High resolution biostratigraphy of the Tournaisian-Viséan boundary interval in the North Staffordshire Basin and correlation with the South Wales-Mendip Shelf

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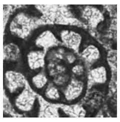

A study of three carbonate sections in the North Staffordshire Basin and two in the South Wales-Mendip Shelf yielded so far the richest foraminiferal associations at the Tournaisian-Viséan boundary in Western Europe enabling a very good correlation with the stratotype area in South China. The biostratigraphic study was refined by sedimentological and gamma-spectrometrical data in order to define and calibrate the high resolution biostratigraphy across the boundary interval. The study illustrates the cryptic entry of the stratigraphically important species of the Chadian index genus *Eoparastaffella* which is abundant in photozoan facies. Across the Tournaisian-Viséan boundary, changes in the character of the foraminiferal associations reflect the gradual change from heterozoan dominated late Tournaisian ramps to Viséan photozoan dominated platforms. The combined application of biostratigraphic and sedimentological methods and gamma ray manifestation of the mid Avonian sequence boundaries have proved useful in the identification of the Tournaisian-Viséan boundary in Carboniferous successions on either side of the Wales-Brabant Massif and has widespread applicability for successions of a similar age across Western Europe. • Key words: Tournaisian, Viséan, foraminiferal biostratigraphy and ecology, carbonate sedimentology, gamma-ray spectrometry.

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In accordance with the definition of the base of the Viséan in Belgium, foraminiferal genus *Eoparastaffella* was used to define the base of the Chadian regional stage in Britain (George *et al.* 1976). However, subsequent workers have failed to repeat this foraminiferal record at the Chatburn stratotype in the Craven Basin (Fewtrell *et al*. 1981a, b; Riley 1990, 1993). Subsequently however refinements in our understanding of foraminiferal lineages across the Tournaisian-Viséan (T-V) boundary have led to the redefinition of the base of the Viséan and its stratotype changed. The base of the Viséan is now defined by first appearance of the foraminifer *Eoparastaffella simplex* within the *Eoparastaffella ovalis – Eoparastaffella simplex* lineage, and a section at Pengchong near Liuzhou in Guangxi, southern China, has been chosen as the GSSP; a redefinition originally proposed by Devuyst *et al.* (2003) and later ratified by the ICS and IUGS (Work 2008). Consequently, the Chadian in its original definition now comprises the T-V boundary interval starting in the last Tournaisian foraminiferal zone MFZ8 and ending at the top of the earliest Viséan zone MFZ9 (Hance & Devuyst *in* Poty *et al.* 2006, Hance *et al.* 2011).

Taking into the account the problems connected with the Chadian in the Craven Basin we tried to identify the recent concept of the T-V boundary in the North Staffordshire Basin where excellent outcrops occur at Brown End Quarry, Ladyside Wood and Ossom's Hill in a deeper ramp setting (Aitkenhead *et al.* 1985, Chisholm *et al.* 1988).

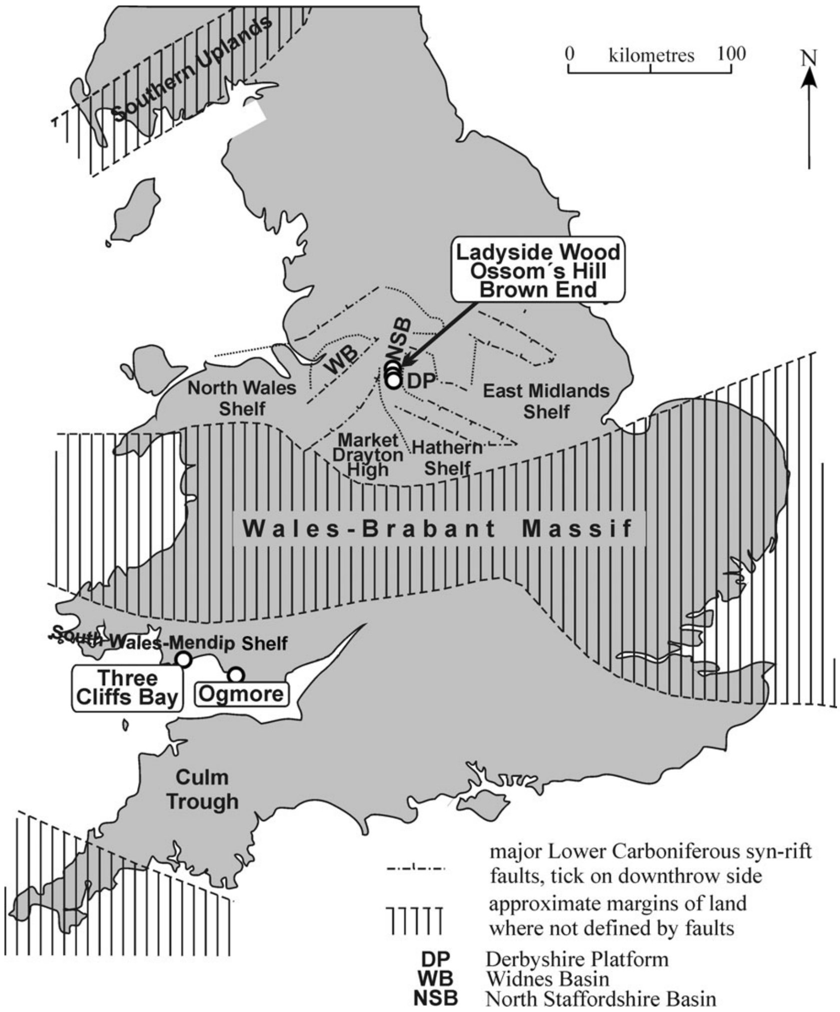

Figure 1. Location of the studied sections on the flanks of the Wales-Brabant Massif (modified after Cossey *et al*. 2004).

For comparison, the same boundary was investigated in some fine sections on the South Wales-Mendip Shelf where sections with distinct sequence boundaries occur at Three Cliffs Bay and Ogmore in a shallow ramp setting (Adams *et al.* 2004, Wright 1986).

As originally outlined by Ramsbottom (1973, 1981) and recently confirmed by Hance *et al.* (2001, 2002), the T-V boundary represents an important sequence boundary around the Wales-Brabant Massif. In this respect gamma-ray spectrometry (GRS) has already proved as a useful tool in tracing sea-level oscillations, supplementing biostratigraphy and improving dramatically the resolution of stratigraphic correlations (Bábek *et al.* 2010, Delius *et al.* 2001, Doveton 1994, Hladil *et al.* 2006, Rider 1999, Thibal *et al.* 1999). The successful application of this method for correlating the T-V boundary interval in the Dublin Basin, Ireland was clearly demonstrated by Kalvoda *et al.* (2011). Although this Irish study demonstrated the utility of foraminifera in high resolution stratigraphy it also demonstrated that foraminiferal assemblages were strongly facies controlled and that detailed microfacies study is required in order to realise their true stratigraphic potential. Consequently the present study aims at improving the resolution of the biostratigraphy and sequence stratigraphy of late Tournaisian and early Viséan rocks of the North Staffordshire Basin and the South Wales-Mendip Shelf by combining high-resolution foraminifer biostratigraphy with sedimentological and petrophysical methods (gamma ray spectrometry).

Material and methods

Five sections were described, bed by bed logged and sampled for foraminifer biostratigraphy and thin section analysis. Petrographic analysis was performed on a large number of standard size (27 × 46 mm) thin sections. Semiquantitative percentages of carbonate and non-carbonate constituents were recorded, using the visual comparison charts of Baccelle & Bosellini (1965). Only the sand and gravel size grains (allochems and detrital grains) were considered, fine-grained matrix and cements were omitted.

Results are presented as percentages of individual compositional groups from the total count of grains.

A first series of thin sections for foraminifer study was typically made and examined to identify the richest levels. Additional numerous thin sections (over 700) were cut in the best beds. Foraminifers were studied with a high-magnification binocular microscope (Nikon 80i) in transmitted light at magnifications ranging from 20× to 400×. The best specimens were photographed with a digital camera (Nikon DXM) and a database was created using Nikon NIS Elements software.

Sedimentology

North Staffordshire Basin

Brown End section

The Brown End Quarry section is ~65 m thick and comprises carbonates of the Milldale Limestone and the Hopedale Limestone (uppermost Tournaisian to lower Viséan). Graded, sometimes amalgamated, bioclastic turbidites (calcarenites to calcirudites) with abundant echinoderms, corals and brachiopods and frequent *Zoophycos* trace fossils, alternating with grey to reddish marls (Milldale Limestone), predominate in the basal part of the section (65 to 47 m). The overlying coarsening-upward succession (47 to 30 m) comprises calcisiltites and fine-grained calcarenites with chert nodules, alternating with thin marl interlayers and scarce graded crinoidal calciturbidite beds. This succession is overlain by a sequence of very thick beds of coarse-grained calcarenites to fine calcirudites (30 to 24 m), a fining-upward succession of graded and parallel-laminated carbonate turbidites (24 to 17 m) and finally by calcisiltites to fine-grained calcarenites with chert nodules and marl interlayers (17 to 8.5 m). The topmost part of the profile (8.5 to 0 m, Hopedale Limestone) is composed of thick beds of coarse-grained, graded and parallel and/or cross-laminated calcarenites and carbonate breccias with abundant bioclasts. Massive micritic carbonate buildups with frequent stromatactis and open-marine fauna ("knoll reefs" or "Waulsortian" carbonate mudmounds) are exposed in the Tournaisian part of the Brown End Quarry, below the measured section (Aitkenhead *et al.* 1985, Cossey *et al.* 1995). Two erosional surfaces are documented at the section, one at the base of a thick layer of massive coarse-grained crinoidal calcarenite (~28.5 m) and another one close to the base of the Hopedale Limestone (~3.3 m, Fig. 2; Cossey *et al.* 1995, 2004).

The carbonates at the Brown End section can be classified as fine-grained to very coarse-grained wacke-packstones, packstones and rare well-sorted grainstones. Skeletal allochems (from 12 to 36% vol.) predominate over non-skeletal ones (from 1 to 30% vol.). Skeletal grains include abundant crinoids and other echinoderm fragments, green algae (dasyclad algae, palaeoberesellids and related forms), unilocular and plurilocular foraminifers, calcispheres, sponge spicules, bryozoan fragments, brachiopods, bivalves, ostracods, less abundant corals, trilobites, gastropods, cyanobacteria (*Girvanella*) and unidentified grains (Fig. 2). Non-skeletal grains include very abundant peloids and aggregate grains and rare intraclasts and ooids.

Crinoids, bryozoans, brachiopods and sponge spicules are quite abundant in the bottom part of the section (Tournaisian, 65 to 48 m). The relative abundance of crinoids then decreases in favour of peloids, which become the dominant compositional group for the remainder of the section (48 to 0 m; uppermost Tournaisian to lower Viséan). There is an ever-increasing abundance of green algae (dasyclad algae, palaeoberesellids and related forms) and multichambered foraminifers starting approximately from the base of the Viséan (~32 m) up to the top of the section while the relative abundance of bryozoans and sponge spicules decreases in the same interval. This upper part of the section is associated with frequent allochem micritization.

Ladyside Wood and Ossom's Hill section

The Ladyside Wood section is ~56 m thick and comprises carbonates of the Milldale Limestone and the Ecton Limestone (uppermost Tournaisian to lower Viséan; Fig. 2). At the base of the section (0–2 m), massive micritic carbonates with stromatactis and abundant echinoderms, bryozoans, ostracods and open-marine fauna are exposed. They are interpreted as "knoll reefs" or "Waulsortian" carbonate mudmounds (Aitkenhead *et al.* 1985, Cossey *et al.* 1995). They are overlain (2– ~56 m) by a succession of graded, parallel laminated fine- to coarse grained calcarenites with occasional scours, ripple-cross lamination, wavy lamination, soft-sediment deformation structures and abundant echinoderms, peloids, dasyclad algae and foraminifers, which alternate with calcisilitites, calcilutites and marls, sometimes cherty, with abundant ostracods and sponge spicules. The sediments are interpreted as proximal and distal carbonate turbidites deposited in outer ramp environment (Aitkenhead *et al.* 1985, Cossey *et al.* 2004).

The carbonates at the Ladyside Wood section range from wackestones through to packstones and usually well-sorted grainstones. Skeletal allochems (from 16 to 37% vol.) predominate over non-skeletal ones (from 0 to 18% vol.). Skeletal grains include abundant crinoids and other echinoderm fragments, green algae (dasyclad algae, palaeoberesellids and related forms), unilocular and plurilocular foraminifers, and less abundant calcispheres,

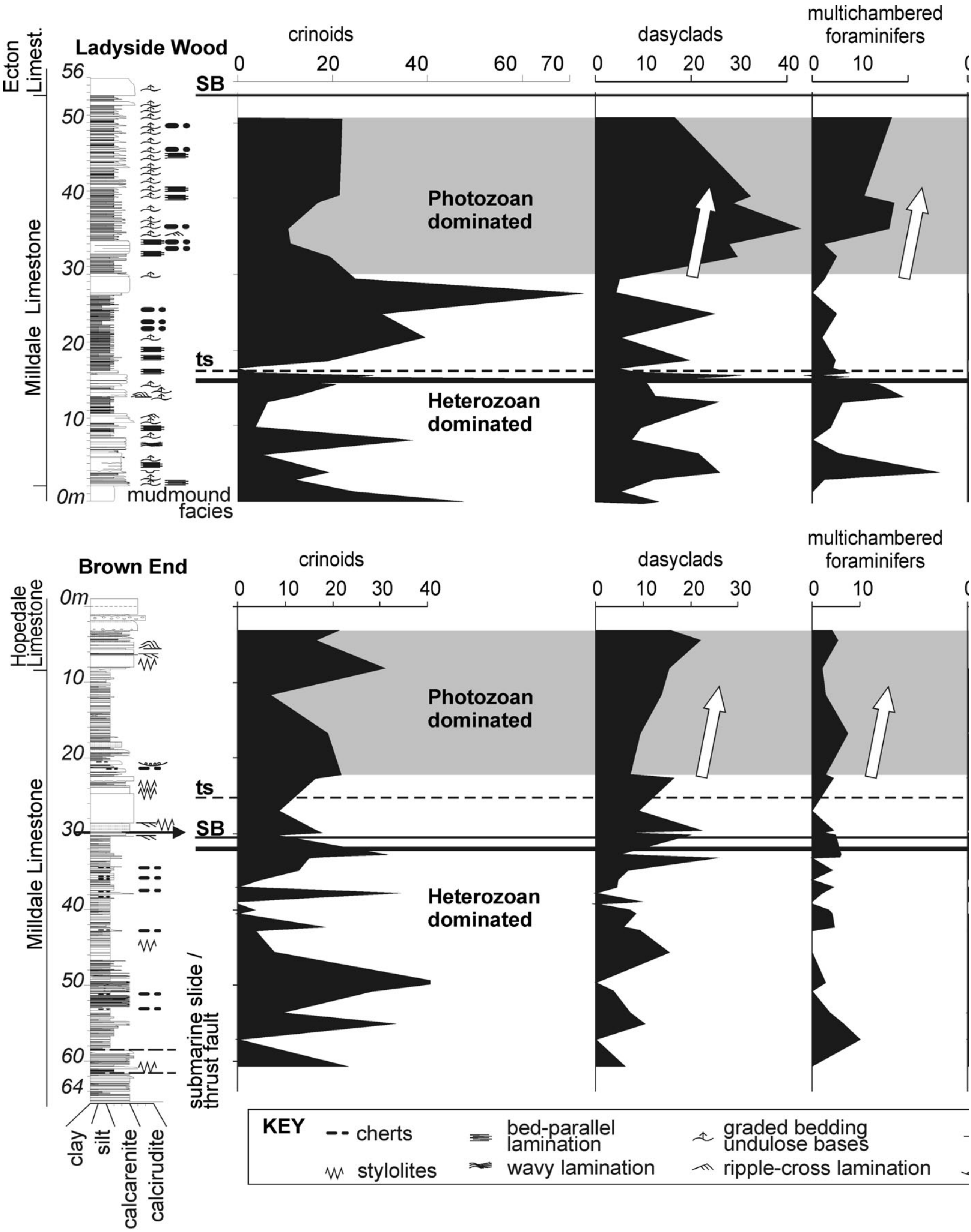

Figure 2. Stratigraphic trends in selected compositional groups (percentages from total rock volume based on visual estimates, using comparative charts) and correlation of the Brown End and Ladyside Wood sections in the North Staffordshire Basin.

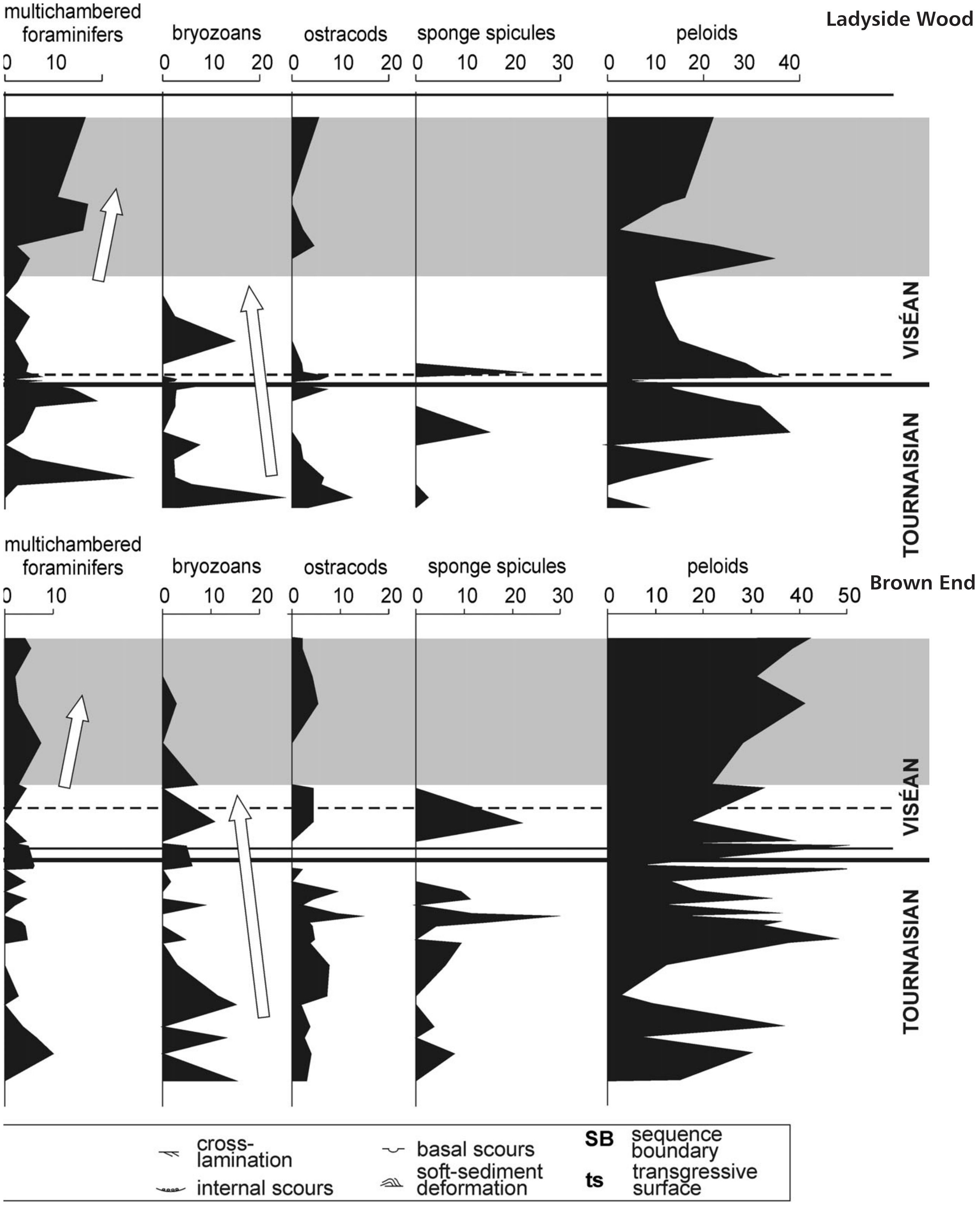

Figure 2. Continued.

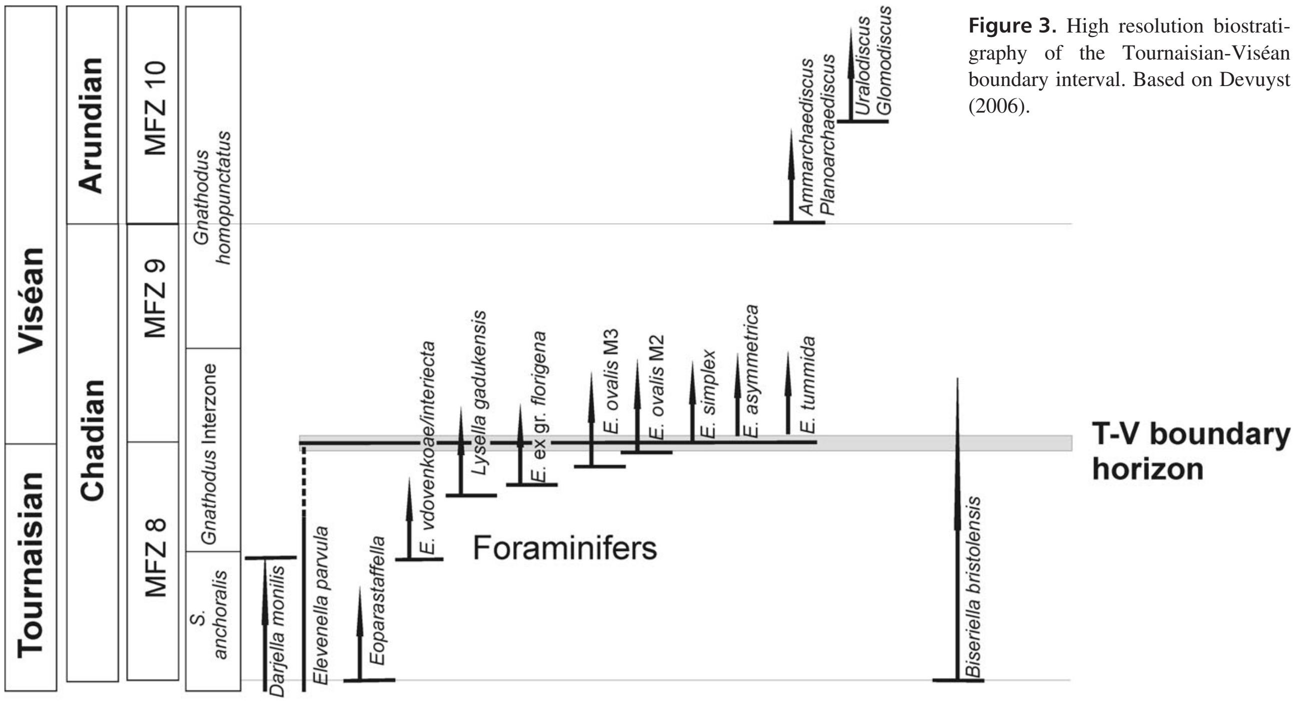

Figure 3. High resolution biostratigraphy of the Tournaisian-Viséan boundary interval. Based on Devuyst (2006).

sponge spicules, bryozoan fragments, brachiopods, bivalves, ostracods, corals, trilobites, gastropods, cyanobacteria (*Girvanella*) and unidentified grains (Fig. 2). Non-skeletal grains include very abundant peloids and aggregate grains and intraclasts. Ooids are almost absent. The allochem composition and the vertical compositional trends at the Ladyside Wood section are similar to those of the Brown End section (Fig. 2). The most prominent features include the sudden composition change at the upper boundary of the mudmound facies (upper Tournaisian) and then an increase in the proportion of dasyclad algae and foraminifers in the top part of the section (~30 to ~50 m, lower Viséan).

The Ossom's Hill section is approximately 42 m thick and comprises carbonates of the Milldale Limestone (0 to 31 m) and the Ecton Limestone (31 to 42 m). The whole section is early Viséan in age. The base of the section (0–9 m) exposes fine-grained calcarenites and calcisiltites with thin, graded, calcarenite beds, abundant cherts and trace fossils (*Chondrites*, *Zoophycos*). The proportion of the graded calcarenites increases upsection. This succession gradually passes upward into a thickening and coarsening upward succession of predominantly graded calcarenites (calciturbidites) with rare chert nodules (9–21 m). The overlying part (21–30.5 m) is fining and thinning-upward, comprising graded calcarenites, calcisiltites and mudstones with cherts and trace fossils. The top part of the section (30.5 to 42 m) comprises relatively thick (up to 60 cm) beds of graded, coarse- to medium grained calcarenites (proximal calciturbidites). The Ossom's Hill section was not studied in detail sedimentologically as its base is already Viséan in age and it shows a similar development to the more complete section at Ladyside Wood.

