text{--}80\text{ }\mu\text{m}$) are probably Oxfordian in age, even though the dinoflagellates indicate Kimmeridgian age.

Kuznetsova and Gorbachik (1985, p. 113, pl. 16, figs. 1, 2) illustrated by means of drawings their new species *Globuligerina parva* (KUZNETSOVA, 1985) from the Early Kimmeridgian of Crimea. The re-illustrations by SEM in Gorbachik and Kuznetsova (1998, pl. 2, figs. 8, 9) reveal that the holotype and the paratype are poorly preserved.

El Kamar (1986) published pictures with few visible details of *Globuligerina oxfordiana* (pl. 2, fig. 8, pl. 5,

figs. 7, 10) and *Globuligerina bathoniana* (PAZDROWA, 1969) (pl. 3, figs. 1, 6; pl. 5, fig. 4) from the earliest Kimmeridgian of Portugal.

Stam (1986) took good pictures of different species from the Early Kimmeridgian (Platynota Zone) of Portugal, like *Globuligerina oxfordiana* (pl. 8, figs. 4–12) (figs. 9–12 could be *Favusella? parva*), *Globuligerina bathoniana* (pl. 10, figs. 9–12) and *Globuligerina balakhmatovae* (MOROZOVA, 1961) (pl. 11, figs. 11, 12), even though the latter forms could be tectonically deformed specimens of *G. oxfordiana*.

Samson (1997, p. 142, pl. 16, figs. 12–19) illustrates poorly preserved specimens of *Globuligerina oxfordiana* from the Early Kimmeridgian of region of Havre, Seine-Maritime, Normandie, France. The individual on plate 16, fig. 12 (re-illustrated in Samson 2001, pl. 5, fig. 30) with a

low extraumbilical aperture could belong to *Haeuslerina helvetojurassica* (HAEUSLER, 1881). Those attributed to *Globuligerina* cf. *balakhmatovae* are deformed (pl. 16, figs. 21–23) while a high trochospiral form (pl. 16, fig. 20) to *Globuligerina bathoniana*.

Simmons et al. (1997) illustrated by SEM a metatype of *Haeuslerina parva* (= *Favusella*? *parva*). In their synthetic table “Stratigraphical distribution of Conoglobigerinidae” (op. cit., fig. 2.2) only two species (*H. parva* and *G. bathoniana*) occur in the Early Kimmeridgian, but not any in the Late Kimmeridgian.

To sum up, the record of the isolated protoglobigerinids in the Kimmeridgian is very poor in the number of sites as well as in the quality of the material. Moreover, the published illustrations do not allow unambiguous identifications. Almost all the finds come from the northern margin and the central part of the Tethys and from the North Atlantic. For these areas, we can retain the occurrences of *Globuligerina oxfordiana*, *G. bathoniana* and *Favusella*? *parva*. Only *Compactogerina stellapolaris* has been found in high latitude (Northern Russia).

The geological setting of the Crussol field section

The studied field section is located in the Montagne de Crussol, near Valence (Ardeche Department), Rhone valley, in SE France (Fig. 1). During the Kimmeridgian, the Crussol area was situated in the northwestern edge of the Vocontian Trough, at the European margin of the Tethys, which formed a gulf opening to the east (Fig. 2). In this direction, it grades into the deep facies of the Valais Trough that is connected with the Alpine Tethys Ocean (Thierry 2000). The Vocontian Trough is bounded to the west, south and southeast by the Corbières-Provence shallow carbonate platform. Exposed lands in proximity are the Massif Central to the west and the Corsica-Sardinia block to the southeast. From the Late Oxfordian to the Early Kimmeridgian the Vocontian Trough is subjected to a subsidence inducing an extension and the enlargement of the basin on its margins. From the Late Kimmeridgian the slowdown of the subsidence coupled with a compression phase produced the progradation of the neritic facies toward the centre of the basin (Enay 1984; Colombié and Strasser 2003).

Materials and methods

The Montagne de Crussol is an abrupt rocky mountain with several abandoned quarries on its western flank, which provide a continuous section from the Oxfordian to the Tithonian. The Kimmeridgian part of the succession has been studied in detail by Atrops (1982) who determined the

ammonites. He numbered the beds in the outcrops so we could use his numbering in our work (Fig. 3). Langoisseux (2001, unpublished) restudied the same outcrops carrying out a sequence stratigraphy using multidisciplinary approach. His collection of rock thin sections (Cru) has been used for the present paper (Fig. 3).

The Kimmeridgian section can be observed from the base to the top, going upwards on the mountain, in the quarry D, then in the quarry B and finally in the quarry F following the nomenclature of Atrops (1982, fig. 55). From the Panula Zone (partly) to the Beckeri Zone (partly) the sampled succession measures about 70 m in thickness.

This is a monotonous series of decimetric to plurimetric limestone or marly limestone beds generally without interbeds, with plane or wavy beddings. Only rare centimetric or thicker marl interbeds can be found. The limestones are essentially mudstones, micritic, beige, grey or pink-grey in colour, with few grains visible in the field. The outcrop represents a typical peri-platform, hemipelagic deposit. Apart from the ammonites, the other macrofossils (belemnites, brachiopoda, aptychii, echinoderms) are relatively rare. The microfossil content is analysed below in the chapter “Micropalaeontological associations”.

From the Kimmeridgian succession, four marl samples have been washed by standard method but we failed to find any protoglobigerinids in these facies. In calcareous indurated rocks, 41 thin sections of rocks collected by O. Langoisseux (coll. Cru) and eight by us (coll. W) have been analysed. All these samples are deposited in the Département de Géologie et Paléontologie, Université de Genève. Eleven samples of calcareous and marly rocks have been treated by means of acetolysis following the method of Lethiers and Crasquin-Soleau (1988). This extraction gave better results than the standard washings. Our records of protoglobigerinids in thin sections and in isolated forms are given in Fig. 3.

