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FORAMINIFERAL BIOSTRATIGRAPHY OF THE VISEAN–SERPUKHOVIAN (MISSISSIPPIAN) BOUNDARY INTERVAL AT SLOPE AND PLATFORM SECTIONS IN SOUTHERN GUIZHOU (SOUTH CHINA)

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ABSTRACT—The Visean–Serpukhovian boundary is not yet defined by a Global Stratotype Section and Point (GSSP) but it is recognizable operationally by the appearance of the conodont *Lochriea ziegleri* in the *L. nodosa*–*L. ziegleri* chronocline. Foraminiferal successions across this boundary in the type area of the Serpukhovian Stage (Moscow Basin, Russia), elsewhere in Russia and in the central United States suggest that the appearances of *Asteroarchaediscus postrugosus*, *Janischewskina delicata*, *Eolasiodiscus donbassicus*, and specimens controversially referred to "*Millerella tortula*" are reliable, auxiliary indices to the base of the Serpukhovian. In southern Guizhou Province, China, Visean–Serpukhovian rock sequences from slope and platform settings have yielded rich associations of conodonts and foraminifers, respectively. The Nashui section is a leading candidate for the Serpukhovian GSSP because its slope deposits contain an uninterrupted record of conodont occurrences including the *L. nodosa*–*L. ziegleri* transition. Foraminifers recovered from the Nashui section are comparatively rare and include none of the basal Serpukhovian indices. In contrast, the nearby Yashui section represents a platform interior setting in which foraminifers flourished and conodonts were nearly absent. The base of the Serpukhovian at Yashui is marked approximately by the appearance of "*tortula*-like" specimens. Although it is not possible to correlate biostratigraphically between the Nashui and Yashui sections, the occurrence of "*tortula*-like" specimens at the Yashui section allows correlation with the mid-Venevian Substage of the Moscow Basin at a level coinciding with the appearance of *L. ziegleri*. Together, the slope and platform sections comprise an informative biostratigraphic reference area for micropaleontologic characterization of the Visean–Serpukhovian boundary in southern Guizhou.

INTRODUCTION

THE TASK GROUP to establish a GSSP close to the existing Visean–Serpukhovian boundary was created in 2002 under the auspices of the Subcommission on Carboniferous Stratigraphy (SCCS) of the International Commission on Stratigraphy, International Union of Geological Sciences (Heckel, 2002; Richards, 2003). Significant progress toward selecting a basal Serpukhovian GSSP occurred in subsequent years (Richards, 2009). Members of the Task Group agree that the evolutionary appearance of the conodont *Lochriea ziegleri* Nemirovskaya, Perret, and Meischner, 1994 in the lineage *Lochriea nodosa*–*Lochriea ziegleri* is the best biostratigraphic event for marking the boundary, although this marker still awaits formal ratification. *Lochriea ziegleri* appeared near the middle of the Brigantian Substage in Western Europe, at a level that is correlated to slightly below the base of the type Serpukhovian Stage in the Moscow Basin and slightly below the base of the Namurian Stage in Western Europe. When formally adopted, the new basis for defining the Visean–Serpukhovian boundary will mean that rocks previously regarded as upper Visean will become lower Serpukhovian. The *L. nodosa*–*L. ziegleri* lineage is best developed in relatively deep-water sections and has been identified at several sites in Western Europe, Russia, and China (Nemirovskaya et al., 1994; Skompski et al., 1995; Wang and Qi, 2003; Qi and Wang, 2005; Nemyrovska, 2005; Nikolaeva et al., 2005; Kulagina et al., 2006; Nikolaeva et al., 2007). The lineage has not been documented in cratonic North America but several relatively long-ranging species including *L. nodosa* (Bischoff, 1957) have been reported there under the genus *Paragnathodus*, a junior synonym of *Lochriea* (Lane and Brenckle, 2005). Richards (2010) reported that a single specimen of *L. zeigleri* had been found in North America. The specimen was recovered by L. L. Lambert from the Barnett Shale in Texas, but it has not been illustrated. Two localities have emerged as leading GSSP candidates: 1) a deep-water, carbonate section along the Ural River opposite the village of Verkhnyaya Kardailovka on the eastern slope of the southern Urals, Russia (Nikolaeva et al., 2005); and 2) Nashui, a carbonate-slope section near an abandoned village with the same name in Luodian County, southern Guizhou Province, China (Wang and Qi, 2003; Qi and Wang 2005).