South Wales – Mendip Shelf

Three Cliffs Bay and Ogmore sections

The studied succession in Three Cliffs Bay (Fig. 7) starts in Courceyan to Chadian bioclastic limestones of the Friars Point Limestone (formerly Tears Point Limestone, see Waters *et al.* 2011) and comprises argillaceous, burrowed beds with a fully marine biota, but lacking very shallow forms (dasycladaceans). It exhibits sharp based, normally graded and hummocky stratified calcarenite beds, sometimes with shell lags. The sedimentology was discussed in detail by Wu (1982), Wright (1986) and Ramsay (1987) and was interpreted as a succession deposited in marine subtidal environments ranging from depths below the zone of significant wave and current activity to depths above storm-wave base. The gradual passage from the bioclastic Friars Point Limestone into the Chadian Gully Oolite (formerly Caswell Bay Oolite, see Waters *et al.* 2011) represents a shallowing-up (regressive) sequence. The shoreface Gully Oolite represents barrier islands and beaches, with preserved shoreface sequences, which developed beach-ridge plains on various scales (Ramsay 1987, Burchette *et al.* 1990). The Caswell Bay Mudstone, overlies the karstic and palaeosol-covered top of the Gully Oolite (Riding & Wright 1981, Wright 1986) and is erosively overlain by bioclastic lower-shoreface deposits of the Arundian High

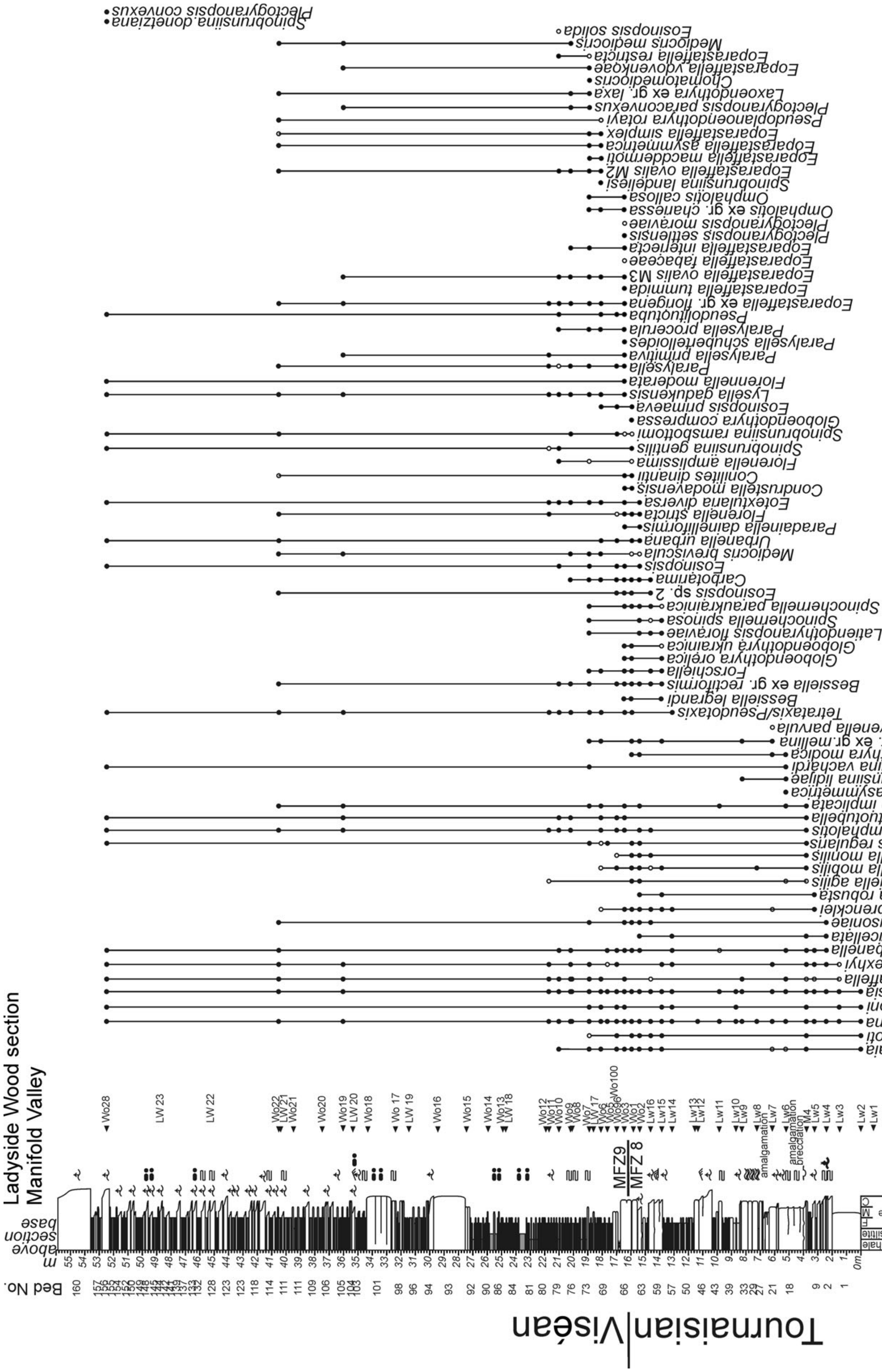

Figure 4. Distribution of most important foraminifers in the Ladyside Wood section in the North Staffordshire Basin. Foraminiferal zones according to Devuyst & Hance *in* Poty *et al.* (2006). White circles mean *cf.* identifications. See www.geology.cz/bulletin for this figure in bigger size.

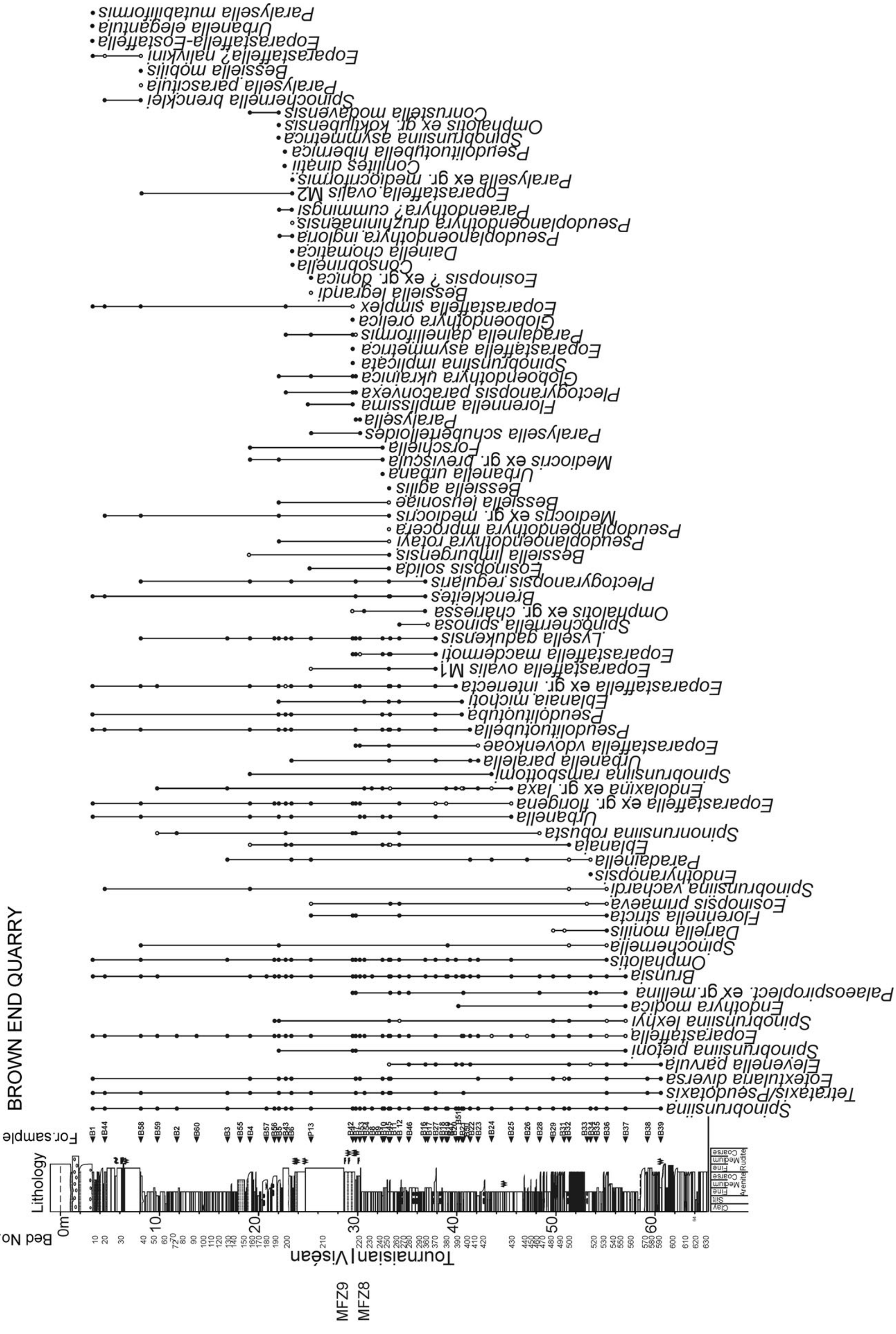

Figure 5. Distribution of most important foraminifers in the Brown End Quarry section in the North Staffordshire Basin. Foraminiferal zones according to Devuyst & Hance *in* Poty *et al.* (2006). White circles mean *cf.* identifications. See www.geology.cz/bulletin for this figure in bigger size.

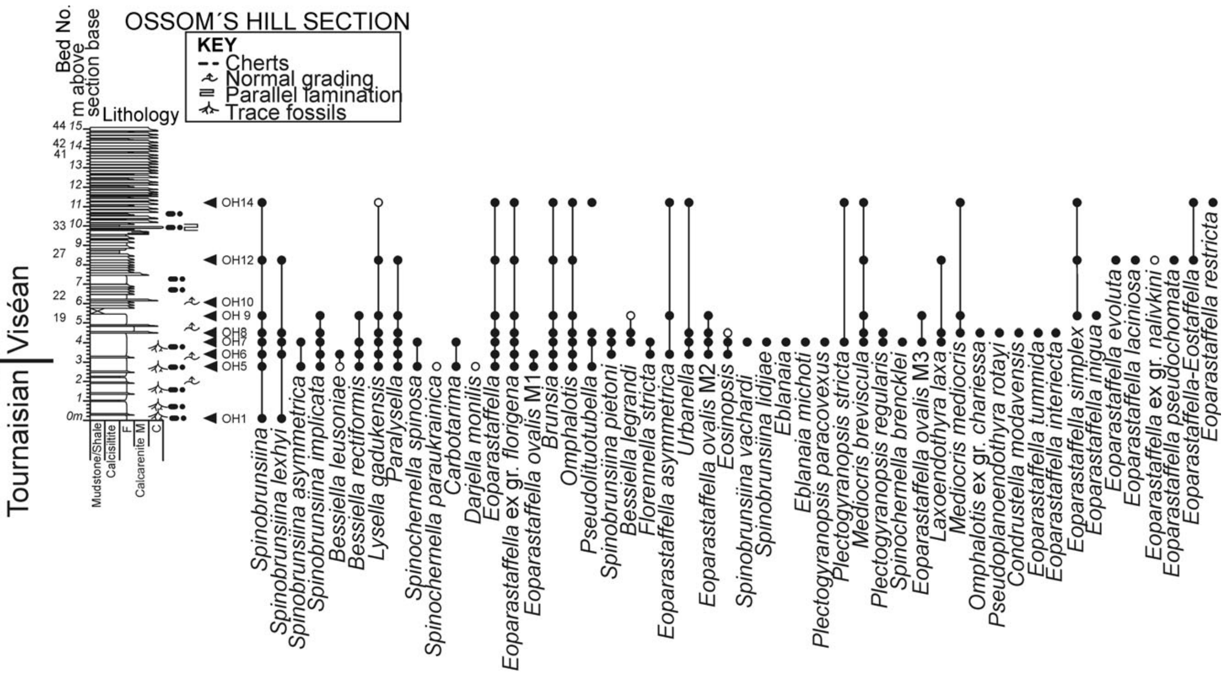

Figure 6. Distribution of most important foraminifers in the Viséan (MFZ9) of the Ossom's Hill section in the North Staffordshire Basin. Foraminiferal zones according to Devuyst & Hance *in* Poty *et al.* (2006). White circles mean *cf.* identifications. See www.geology.cz/bulletin for this figure in bigger size.

Tor Limestone (Riding & Wright 1981, Wright 1986, Ramsay 1987).

The Ogmore section (SS 86857425, Fig. 8) is ~25 m thick and comprises a comparable sequence to that at Three Cliffs Bay, recording the passage from the upper part of the Gully Oolite into the Caswell Bay Mudstone and overlain by the High Tor Limestone (Chadian to Arundian substages). The basal part of the section (0 to 7.75 m) consists of thickly-bedded, poorly-sorted, skeletal-peloidal packestones of the Gully Oolite, with some finer grained packestones and in places wackestones. Their lithology is similar to the Gully Oolite at Three Cliffs Bay, but the lack of typical oolites suggests deeper water deposits. Waters (1984) records a thickness of 83 m of Gully Oolite in the St Lythan's borehole (ST 10547290) where it comprises four shoaling upward cycles, the top two becoming subaerial. A major bedding plane at Ogmore records the passage into the overlying Caswell Bay Mudstone (7.75 to 16.75 m) comprising thinner-bedded wackestones with coarser shelly debris, small crinoid ossicles, occasional zaphrentid corals and pleurotomarid gastropods. Some bedding planes are bioturbated with sub-horizontal *Thalassinoides* burrows. At ~13.5 m a palaeokarst and palaeosol with calcrete is developed and is followed by crinoidal wackestones with large pleurotomarid gastropods, which are overlain (15.75 to 16.75 m) by a soft, poorly-consolidated mudstone. As in Three Cliffs Bay the mudstone is followed by bioclastic, lower-shoreface deposits of the High Tor Limestone, with a rich fauna of rugose and tabulate corals, thick-shelled brachiopods and gastropods.

Biostratigraphy

The definition of the regional stages for the British Isles and Ireland proposed by George *et al.* (1976) capitalized on the progress of foraminiferal biostratigraphy introduced in Western Europe by Raphael Conil (Conil & Lys 1964, Conil *et al.* 1977) who subsequently progressively applied his zonation to British and Irish regional stages (Conil *et al.* 1980). Later, Fewtrell *et al.* (1981b) documented foraminiferal generic ranges in relation to the British Dinantian stages but failed to repeat the *Eoparastaffella* record of George *et al.* (1976) in the Chadian stratotype at Chatburn. The absence of this guide fossil in the Chatburn section and the Chadian biostratigraphy of the Craven Basin were discussed in detail by Riley (1990, 1993, 1995) who stressed that the correlation of the base of the Chadian is impossible and that it is only the late Chadian that has a distinct biostratigraphic signature. A review of the validity of the Chadian and of the suitability of the Chatburn section as its stratotype is provided in Adams *et al.* (2004).

In the last decade the search for a new T-V boundary stratotype in Eurasia has contributed to a substantial improvement in biostratigraphic resolution in this early Carboniferous interval (Devuyst 2006, Devuyst & Kalvoda 2007, Hance *et al.* 2011, Kalvoda *et al.* 2010, Poty *et al.* 2006). In the zonation of Devuyst & Hance (*in* Poty *et al.* 2006) the latest Tournaisian foraminiferal zone MFZ8 is defined by the entry of *Eoparastaffella* and *Biseriella bristolensis* (Reichel). That is, it is coincident with the

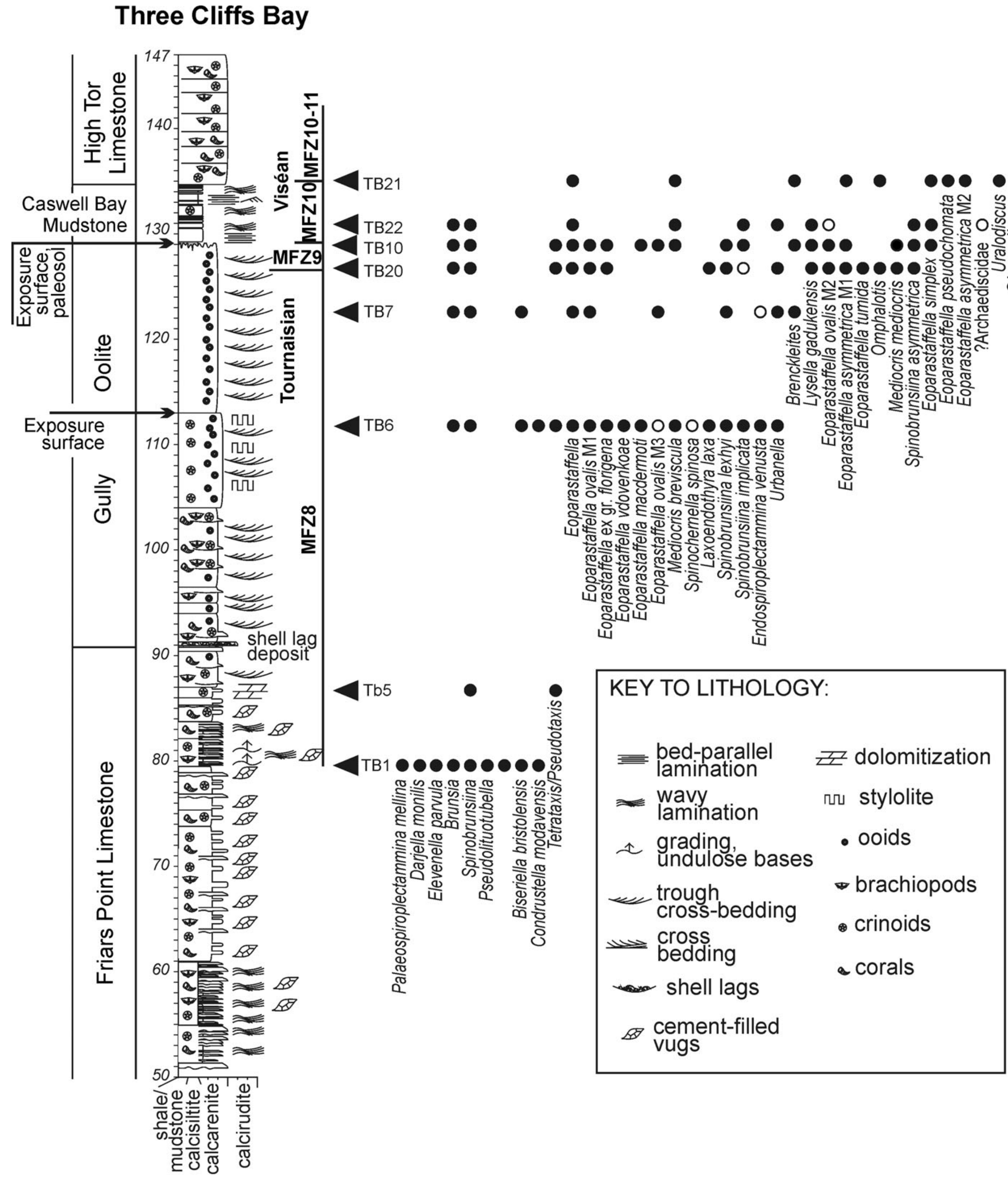

Figure 7. Distribution of most important foraminifers in the Three Cliffs Bay section in South Wales-Mendip Shelf. Foraminiferal zones according to Devuyst & Hance *in* Poty *et al.* (2006). White circles mean *cf.* identifications. MFZ10 in Caswell Bay Mudstone is based on the correlation with the Ogmore section.

original definition of the Chadian base. The base of the first Viséan zone MFZ 9 coincides with the FAD of *Eoparastaffella simplex* Vdovenko in an evolutionary lineage from *Eoparastaffella ovalis* Vdovenko (Devuyst *et al.* 2003, Work 2008). The detailed biostratigraphy of the T-V boundary interval (Fig. 3) is characterized by successive

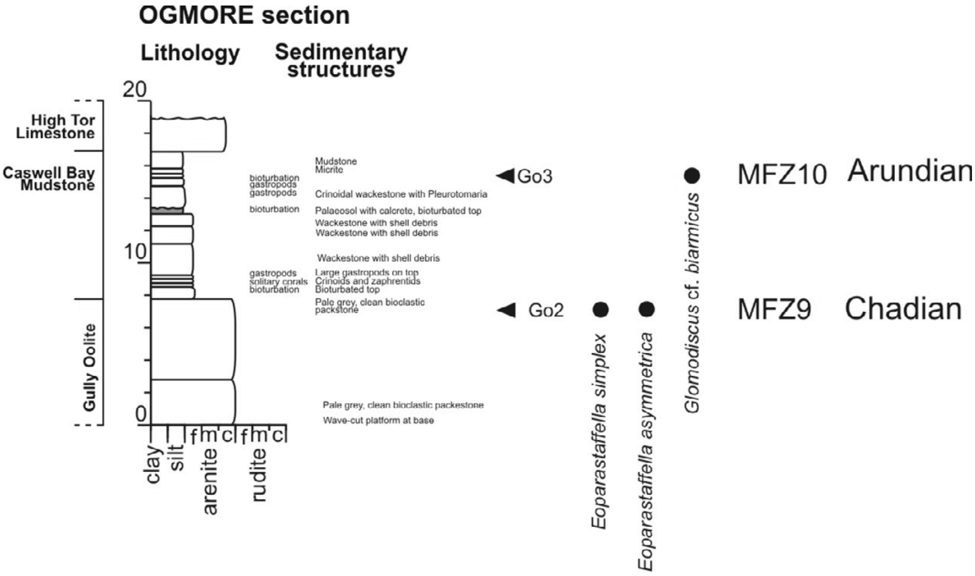

Figure 8. Distribution of most important foraminifers in the Ogmore section in the Vale of Glamorgan in South Wales-Mendip Shelf. Foraminiferal zones according to Devuyst & Hance *in* Poty *et al.* (2006).

FADs of *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, *Lysella gadukensis* Bozorgnia, *Eoparastaffella* ex gr. *florigena* (Pronina), *Eoparastaffella ovalis* M3 and *Eoparastaffella ovalis* M2 below the T-V boundary and *Eoparastaffella asymmetrica* Vdovenko and *Eoparastaffella tummida* (Pronina) just above the boundary (Devuyst 2006, Devuyst & Kalvoda 2007; Fig. 3). The entry of *Eoparastaffella ovalis* M2 is very close to the entry of *E. simplex* and because in many sections *E. ovalis* M2 is more common than *E. simplex*, it can be used as an alternative criterion to identify the T-V boundary (Devuyst 2006; Kalvoda *et al.* 2010, 2011). In accord with the base of the Arundian, the base of MFZ10 coincides with the entry of Archaediscidae represented by *Ammarchaediscus* and *Planoarchaediscus,* while the evolutionary younger *Uralodiscus* and *Glomodicus* occur in the upper part of the zone (Devuyst & Hance *in* Poty *et al.* 2006).

North Staffordshire

Ladyside Wood

Figures 10–19

At Ladyside Wood the top of the Waulsortian facies is characterised by the dominance of skeletal debris of crinoids, ostracods, brachiopods and bryozoans. The multichambered foraminifers present included mostly only small juvenile *Endothyra*, *Spinobrunsiina* and *Brunsia.* These are accompanied by rare *Eblanaia michoti* (Conil & Lys) and ?*Eoparastaffella* (Fig. 4). The presence of ?*Eoparastaffella* may indicate latest Tournaisian age (MFZ8). Unlike at Brown End Quarry, *Tetrataxis* and *Eotextularia diversa* (Chernysheva) are absent while *Eblanaia* is present. The richest foraminiferal association in the lowermost part of the section was obtained in sample M4. In addition to previous taxa, *Bessiella* cf. *agilis* Conil*, Bessiella mobilis* (Conil & Lys), *Darjella monilis* Malakhova, *Plectogyranopsis regularis* (Rauzer-Chernousova), *Pseudolituotubella* and *Omphalotis* occur, the association being characteristic of MFZ8. On the other hand a guide of MFZ4 in Belgium *Spinochernella brencklei* Conil & Lys, occurs and continues to the lowermost Viséan. This bed is followed by an interval up to the level of sample LW14 where micritic facies dominate with small juveniles multichambered foraminifers represented mostly by *Endothyra*, *Spinobrunsiina* and *Brunsia*. The very rare presence of *Eoparastaffella* supports the latest Tournaisian age of MFZ8.