Micropalaeontological associations of the Crussol section

In rock thin sections the microfossils are relatively rare, forming a very monotonous and constant association in these mudstones all along the succession. There are tuberoids (sensu Gaillard 1983), small *Globochaete*, recrystallized radiolarians (dominant spumellarians), calcispherulids (*Colomisphaera* spp.), Saccocomidae, microgastropods, microbrachiopods and some “filaments” and aptychii. The foraminifera fauna is subordinate: besides the protoglobigerinids, it contains small, simple agglutinated forms (*Ammobaculites irregularis* (GÜMBEL, 1862), *Reophax* sp.), tiny Nubeculariidae, some Nodosariidae (*Lenticulina*, *Nodosaria*), Polymorphinidae and Spirillinidae.

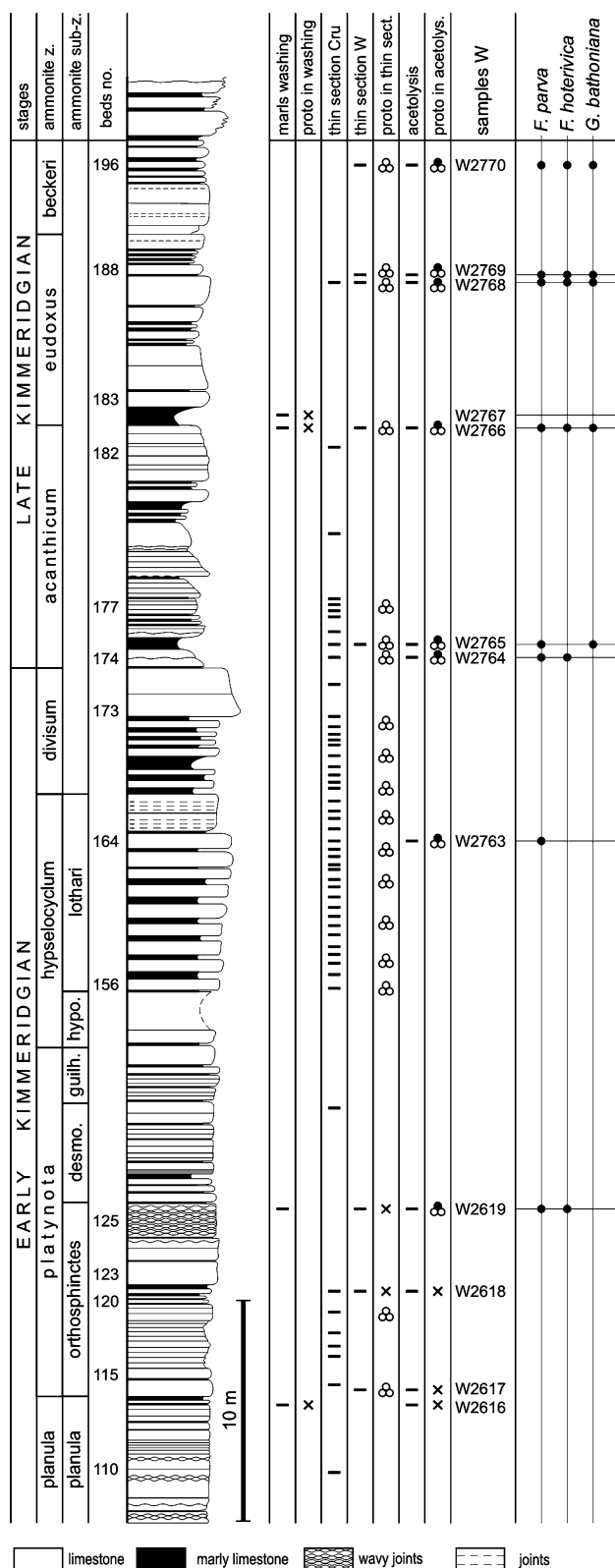


Fig. 3 Lithostratigraphic log of the Crussol section (simplified after Atrops 1982) and distribution of the protoglobigerinids. X no protoglobigerinids, Cru collection of O. Langoisseux, W collection of R. Wernli

The record of the isolated microfossils extracted by standard washing as well as by the acetolysis is very variable from bed to bed. Hence, the plankton–benthos ratio ($P/P + B$) varies from 5 to 40%. However, these figures must be used with caution because of the inconsistent extraction method. This technical distortion can be well illustrated in some samples, for example at the base of the outcrop (W2617), where the protoglobigerinids are present in rock thin sections but absent in the acetolysis residues. Hereinafter we give only a succinct analysis because the benthic foraminifera have not been studied in detail.

In the Early Kimmeridgian the associations are poor and less diverse, with radiolarians, some Nodosariidae (mostly *Lenticulina*), *Spirillina*, Polymorphinidae and some agglutinated species and *Paalzowella*. The Late Kimmeridgian reveals a richer and more diverse fauna: dominant groups are lenticulinids (*Lenticulina muensteri* ROEMER, 1839, *L. subalata* (REUSS, 1854), *Astacolus varians* (BORNEMANN, 1854), *L. quenstedti* (GÜMBEL, 1862), Polymorphinidae (*Eoguttulina oolithica* (TERQUEM, 1874), *E. bilocularis* (TERQUEM, 1864), *Guttulina pera* LALICKER, 1950, *Sigmomorphina* ssp.) and spirillinids (*Spirillina elongata* BIELECKA POZARYSKI, 1954, *S. tenuissima* Gümbel, 1862). Other Nodosariidae (*Dentalina* and *Nodosaria*) are relatively diverse, but not frequent; smooth and ornamented forms are also present. In some samples agglutinated specimens are also abundant, mostly small-sized *Haplophragmoides*, and *Glomospira*. Besides them, rhizamminids, *Textularia jurassica* GÜMBEL, 1862, *Ammodiscus* sp., *Reophax* sp. and *Ammobaculites* sp. also occur. The epistominids are rare.

All samples of the succession contain radiolarians, sponge spicules, saccocomids, other echinoderm fragments, microgastropods, ammonite protoconchs and a few ostracods.

In all samples, the abundance of the protoglobigerinids diminishes when the number of radiolarians increases.