Conodonts from the Nashui section have been studied exhaustively (see Localities and Sampling, below). In May, 2008, members and associates of the Visean–Serpukhovian Task Group visited the Nashui section for a detailed sedimentologic study and to collect samples for foraminiferal biostratigraphic analysis. Following their work at Nashui they conducted similar work at the nearby shallow-water Yashui section that was known to span the Visean–Serpukhovian boundary and contain an unusually rich association of foraminifers (Fig. 1). The purpose of the present paper is to report on foraminifers from the boundary interval at both sections in order to establish auxiliary means for intercontinental biostratigraphic correlation at the level of the *L. nodosa*–*L. ziegleri* transition.

LOCALITIES AND SAMPLING

The 2008 field party consisted of He Hongwei, Wang Jin, Zhang Yiqiang, H. Richard Lane, and the authors of this article. Barry C. Richards measured and described the sections and supervised the installation of metal pins at one meter intervals for permanently marking stratigraphic measurements. Each pin was stamped with a numeral corresponding to its position above the base of the respective section. Foraminiferal occurrences at the Yashui section are reported herein in terms of the 2008

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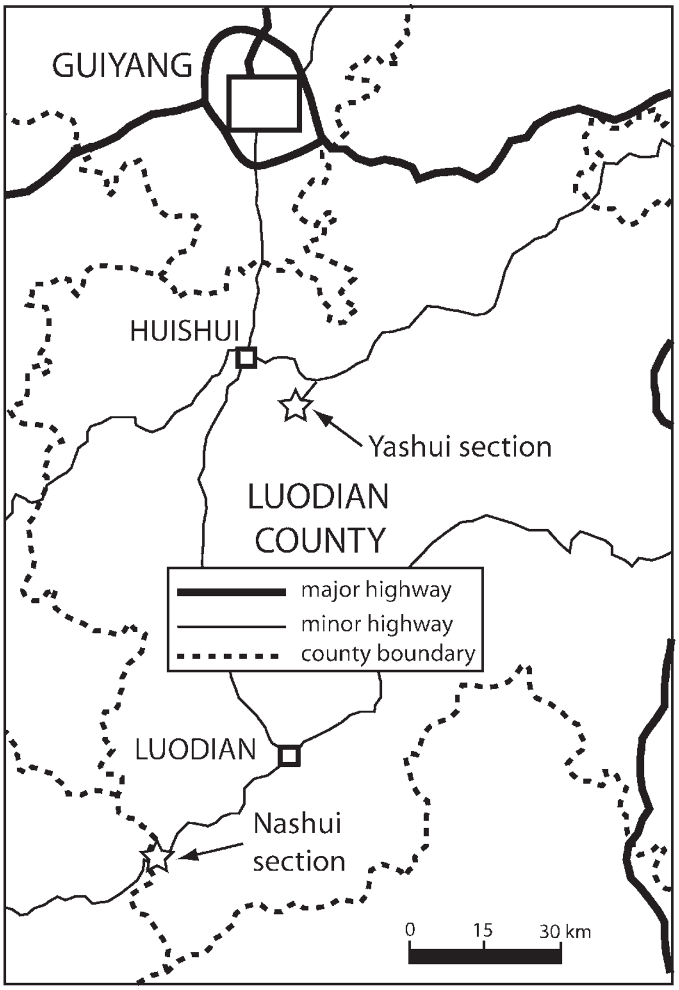

FIGURE 1—Index map showing Nashui and Yashui sections in Luodian County, southern Guizhou Province, China.