The end of the Tournaisian is marked by bioclastic limestones with a very rich foraminiferal association in which *Bessiella*, *Spinobrunsiina*, *Spinochernella* and *Eblanaia* are abundant. This and the absence or very rare occurrence of *Florennella* show very good fit with the Chadian stratotype in Chatburn (Riley 1995), Irish sections in Oughterard, Lane and Rush (Devuyst 2006, Kalvoda *et al.* 2011) and sections in the Namur Basin (Hance *et al.* 1981, Hance 1988). There is also some faunistic similarity with the North American Cordillera (Brenckle 1973, Mamet *et al.* 1986, Skipp 1969). The presence of *Bessiella legrandi* Conil & Hance, *Eosinopsis* sp. 2 Vachard & Hance, *Carbotarima* or *Forschiella* may indicate already the upper part of the MFZ8 but the important *Eoparastaffella* guides are missing. *Forschiella* – once regarded as an early Viséan guide (Rauser-Chernoussova *et al.* 1996) has been recently reported from the latest Tournaisian of the Dublin Basin (Kalvoda *et al.* 2011). *Carbotarima* was originally described by Brenckle (2004) from early late Viséan beds along the northern margin of the Tarim Basin. Recently Hance *et al.* (2011) reported the genus from the late Tournaisian to middle Viséan of south China. The occurrences of *Eosinopsis* are typical for the latest Tournaisian and earliest Viséan MFZ8 and MFZ9 in China, the Urals and Western Europe; *Eosinopsis* sp. 2 being reported in the MFZ8 (Hance *et al.* 2011). Among abundant *Bessiella* the variable group *B. rectiformis* (Bogush & Yuferev) dominates (Groessens *et al.* 1982, Hance 1988).

A distinctly different foraminiferal association is recognised in sample Wo3 in which *Eoparastaffella* and *Lysella* are abundant and *Paralysella* is also present. *Lysella gadukensis* becomes an important component of tuberculate foraminiferal association at this level. *Bessiella* is still abundant dominated by the *B. rectiformis* group and *Eblanaia* is still present. *Eblanaia* and *Eoparastaffella* usually do not co-occur, the sample thus probably records the transportation of foraminifers from different environments. Among *Eoparastaffella,* members of the *Eoparastaffella florigena* group are especially common while members of the *Eoparastaffella ovalis-simplex* group are virtually absent. Nevertheless, the presence of *Eoparastaffella tummida* (Pronina) indicates already a Viséan age of the MFZ9.

Above, an interval of biomicritic limestones follows (see Fig. 4). The sample Wo96 shows a complete return to a foraminifera association, which consists exclusively of taxa known from the Tournaisian, dominated by *Spinobrunsiina*, *Bessiella*, *Eblanaia*, *Brunsia,* while *Eoparastaffella* is completely absent here. An interval of biomicritic limestones follows with low foraminiferal representation in which again small juveniles dominate (*Spinobrunsiina*, *Brunsia*, *Endothyra*) similarly as in some late Tournaisian facies.

In the first bioclastic limestone (sample Wo6) a return to the trend initiated in the first Viséan sample Wo3 is apparent. The *Eoparastaffella* association is abundant but more diversified than in Wo3. This association is dominanted by members of the *E. florigena* group, but *E. ovalis* M2 is also abundant. *E. simplex* is however very rare – only one specimen being recorded from close to one hundred *Eoparastaffella* axial sections. *E. asymmetrica* represents another important Viséan guide. Among the tuberculate foraminifers *Lysella gadukensis* becomes a dominant component while *Spinobrunsiina* is still abundant and *Bessiella* becomes rare. Characteristic deviations in the last coil of *Eoparastaffella*, recorded also in some of the samples above (including Wo3), and in samples described by Devuyst from Irish sections (Devuyst 2006), are typical. These are most likely to have been caused by environmental factors and are of no stratigraphic significance.

A similarly rich foraminifer association is present in Wo7. Here representatives of *Eoparastaffella* are diverse and abundant once again with members of the *E. florigena* group dominating the association. *E. ovalis* and group *E. interiecta* Vdovenko group are also present. Viséan guides are represented by very rare *E. asymmetrica* and *E. simplex* (1 specimen in more than 100 axial sections) but *E. ovalis* M2 and M3 are both common. Among the tuberculate foraminifers *Spinobrunsiina*, *Bessiella* and the *L. gadukensis* group are dominant. *Brunsia* is abundant and *Eblanaia* still present. The richness of *Spinobrunsiina*, abundant *Brunsia* and *Bessiella* is similar to that seen in sections of equivalent age in the Namur Basin (Hance 1979, Hance *et al.* 1981). The common occurrence of both *Eoparastaffella* and the aforementioned association of tuberculate foraminifers within calciturbidites indicates that they were derived from different source areas.

Wo9 is dominated by smaller foraminifers often represented by juveniles. *Spinobrunsiina* and *Brunsia* are abundant. Despite the granulometry being suitable for *E. simplex*, the assemblage is dominated by juvenile members of *E. florigena* or *E. interiecta* group, indicating a derivation from those parts of the ramp where *E. simplex* was absent. Evidently the niches of *Eoparastaffella* species were varied.

A diverse association of dainellids including *Lysella*, *Bessiella* and *Florennella* is present again in Wo10 where juveniles are especially abundant. *Spinobrunsiina* is not as abundant as in previous cases. Among the *Eoparastaffella*, members of the variable *E. florigena* group continue to dominate. Stratigraphically important is the FAD of *Eoparastaffella restricta* Postoyalko. *Eosinopsis* resembling *E. solida* Vachard & Hance enters. Similar trends can be seen also in Wo11, monotonous *Eoparastaffella* is represented only by the *E. florigena* group.

In Wo19 dainellids are represented mainly by the *L. gadukensis* group while *Bessiella* is absent and *Spinobrunsiina* is more abundant. In *Eoparastaffella* the dominance of the variable *E. florigena* group continues as it does in Wo22 where also rare occurrence of *E. asymmetrica* and *E*. cf. *simplex* are recorded. A diverse association of dainellids is present once again dominated by *L. gadukensis. Bessiella* and *Florennella* are also present. In the last studied sample Wo28 the dominance of *Lysella* ex gr. *gadukensis* and *E. florigena* group continues, while the entry of *Plectogyranopsis convexus* (Rauser-Chernousova) is stratigraphically important.

Brown End

Figures 24–28

At the base of the measured section (B38–B40) in Brown End Quarry is a peri-Waulsortian facies characterised by crinoids, ostracods, bryozoans and salebrids. Foraminifers are also present including *Eotextularia diversa* and *Tetrataxis* (Lees 1997).

The interval above (B37–B12) is dominated by micritic limestones (mostly wackestones) with abundant sponge

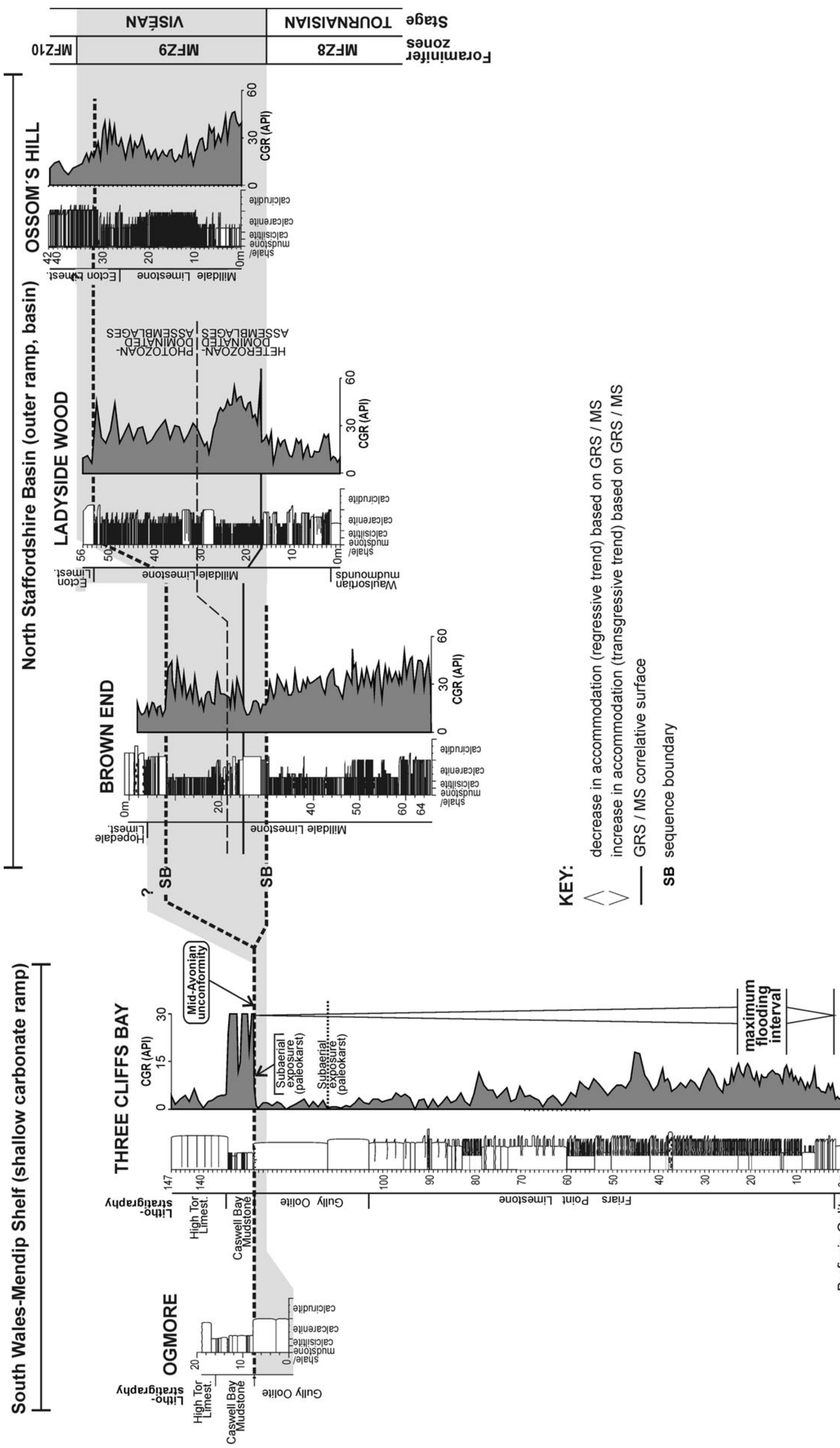

Figure 9. Correlation of the sections in the North Staffordshire Basin and on the South Wales-Mendip Shelf. See www.geology.cz/bulletin for this figure in bigger size.

Figure 10. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. • A – *Spinochernella* sp., Ladyside Wood, LW5, t.s. 5. • B – *Spinochernella* sp., Ladyside Wood, Wo1, t.s. 27. • C – *Spinochernella spinosa* (Chernysheva), Ladyside Wood, Wo2, t.s. 4. • D – *Spinochernella spinosa* (Chernysheva), Ladyside Wood, Wo1, t.s. 2. • E – *Spinochernella spinosa* (Chernysheva), Ladyside Wood M4, t.s. 1. • F – *Spinochernella paraukrainica* (Lipina), Ladyside Wood, Wo2, t.s. 17. • G – *Spinochernella spinosa* (Chernysheva), Ladyside Wood, LW15, t.s. 4. • H – *Spinochernella spinosa* (Chernysheva), Ladyside Wood, Wo2, t.s. 12. • I – *Spinochernella spinosa* (Chernysheva), Ladyside Wood, Wo2, t.s. 7. • J – *Spinochernella* sp., Ladyside Wood, Wo1, t.s. 8. • K – *Spinobrunsiina vachardi* Conil, Wo2, t.s. 1. • L – *Spinobrunsiina pietoni* (Conil & Lys), Ladyside Wood, M4, t.s. 5. • M – *Spinobrunsiina landeliesi* Conil, Ladyside Wood, Wo6, t.s. 7. • N – *Spinobrunsiina vachardi* Conil, Ladyside Wood, Wo28, t.s. 1. • O – *Spinobrunsiina lidijae* (Brazhnikova), Ladyside Wood, LW6, t.s. 3. • P – *Spinochernella* cf. *spinosa* (Chernysheva), Ladyside Wood, Wo1, t.s. 18. • Q – *Spinochernella brencklei* Conil & Lys, Ladyside Wood, LW15, t.s. 1. • R – *Spinochernella brencklei* Conil & Lys, Ladyside Wood, Wo1, t.s. 3. • S – *Spinochernella brencklei* Conil & Lys, Ladyside Wood, Wo3, t.s. 14. Enlargement: 75×, L 100×.

Figure 11. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. A plate showing the variability of the *Spinobrunsiina lexhyi* group. • A – *Spinobrunsiina* cf. *lexhyi* Conil & Hance, Ladyside Wood, LW15, t.s. 1. • B – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo1, t.s. 24. • C – *Spinobrunsiina* cf. *lexhyi* Conil & Hance, Ladyside Wood, Wo11, t.s. 2. • D – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo2, t.s. 13. • E – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo1, t.s. 3. • F – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo2, t.s. 18. • G – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo22, t.s. 6. • H – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo7, t.s. 54. • I – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo22, t.s. 3. • J – *Spinobrunsiina* cf. *lexhyi* Conil & Hance, Ladyside Wood, Wo1, t.s. 2. • K – *Spinobrunsiina* cf. *lexhyi* Conil & Hance, Ladyside Wood, LW16, t.s. 7. • L – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, M4, t.s. 2. • M – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, M4, t.s. 5. • N – *Spinobrunsiina* cf. *lexhyi* Conil & Hance, Ladyside Wood, Wo2, t.s. 11. • O – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, LW5, t.s. 5. • P – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo28, t.s. 1. • Q – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo7, t.s. 16. • R – *Spinobrunsiina lexhyi* Conil & Hance, Ladyside Wood, Wo19, t.s. 3. • S – *Spinobrunsiina* cf. *lexhyi* Conil & Hance, Ladyside Wood, M4, t.s. 5. • T – *Spinobrunsiina* sp., Ladyside Wood, Wo2, t.s. 16. • U – *Spinobrunsiina imlicata* (Conil & Lys), Ladyside Wood, Wo19, t.s. 1. • V – *Spinobrunsiina imlicata* (Conil & Lys), Ladyside Wood, Wo6, t.s. 4. • W – *Spinobrunsiina* cf. *imlicata* (Conil & Lys), Ladyside Wood, LW6, t.s. 2. Enlargement: 75×, U and W 100×.

Figure 12. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. • A – *Carbotarima* sp., Ladyside Wood, LW16, t.s. 3. • B – *Carbotarima* sp., Ladyside Wood, Wo1, t.s. 8. • C – *Carbotarima* sp., Ladyside Wood, Wo2, t.s. 10. • D – ?*Carbotarima* sp., Ladyside Wood, LW15, t.s. 1. • E – *Eosinopsis* sp. 2 Vachard & Hance, Ladyside Wood, LW16, t.s. 7. • F – *Eosinopsis* sp. 2 Vachard & Hance, Ladyside Wood, Wo1, t.s. 25. • G – *Spinobrunsiina ramsbottomi* Conil & Longerstaey, Ladyside Wood, Wo28, t.s. 2. • H – *Eosinopsis primaeva* Vachard & Hance, Ladyside Wood, Wo1, t.s. 7. • I – *Eosinopsis* sp. 2 Vachard & Hance, Ladyside Wood, LW16, t.s. 4. • J – *Eosinopsis primaeva* Vachard & Hance, Ladyside Wood, Wo1, t.s. 25. • K – *Eosinopsis* sp., Ladyside Wood, Wo22, t.s. 4. • L – *Plectogyranopsis convexa* (Rauser-Chernousova), Ladyside Wood, Wo28, t.s. 2. • M – *Eosinopsis* sp. 2 Vachard & Hance, Ladyside Wood, Wo1, t.s. 6. • N – *Plectogyranopsis regularis* (Rauser-Chernousova), Ladyside Wood, M4, t.s. 1. Enlargement: 75×, N 100×.

Figure 13. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. • A – *Plectogyranopsis* sp., Ladyside Wood, Wo28, t.s. 6. • B – *Plectogyranopsis paraconvexus* (Brazhnikova & Rostovtseva), Ladyside Wood, Wo7, t.s. 28. • C – *Eosinopsis* sp., Ladyside Wood, Wo6, t.s. 10. • D – *Forschiella* sp., Ladyside Wood, Wo6, t.s. 21. • E – *Condrustella modavensis* (Conil & Lys), Ladyside Wood, Wo3, t.s. 28. • F – *Conilites dinantii* (Conil & Lys), Ladyside Wood, Wo1, t.s. 6.• G – *Conilites dinantii* (Conil & Lys), Ladyside Wood, Wo3, t.s. 32. • H – *Conilites dinantii* (Conil & Lys), Ladyside Wood, Wo3, t.s. 29. • I – *Conilites dinantii* (Conil & Lys), Ladyside Wood, Wo1, t.s. 19. • J – *Eblanaia michoti* (Conil & Lys), Ladyside Wood, Wo10, t.s. 13. • K – *Eblanaia michoti* (Conil & Lys), Ladyside Wood, LW16, t.s. 6. • L – *Eblanaia michoti* (Conil & Lys), Ladyside Wood, Wo1, t.s. 27. • M – *Eblanaia michoti* (Conil & Lys), Ladyside Wood, Wo1, t.s. 17. • N – *Valvulinella ceunacumensis* Hance, Ladyside Wood, Wo3, t.s. 30. Enlargement: A–C, E, H–I 75×; D, F–G, J–N 50×.

Figure 14. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. • A – *Bessiella rectiformis* (Bogush & Yuferev), Ladyside Wood, Wo1, t.s. 11. • B – *Bessiella rectiformis* (Bogush & Yuferev), Ladyside Wood, Wo1, t.s. 25. • C – *Bessiella rectiformis* (Bogush & Yuferev), Ladyside Wood, Wo2, t.s. 10. • D – *Bessiella rectiformis* (Bogush & Yuferev), Ladyside Wood, Wo2, t.s. 6. • E – *Bessiella rectiformis* (Bogush & Yuferev), Ladyside Wood, Wo2, t.s. 5. • F – *Bessiella rectiformis* (Bogush & Yuferev), Ladyside Wood, Wo7, t.s. 15. • G – *Bessiella leusoniae* Conil, Ladyside Wood, M4, t.s. 5. • H – *Mediocris mediocris* (Vissarionova), Ladyside Wood, Wo9, t.s. 6. • I – *Bessiella* cf. *agilis* Conil, Ladyside Wood, Wo1, t.s. 9. • J – *Bessiella leusoniae* Conil, Ladyside Wood, Wo3, t.s. 12. • K – *Bessiella rectiformis* (Bogush & Yuferev), Ladyside Wood, Wo2, t.s. 6. • L – *Mediocris mediocris* (Vissarionova), Ladyside Wood, Wo3, t.s. 12. • M – *Bessiella agilis* Conil, Ladyside Wood, Wo2, t.s. 7. • N – *Bessiella leusoniae* Conil, Ladyside Wood, Wo1, t.s. 9. • O – *Bessiella agilis* Conil, Ladyside Wood, Wo2, t.s. 5. • P – *Bessiella legrandi* Conil & Hance, Ladyside Wood, Wo1, t.s. 9. • Q – *Bessiella leusoniae* Conil, Ladyside Wood, Wo1, t.s. 23. • R – *Bessiella legrandi* Conil & Hance, Ladyside Wood, Wo2, t.s. 17. Enlargement: 75×, H and L 100×.

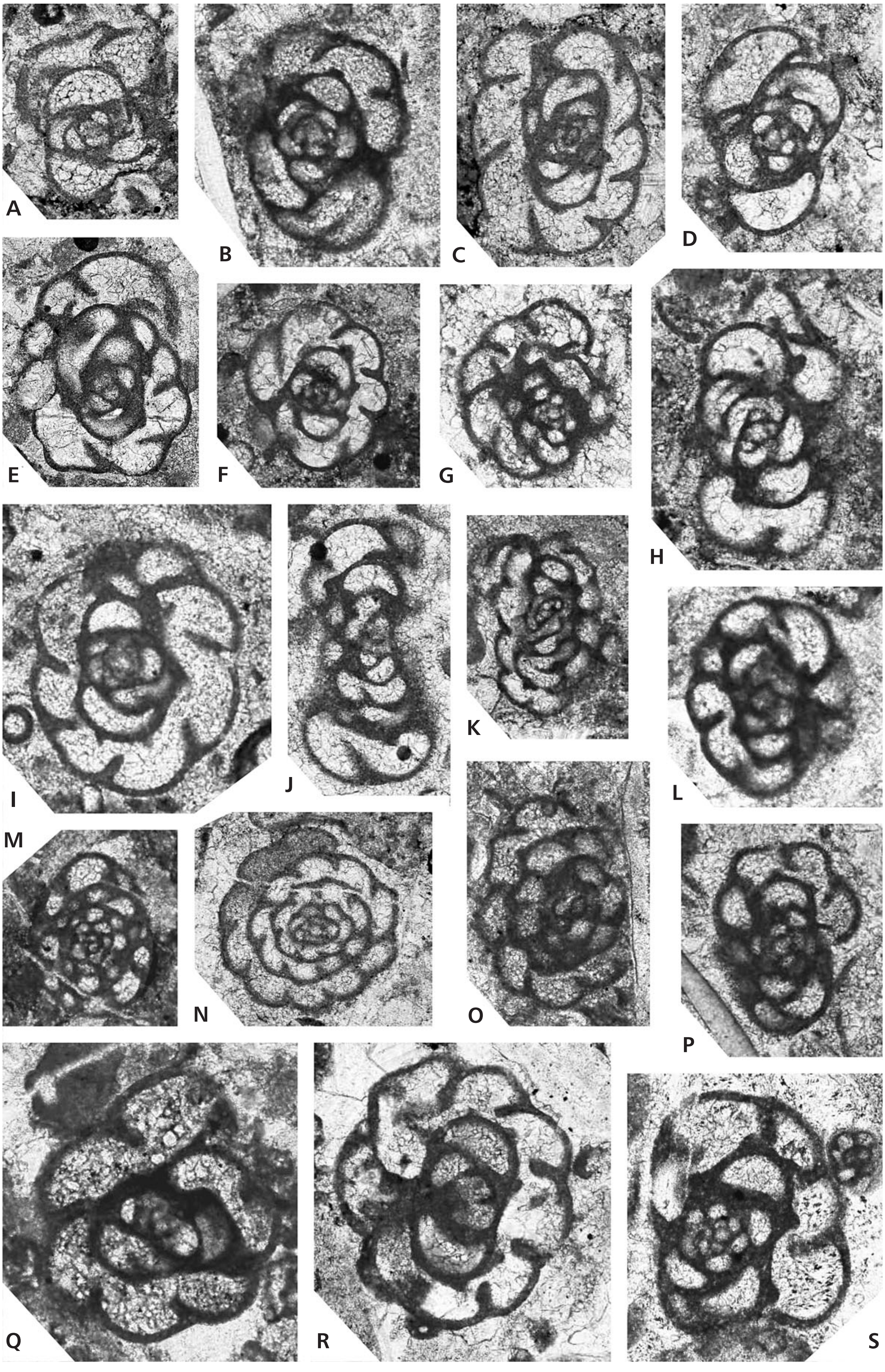

Figure 10. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. For explanation see page 510.