Protoglobigerinids of the Crussol section

Protoglobigerinids in rock thin sections

Almost all 49 rock thin sections analysed from Crussol yield protoglobigerinids (see Fig. 3). They are scarce, usually about ten per slide (1–2 sections by cm^2) and never appearing as bloom like in the oceanic Middle Jurassic. The most frequent sections are small, about 70–160 μm in the largest diameter, some rare reaching up to 250 μm . A large part of them are entirely filled with sparicalcite. Some are partially filled, generally in the early whorls, leaving only the last chambers empty. In this case the thickness of the wall measures about 6–7 μm , which is always

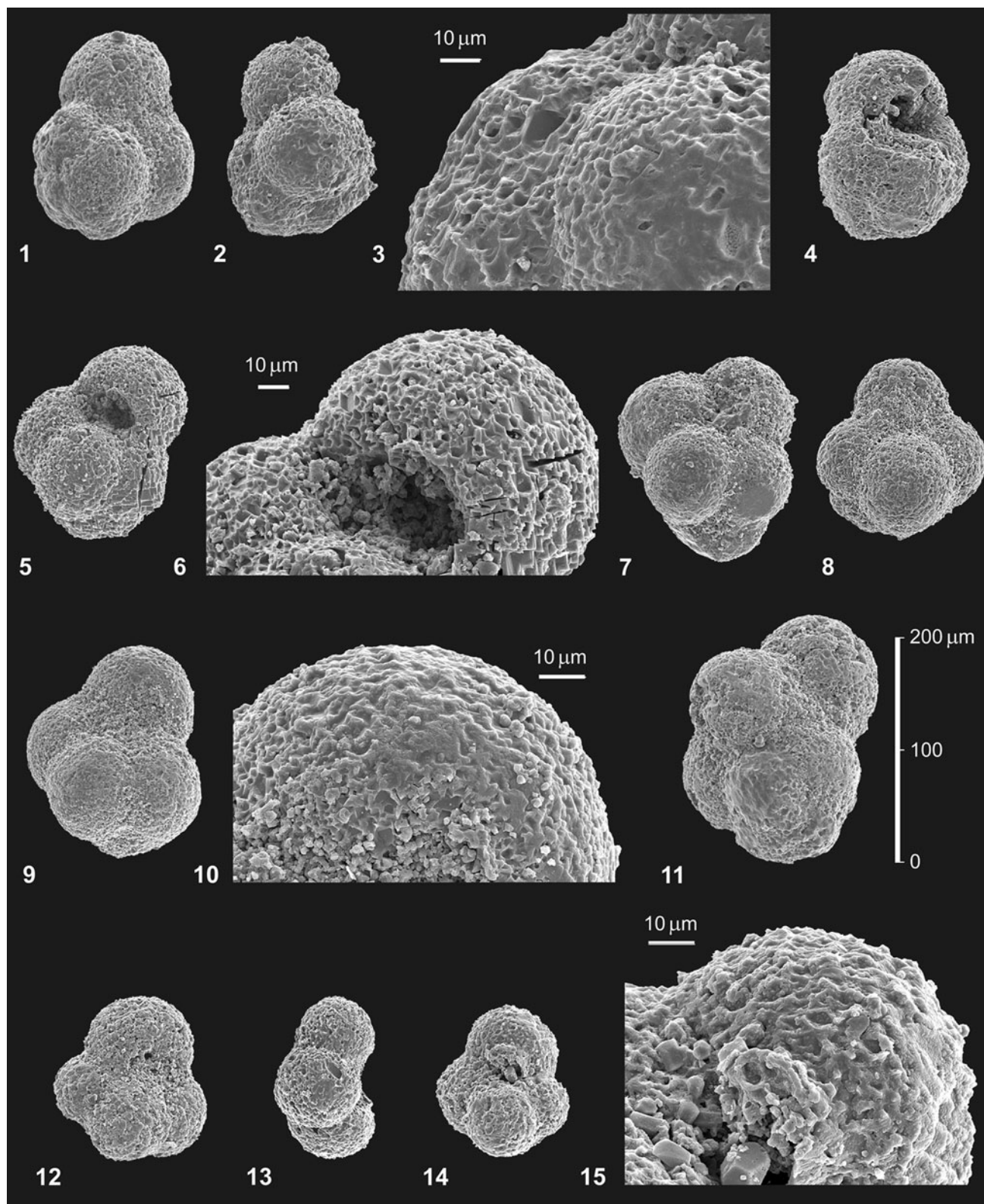


Fig. 4 Scale bars are 200 µm in 1–2, 4–5, 7–9 and 11–14, and 10 µm in 3, 6, 10 and 15. *umb.* umbilical view, *lat.* lateral view, *enlarg.* enlargement. **1–11** *Globuligerina bathoniana* (PAZDROWA), **1** lat.-umb. W2619, **2** lat. W2764, **3** enlarg. of **2**, **4** umb. W2766, **5** umb. W2766,

6 enlarg. of **5**, **7** umb. W2768, **8** umb. W2769, **9** umb. W2769, **10** enlarg. of **9**, **11** lat.-dorsal, W2769. **12–15** *Favusella? parva* (KUZNETSOVA), **12** umb. W2765, **13** lat. W2766, **14** umb. W2769, **15** enlarg. of **14**

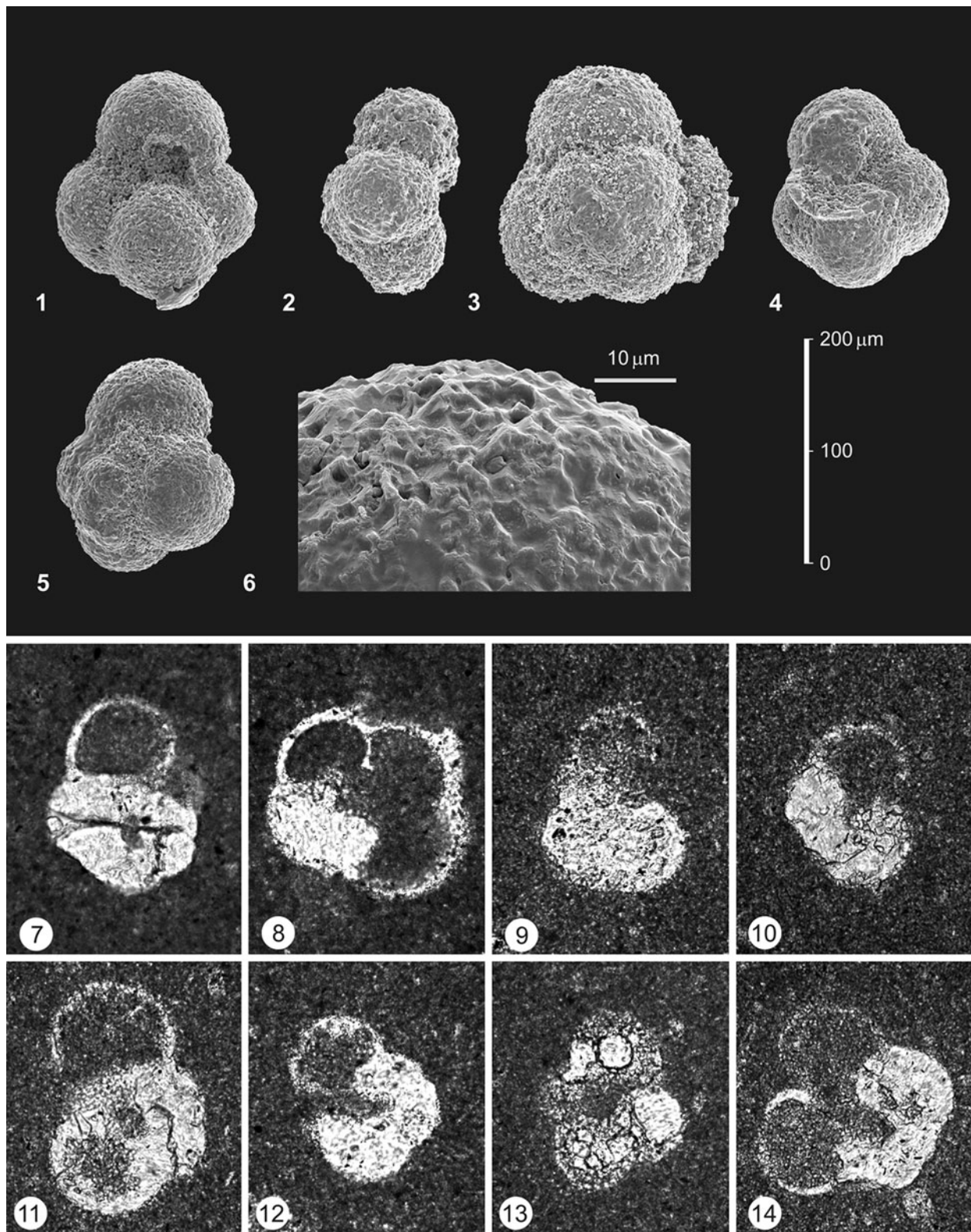


Fig. 5 Scale bars are 200 µm in 1–5 and 7–14, and 10 µm in 6. *umb.* umbilical view, *lat.* lateral view, *spiral* spiral view, *enlarg.* enlargement. **1–6** *Favusella hoterivica* (SUBBOTINA), **1** umb. W2619, **2** lat. W2768, **3** spiral with broken bulla, W2763, **4** umb. with broken bulla, W2769, **5** spiral oblique, W2619. **7–14** Protoglobigerinids in

rock thin sections. The *numbers* indicate the bed numbers. **7, 9, 12, 14** *Globuligerina* cf. *bathoniana* (PAZDROWA), **7, 8** 156, **9, 12** 119, **14** W2768. **8, 10** undetermined protoglobigerinids. **8** 156, **10** W2768. **11** *Favusella* cf. *hoterivica* (SUBBOTINA), W2768. **13** *Favusella*? cf. *parva* (KUZNETSOVA), W2766

recrystallised in sparicalcite, that is also visible on some isolated forms (Fig. 4.6). No sections clearly show the details of the juvenile stage. In several sections displaying the three last successive empty chambers, the thickness of the wall seems to be constant and so the building of the test appears consecutive.

The specific, even generic determination of the protoglobigerinids based on sections is very difficult (Wernli and Görög 2000). In the case of the Kimmeridgian of Crussol where there are isolated shells as well as sections from the same levels, it is possible to tentatively attribute:

- the high trochospiral forms to *Globuligerina* cf. *bathoniana* (Fig. 5.7, 5.9, 5.12, 5.14),
- the low trochospiral forms to *Favusella* cf. *hoterivica* (Fig. 5.11),
- the small petaloids equatorial sections to *Favusella*? cf. *parva* (Fig. 5.13).

The habit of the protoglobigerinids of Crussol well coincides with those of Giovagnoli and Schiavinotto (1990) from the Kimmeridgian of Apennines. In our opinion, the building of the tests (consecutive or concurrent) cannot clearly be identified in both occurrences. We can confirm contrary to these authors (op. cit., fig. 12) and also Wernli (1988), that high trochospiral tests as well as low trochospiral ones exist together in the Kimmeridgian (Figs. 3, 5.7–5.14).

Protoglobigerinids in isolated forms

In general, the isolated tests are moderately well preserved and not deformed. Although the wall is recrystallized in some cases the surface ornamentation is still retained. The number of the specimens strongly varies from sample to sample, from 3 to 5 up to 150. The vertical distribution of the different species can be seen in Fig. 3.

Superfamily Favusellacea Longoria, 1974 emend. Banner and Desai, 1988

Family Conoglobigerinidae Simmons, BouDagher-Fadel, Banner and Whittaker, 1997

Genus *Globuligerina* Bignot & Guyader, 1971, emend. Simmons, BouDagher-Fadel, Banner and Whittaker, 1997

Globuligerina bathoniana (PAZDROWA, 1969)

Figure 4.1–11.

- ?1961 *Globigerina conica* n. sp.; Iovčeva & Trifonova, p. 343, pl. II, figs. 1–8.
- pars 1969 *Globigerina bathoniana* n. sp.; Pazdrowa, p. 45, pl. I, figs. 1, 2, 4 (non fig. 3), figs. 5–9, pl. II, figs. 1–5, ??, 8, 9, pl. III, fig. pl. IV, 1–3. non pl. II, figs. 6 ab.