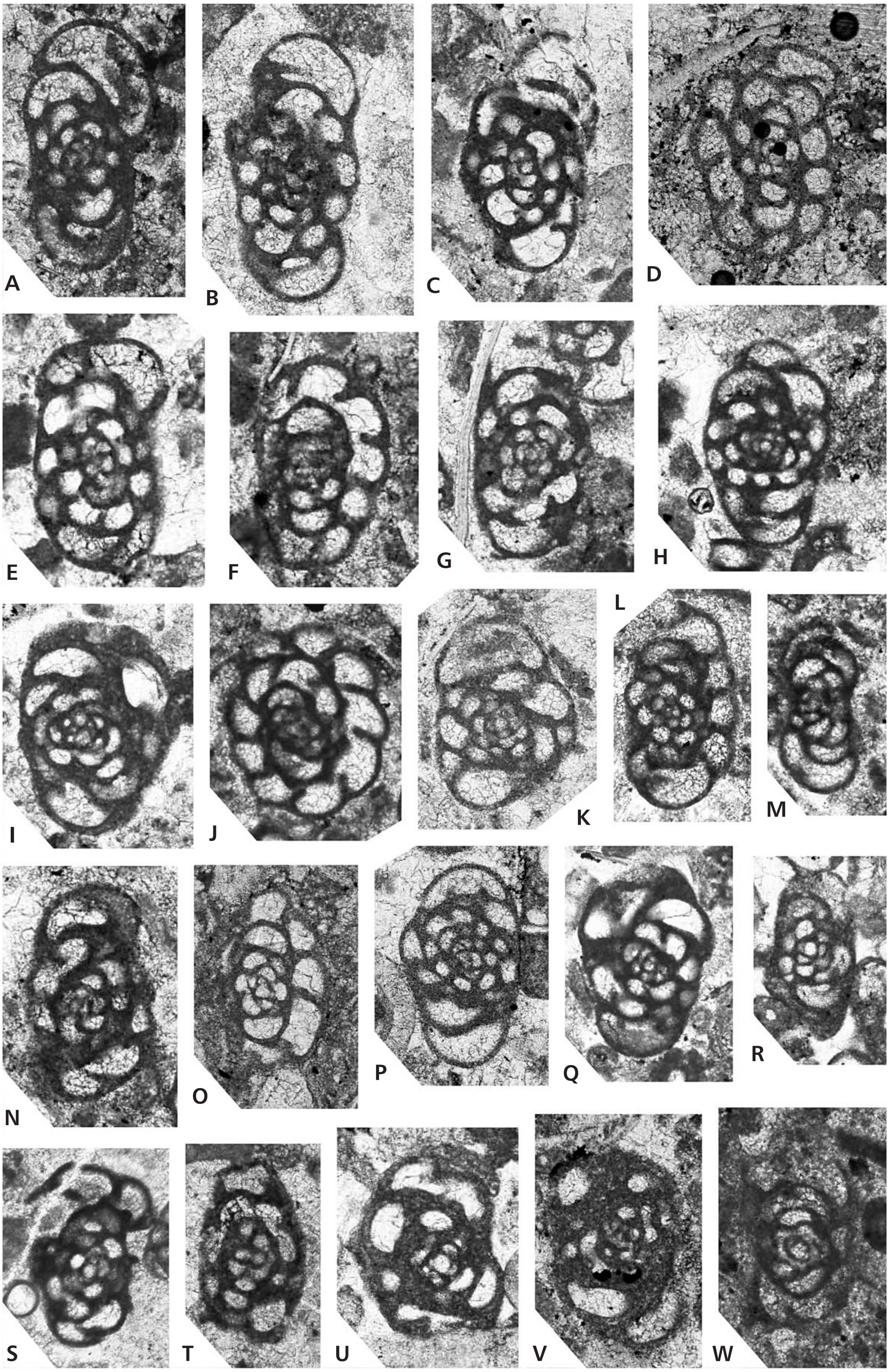

Figure 11. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. A plate showing the variability of the *Spinobrunsiina lexhyi* group. For explanation see page 510.

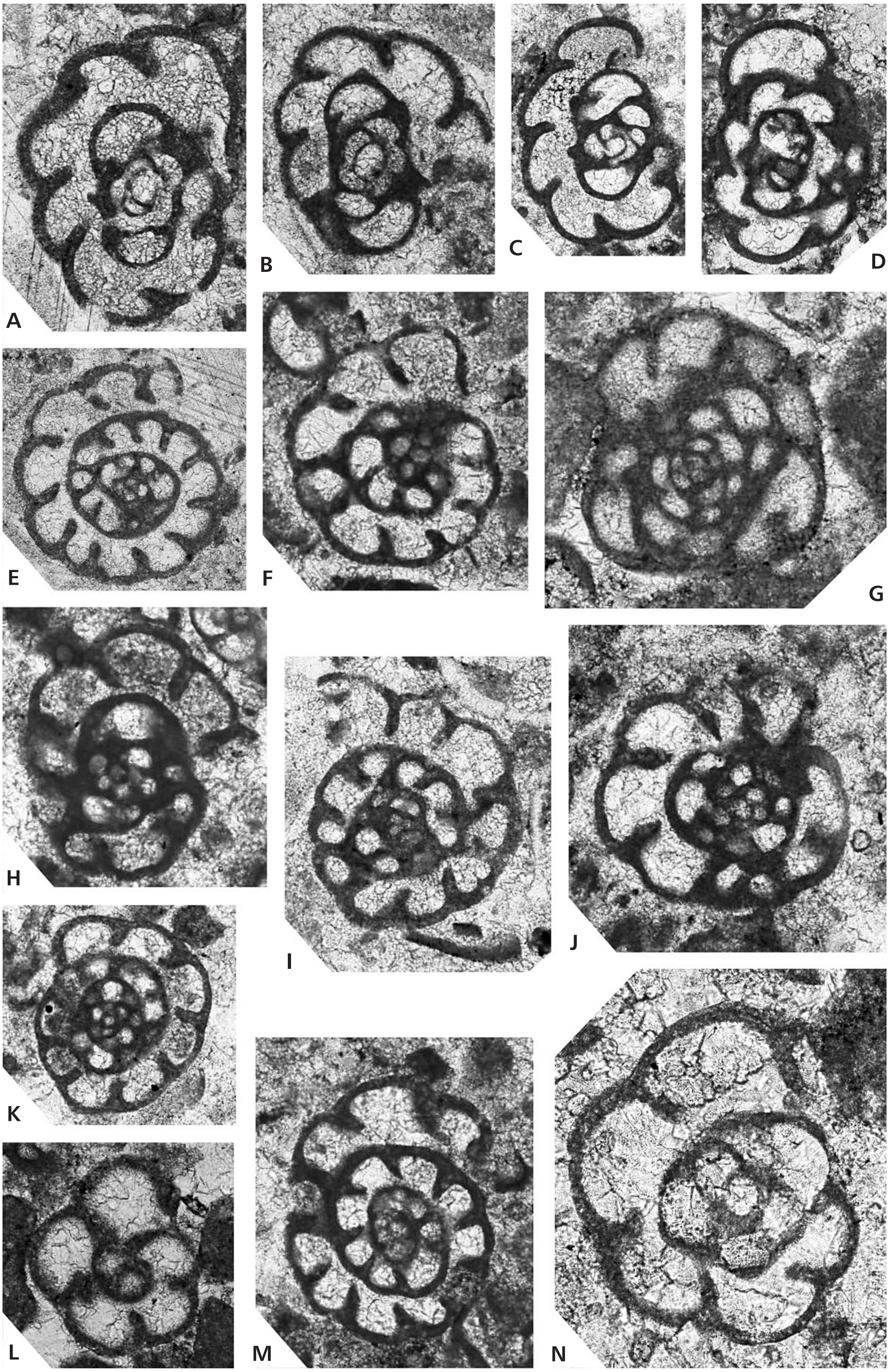

Figure 12. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. For explanation see page 510.

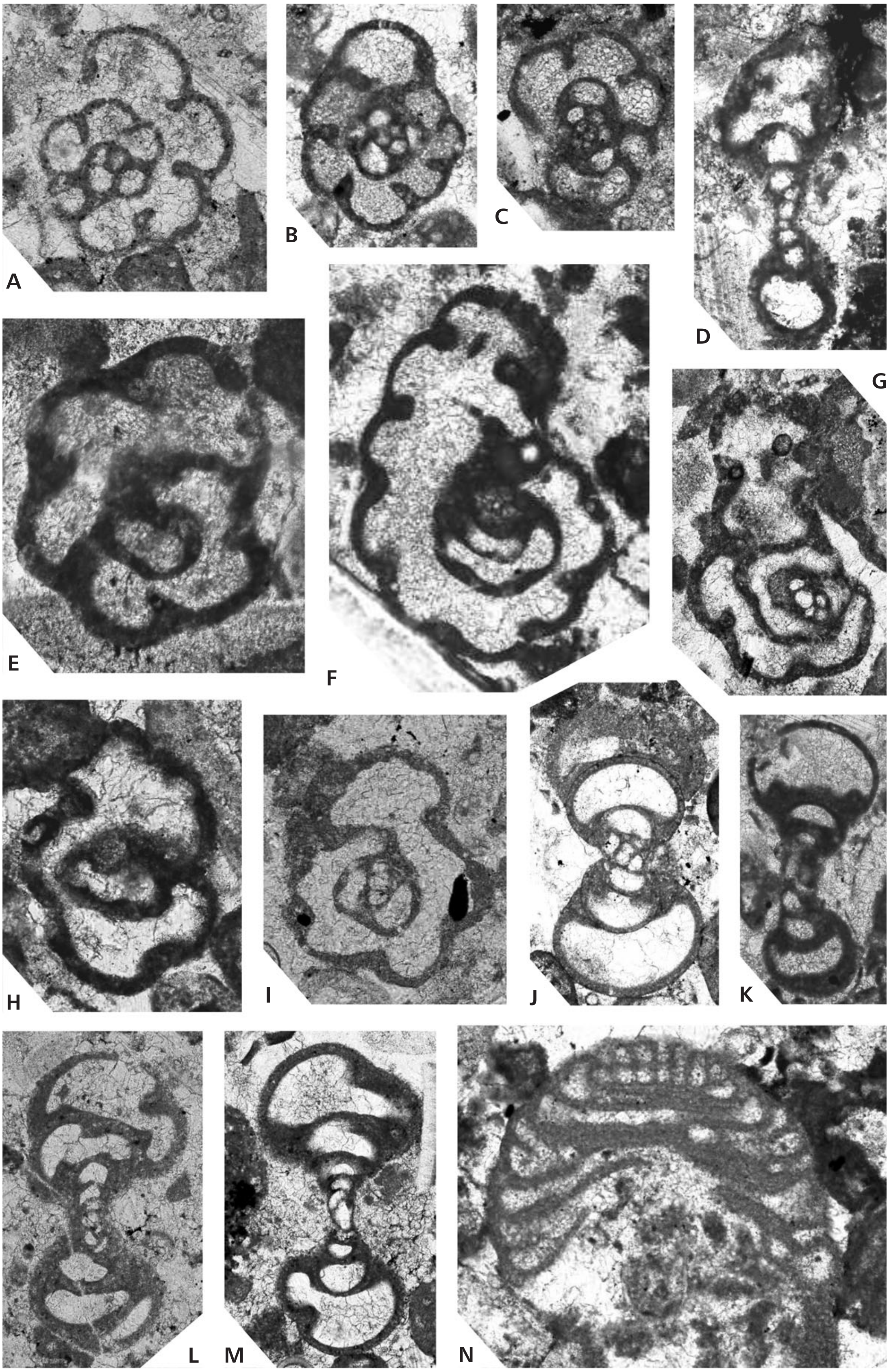

Figure 13. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. For explanation see page 510.

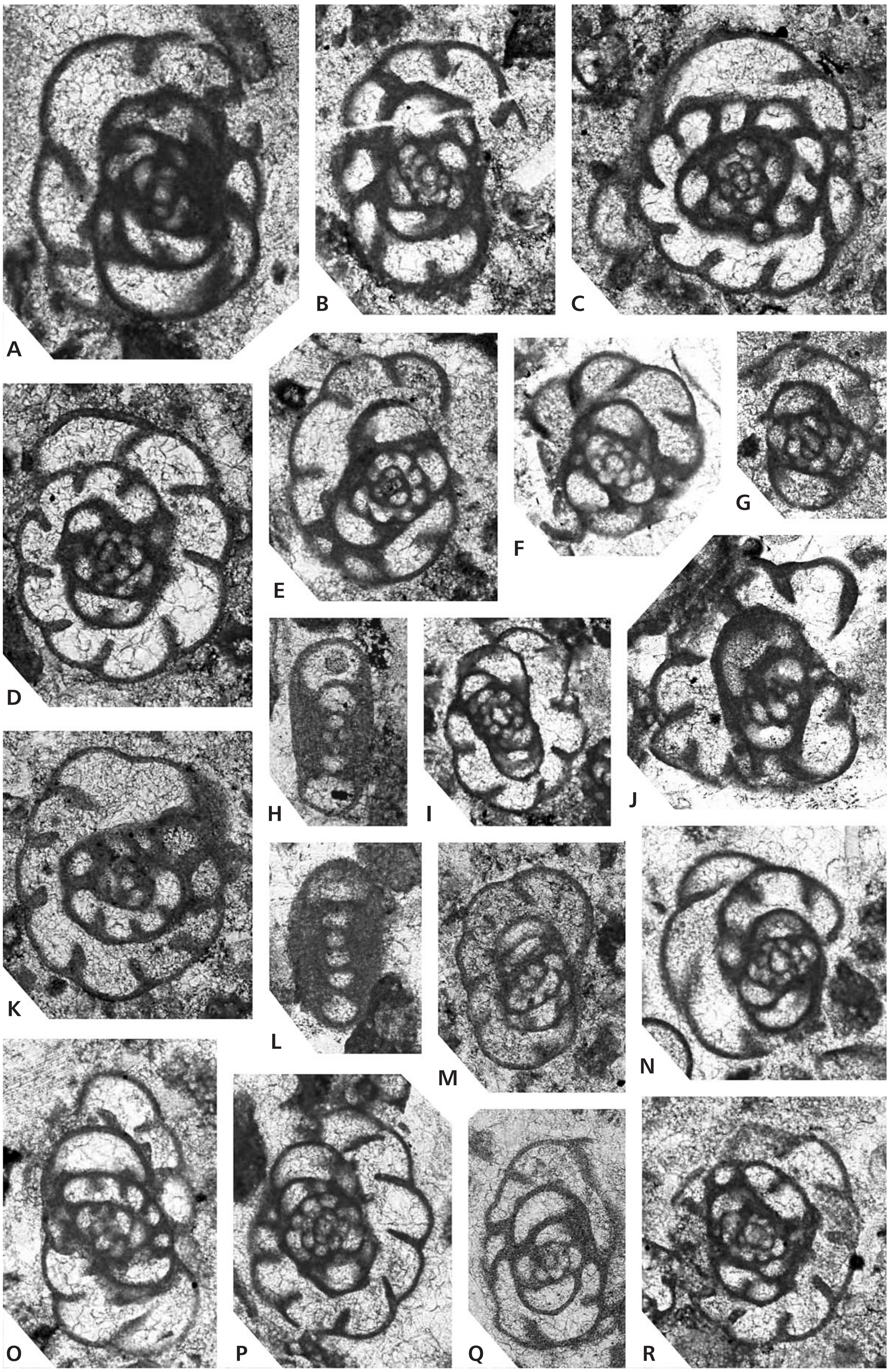

Figure 14. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. For explanation see page 510.

spicules and ostracods. Other than *Earlandia*, foraminifers are quite rare, these being represented by small juveniles which were difficult to identify. Foraminifers that were identified include *Endothyra*, *Spinobrunsiina*, *Brunsia* and the stratigraphically important *Elevenella parvula* which together suggest an uppermost MFZ7–MFZ8 age.

Figure 15. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. • A – *Florennella stricta* (Conil & Lys), Ladyside Wood, LW8, t.s. 4. • B – *Florennella stricta* (Conil & Lys), Ladyside Wood, LW15, t.s. 5. • C – *Florennella stricta* (Conil & Lys), Ladyside Wood, Wo1, t.s. 12. • D – *Bessiella mobilis* (Conil & Lys), Ladyside Wood, M4, t.s. 5. • E – *Florennella stricta* (Conil & Lys), Ladyside Wood, Wo1, t.s. 24. • F – *Florennella stricta* (Conil & Lys), Ladyside Wood, Wo1, t.s. 21. • G – *Florennella* cf. *amplissima* Conil, Ladyside Wood, LW15, t.s. 1. • H – *Florennella stricta* (Conil & Lys), Ladyside Wood, Wo2, t.s. 12. • I – *Lysella gadukensis* Bozorgnia, Ladyside Wood, Wo9, t.s. 10. • J – *Florennella stricta* (Conil & Lys), Ladyside Wood, Wo10, t.s. 7. • K – *Florennella stricta* (Conil & Lys), Ladyside Wood, LW16, t.s. 3. • L – *Florennella stricta* (Conil & Lys), Ladyside Wood, Wo2, t.s. 12. • M – *Lysella gadukensis* Bozorgnia, Ladyside Wood, Wo3, t.s. 31. • N – *Lysella gadukensis* Bozorgnia, Ladyside Wood, Wo19, t.s. 4. • O – *Lysella gadukensis* Bozorgnia, Ladyside Wood, Wo3, t.s. 39. Enlargement: 75×.

Figure 16. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. • A – *Lysella gadukensis* Bozorgnia, Ladyside Wood, Wo3, t.s. 26. • B – *Lysella gadukensis* Bozorgnia, Ladyside Wood, Wo22, t.s. 6. • C – *Paralysella* sp., Ladyside Wood, Wo3, t.s. 7. • D – *Paralysella* sp., Ladyside Wood, Wo3, t.s. 7. • E – *Paralysella* sp., Ladyside Wood, Wo28, t.s. 5. • F – ?*Paralysella* sp., Ladyside Wood, Wo3, t.s. 44. • G – *Paralysella* sp., Ladyside Wood, Wo3, t.s. 49. • H – *Brenckleites* sp., Ladyside Wood, Wo3, t.s. 49. • I – *Paralysella* cf. *procerula* (Malakhova), Ladyside Wood, Wo6, t.s. 3. • J – *Paralysella* sp., Ladyside Wood, Wo7, t.s. 22. • K – *Urbanella urbana* (Malakhova), Ladyside Wood, Wo6, t.s. 1. • L – *Urbanella urbana* (Malakhova), Ladyside Wood, Wo6, t.s. 28. • M – *Urbanella urbana* (Malakhova), Ladyside Wood, Wo28, t.s. 5. • N – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Ladyside Wood, Wo7, t.s. 16. • O – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Ladyside Wood, Wo7, t.s. 39. • P – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Ladyside Wood, Wo6, t.s. 16. • Q – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Ladyside Wood, Wo22, t.s. 1. • R – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Ladyside Wood, Wo28, t.s. 2. • S – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Ladyside Wood, Wo7, t.s. 39. • T – *Eoparastaffella ovalis* Vdovenko, M2, Ladyside Wood, Wo7, t.s. 33. • U – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Ladyside Wood, Wo6, t.s. 17. • V – *Eoparastaffella* sp., Ladyside Wood, Wo7, t.s. 14. • W – *Eoparastaffella* ex gr. *interiecta* Vdovenko, Ladyside Wood, Wo6, t.s. 38. • X – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo7, t.s. 9. • Y – *Eoparastaffella* ex gr. *florigena* (Pronina), juvenile, Ladyside Wood, Wo7, t.s. 48. Enlargement: 75×, V and Y 100×.

Figure 17. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. • A – *Eoparastaffella* ex gr. *interiecta* Vdovenko, Ladyside Wood, Wo7, t.s. 16. • B – *Eoparastaffella interiecta* Vdovenko, Ladyside Wood, Wo11, t.s. 3. • C – *Eoparastaffella interiecta* Vdovenko, Ladyside Wood 17, t.s. 9. • D – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 8. • E – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo10, t.s. 15. • F – *Eoparastaffella* cf. *restricta* Postoyalko, Ladyside Wood, Wo10, t.s. 4. • G – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 36. • H – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 17. • I – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo6, t.s. 1. • J – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo10, t.s. 15. • K – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo6, t.s. 14. • L – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 37. • M – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 21. • N – *Eoparastaffella* cf. *florigena* (Pronina), Ladyside Wood, Wo7, t.s. 41. • O – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo11, t.s. 5. • P – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo10, t.s. 6. • Q – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo22, t.s. 6. • R – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo7, t.s. 48. • S – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo6, t.s. 27. • T – *Eoparastaffella* sp., Ladyside Wood, Wo3, t.s. 44. • U – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 21. • V – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 22. • W – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 18. Enlargement: 75×, B 100×.

Figure 18. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. • A – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 18. • B – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 26. • C – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo7, t.s. 44. • D – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo10, t.s. 20. • E – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo28, t.s. 1. • F – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo6, t.s. 3. • G – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo7, t.s. 27. • H – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo19, t.s. 5. • I – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo10, t.s. 4. • J – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo28, t.s. 4. • K – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo28, t.s. 1. • L – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo19, t.s. 3. • M – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo19, t.s. 1. • N – *Eoparastaffella* cf. *tummida* (Pronina), Ladyside Wood, Wo7, t.s. 9. • O – *Eoparastaffella tummida* (Pronina), Ladyside Wood, Wo6, t.s. 16. • P – *Eoparastaffella* cf. *tummida* (Pronina), Ladyside Wood, Wo28, t.s. 5. • Q – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo3, t.s. 15. • R – *Eoparastaffella* sp., Ladyside Wood, Wo22, t.s. 1. • S – *Eoparastaffella tummida* (Pronina), Ladyside Wood, Wo3, t.s. 16. • T – *Eoparastaffella cf. tummida* (Pronina), Ladyside Wood, Wo6, t.s. 26. • U – *Eoparastaffella* cf. *tummida* (Pronina), Ladyside Wood, Wo28, t.s. 4. • V – *Eoparastaffella* cf. *tummida* (Pronina), Ladyside Wood, Wo3, t.s. 45. • W – *Eoparastaffella* ex gr. *florigena* (Pronina), Ladyside Wood, Wo10, t.s. 6. Enlargement: 75×, E 50×.

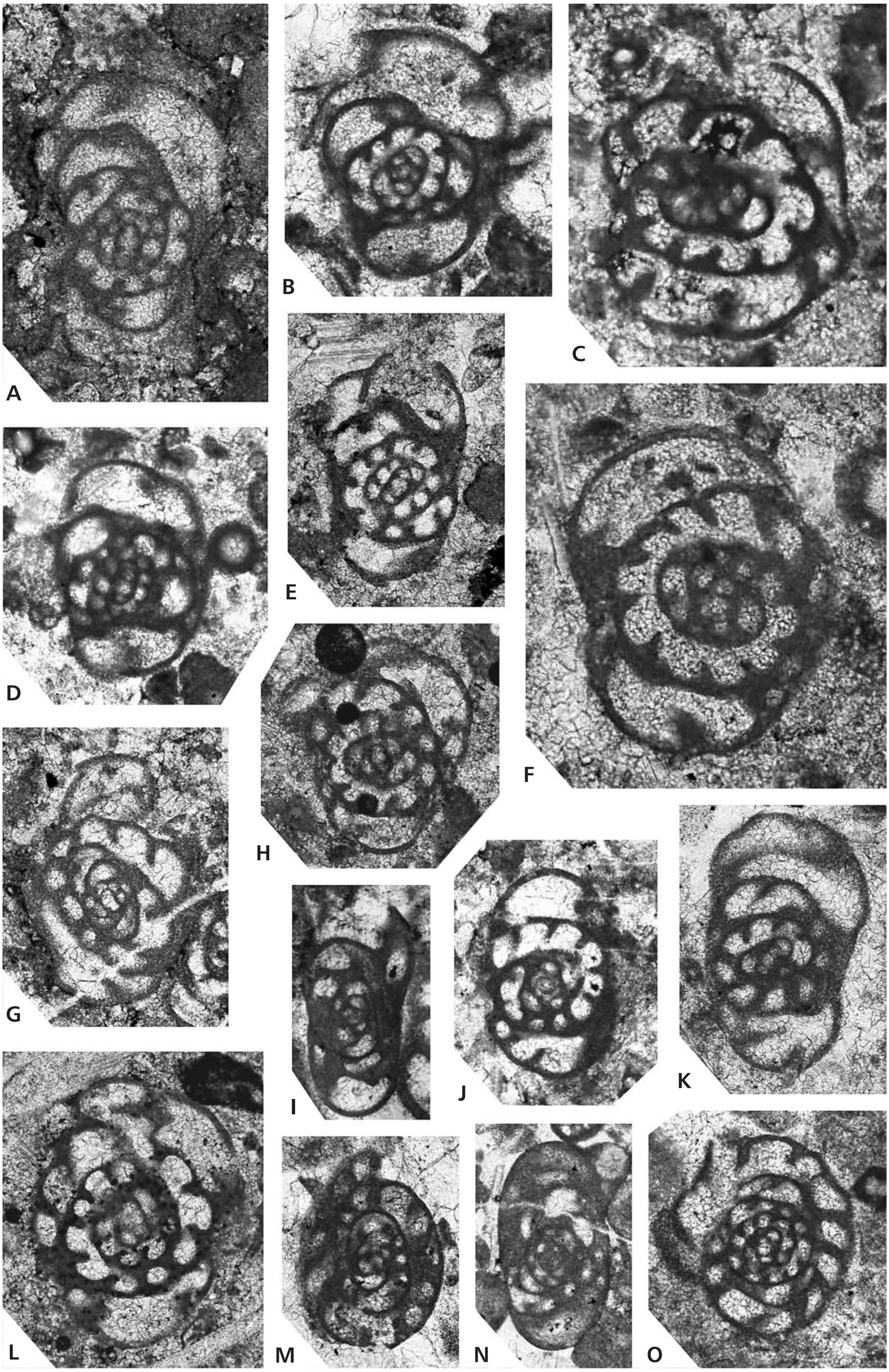

Figure 15. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. For explanation see page 516.