- ?1973 *Conoglobigerina bathoniana* (PAZDROWA, 1969); Fuchs, p. 455, pl. 1, fig. 2 (glauconitic moulds).
- 1976 *Gubkinella bathoniana* PAZDRO (sic); Ascoli, p. 672, 713, pl. 1, fig. 1.
- pars 1976 “*Globigerina*” *bathoniana* (PAZDROWA); Gradstein, p. 560, pl. 3, fig. 1 non? 2ab. (transitional form to *G. oxfordiana*).
- 1977 *Globigerina hoterivica* SUBBOTINA; Masters, p. 460, pl. 22, figs. 1–3.
- 1980a *Conoglobigerina bathoniana* (PAZDRO) (sic); Grigelis & Gorbachik, p. 9, pl. 1, figs. 3a–c. Refigured in:
- 1980b *Conoglobigerina bathoniana* (PAZDRO) (sic); Grigelis & Gorbachik, pl. 1, figs. 3ab (topotype).
 - 1981 *Conoglobigerina bathoniana* (PAZDRO) (sic); Alekseeva & Gorbachik, pl. 1, figs. 1ab.
- 1981 ? *Globigerina bathoniana* PAZDRO (sic), 1969; Bielecka & Styk, p. 34, pl. 3, figs. 21ab.
- pars 1986 *Globuligerina bathoniana* (PAZDROWA); Stam, p. 108, pl. 9, figs. 6, 7, 9, 11–13; pl. 10, figs. 1–12; pl. 11, figs. 1–10; pl. 13, figs. 1–12; pl. 14, figs. 1, 2, 5–7. (non pl. 9, figs. 8, 10). The pl. 9, fig. 12 is refigured in:
- 1988 *Globuligerina bathoniana* (PAZDROWA); Banner & Desai, pl. 1, fig. 4.
- 1987a *Globuligerina bathoniana* (PAZDROWA, 1969); Riegraf, p. 195, pl. 1, figs. 1–11 and text-figs. 5a–e (drawings). Reillustrated in:
- 1987b *Globuligerina bathoniana* (PAZDROWA); Riegraf, figs. 3–13.
 - 1988 *Globuligerina bathoniana* (PAZDROWA); Riegraf, p. 474, pl. 5, figs. 23–25.
- non 1996 *Globuligerina bathoniana* (PAZDRO) (sic); Kuznetsova et al., p. 191, pl. 15, fig. 14.
- 1997 *Globuligerina bathoniana* (PAZDROWA, 1969); Simmons et al., p. 27, pl. 2.8, figs. 4–12.
- 2002 *Globuligerina bathoniana* PAZDROWA (sic); Görög & Wernli, p. 30, pl. 1, figs. 28, 29.

Description: The relatively small tests reaching the maximum 200 µm in the largest dimension are high trochospiral ($H/D > 0.9$) with $3\frac{1}{2}$ –4 chambers in the last whorl. The general shape is roughly conical with a rounded apex giving a U profile in lateral view. The juvenile stage has not been clearly analysed because the chambers are strongly appressed. On the umbilical side, the last $3\frac{1}{2}$ –4 chambers are globular with incised sutures

giving a strongly lobulated outline. The aperture is an umbilical, asymmetric, globuligerine-like arch as high as wide surrounded by a lip. The distal part of this arch (following the ontogenic progression) is protruding when the proximal one is re-entrant into the chamber (Fig. 4.4). The aperture is commonly damaged, in this case it appears like a single arch without lip. The umbilicus is well marked, depressed, but in the majority of the specimens it is filled by sediment therefore the aperture is not clearly visible.

The wall is generally recrystallised with a surface showing the quadrate and rhombic network of the diagenetic sparalcalcite (Fig. 4.6). Only in some case, we can see a surface with few elevated, more or less vermiculated discontinuous pustules (Fig. 4.10) but never forming a meshwork like in the favusellids. Perforations have not been observed.

In the rock thin sections the wall measures about 7 µm in thickness and the building of the tests seems to be consecutive.

Remarks: *Globigerina conica* IOVČEVA & TRIFONOVA from the Tithonian of Bulgaria is a high trochospiral form strongly resembling to *G. bathoniana* in general shape. However, all specimens are glauconitic molds, without characteristic details of the wall and the aperture.

In the original description, Pazdrowa (1969) accepts a very large variability for her new species *G. bathoniana* especially in the height of the trochospire. However, we consider the middle to high trochospiral forms with a minimum H/D ratio of 0.9 as *G. bathoniana*, and the low trochospiral forms as *Globuligerina oxfordiana* (GRIGELIS) (pl. II, fig. 6ab). This applies also to Gradstein's (1976, pl. 3, fig. 2ab) and Stam's specimens (1986, pl. 9, figs. 8, 10). Disregarding the height of the trochospire *G. bathoniana* is strongly related to *G. oxfordiana* as illustrated by of Pazdrowa (1969), Stam (1986) or Simmons et al. (1997).

The specimens of Kuznetsova et al. (1996) have an exceptional large size, 380–460 µm, and very low trochospires.

Occurrence: *G. bathoniana* occurs in the Late Kimmeridgian of the Crussol section, relatively in small number.

Distribution: Late Bajocian—Late Kimmeridgian (Tithonian?).

Ogrodzieniec area, north from Krakow, Poland: Bathonian (Pazdrowa 1969; Masters 1977; Grigelis and Gorbachik 1980a, b; Alekseeva and Gorbachik 1981; Stam 1986, Simmons et al. 1997), Late Callovian—Early Oxfordian (Fuchs 1973); North Western Poland: Bathonian (Bielecka and Styk 1981); Scotian shelf: Bathonian?—Callovian (Ascoli 1976); Grand Banks, New Foundland: Late Bathonian—Early Callovian (Gradstein 1976), Late Bajocian—Bathonian (Stam 1986); Brenha section,

Portugal: Early Bathonian (Stam 1986); Mareta Beach, Portugal: Callovian (Stam 1986); Tojeira 1 section, Portugal: Early Kimmeridgian (Platynota Zone) (Stam 1986); SW Germany: Callovian (Riegraf 1987a, b, 1988); Bakony Mts, Hungary: Bathonian (Görög and Wernli 2002); Stubel village, Moesian Platform, NW Bulgaria: Tithonian (Iovčeva and Trifonova 1961).

Family Favusellidae Longorina, 1974

Genus *Favusella* Michael, 1973

***Favusella hoterivica* (SUBBOTINA, 1953)**

Figure 5.1–5.6.