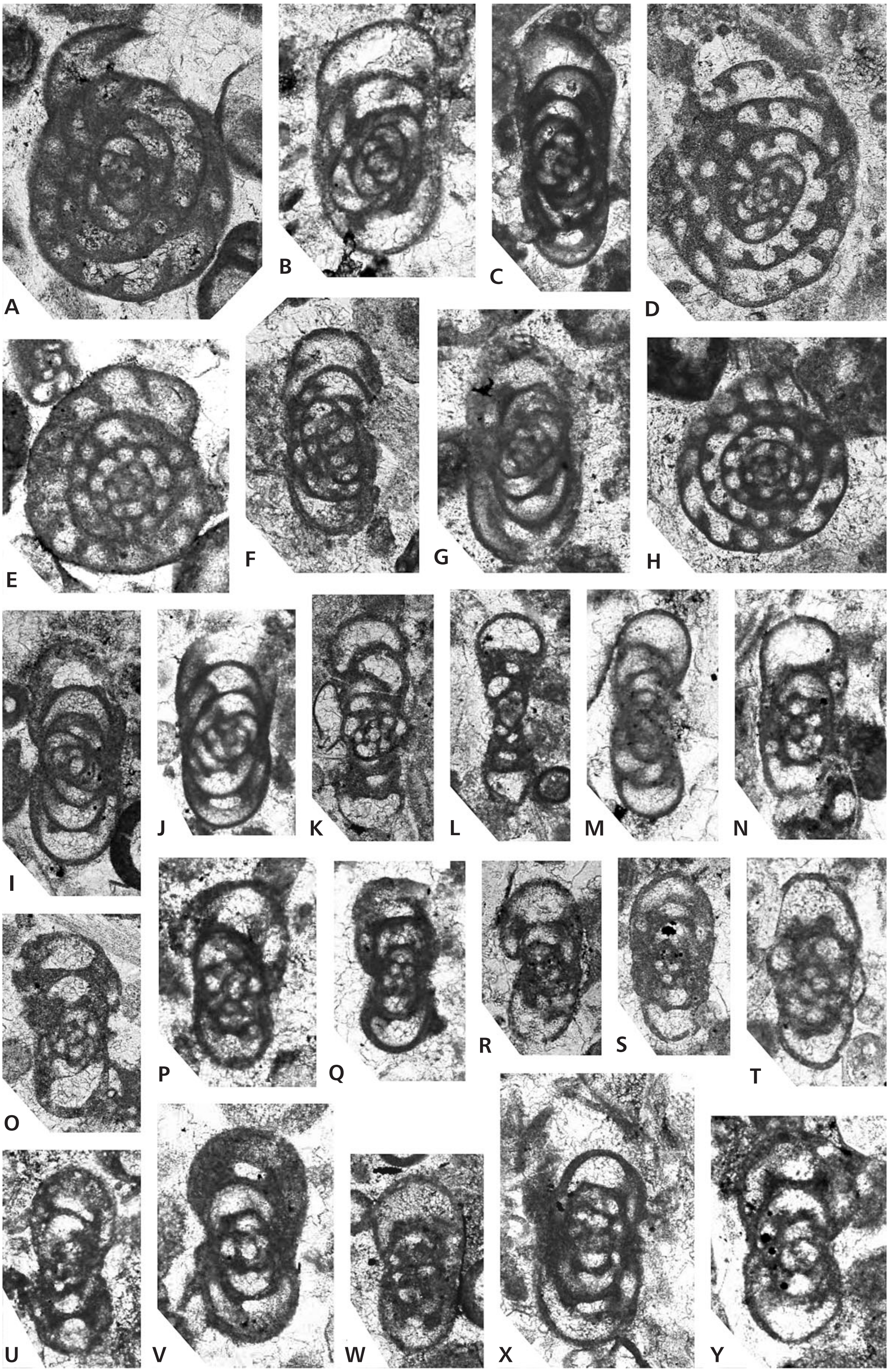

Figure 16. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. For explanation see page 516.

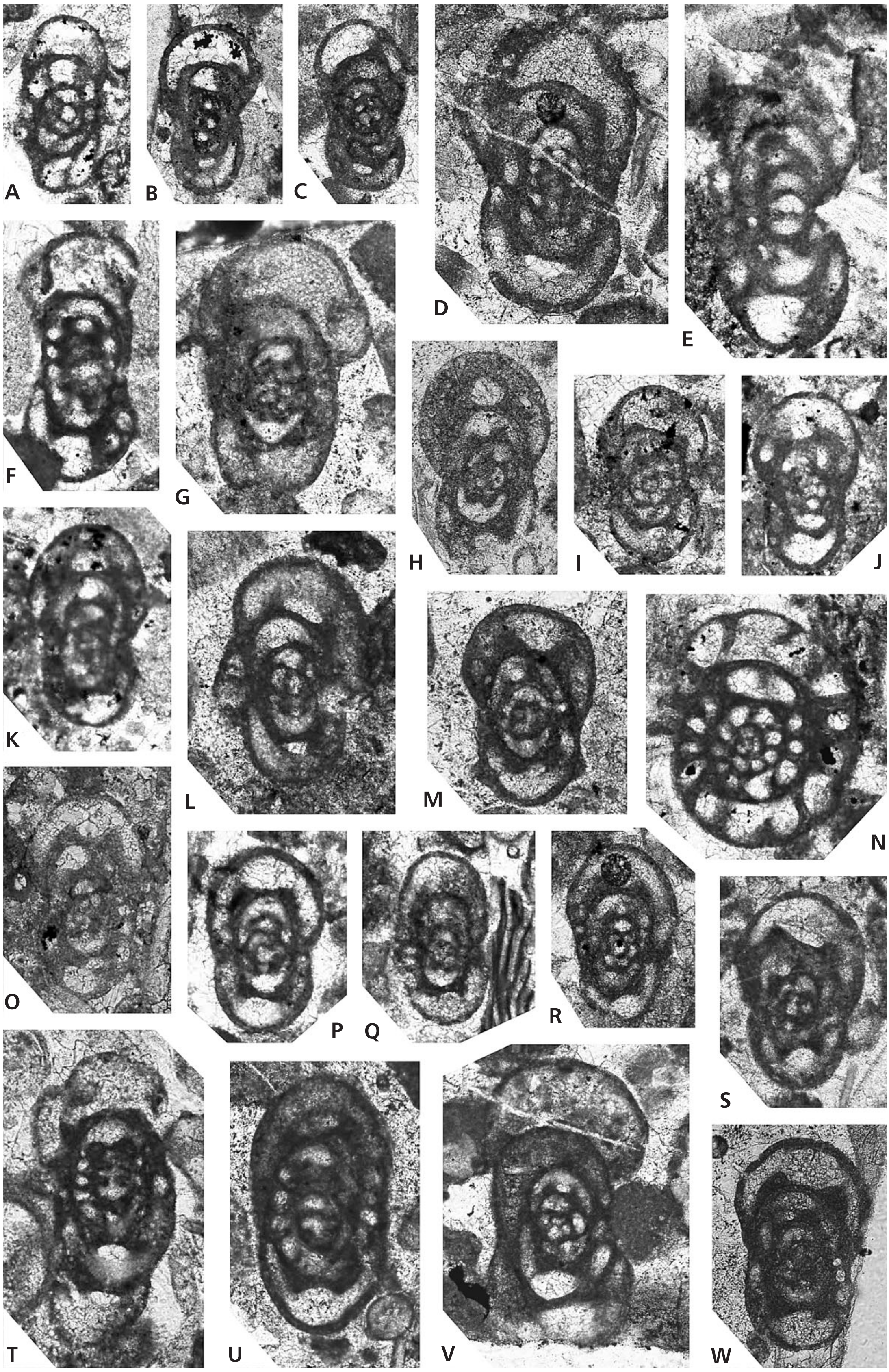

Figure 17. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. For explanation see page 516.

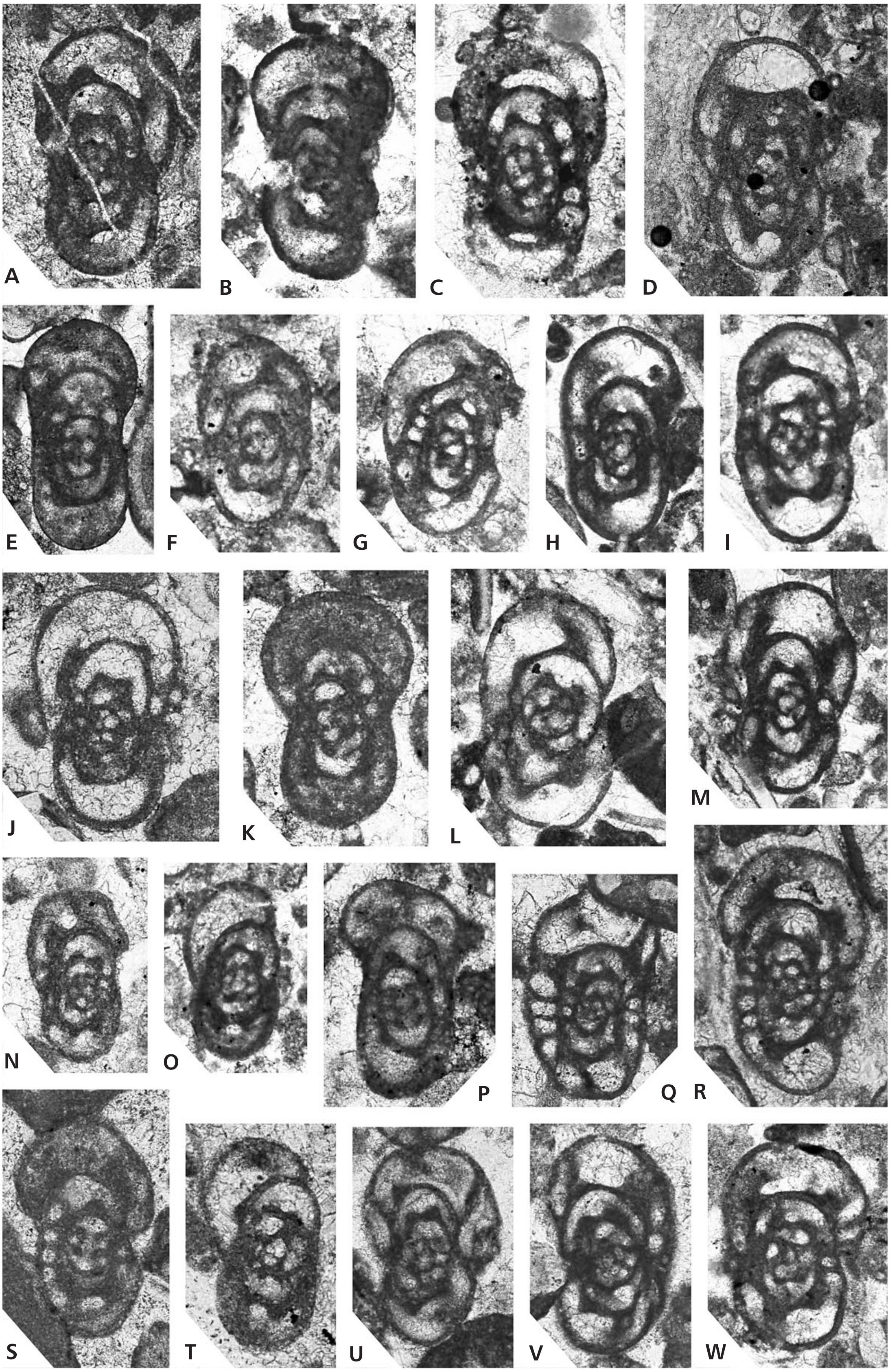

Figure 18. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin. For explanation see page 516.

The lack of diagnostic sections and the presence only of rare juveniles make it difficult to determine the level of *Eoparastaffella* entry. However, the presence of ?*Eoparastaffella* at the very base of the interval, and the fact that the first richer *Eoparastaffella* occurrence above is represented by upper MFZ8 taxa, indicate that most probably the interval corresponds to MFZ8. This interpretation is corroborated by the presence of *Eosinopsis* the FAD of which has not been traced below MFZ8 (Hance *et al.* 2011). These data clearly illustrate the problems in recognising the base of the Chadian which correlates with the base of MFZ8. The Waulsortian and peri-Waulsortian facies and spiculitic limestone are all quite unfavourable for *Eoparastaffella* (Lees 1997).

The first bioclastic layer B27 contains already *L. gadukensis* which follows both the occurrences of *E.* cf. *interiecta* and *E.* cf. *vdovenkoae* indicating close proximity of the T-V boundary. Higher up in B11 the entry of *Eosinopsis solida* so far reported only in Viséan MFZ9 is accompanied by a form transitional between *Eoparastaffella ovalis* M1 and M2. Similar forms enter just below the T-V boundary in the stratotype in Pengchong (Devuyst 2006). Above B11 richer foraminiferal associations occur especially in the growing number of bioclastic limestones at this level, and, in a parallel trend, foraminifers become more common in wackestones; this accords with the growing number of dasyclads present, which have been derived from more shallow water environments.

In sample B53 forms similar to the paratype of *Paralysella schubertelloides* (Bozorgnia 1973, pl. 13, fig. 10) occur, a form previously only recorded from the Viséan (Devuyst 2006, Kalvoda *et al.* 2011). The FAD of *E.* cf. *simplex* (B42) is preceded by the entries of *Mediocris* ex gr. *mediocris*, *Eosinopsis solida* and *Paralysella schubertelloides* whose ranges are still not so well established but which have been reported only in the Viséan.

The massive bed with sample P13 in the centre of the section contains only larger *Eoparastaffella* mostly of the variable *E. florigena* group together with a rich association of specimens *Eosinopsis solida* and *Eosinopsis*? ex gr. *donica* (Brazhnikova & Rostovtseva) and the *Paralysella schubertelloides*. Above this bed, *Eoparastaffella* is represented mostly by the *E. florigena* and *E. interiecta* group, while *E. simplex* and *E. ovalis* M2 continue to be rare. Another important entry at this this level is the appearance of *Paralysella* ex gr. *mediocriformis* (Bozorgnia).

Above B4 there is an interval of micritic limestone in which foraminifers are both rare and stratigraphically unimportant. Bioclastic limestones at the top of the section contain advanced forms of *Eoparastaffella* with walls transitional to *Eostaffella* (Conil *et al.* 1980; Groessens *et al.* 1982, 1964; Hance 1997; Devuyst 2006) including *Eoparastaffella nalivkini* (Malakhova). No archaediscids have been encountered at the base of the Hopedale Limestone in the sample B1. However, the presence of *Paralysella* cf. *mutabiliformis* Popova reported in the Ust-Grekhov horizon (MFZ10–11) of the Urals (Simonova 1975, Ivanova 2008, Kulagina 2011) may indicate the proximity of the Arundian.

Ossom's Hill

Figures 21–24

At Ossom's Hill the section starts in wackestone facies with only rare endothyrids represented mostly by small juveniles. As in other sections *Endothyra* and *Spinobrunsiina* are present. The first richer association comes from a well graded calciturbidite OH5 (Fig. 6). The presence of variable *Eoparastaffella* ex gr. *florigena* (the dominant form among *Eoparastaffella*), *Eoparastaffella ovalis* transitional between M1 and M2, *Lysella gadukensis* and *Paralysella* indicates close proximity to the T-V boundary. In the following samples OH6 juveniles dominate with *Brunsia* and *Spinobrunsiina* still very abundant. A Viséan MFZ9 age is indicated by the presence of *E. asymmetrica* and *E. ovalis* M2. In OH7, in addition to the Viséan indicators *E. ovalis* M2 and *E. tumida,* Tournayellida including *Spinobrunsiina*, *Brunsia, Eblanaia michoti, Eblanaia* sp. and *Spinochernella brenklei* are all present. *S. brencklei* is reported in Belgium only in MFZ4 (Devuyst & Hance *in* Poty *et al.* 2006). Although *E. michoti* was formerly regarded as only late Tournaisian in Belgium, it has recently been reported from the early Viséan of the Urals by Kulagina (2011). The presence of *E. michoti* together with Viséan *Eoparastaffella* guides indicates a lower part of MFZ9. More abundant too is *Bessiella* and, a similar trend was encountered in OH9. The increased variability within the foraminiferal association at this level demonstrates derivation from different parts of the ramp as genera not usually found together are present (*Eoparastaffella* – *Eblanaia*). In OH9 the first representatives of the *E. simplex* group appear (*E. simplex*, *E. iniqua* Postoyalko) and the number of *Spinobrunsiina* and *Brunsia* decrease. There is a further sharp decline of these taxa in OH12 where *Eoparastaffella* species show the highest variability. Beside *E. simplex* the presence of *E. evoluta*, *E. laciniosa* and *E. pseudochomata*, together with *Eoparastaffella* in which the wall resembles *Eostaffella,* indicate a higher part of MFZ9. A similar foraminiferal association also characterises the last studied sample OH14.

Although different ontogenetic stages of *E.* ex gr. *florigena* dominate in the Ossom's Hill section, the *Eoparastaffella* association is more diverse than that at either the Ladyside Wood or Brown End Quarry sections.

South Wales – Mendip Shelf

Three Cliffs Bay

Figures 19, 20

The upper part of the Friars Point Limestone is dolomitized and only few samples yielded foraminifers. The first sample TB1 contained mostly small juveniles or fragments. *Eoparastaffella* is absent, an the MFZ8 age is indicated by other MFZ8 guide, namely *Biseriella bristolensis* and the late Tournaisian guides *Darjella monilis* and *Elevenella parvula* (Fig. 7).

In the lower part of the Gully Oolite below the palaeosol horizon *Biseriella bristolensis* is accompanied by advanced

Figure 19. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin (A–W), and Three Cliffs Bay in the South Wales-Mendip Shelf (Y–AB). • A – *Eoparastaffella ovalis* Vdovenko, M1, Ladyside Wood, Wo6, t.s. 12. • B – *Eoparastaffella* sp., Ladyside Wood, Wo22, t.s. 6. • C – *Eoparastaffella ovalis* Vdovenko, M2, Ladyside Wood, Wo6, t.s. 25. • D – *Eoparastaffella ovalis* Vdovenko, M2, aberant form, Ladyside Wood, Wo6, t.s. 1. • E – *Eoparastaffella* cf. *simplex* Vdovenko, transitional form to *Eoparastaffella ovalis* Vdovenko, M2, Ladyside Wood, Wo6, t.s. 29. • F – *Eoparastaffella ovalis* Vdovenko, M1, Ladyside Wood 17, t.s. 11. • G – *Eoparastaffella* sp., Ladyside Wood, Wo12, t.s. 6. • H – *Eoparastaffella ovalis* Vdovenko, M1, Ladyside Wood, Wo6, t.s. 3. • I – *Eoparastaffella* sp., aberant form, Ladyside Wood, Wo22, t.s. 6. • J – *Eoparastaffella* sp., Ladyside Wood, Wo12, vt.s. 6. • K – *Eoparastaffella* sp., Ladyside Wood, Wo19, t.s. 6. • L – *Eoparastaffella* sp., Ladyside Wood, Wo19, t.s. 1. • M – *Eoparastaffella* ex gr. *simplex* Vdovenko, Ladyside Wood, Wo22, t.s. 2. • N – *Eoparastaffella* ex gr. *simplex* Vdovenko, Ladyside Wood, Wo7, t.s. 12. • O – *Eoparastaffella* ex gr. *simplex* Vdovenko, Ladyside Wood, Wo10, t.s. 20. • P – *Eoparastaffella* cf. *simplex* Vdovenko, Ladyside Wood, Wo10, t.s. 22. • Q – *Eoparastaffella* sp., Ladyside Wood, Wo12, t.s. 5. • R – *Eoparastaffella asymmetrica* Vdovenko, Ladyside Wood, Wo7, t.s. 1. • S – *Eoparastaffella asymmetrica* Vdovenko, Ladyside Wood, Wo7, t.s. 15. • T – *Eoparastaffella asymmetrica* Vdovenko, Ladyside Wood, Wo6, t.s. 27. • U – *Eoparastaffella asymmetrica* Vdovenko, Ladyside Wood, Wo7, t.s. 15. • V – *Eoparastaffella asymmetrica* Vdovenko, Ladyside Wood, Wo6, t.s. 40. • W – *Eoparastaffella* sp., Ladyside Wood, Wo22, t.s. 6. • X – *Elevenella parvula* (Bozorgnia), Three Cliffs Bay, TB1, t.s 1. • Y – *Biseriella bristolensis* (Reichel), Three Cliffs Bay, TB1, t.s. 4. • Z – *Biseriella bristolensis* (Reichel), Three Cliffs Bay, TB1, t.s. 2. • AA – *Lysella gadukensis* Bozorgnia, Three Cliffs Bay, TB20, t.s. 9. • AB – *Eoparastaffella* ex gr. *florigena* (Pronina), Three Cliffs Bay, TB6, t.s. 21. Enlargement: A–K, N, P–X, AA–AB 75×, L–M, O, Y–Z 100×.

Figure 20. Typical foraminifers from Three Cliffs Bay in the South Wales-Mendip Shelf. • A – *Eoparastaffella* ex gr. *florigena* (Pronina), Three Cliffs Bay, TB10, t.s. 5. • B – *Eoparastaffella* ex gr. *florigena* (Pronina), Three Cliffs Bay, TB10, t.s. 5. • C – *Eoparastaffella* ex gr. *interiecta* Vdovenko, Three Cliffs Bay, TB6, t.s. 30. • D – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda transitional form to *Eoparastaffella macdermoti* Devuyst & Kalvoda, Three Cliffs Bay, TB6, t.s. 4. • E – *Eoparastaffella ovalis* Vdovenko, M1, Three Cliffs Bay, TB6, t.s. 1. • F – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Three Cliffs Bay, TB6, t.s. 24. • G – *Eoparastaffella ovalis* Vdovenko, M2, Three Cliffs Bay 10, t.s. 3. • H – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Three Cliffs Bay, TB10, t.s. 16. • I – *Eoparastaffella ovalis* Vdovenko, M1, Three Cliffs Bay, TB10, t.s. 5. • J – *Eoparastaffella ovalis* Vdovenko, M1, Three Cliffs Bay, TB6, t.s. 13. • K – *Eoparastaffella simplex* Vdovenko, Three Cliffs Bay, TB20, t.s. 14. • L – *Eoparastaffella asymmetrica* Vdovenko, Three Cliffs Bay, TB20, t.s. 6. • M – *Eoparastaffella ovalis* Vdovenko, M1, Three Cliffs Bay, TB7, t.s. 6. • N – *Eoparastaffella* sp., Three Cliffs Bay, TB20, t.s. 1. • O – *Eoparastaffella simplex* Vdovenko, Three Cliffs Bay, TB21, t.s. 6. • P – *Eoparastaffella ovalis* Vdovenko, M1, Three Cliffs Bay, TB10, t.s. 13. • Q – *Eoparastaffella* cf. *macdermoti* Devuyst & Kalvoda, Three Cliffs Bay, TB10, t.s. 5. • R – *Eoparastaffella* sp., Three Cliffs Bay, TB10, t.s. 6. • S – *Eoparastaffella ovalis* Vdovenko, M2, Three Cliffs Bay, TB10, t.s. 7. • T – *Eoparastaffella simplex* Vdovenko, Three Cliffs Bay, TB21, t.s. 5. Enlargement: A, B–D, F, H, J–K, M–O, R–T 75×; B, E, G, I, L, P–Q 100×.