- 1953 *Globigerina hoterivica* n. sp.; Subbotina, p. 50, pl. 1, figs. 1–4. *fide* Catalogue Ellis and Messina. Fossil foraminifera of the USSR: Globigerinidae, Hantkeninidae and Globorotaliidae. VNIGRI 76, Leningrad.
- ?1961 *Globigerina terquemi* n. sp.; Iovčeva & Trifonova, p. 344, pl. II, figs. 9–14.
- 1964 *Globigerina tardita* ANTONOVA sp. n.; Antonova et al., p. 60, pl. 12, figs. 4a–c, 5a–c.
- 1964 *Globigerina quadricamerata* ANTONOVA sp. n.; Antonova et al., p. 60, pl. 12, figs. 6a–c.
- 1976 *Caucasella hoterivica* (SUBBOTINA); Ascoli, p. 674, pl. 1, fig. 3.
- 1980a *Globuligerina haterivica* (sic) (SUBBOTINA); Grigelis & Gorbachik, pl. 2, figs. 3ab.
- 1980b *Globuligerina haterivica* (sic) (SUBBOTINA); Grigelis & Gorbachik, pl. 2, figs. 7ab.
- 1981 *Globuligerina haterivica* (sic) (SUBBOTINA) 1953; Gorbachik & Antonova, p. 84, pl. 1, figs. 1–4. Refigured in:
 - 1986 *Globuligerina haterivica* (sic) (SUBBOTINA); Gorbachik, pl. 11, figs. 1ab, 2.
 - 1988 *Favusella hoterivica* (SUBBOTINA); Banner & Desai, pl. 1, figs. 6ab.
- 1986 *Globuligerina quadricamerata* (ANTONOVA); Gorbachik, pl. 12, figs. 1a–c, 2ab, 3. The pl. 12 figs. 1bc refigured as:
 - 1988 *Favusella tardita quadricamerata* (ANTONOVA); Banner & Desai, pl. 1, figs. 8ab.
- 1986 *Globuligerina tardita* (ANTONOVA); Gorbachik, pl. 13, figs. 1 ab, 2, 3. Refigured in:
 - 1988 *Favusella tardita* (ANTONOVA); Banner & Desai, pl. 1, figs. 7ab.
- 1988 *Globuligerina hoterivica* (SUBBOTINA); Ascoli, pl. 1, figs. 14–16.

- 1995 *Favusella hoterivica* (SUBBOTINA); Wernli et al., p. 388, pl. 1, figs. 1–7, pl. 2, figs. 1–16, pl. 3, figs. 1–15; Text-fig. 5. The pl. 4.2, figs. 1–8 refigured in Simmons et al. 1997.
- 1997 *Favusella hoterivica* (SUBBOTINA, 1953); BouDagher-Fadel et al., p. 60, pl. 2.5, figs. 11–14 (same pictures on pl. 4.1, figs. 2–5!), pl. 4.1, figs. 1, 6–17, pl. 4.2, figs. 1–8.
- ?2004 “transitional forms between *Globuligerina oxfordiana* (GRIGELIS, 1958) and *Favusella hoterivica* (SUBBOTINA, 1953)”; Görög and Wernli, p. 41, pl. 1, figs. 3–11.

Description: The small tests between 180 and 220 µm in the largest diameter are low trochospiral ($H/D = 0.6–0.8$) with typically four chambers, sometimes $3\frac{1}{2}$ in the last whorl. These last chambers increasing regularly in size are fully globular and separated by incised sutures giving a well quadrilobated umbilical side. The aperture is (intra-)umbilical in position drawing a weakly asymmetric arch, as wide as high, surrounding by a lip. Its form is more regular and less “globuligerine” than in *Globuligerina oxfordiana* and there is no fossa.

On the spiral side which is moderately convex we count 11 or more chambers, since the details of the first whorls are not visible, coiled in at least three whorls. The arrangement of the chambers is relatively compact and the juvenile part is blunted, not forming a protruding apex.

A large part of the material is recrystallised and shows the quadrate and rhombic texture of the shell, typical of the diagenetic calcite. Only in some cases, there appears a reticulate surface ornamentation with small irregular and polygonal meshes of 5–7 µm in diameter that is diagnostic of the genus *Favusella* (Fig. 5.6). No perforations have been observed.

Some of the shells have a bulla variable in size that can be flat, small or as large and inflated as the last chamber. Its position is more or less umbilical. On a broken isolated individual the thickness of the wall of the bulla is about 10 µm (Fig. 5.4).

In rock thin sections the wall is about 7 µm in thickness and the building of the tests seems to be consecutive.

Remarks: Distinguishing *F. hoterivica* from *G. oxfordiana* can be difficult on poorly preserved tests without arguments regarding the wall, and if the aperture is not clear. Besides, transitional specimens between the two species probably occur in the Kimmeridgian–Tithonian (Görög and Wernli 2004). Following our experience:

- *F. hoterivica* has a larger, more symmetrical, less virguline aperture than *G. oxfordiana*.
- *F. hoterivica* has no fossa. In *G. oxfordiana* the position of the aperture is not strictly umbilical but slightly shifted toward the distal direction. The re-entrant (proximal) part

of the aperture produces a narrow umbilical depression (fossa). This feature is well developed in the Oxfordian individuals of *G. oxfordiana* (see for example illustrations in Bignot and Guyader 1971; Wernli and Kindler 1986; Grigelis and Norling 1999; Simmons et al. 1997).

- *F. hoterivica* more frequently possess a bulla. A big bulla can be confused with a normal last chamber and raises the question of the standard orientation of the test as discussed by Wernli et al. (1995). The bulla is not situated in the line of the trochospiral ontogenic progression. It also differs from the rest of the test in its whitish colour and less hyaline, sugar-like aspect. It never shows a reticulate or favose surface.
- *F. hoterivica* generally has a more compact test with more fully globular chambers.

Occurrence: *F. hoterivica* occurs in the Early as well as in the Late Kimmeridgian of the Crussol section, relatively frequent.

Distribution: Early Kimmeridgian–Early Aptian.