Figure 21. Typical foraminifers from Ossom's Hill in the North Staffordshire Basin. • A – *Plectogyranopsis regularis* (Rauser-Chernousova), Ossom's Hill, OH7, t.s. 20. • B – *Plectogyranopsis regularis* (Rauser-Chernousova), Ossom's Hill, OH7, t.s. 11. • C – *Eblanaia michoti* (Conil & Lys), Ossom's Hill, OH7, t.s. 1. • D – *Spinochernella brencklei* Conil & Lys, Ossom's Hill, OH7, t.s. 10. • E – *Spinobrunsiina* cf. *implicata* (Conil & Lys), Ossom's Hill, OH7, t.s. 18. • F – *Spinochernella spinosa* (Chernysheva), Ossom's Hill, OH5, t.s. 1. • G – *Spinobrunsiina lexhyi* Conil & Hance, Ossom's Hill, OH8, t.s. 3. • H – *Spinobrunsiina lexhyi* Conil & Hance, Ossom's Hill, OH7, t.s. 9. • I – *Ammarchaediscus* sp., Ossom's Hill, OH25, t.s. 2. • J – *Bessiella* cf. *leusoniae* Conil, Ossom's Hill, OH6, t.s. 1. • K – *Bessiella legrandi* (Conil & Hance), Ossom's Hill, OH8, t.s. 12. • L – *Omphalotis* ex gr. *chariessa* (Conil & Lys), Ossom's Hill, OH7, t.s. 18. • M – *Eosinopsis primaeva* Vachard & Hance, Ossom's Hill, OH7, t.s. 2. Enlargement: 75×, M 50×.

Figure 22. Typical foraminifers from Ossom's Hill in the North Staffordshire Basin. • A – *Bessiella rectiformis* (Bogush & Yuferev), Ossom's Hill, OH5, t.s. 12. • B – *Bessiella rectiformis* (Bogush & Yuferev), Ossom's Hill, OH9, t.s. 6. • C – *Bessiella rectiformis* (Bogush & Yuferev), Ossom's Hill, OH9, t.s. 2. • D – *Paralysella* sp., Ossom's Hill, OH7, t.s. 8. • E – *Lysella gadukensis* Bozorgnia, Ossom's Hill, OH7, t.s. 17. • F – *Lysella gadukensis* Bozorgnia, Ossom's Hill, OH7, t.s. 3. • G – *Paralysella* sp., Ossom's Hill, OH 6, t.s. 5. • H – *Bessiella legrandi* Conil & Hance, Ossom's Hill, OH8, t.s. 12. • I – *Lysella gadukensis* Bozorgnia, Ossom's Hill, OH7, t.s. 4. J– *Paralysella* sp., Ossom's Hill, OH9, t.s. 5. • K – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH7, t.s. 19. • L – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH5, t.s. 1. • M – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH5, t.s. 6. • N – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH6, t.s. 6. • O – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH5, t.s. 5. • P – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH5, t.s. 4. • Q – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH6, t.s. 8. • R – *Eoparastaffella* sp., Ossom's Hill, OH7, t.s. 9. • S – *Eoparastaffella* ex gr. *interiecta* Vdovenko, Ossom's Hill, OH6, t.s. 7.

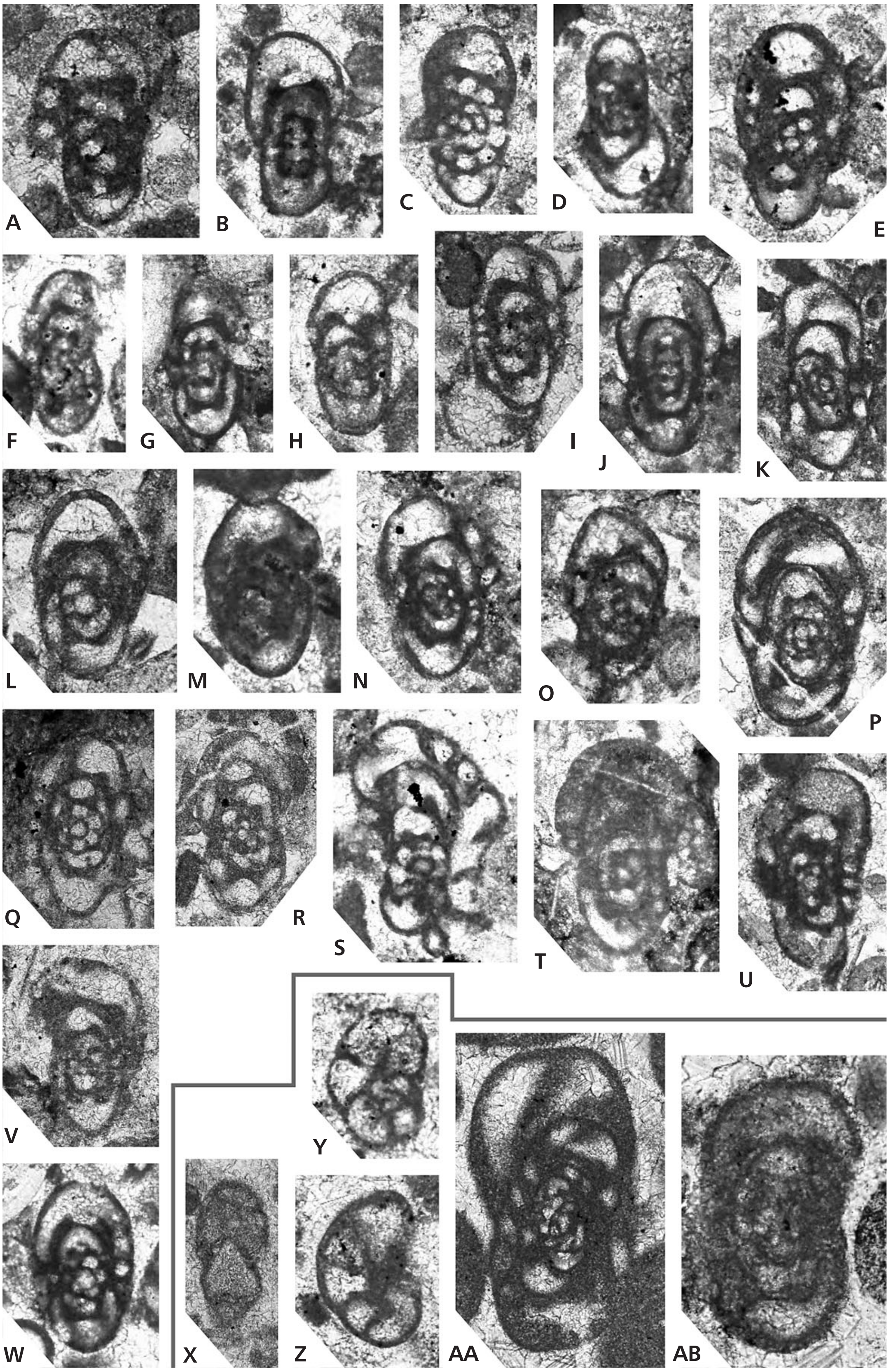

Figure 19. Typical foraminifers from Ladyside Wood in the North Staffordshire Basin (A–W), and Three Cliffs Bay in the South Wales-Mendip Shelf (Y–AB). For explanation see page 522.

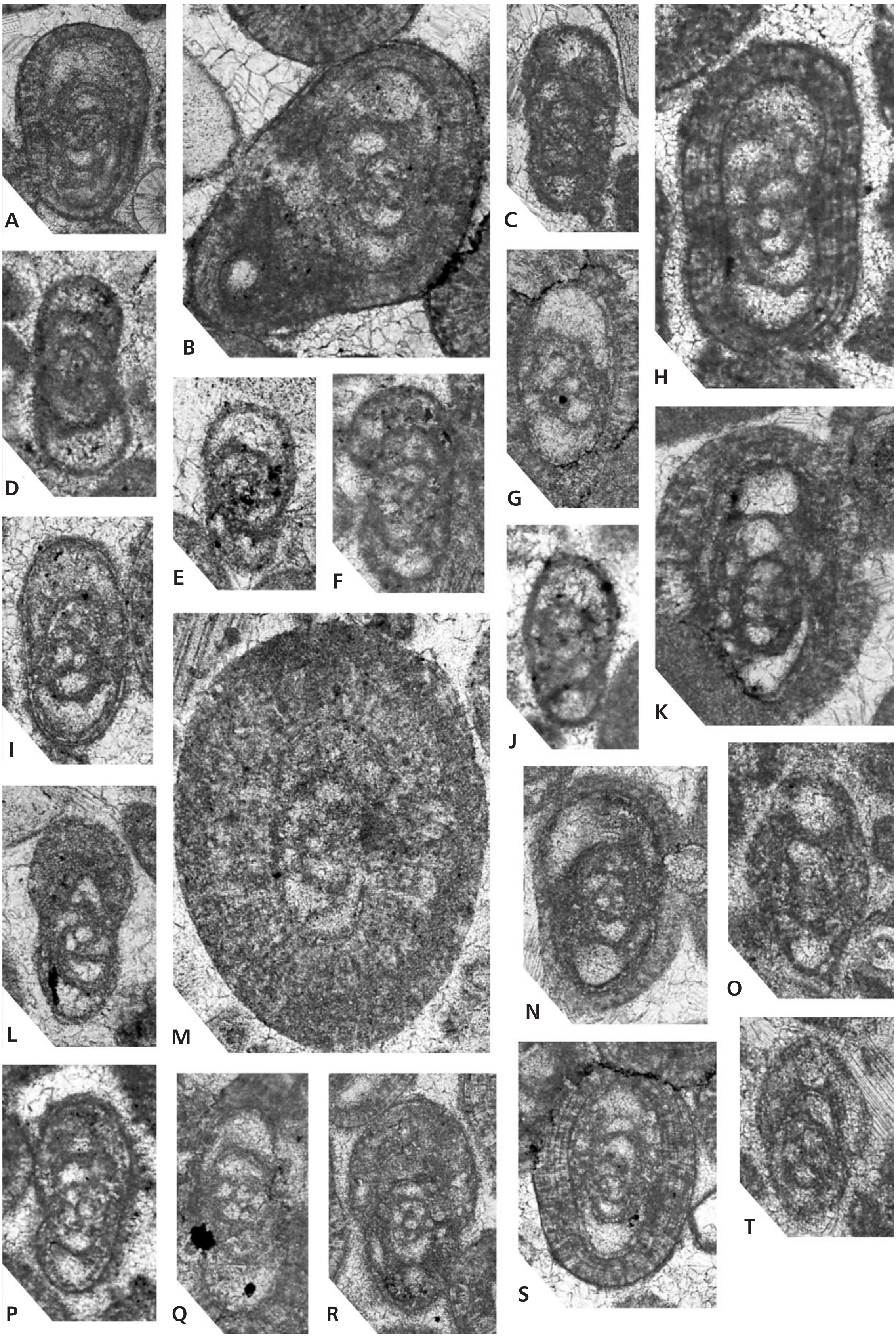

Figure 20. Typical foraminifers from Three Cliffs Bay in the South Wales-Mendip Shelf. For explanation see page 522.

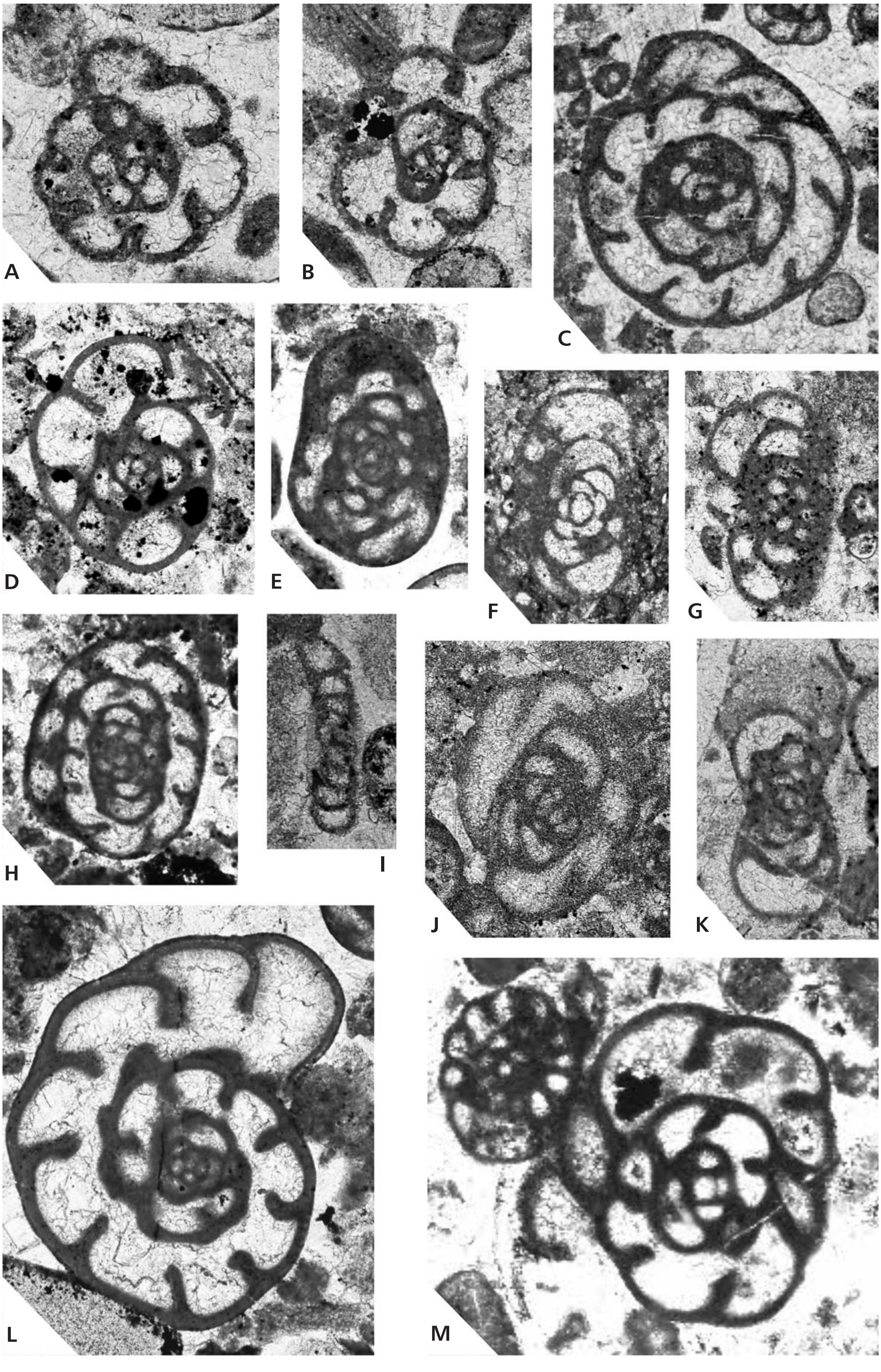

Figure 21. Typical foraminifers from Ossom's Hill in the North Staffordshire Basin. For explanation see page 522.

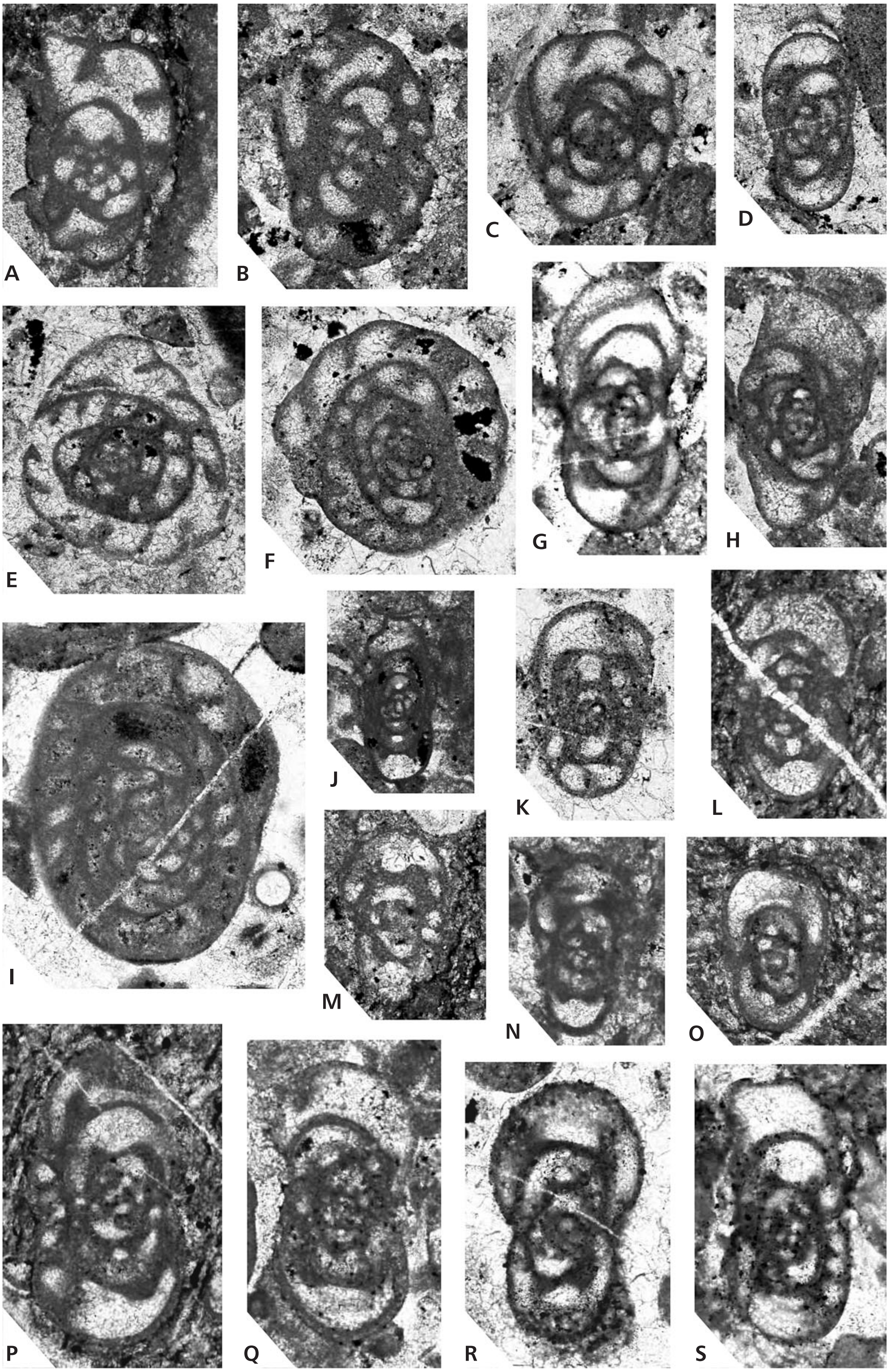

Figure 22. Typical foraminifers from Ossom's Hill in the North Staffordshire Basin. For explanation see page 522.

Eoparastaffella, namely *E.* ex gr. *florigena*, *E. macdermoti* Devuyst & Kalvoda, *E. vdovenkoae* Devuyst & Kalvoda and *E. ovalis* M3 which indicate the uppermost part of MFZ8. In contrast to the North Staffordshire Basin localities, members of the *E. ovalis* group dominate at Three Cliffs Bay. In the upper part of the Gully Oolite a Viséan MFZ9 age is indicated by the presence of *E. ovalis* M2, *E. asymmetrica* M1, *E. tummida* (sample TB10). As in sections in the North Staffordshire Basin, *Spinobrunsiina* is abundant but *E. simplex* is quite rare. *Eoparastaffella* is however the dominant foraminifer here and forms the cores of most ooids.

The Caswell Bay Mudstone contains only poorly preserved foraminifers such that the distinction between MFZ9 and MFZ10 is not possible. The base of the High Tor Limestone is characterised by a widespread occurrence of *E. simplex* and the advanced forms *Eoparastaffella pseudochomata* and *E. asymmetrica* M2 (Devuyst 2006). The very rare presence of archaediscids represented by *Uralodiscus* and *Glomodiscus* indicates a higher part of MFZ10 or even a lower MFZ11.

Ogmore (Vale of Glamorgan)

As the Arundian age of the Caswell Bay Mudstone was only supposed (Waters *et al.* 2009) and it was not possible to determine it in Three Cliffs Bay, the locality was chosen in addition. The Viséan age of the upper part of the Gully Oolite is indicated by presence of MFZ9 guide *E. simplex* and *E. asymmetrica* (Fig. 8). The sample Go3 about 7 m above the base of the Caswell Bay Mudstone contained relatively rich foraminiferal association with important Arundian guides *Viseidiscus* sp., *Glomodiscus* sp. and *Glomodiscus* cf. *biarmicus* Malakhova indicating already higher part of MFZ10 (Fig. 8).

Discussion

Brown End Quarry and Ladyside Wood both provide important British sections across the T-V boundary, but the better section is arguably that at Brown End Quarry because it displays the evolutionary lineages of *Eoparastaffella* from the latest Tournaisian to the early Viséan and it has good conodont record (Chisholm *et al.* 1988). The section therefore appears to be much better for the definition of the base of the Chadian than the stratotype in Chatburn Bypass (George *et al.* 1976).

By way of contrast however, the Ladyside Wood section is a better section for understanding problems of the Chadian biostratigraphy. Here the absence of *Eoparastaffella* in the latest Tournaisian is followed by the entry of advanced basal Viséan *Eoparastaffella* species such as *E. tummida*, *E. asymmetrica* and *E. ovalis* M2. In order to locate the T-V boundary accurately in these sections it is important to consider the microfacies. In the North Staffordshire Basin and the Dublin Basin (Kalvoda *et al.* 2011) *Eoparastaffella* is absent or very rare in the heterozoan dominated associations. However, in the absence of *Eoparastaffella* other taxa can prove useful to approximate the boundary. The FAD of *Mediocris* which is coincident with the base of MFZ8 may provide an alternative guide (Devuyst & Hance *in* Poty *et al.* 2006) even though in the sections studied here it occurs at a much higher stratigraphic level (Figs 4, 5). Another possibility is the entry of *Plectogyranopsis regularis* reported only from the latest Tournaisian and Viséan in the Urals (Postoyalko 1975, Simonova 1975) and from the Viséan of the Pengchong GSSP (Hance *et al.* 2011). Interestingly, in the Craven Basin, both *Plectogyranopsis regularis* and *Mediocris* have been reported in the Chadian stratotype at Chatburn (Riley 1995). Given the broadly similar deep ramp settings of the Craven and North Staffordshire basins, this raises the possibility that even though *Eoparastaffella* is absent at Chatburn, as at Ladyside Wood, limestones of MFZ8, that is of Chadian age, may be present at Chatburn. In this context it is important to note that the entry of richer foraminiferal associations above the Waulsortian and peri-Waulsortian facies in the British Isles is strongly facies controlled and that only the late Chadian has a distinctive biostratigraphic signature (Riley 1990, 1993, 1995). In order to resolve such stratigraphic difficulties the best solution would be to equate the base of the Chadian with the base of the Viséan (Somerville 2008). However, given that *E. simplex* is quite rare in the Chadian of the British Isles other important Viséan guides such as *E. ovalis* M2, *E. asymmetrica* and *E. tummida* are required in defining the position of this important boundary.

Our study of *Eoparastaffella* evolution in the early Viséan MFZ9 of England and Wales has shown that higher parts of the zone are characterized by the entry of more advanced species such as *Eoparastaffella restricta*, *E. laciniosa*, *E. pseudochomata* and *E. evoluta*. This is in accord with the data from Ireland (Kalvoda *et al.* 2011), the Urals and the Donetz Basin (Postoyalko 1975, Stepanova *et al.* 2008, Brazhnikova & Vdovenko 1973). In addition, forms with a wall transitional between *Eoparastaffella* and *Eostaffella* occur, as they do in Belgium and at the Pengchong stratotype (Conil & Naum 1977, Devuyst 2006, Hance 1997, Hance *et al.* 2011). Candidates for the distinction of this higher part of MFZ9 are *Eoparastaffella nalivkini* (Malakhova) (Ivanova 2008, Malakhova 1975, Simonova 1975) and *Plectogyranopsis convexus.* Also promising are species of *Paralysella* despite some taxonomic difficulties (Hance *et al.* 2011), but the stratigraphic potential and precise level of the FADs of these species have still to be tested.

In the North Staffordshire Basin the boundary between the Milldale Limestone and the overlying Hopedale

Limestone or Ecton Limestone lies within the upper part of MFZ9, thus within the Chadian. However, the entry of the first archaediscids is not a very reliable criterion for the detection of the Arundian. The discontinuous and very rare presence of the first archaediscids documented in the Dublin Basin (Kalvoda *et al.* 2011) indicates that their occurrence is facies controlled (Gallagher 1998). Such difficulties are, however, not exceptional as similar problems are encountered in Belgium (Hance *et al.* 1981, Hance 1988) and at the Pengchong stratotype (Devuyst 2006). Consequently, the definition of the base of the Arundian by the FADs of *Planoarchaediscus* or *Ammarchaediscus* should be supplemented by other non archaediscid taxa to minimize the effects of facies control (Simpson & Kalvoda 1987) and calibrated by geophysical (gamma ray spectrometry) and geochemical means (isotopes of O, C and Sr).

In South Wales the T-V boundary is closely followed by a distinctive mid-Avonian unconformity and thicknesses of limestones corresponding to MFZ9 and 10 are rather reduced. The shoreface Gully Oolite, however, yielded quite numerous *Eoparastaffella* associations showing the lineage from *Eoparastaffella ovalis* to *Eoparastaffella simplex* crucial for the T-V boundary definition (Fig. 7). For the first time the Arundian age (MFZ10) of the overlying Caswell Bay Mudstone can be confirmed by foraminifers.

The biostratigraphic analyses of the Tournaisian to early Viséan carbonate ramp and basin successions of the South Wales-Mendip Shelf (SWMS) and the North Staffordshire Basin (NSB) were also correlated independently using gamma ray spectrometry (GRS) and magnetic susceptibility (MS). The sedimentary facies and petrophysical log patterns show a robust ramp-to-basin correlation and a

Figure 23. Typical foraminifers from Ossom's Hill in the North Staffordshire Basin. • A – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH7, t.s. 22. • B – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH12, t.s. 2. • C – *Eoparastaffella* sp., Ossom's Hill, OH14, t.s. 3. • D – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH12, t.s. 3. • E – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH7, t.s. 19. • F – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH14, t.s. 7. • G – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH14, t.s. 7. • H – *Eoparastaffella* aff. *laciniosa* Postoyalko, Ossom's Hill, OH12, t.s. 1. • I – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH14, t.s. 4. • J – *Eoparastaffella* sp., Ossom's Hill, OH12, t.s. 2. • K – *Eoparastaffella* sp., Ossom's Hill, OH14, t.s. 1. • L – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Ossom's Hill, OH7, t.s. 25. • M – *Eoparastaffella* sp., Ossom's Hill, OH14, t.s. 6. • N – *Eoparastaffella restricta* Postoyalko, Ossom's Hill, OH14, t.s. 5. • O – *Eoparastaffella* sp., Ossom's Hill, OH9, t.s. 1. • P – *Eoparastaffella ovalis* Vdovenko, M3, Ossom's Hill, OH7, t.s. 5. • Q – *Eoparastaffella* sp., Ossom's Hill, OH12, t.s. 3. • R – *Eoparastaffella ovalis* Vdovenko, M2, Ossom's Hill, OH5, t.s. 12. • S – *Eoparastaffella ovalis* Vdovenko, M2, Ossom's Hill, OH6, t.s. 4. • T – *Eoparastaffella* sp., Ossom's Hill, OH14, t.s. 4. • U – *Eoparastaffella ovalis* Vdovenko, M2, Ossom's Hill, OH6, t.s. 5. • V – *Eoparastaffella ovalis* Vdovenko, M2, Ossom's Hill, OH9, t.s. 6. • W – *Eoparastaffella pseudochomata* Vdovenko, Ossom's Hill, OH12, t.s. 3. • X – *Eoparastaffella asymmetrica* Vdovenko, Ossom's Hill, OH6, t.s. 3. Enlargement: 75×.

Figure 24. Typical foraminifers from Ossom's Hill (A–P) and Brown End (Q–W) in the North Staffordshire Basin. • A – *Eoparastaffella asymmetrica* Vdovenko, Ossom's Hill, OH9, t.s. 4. • B – *Eoparastaffella asymmetrica* Vdovenko, Ossom's Hill, OH14, t.s. 1. • C – *Eoparastaffella* sp., Ossom's Hill, OH12, t.s. 7. • D – *Eoparastaffella pseudochomata* Vdovenko, Ossom's Hill, OH12, t.s. 1. • E – *Eoparastaffella* sp., Ossom's Hill, OH12, t.s. 5. • F – *Eoparastaffella asymmetrica* Vdovenko, Ossom's Hill, OH9, t.s. 1. • G – *Eoparastaffella iniqua* Postoyalko, Ossom's Hill, OH9, t.s. 1. • H – *Eoparastaffella evoluta* Vdovenko, Ossom's Hill, OH12, t.s. 2. • I – *Eoparastaffella* sp., Ossom's Hill, OH9, t.s. 6. • J – *Eoparastaffella* cf. *nalivkini* (Malakhova), Ossom's Hill, OH12, t.s. 2. • K – *Eoparastaffella* ex gr. *florigena* (Pronina), Ossom's Hill, OH12, t.s. 1. • L – *Eoparastaffella* sp., Ossom's Hill, OH14, t.s. 3. • M – *Eoparastaffella simplex* Vdovenko, Ossom's Hill, OH9, t.s. 4. • N – *Eoparastaffella* sp., Ossom's Hill, OH14, t.s. 2. • O – *Eoparastaffella* ex gr. *simplex* Vdovenko Ossom's Hill, OH9, t.s. 1. • P – *Eoparastaffella* cf. *nalivkini* (Malakhova), Ossom's Hill, OH14, t.s. 4. • Q – *Plectogyranopsis regularis* (Rauser-Chernousova), Brown End, B1, t.s. 4. • R – *Plectogyranopsis regularis* (Rauser-Chernousova), Brown End, B16, t.s. 3. • S – *Plectogyranopsis regularis* (Rauser-Chernousova), Brown End, B45, t.s. 6. • T – *Plectogyranopsis regularis* (Rauser-Chernousova), Brown End, B4, t.s. 2. • U – *Plectogyranopsis regularis* (Rauser-Chernousova), Brown End, B42, t.s. 6. • V – *Plectogyranopsis regularis* (Rauser-Chernousova), Brown End, B58, t.s. 2. • W – *Endospiroplectammina venusta* (Vdovenko), Brown End, B42, t.s. 6. Enlargement: 75×, T 100×.

Figure 25. Typical foraminifers from Brown End in the North Staffordshire Basin. • A – *Spinochernella brencklei* Conil & Lys, Brown End, B44, t.s. 4. • B – *Spinochernella brencklei* Conil & Lys, Brown End, B58, t.s. 3. • C – *Conilites dinantii* (Conil & Lys), Brown End, B43, t.s. 4. • D – *Florennella amplissima* Conil, Brown End, P13, t.s. 8. • E – *Elevenella parvula* (Bozorgnia), Brown End, P7, t.s. 1. • F – *Paradainella* sp., Brown End, P13, t.s. 3. • G – *Spinobrunsiina lexhyi* Conil & Hance, Brown End, B42, t.s. 3. • H – *Bessiella* sp., Brown End, B58, t.s. 3. • I – *Spinobrunsiina vachardi* Conil, Brown End, B4, t.s. 5. • J – *Spinobrunsiina lexhyi* Conil & Hance, Brown End, B27, t.s. 2. • K – *Bessiella legrandi* Conil & Hance, Brown End, P13, t.s. 9. • L – *Florennella stricta* (Conil & Lys), Brown End, P13, t.s. 1. • M – *Bessiella legrandi* Conil & Hance, Brown End, P13, t.s. 1. • N – *Bessiella limburgensis* Conil & Vieselet, Brown End, B11, t.s. 5. • O – *Lysella gadukensis* Bozorgnia, Brown End, B4, t.s. 1. • P – *Lysella gadukensis* Bozorgnia, Brown End, B45, t.s. 1. • Q – *Paradainella dainelliformis* Brazhnikova & Vdovenko, Brown End, B43, t.s. 3. • R – *Bessiella limburgensis* Conil & Vieselet, Brown End, B4, t.s. 3. Enlargement: 75×, C 50×.

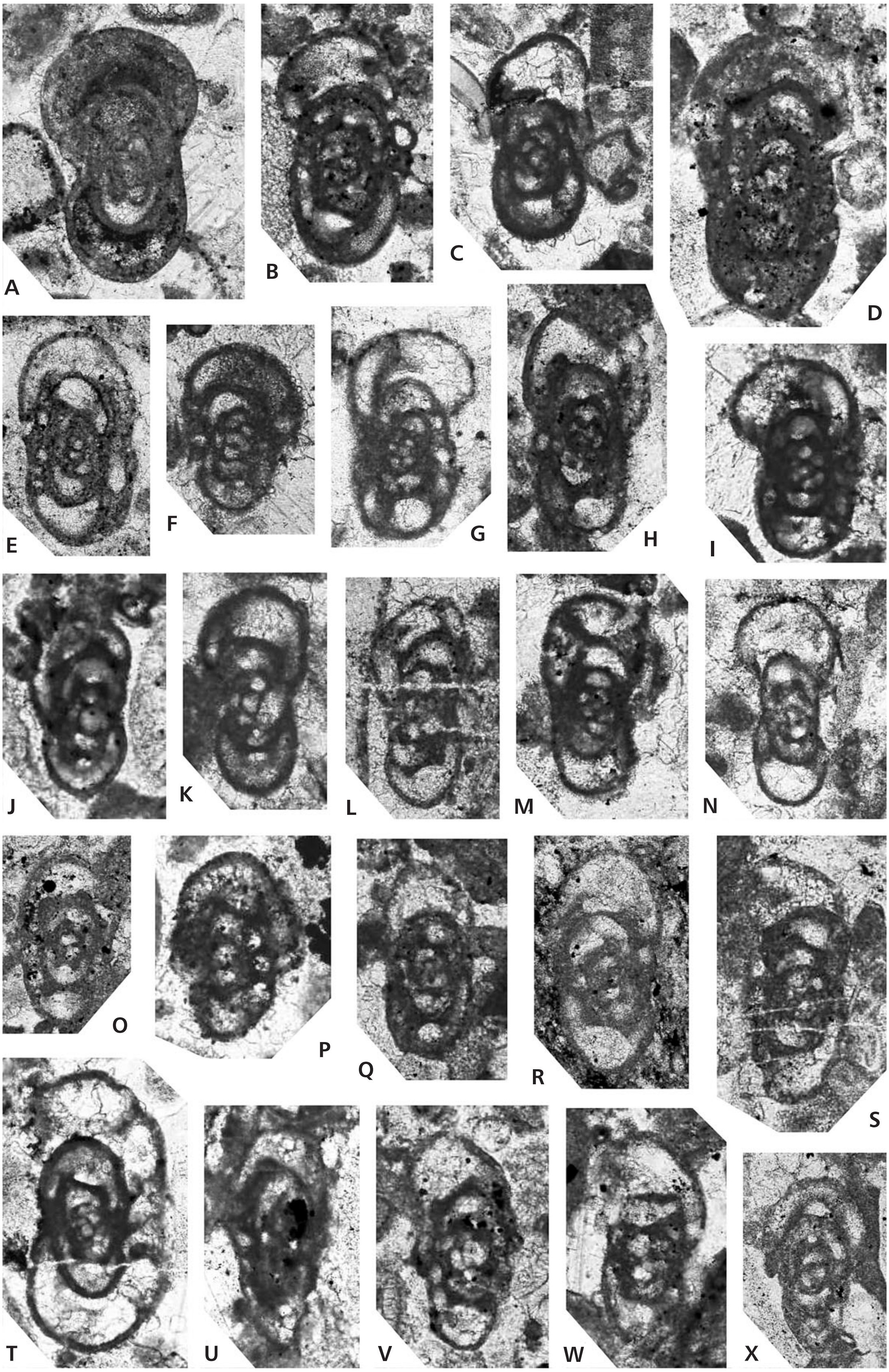

Figure 23. Typical foraminifers from Ossom's Hill in the North Staffordshire Basin.For explanation see page 528.

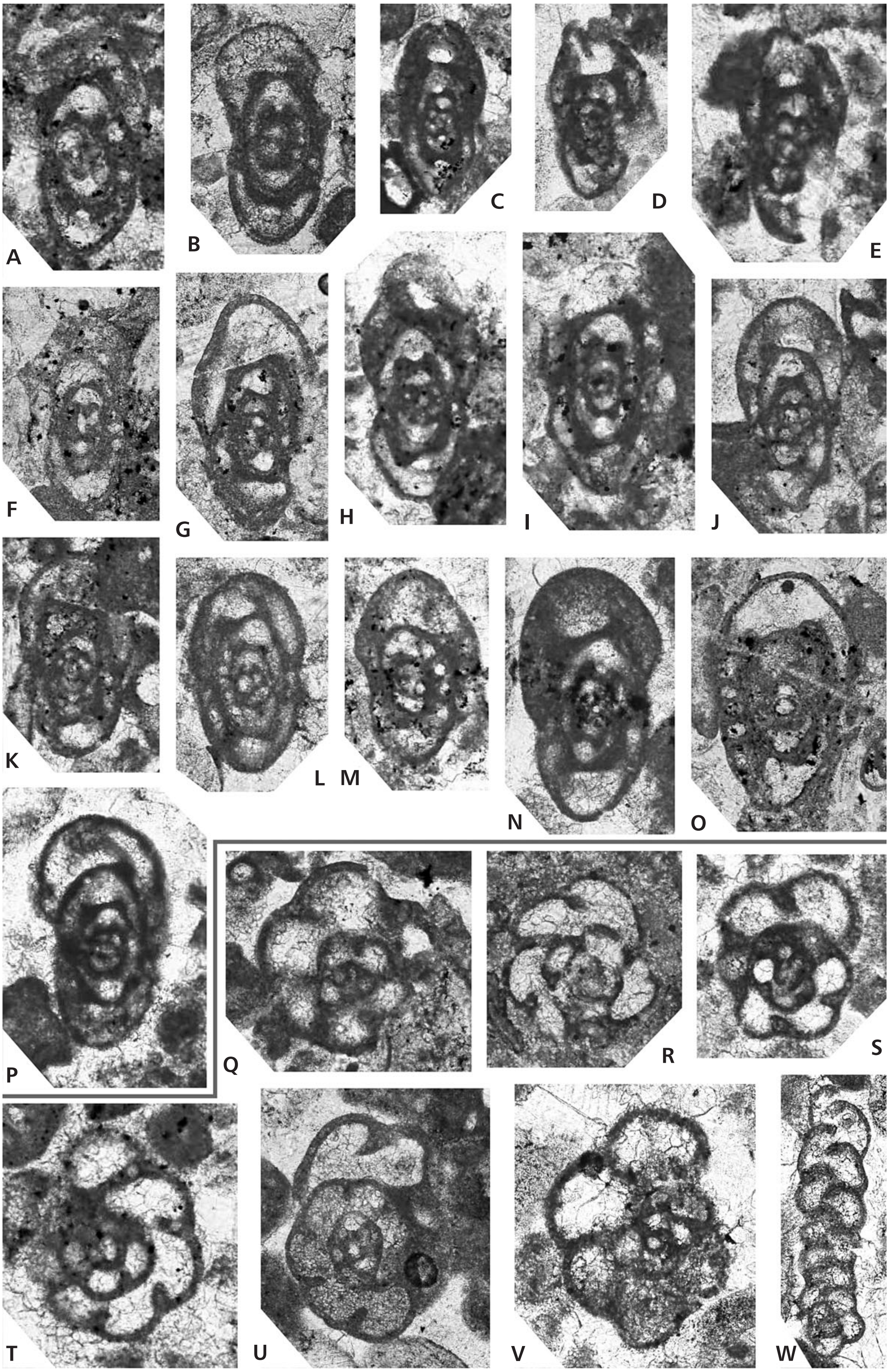

Figure 24. Typical foraminifers from Ossom's Hill (A–P) and Brown End (Q–W) in the North Staffordshire Basin. For explanation see page 528.

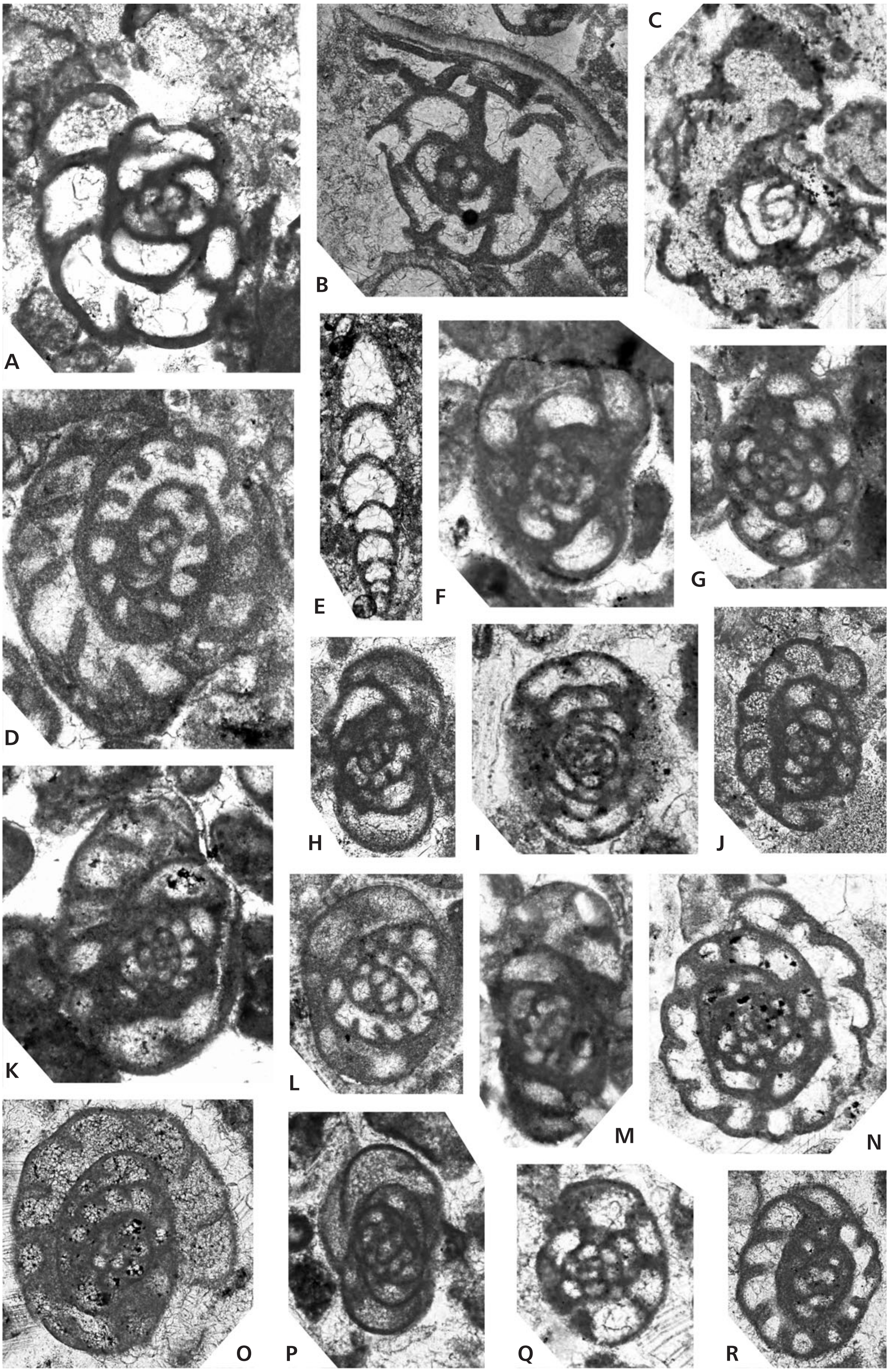

Figure 25. Typical foraminifers from Brown End in the North Staffordshire Basin. For explanation see page 528.

distinct, late Tournaisian to early Viséan regressive-to-transgressive cycle with a prominent sequence boundary located close to the T-V stage boundary (Hance *et al.* 2002) in both the NSB and SWMS sections (Fig. 9). A turnover to decreasing CGR (clay gamma ray) values calculated from the concentrations of K and Th (see Rider 1999) in the upper part of MFZ 9 in the NSB, which roughly coincides with the base of the Ecton Limestone and the Hopedale Limestone, represents another sequence boundary capping the lower Viséan depositional sequence. This correlates with the gap associated with the mid-Avonian sequence boundary between the Chadian Gully Oolite and Arundian Caswell Bay Mudstone in the Three Cliffs Bay and Ogmore section (SWMS).

The sea-level changes close to the T-V boundary are possibly of glacio-eustatic origin (Kalvoda 1986, 1989, 2002; Ross & Ross 1987). The conodont apatite δ^{18}O values suggest that a potential glaciation persisted from the Tournaisian to the Viséan with a distinct cooling at the T-V boundary (Buggish *et al.* 2008) which is in accord with a major positive δ^{13}C shift recognized in the T-V boundary stratotype area in South China (Qie *et al.* 2011).

The foraminiferal associations from the Milldale Limestone in the North Staffordshire Basin occur within proximal and distal carbonate turbidites. A lower degree of transportation is expected in the Friars Point Limestone in Three Cliffs Bay (Ramsay 1987, Wright 1986) but the upper dolomitized part yielded only few foraminifers. Foraminifers are however relatively abundant in the inner ramp Gully Oolite where they form the cores of most ooids.

Even though most of the foraminiferal associations in the NSB are a product of different environments their ecology represents an important issue. Heterozoan dominated facies in the latest Tournaisian limestones may indicate either the supply from the middle part of the ramp or from shallow water parts of the inner ramp influenced by higher nutrient levels (Carannante *et al.* 1988, Schlager 2003,

Figure 26. Typical foraminifers from Brown End in the North Staffordshire Basin. • A – *Lysella gadukensis* Bozorgnia, Brown End, B53, t.s. 4. • B – *Lysella gadukensis* Bozorgnia, Brown End, B43, t.s. 3. • C – *Lysella gadukensis* Bozorgnia, Brown End, B7, t.s. 17. • D – *Lysella gadukensis* Bozorgnia, Brown End, B53, t.s. 5. • E – *Lysella gadukensis* Bozorgnia, Brown End, B7, t.s. 3. • F – *Lysella gadukensis* Bozorgnia, Brown End, B43, t.s. 1. • G – *Lysella gadukensis* Bozorgnia, Brown End, B12, t.s. 2. • H – *Paralysella* sp., Brown End, P13, t.s. 5. • I – *Lysella gadukensis* Bozorgnia, Brown End, B53, t.s. 4. • J – *Lysella gadukensis* Bozorgnia, Brown End, B4, t.s. 2. • K – *Darjella monilis* Malakhova, Brown End, B36, t.s. 1. • L – *Eoparastaffella interiecta* Vdovenko, Brown End, B53, t.s. 5. • M – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Brown End, B7, t.s. 1. • N – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Brown End, B11, t.s. 1. • O – *Eoparastaffella macdermoti* Devuyst & Kalvoda transitional to *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Brown End, B4, t.s. 1. • P – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Brown End, B53, t.s. 5. • Q – *Eoparastaffella* ex gr. *interiecta* Vdovenko, Brown End, B5, t.s. 6. • R – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Brown End, B5, t.s. 2. • S – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Brown End, B5, t.s. 1. • T – *Eoparastaffella* ex gr. *florigena* (Pronina), Brown End, B45, t.s. 5. • U – *Eoparastaffella* sp., Brown End, P13, t.s. 15. Enlargement: 75×.

Figure 27. Typical foraminifers from Brown End in the Staffordshire Basin. • A – *Lysella gadukensis* Bozorgnia, Brown End, B7, t.s. 10. • B – *Paralysella* sp., Brown End, B53, t.s. 4. • C – *Eoparastaffella* ex gr. *florigena* (Pronina), Brown End, B1, t.s. 3. • D – *Eosinopsis solida* Vachard & Hance, Brown End, P13, t.s. 2. • E – *Paralysella* sp., Brown End, B27, t.s. 2. • F – *Paralysella*, Brown End, P13, t.s. 8. • G – *Eosinopsis primaeva* Vachard & Hance, Brown End, B36, t.s. 1. • H – *Eosinopsis primaeva* Vachard & Hance, Brown End, P13, t.s. 6. • I – *Eoparastaffella* ex gr. *florigena* (Pronina), Brown End, B7, t.s. 19. • J – *Eoparastaffella* sp., Brown End, B5, t.s. 6. • K – *Lysella gadukensis* Bozorgnia, Brown End, P13, t.s. 4. • L – *Eoparastaffella* ex gr. *florigena* (Pronina), Brown End, B7, t.s. 19. • M – *Eoparastaffella* sp., Brown End, B54, t.s. 6. N – *Lysella gadukensis* Bozorgnia, Brown End, B7, t.s. 10. • O – *Eoparastaffella ovalis* Vdovenko, M1, Brown End, B27, t.s. 1. • P – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Brown End, B27, t.s. 1. • Q – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Brown End, B 20, t.s. 4. • R – *Eoparastaffella macdermoti* Devuyst & Kalvoda, Brown End, B45, t.s. 5. • S – *Eoparastaffella* sp., Brown End, B7, t.s. 19. Enlargement: 75×, M and P 100×.