Pshish, NW Caucasus: Hauterivian (Subbotina 1953; Gorbachik 1986; Gorbachik and Antonova 1981); Shise and Tusheps river, Mazutka, NW Caucasus: Late Barremian–Early Aptian (Antonova et al. 1964; Gorbachik 1986; BouDagher-Fadel et al. 1997); Kura river, NW Caucasus: Early Aptian (Antonova et al. 1964; Gorbachik 1986; BouDagher-Fadel et al. 1997); 397A site, N Atlantic: Late Barremian (Gorbachik 1986); NW Atlantic margin of North America: Valanginian (Ascoli 1988); Scotian shelf: Valanginian (Ascoli 1976), Berriasian–Valanginian (Wernli et al. 1995); Uruk river, N. Caucasus: Hauterivian (Grigelis and Gorbachik 1980a, b).

Favusella? parva (KUZNETSOVA, 1985)

Figure 4.12–415.

- non 1973 *Globuligerina parva* n. sp.; Fuchs, p. 466, pl. 4, fig. 6.
- ?1983 *Globuligerina* aff. *oxfordiana* (GRIGELIS); Gradstein, pl. 2, figs. 9, 10. (surface with tubercles). ? pl. 2, figs. 1–8 (strongly corroded specimens).
- 1985 *Globuligerina parva* K. KUZNETSOVA, sp. nov.; Kuznetsova (in Kuznetsova and Gorbachik), p. 113, pl. 16, figs. 1a–c, 2ab. (drawings).
- 1986 *Globuligerina oxfordiana* (GRIGELIS); Stam, pl. 8, figs. 9–12; pl. 14, figs. 13–15.
- ?1997 *Haeuslerina parva* (KUZNETSOVA, 1985); Simmons et al., p. 29, pl. 2.5, fig. 4. (badly preserved).
- 1998 *Tenuigerina parva* (K. KUZNETSOVA, 1985); Gorbachik and Kuznetsova, pl. 2, figs. 8a–c (re-illustration of the holotype by MEB), and fig. 9, paratype.

Description: The tests are very small, rarely reaching 150 µm, the majority being between 100 and 120 µm in

larger diameter. The trochospire is very low, the H/D ratio is about 0.6. The four well globular chambers in the last whorl give a petaloid outline in umbilical view. The aperture is intra-umbilical in position, forming a regular arch as wide as high, underlined by a lip. The flattened spiral side has not been clearly analysed because of the compact arrangement of the juvenile stage. The wall surface that is rarely preserved sometimes shows a weak polygonal reticulation (Fig. 4.15) similar to that of *F. hoterivica*, which explains the questionable placement of our individuals in the genus *Favusella*.

Remarks: The holotype of Kuznetsova (in Kuznetsova and Gorbachik 1985) is illustrated by a schematic drawing not showing clearly the aperture. The author writes that it is umbilical, in small arch bordered by a weak lip. In 1998, Gorbachik and Kuznetsova re-illustrated the holotype by means of SEM, but the pictures did not reveal any additional information. An enlargement of the test surface (pl. 2, fig. 8c) shows, according to these authors, low tubercles and pores, which in our opinion are not convincing. The paratype (fig. 9) is strongly corroded and deformed.

The metatype illustrated with the SEM by Simmons et al. (1997) has the umbilical area strongly damaged, does not give any information about the form and the position of the aperture. These authors include *parva* in the genus *Haeslerina* considering that the aperture is intra-extraumbilical.

Despite the inadequate definition of *Favusella? parva*, that has been little cited and illustrated in the literature, we tentatively attribute our individuals of Crussol to this species.

Occurrence: *Favusella? parva* is the most frequent forms in our material, occurs in all the Kimmeridgian of Crussol.

Distribution: Late Oxfordian–Late Kimmeridgian.

Meganom Peninsula, East Crimea: Early Kimmeridgian (Kuznetsova and Gorbachik 1985; Gorbachik and Kuznetsova 1998; Simmons et al. 1997); DSDP site 534, Blake-Bahama Basin; Oxfordian–Kimmeridgian? (Gradstein 1983); Tojeira section, Mareta beach, Portugal: Late Oxfordian–Early Kimmeridgian (Stam 1986).

Results and comparisons

For study of the protoglobigerinids of the classical Kimmeridgian outcrop of Crussol, 49 rock thin sections, 11 acetolysis extractions on hard rocks and four standard washings in the rare marl interbeds has been analysed. In all rock thin sections the microfossils are rare. The protoglobigerinids are also scarce and never appear as oozes. Their distribution is constant in all the succession.

Generally speaking, the determination of the Jurassic protoglobigerinids from sections is very difficult (Wernli and Görög 2000), but in the present work they could be compared with the isolated forms from the same levels. Thus, the high trochospiral sections can tentatively be attributed to *Globuligerina* cf. *bathoniana* (PAZDROWA), the low to middle trochospiral ones to *Favusella* cf. *hoterivica* (SUBBOTINA) and the small sized, low trochospiral forms to *F.? parva* (KUZNETSOVA). These results demonstrate that high and low trochospiral shells coexist in the Kimmeridgian contrary to our previous opinion (Wernli 1988) and to that of Giovagnoli and Schiavinotto (1990). In all thin sections the wall is recrystallized in sparicalcite and the building of the tests seems to be consecutive.

All isolated protoglobigerinids come from hard rock treated by acetolysis. Their abundance as well as the plankton–benthos ratio is very variable due to the facies of the rocks and to the other factors. For example, the aragonite lysocline could play an important role in the preservation of the shells. It well coincides that the abundance of the protoglobigerinids diminishes when the amount of the radiolarians (indicating deeper environment) increase. Generally speaking, in this type of sequences the acetolysis on hard rocks gives better results than the standard washing of marly interbeds, indicating probably a lower sedimentation rate of these calcareous beds.

The isolated protoglobigerinids of the Crussol section are moderately preserved and undeformed, but the apertures are frequently obscured. The wall, which was originally aragonitic is recrystallized in calcisparite and only in rare cases retains the original ornamentation of its surface.

The associations of the isolated protoglobigerinids of the Kimmeridgian of Crussol comprise the following three species:

- High trochospiral *Globuligerina bathoniana*, with typical globuligerine aperture and wall with vermiculated discontinuous pustules.
- Low to middle trochospiral *Favusella hoterivica* with wall showing the characteristic favusellid ornamentation. Contrary to *Globuligerina oxfordiana*, it has no umbilical fossa and more frequently possesses a bulla.
- Small, low trochospiral *F.? parva* reveals a reticulated surface ornamentation, justifying its transfer from the genus *Globuligerina* into the genus *Favusella*.