Figure 28. Typical foraminifers from Brown End in the North Staffordshire Basin. • A – *Eoparastaffella* ex gr. *interiecta* Vdovenko, Brown End, B43, t.s. 4. • B – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda, Brown End, B54, t.s. 6. • C – *Eoparastaffella vdovenkoae* Devuyst & Kalvoda transitional to *Eoparastaffella macdermoti* Devuyst & Kalvoda, Brown End, B27, t.s. 1. • D – *Eoparastaffella ovalis* Vdovenko, M2, Brown End, B58, t.s. 2. • E – *Eoparastaffella ovalis* Vdovenko, M2, Brown End, B6, t.s. 10. • F – *Eoparastaffella* cf. *simplex* Vdovenko, Brown End, B44, t.s. 1. • G – *Eoparastaffella pseudochomata* Vdovenko, Brown End, B1, t.s. 4. • H – *Eoparastaffella* sp., Brown End, B58, t.s. 4. • I – *Eoparastaffella* sp., Brown End, B5, t.s. 2. • J – *Eoparastaffella* cf. *simplex* Vdovenko, Brown End, B58, t.s. 2. • K – *Eoparastaffella* sp., Brown End, B4, t.s. 4. • L – *Eoparastaffella* sp., Brown End, B1, t.s. 1. • M – *Eoparastaffella* sp., Brown End, B1, t.s. 3. • N – *Eoparastaffella* sp., Brown End, B1, t.s. 4. • O – *Eoparastaffella* sp., Brown End, B44, t.s. 4. • P – *Eoparastaffella* sp., Brown End, B58, t.s. 3. • Q – *Eoparastaffella* sp., Brown End, B1, t.s. 4. • R – *Eoparastaffella* sp., Brown End, B1, t.s. 4. • S – *Eoparastaffella* sp., Brown End, B1, t.s. 4. • T – *Eoparastaffella* sp., Brown End, B6, t.s. 17. • U – *Eoparastaffella* sp., Brown End, B58, t.s. 2. • V – *Eoparastaffella* sp., Brown End, B44, t.s. 1. • W – *Eoparastaffella* sp., Brown End, B58, t.s. 4. • X – *Eoparastaffella* sp., Brown End, B7, t.s. 4. • Y – *Eoparastaffella* sp., Brown End, B12, t.s. 3. • Z – *Eoparastaffella* sp., Brown End, B58, t.s. 2. • AA – *Eoparastaffella* ex gr. *florigena* (Pronina), Brown End, B45, t.s. 6. • AB – *Eoparastaffella* sp., Brown End, B1, t.s. 5. Enlargement: 75×, E, G, S, V 100×.

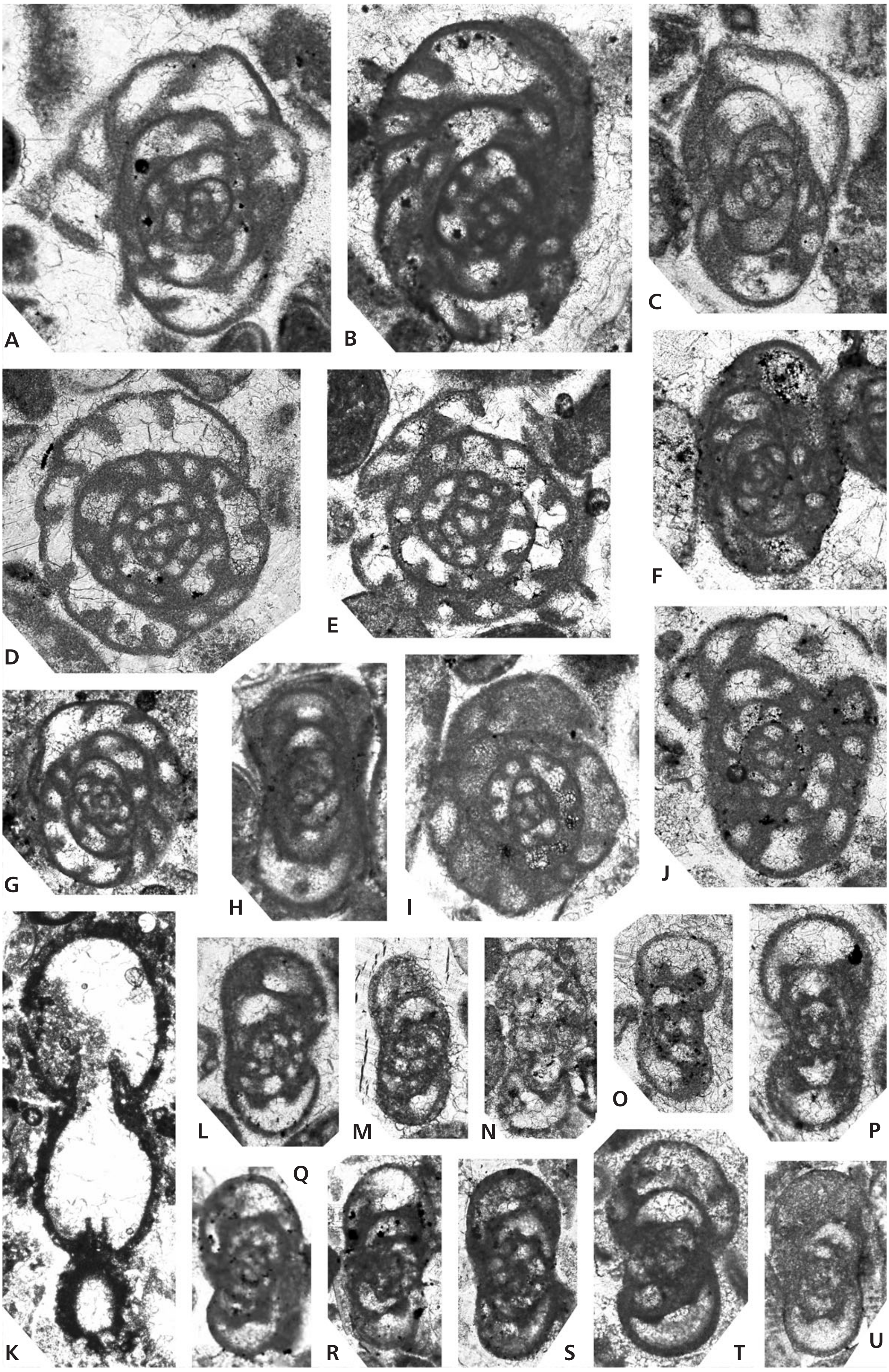

Figure 26. Typical foraminifers from Brown End in the North Staffordshire Basin. For explanation see page 532.

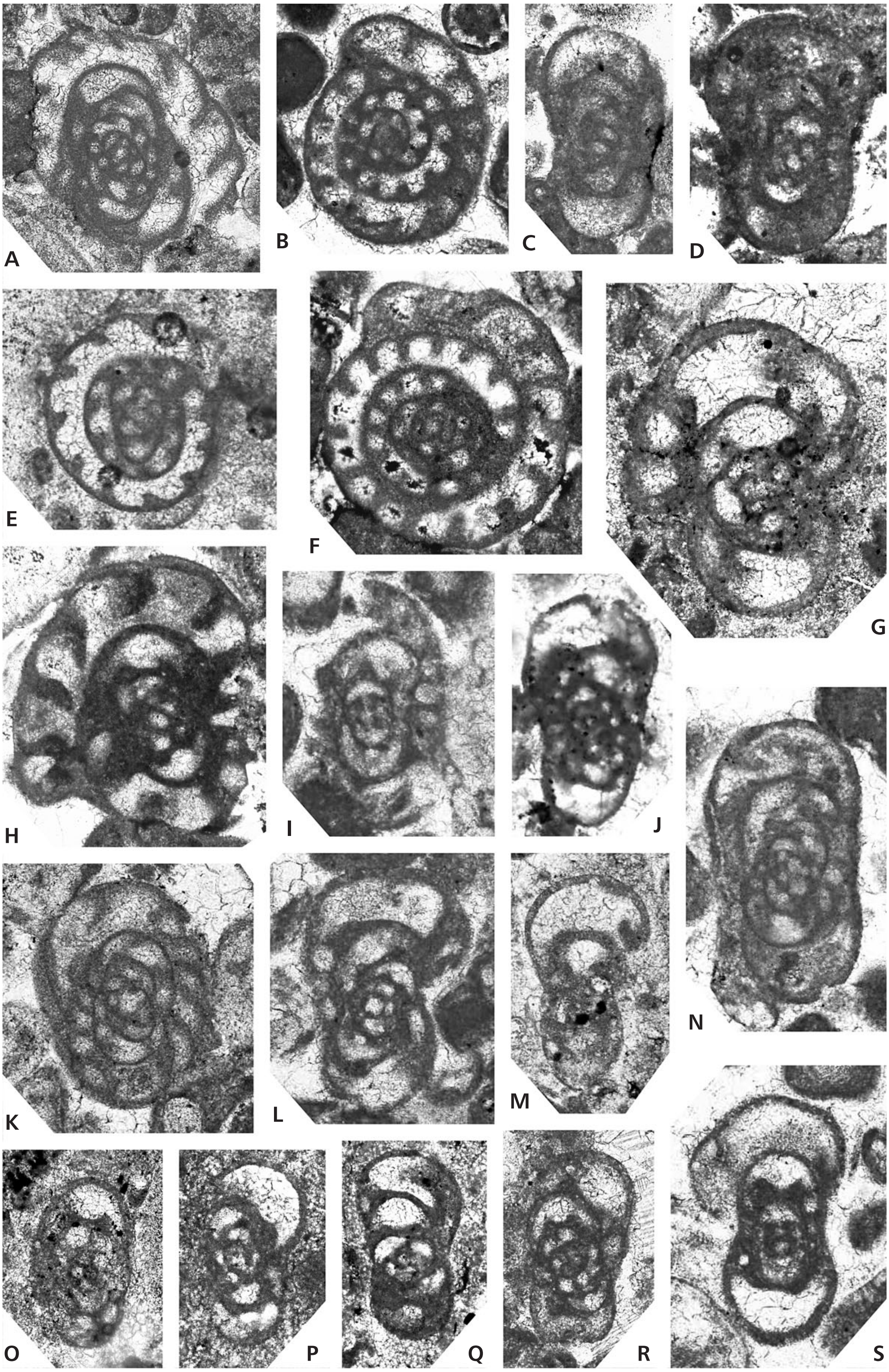

Figure 27. Typical foraminifers from Brown End in the Staffordshire Basin. For explanation see page 532.

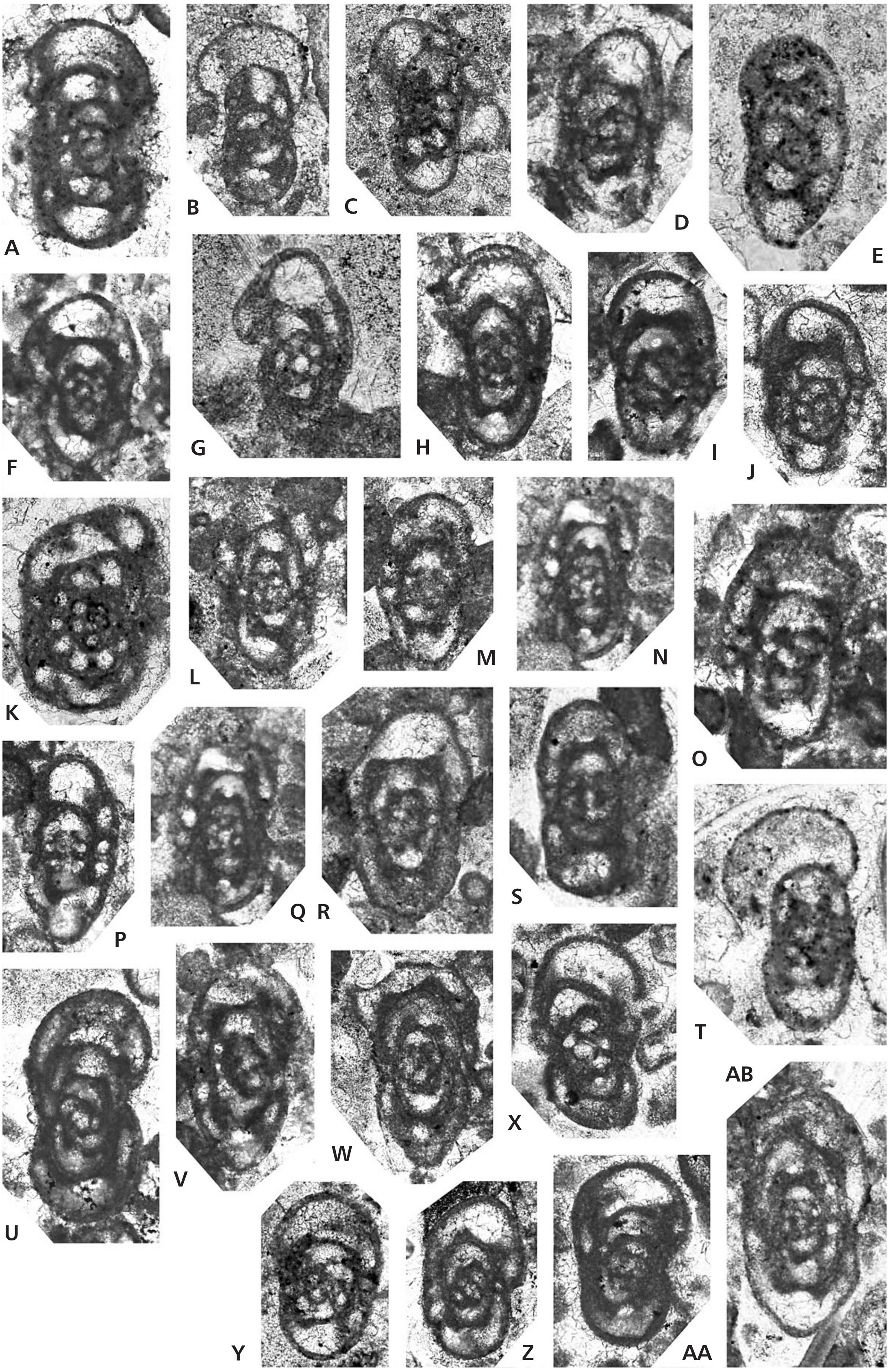

Figure 28. Typical foraminifers from Brown End in the North Staffordshire Basin. For explanation see page 532.

Kabanov 2009, Westphal *et al.* 2010). They contain a distinctive foraminiferal association comprising abundant *Endothyra*, *Bessiella* and the tournayellid genera *Spinobrunsiina*, *Brunsia*, *Eblanaia* and *Spinochernella* but are without stratigraphically important *Eoparastaffella* or *Lysella*. In the British Isles very similar foraminiferal associations were described by Riley (1995) from the Chadian stratotype in the Craven Basin and both foraminiferal associations and the bioclast compositional trends compare well with those described in the Dublin Basin (Kalvoda *et al.* 2011) and in the Oughterard area (Devuyst 2006) of Ireland.

On the contrary, *Eoparastaffella*, totally absent in the Tournaisian component of the Milldale Limestone at Ladyside Wood, is a most common genus in the photozoan inner ramp Gully Oolite. *Endothyra*, *Spinobrunsiina* and *Brunsia* occur both in the photozoan Gully Oolite (SWMS) and in the heterozoan facies of the Milldale Limestone (NSB) which indicates their wider facies range (Gallagher 1998; Hance 1979, 1988; Hance *et al.* 1981; Herbig & Mamet 1994; Mamet & Armstrong 1972; Mamet *et al.* 1993). *Eoparastaffella* evidently inhabited only very shallow water parts of the inner ramp which is in accord with the ecology of descendant Staffelloidea (Vachard *et al.* 2010). This is also evident in Belgium where in basinal settings *Eoparastaffella* occurs in platform derived tempestites (Devuyst 2006, Lees 1997).

It is generally accepted that the most important factors controlling the distribution of benthic foraminiferal assemblages are trophic level and oxygen level (Jorrisen *et al.* 1995, 2007; Van der Zwaan *et al.* 1999) not depth. The occurrence of individual species thus indicate a certain level of organic flux to the sea floor and redox regime rather than a specific water depth (De Rijk *et al.* 2000, Van der Zwaan *et al.* 1999). The presence of heterozoan associations in shallow water Tournaisian limestones in British Isles instead of oligotrophic photozoan ones (Wright & Faulkner 1990) may indicate higher nutrient levels (Carannante *et al.* 1988, Schlager 2003, Westphal *et al.* 2010). This interpretation is corroborated by the presence of foraminiferal genera *Eblanaia* or *Spinochernella* which are widespread in facies with higher nutrient and lower oxygen levels at the T-V boundary in the west and south facing ramps of the North American part of Laurussia (Ahr & Stanton 1994, Armstrong & Mamet 1988, Brandley & Krause 1997, Mamet *et al.* 1986) and in dysoxic facies at the at the middle/upper Tournaisian boundary in Belgium (MFZ4) (Conil *et al.* 1991, Saltzman *et al.* 2004).

In summary, the compositional trends of foraminiferal associations are closely tied to the variations in the composition of skeletal debris. The *Endothyra, Spinobrunsiina, Brunsia, Spinochernella, Bessiella*, *Eblanaia* assemblage is associated with the dominance of heterozoan skeletal debris of the cool water factory (C factory) (Schlager 2005) which follows the mud-mound factory (M factory) of the Waulsortian and dominates in the latest Tournaisian in British Isles (Waters *et al.* 2009, 2011). The increase in photozoan components at the T-V boundary interval is gradual and indicates the gradual transition to the tropical factory (T factory) (Betzler *et al.* 1999, Wright & Burgess 2005). It contributed to the production of skeletal debris of a more diverse composition on carbonate ramps resulting in higher representation of photozoan component and the growing presence of *Eoparastaffella* in calciturbidites. The diachronous transition from the C to T factory connected with the entry of *Eoparastaffella* in the North Staffordshire Basin [occurring later in Ladyside Wood (earliest Viséan) than in the Brown End Quarry (latest Tournaisian)] illustrates the problems of high resolution biostratigraphy at this stratigraphic level very well.

Variations in the composition of the skeletal bioclasts and the foraminiferal associations are thought to have been influenced by 4 factors.

1) Nutrients. According to the nutrient limitation model of Wood (1993) the heterotroph-dominated skeletal composition might be indicative of mesotrophic conditions. It is tempting to imagine a possible link between nutrient excess and the remarkable development of Waulsortian mounds during the late Tournaisian in British Isles (Lees 1982, 1997; Wright & Faulkner 1990) as well as the heterotroph-dominated overlying carbonates.

2) Ramp topography. Tournaisian ramp topography is characterized by low shallow water production and higher production in deeper water (Wright & Faulkner 1990). Where the nutrient flux is higher, however, heterozoan facies can occur also in shallow water environment, which may have also been the case in the British Isles (Wright 1986, Wright & Faulkner 1990). The higher representation of photozoan skeletal debris in Viséan times (Somerville *et al.* 1992, Strogen *et al.* 1996) appears to be connected with the change in ramp architecture (transition from homoclinal to distally steepened ramp) favouring wider extent of shallow water production.

3) Biotic factors. Substantially reduced biological fixation of skeletal carbonates followed the Devonian-Carboniferous extinction (Kalvoda 2002, Wright & Faulkner 1990). The major Carboniferous phototroph constituent, green algae, widepspread in shallow water environments in late Famennian (Berchenko 1981, Bogush *et al.* 1990, Matyja 2009) became quite rare in the Tournaisian regaining wider distribution only at the end of this stage (Devuyst 2006, Kalvoda *et al.* 2011).

4) Eustasy. Sea-level rise after the platform exposure during preceding sea-level fall may reconfigure the carbonate production portfolio owing to the different aggradation potential of the C and T carbonate factories during start-up, catch-up and keep-up phase of platform growth. The compositional data of the Ladyside Wood and

Brown End sections suggest that heterotrophic assemblages (C-factory) shed their skeletal material into the basin continuously, even in the early Viséan start-up phase (*cf.* Schlager 2005, p. 25) above the T-V sequence boundary (Bábek *et al.* 2010). They became replaced by rapidly aggrading photozoan (T-factory) assemblages, dominated by dasyclads, during the following catch-up and keep-up phase.

It is apparent that some factors may have been interconnected and even though the resulting state represents a response to complex interactions, the contribution of single factors was differentiated. Nutrient flux may influence both the production on ramps and the distribution of calcareous green algae and thus appears to be the most important factor. The most common explanation of higher nutrient flux is upwelling (Carannante *et al.* 1988, Schlager 2003, Westphal *et al.* 2010). Although upwelling is not common in intra-cratonic basins it may have been supported by monsoonal system (James *et al.* 2004) assumed over southern western Laurussia during the studied time interval (Wright 1990, Wright & Faulkner 1990). An increased nutrient flux might also have been caused by increased surface runoff connected with increased humidity (Wright 1990) and documented by the widespread distribution of late Tournaisian alluvial sediments in Great Britain at this time (Waters *et al.* 2009). The following decline in nutrient levels may be attributed to smaller river discharge from the diminishing relief of the Southern Uplands and Wales-Brabant High due to marine transgressions (Waters & Davies 2006). An alternative explanation of variations in nutrient levels comes from Algeo & Scheckler (1998) and Algeo *et al.* (2001) who argued that increased nutrient mobilization in the Late Devonian and Carboniferous was related to the evolution of deep-rooting vascular plants. In summary there may have been an interplay between different pathways of nutrient supply but the relative importance of these different pathways and their interactions with documented eustatic oscillations still have to be assessed.

Conclusions

The study of sections in the North Staffordshire Basin and South Wales-Mendip Shelf have so far revealed the richest foraminiferal associations at the T-V boundary in Western Europe. Among the stratigraphically most important *Eoparastaffella* species, the variable *Eoparastaffella florigena* group dominates and the index Viséan species *Eoparastaffella simplex* is quite rare. The FADs of other Viséan guides *Eoparastaffella ovalis* M2, *Eoparastaffella asymmetrica* and *Eoparastaffella tummida* and other bioevents such as the FAD of *Lysella gaukensis* close below the T-V boundary and the LAD of *Eblanaia michoti* close above the T-V boundary all help to define a refined high resolution biostratigraphic profile across the boundary interval and this facilitates a very good correlation with the stratotype area in South China. The study shows that the *Eoparastaffella* occurrences, and especially the evolutionary lineage from *E. ovalis* M2 to *E. simplex,* can be best followed in inner ramp photozoan dominated limestones. Their presence in carbonate turbidites therefore indicates supply from shallow water photozoan dominated areas. In the heterozoan dominated associations *Eoparastaffella* is absent or only very rare and a high representation of Tournayellidae and *Bessiella* is characteristic. The entry of *Eoparastaffella* is thus cryptic and the base of Chadian in the original definition is diachronous. This is well illustrated by the diachronous entry of *Eoparastaffella* at Brown End and Ladyside Wood in the North Staffordshire Basin. The Brown End quarry section with its excellent foraminiferal and good conodont record appears to provide a much better section for the definition of the base of the Chadian than the current stratotype at Chatburn bypass.

In the latest Tournaisian the facies development in British Isles shows some parallels with North America as Waulsortian buildups are followed by heterozoan dominated facies deposited on southward sloping homoclinal ramps of the Laurussian margin (Ahr & Stanton 1994). This facies similarity is accompanied also by some similarity of the foraminiferal associations with abundant *Eblanaia* and *Spinochernella*). The change in the composition of the latest Tournaisian and Viséan foraminiferal associations follows the progressive increase in photozoan constituents typical for the ramp – platform transition. Compositional variations in foraminiferal associations are thus closely tied to facies variations indicating that further work is required on the ecology of these important foraminifer guides. This detailed sedimentological and microfacies study has provided important stratigraphic information by techniques appropriate for investigations of the T-V boundary elsewhere. Its value is, however, limited by the fact that most West European sections and the stratotype of the T-V boundary in South China contain only those foraminiferal bioclasts which have been transported to deeper environments (calciturbidites, tempestites). Moreover, the representation of *Eoparastaffella* ex gr. *florigena* and *Eoparastaffella simplex* in the studied sections shows that ecological distinctions have to be drawn in some cases at the species level.

Notwithstanding the problems discussed above the geophysical manifestation of the important ‘mid Avonian’ sequence boundaries provides a useful means of calibrating the detailed biostratigraphic changes at the T-V boundary. Their widespread recognition in Western Europe (Hance *et al.* 2002) and positive correlation with a $\delta^{13}C$ shift recognized at the T-V boundary in the stratotype area of South China (Qie *et al*. 2011) support glacio-eustatic interpretations of the mid Mississippian sequences.

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