F.? parva is distributed almost throughout the entire section studied from the Orthosphinctes to the Beckeri zones. *F. hoterivica* has been retrieved less frequently from the Platynota to the Beckeri zones, when the rarer *Globuligerina bathoniana* occurs only in the Late Kimmeridgian.

Concerning the isolated forms, the comparisons of our results with the literature is difficult because of the few available data, the poor preservation of the shells and often, the poor quality of many of the published pictures. On the base of the best recognizable illustrations, we can draw the following record of the Kimmeridgian protoglobigerinids:

- The most common species of the Crussol section, *Favusella? parva* previously has been known only from Crimea (Kuznetsova and Gorbachik 1985; Gorbachik and Kuznetsova 1998).
- *Globuligerina bathoniana* is reported of the Early Kimmeridgian of Portugal (El Kamar 1986; Stam 1986) and France (Samson 1997), and appears in the Late Kimmeridgian of the Crussol section.
- Occurrences of *Globuligerina balakhmatovae* (MOROZ-ova) in the Kimmeridgian are highly doubtful because of all the figured specimens in the literature look like deformed tests of *G. oxfordiana* or *G. hoterivica*. According to Wernli and Görög (2007), the stratigraphical range of this species is Late Bajocian–Late Bathonian.
- *Globuligerina oxfordiana* and affinis was in offshore NW Atlantic (Gradstein 1983) and Portugal (El Kamar 1986; Stam 1986; Samson 1997).
- *Compactogerina stellapolaris* (GRIGELIS) is known from the Early Kimmeridgian of Crimea and from the Kimmeridgian–Tithonian of Pechora basin, N Russia.

In summary, the protoglobigerinid associations of the Crussol section differ essentially from those of other Tethyan areas, by the absence of *Globuligerina oxfordiana* and the presence of *Favusella hoterivica*. Furthermore, the latter shows here its oldest occurrence.

Regarding the Late Jurassic records of the protoglobigerinids worldwide (e.g. Gorbachik and Kuznetsova 1983; Gorbachik and Kuznetsova 1998; Simmons et al. 1997; present work) we can draw the following provisional scheme of the stratigraphical range of the different species:

- *Globuligerina bathoniana* is known from the Early Bajocian (Wernli and Görög 1999), continues into the Oxfordian and becomes extinct in the Kimmeridgian–Tithonian. The status of the similar high trochospiral *Globigerina conica* IOVČEVA & TRIFONOVA (Tithonian) is actually not clear because it is based on glauconitic moulds. It is known only from the type locality and could be a synonym of *G. bathoniana*. We note that no high trochospiral forms are known in the Berriasian–Valanginian.
- *F. hoterivica* has already appeared in the Kimmeridgian, continues into the Tithonian (Görög and Wernli 2003), Berriasian and Valanginian (Wernli et al. 1995) and up to the Early Aptian (BouDagher-Fadel et al.

1997, fig. 4.1). It evolves slowly from *G. oxfordiana* by simplification of the aperture and acquisition of a favusellid network. *Favusella? parva* is recorded in the Early and Late Kimmeridgian.

- *Compactogerina stellapolaris* (Kimmeridgian–Tithonian) seems to be the only species appearing in high latitude.
- Neither turborotalid nor hedbergellid forms with extra-umbilical aperture like *Haeuslerina helvetojurassica* (HAEUSLER) have been found in post-Oxfordian deposits in the Tethyan realm.

Conclusions

The Kimmeridgian of the Montagne Crussol, SE France is represented by a monotonous succession of predominantly hemipelagic, micritic limestones. The section well dated by ammonites has been analysed in detail by means of numerous rock thin sections, acetolysis extractions and standard washings.

The relatively well-preserved associations of the isolated protoglobigerinids comprise three species: *Globuligerina bathoniana*, *Favusella hoterivica* and *F.? parva*. The smallest form *F.? parva* (based on surface ornamentation it was classified to genus *Favusella*) is the most common species distributed almost throughout the entire section from the Orthosphinctes to the Beckeri zones. *Globuligerina hoterivica* was identified less frequently from the Platynota to the Beckeri zones, while the rarer *Globuligerina bathoniana* occurs only in the Late Kimmeridgian. Similar faunas have been recognised in the rock thin sections.

The exhaustive review of the literature reveals that the records of the Kimmeridgian protoglobigerinids are rare and generally of poor quality.

The protoglobigerinid associations of the studied Crussol section essentially differ from that of the other Tethyan faunas by the absence of *G. oxfordiana* and the presence of *F. hoterivica*, showing its oldest occurrence at Crussol.

Based on our study we can amend the synthesis of Simmons et al. (1997) and BouDagher-Fadel et al. (1997), table fig. 4.1.) about the Kimmeridgian protoglobigerinids:

- In the Early Kimmeridgian, besides the *F.? parva* and *G. bathoniana*, *F. hoterivica*, *G. oxfordiana* and *C. stellapolaris* also exist,
- We demonstrate the occurrence of *F.? parva* and *F. hoterivica* in the Late Kimmeridgian.

Data plotted on a palaeogeographical map show that the majority of the hitherto known occurrences come from the northern margin and central part of the Tethys besides some from the North Atlantic.

Hence, the data of the present study add very important contribution to the knowledge of the Kimmeridgian protoglobigerinids and fill an important gap in the stratigraphical range, the palaeogeographical distribution and the evolution of these foraminifers in the Late Jurassic.

Acknowledgments Sincere thanks are due to F. Athrops (Lyon) for his information about the Crussol field section. We benefited from the assistance of P. Desjacques (Labo processing), R. Martini (SEM photography), G. Frébourg (thin sections photography) and J. Metzger (infography) who are warmly thanked. Thank to J.-M. Jaquet who greatly improved the English. We are grateful to the referees M. BouDagher-Fadel and to M. B. Hart for their comments and suggestions and to S. Spezzaferri and D. Marty for their exhaustive editorial work. The fieldwork has been supported by the "Fondation Dr. Joachim De Giacomi" of the Swiss Academy of Sciences and by the Hungarian OTKA Foundation (contract K68791), which is greatly acknowledged.

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