FIGURE 2—Outcrop photograph of the proposed Visean–Serpukhovian boundary at the Nashui section where the strata are steeply dipping, thin- to medium-bedded calciturbidites. Pen (∼14 cm long) is positioned at 60.1 m above the base of the section, at the lowest observed occurrence of the conodont *Lochriea ziegleri*. Position of metal pin=18 m above the base of the section measured by B. C. Richards in 2008.

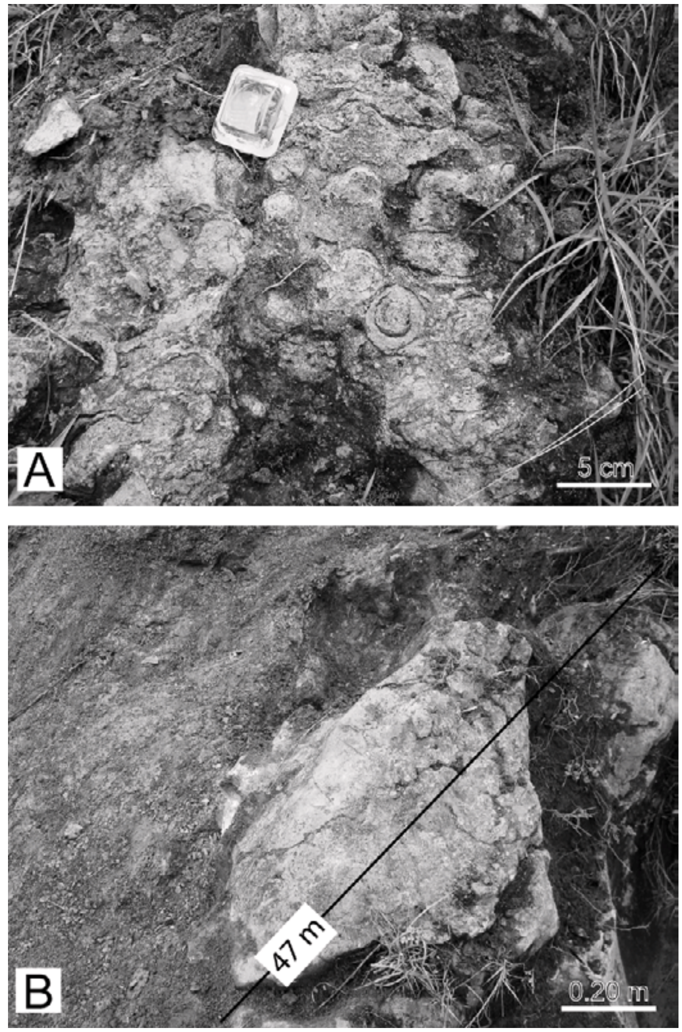

FIGURE 3—Outcrop photographs of vadose solution features near the Visean–Serpukhovian boundary interval at the Yashui section. *A*, large, spherical, concentric oncolites or lithorelicts (50.9–51.1 m above base of section); *B*, highly weathered limestone with lithorelicts and rundkarren (46.5–47.2 m above base of section) overlain by greenish grey shale (probable paleosol).

measurements. In order to avoid confusion, occurrences at the Nashui section are reported in terms of an earlier set of measurements published by Wang and Qi (2003) and subsequent authors.

Strata at the Nashui section accumulated in a relatively deep-water slope environment in which sediment gravity flows (grain flows and calciturbidites) delivered bioclasts from shallow-water settings. The succession now comprises limestones, silicified limestones and bedded cherts with no apparent unconformities. The section was discovered in the 1970s by geologists with the Yunnan Institute of Petroleum Geology, Headquarters of Petroleum Prospecting and Exploration. Its significance was recognized almost immediately, so that by the 1980s it was designated as the type section for the Luosuan Stage of the Chinese regional chronostratigraphic scale (Xiong and Zhiqiang, 1986). Microfossils from Nashui were first described in papers by Rui et al. (1987) and Wang et al. (1987) in connection with the 11th International Congress on Carboniferous Stratigraphy and Geology (Beijing). A field

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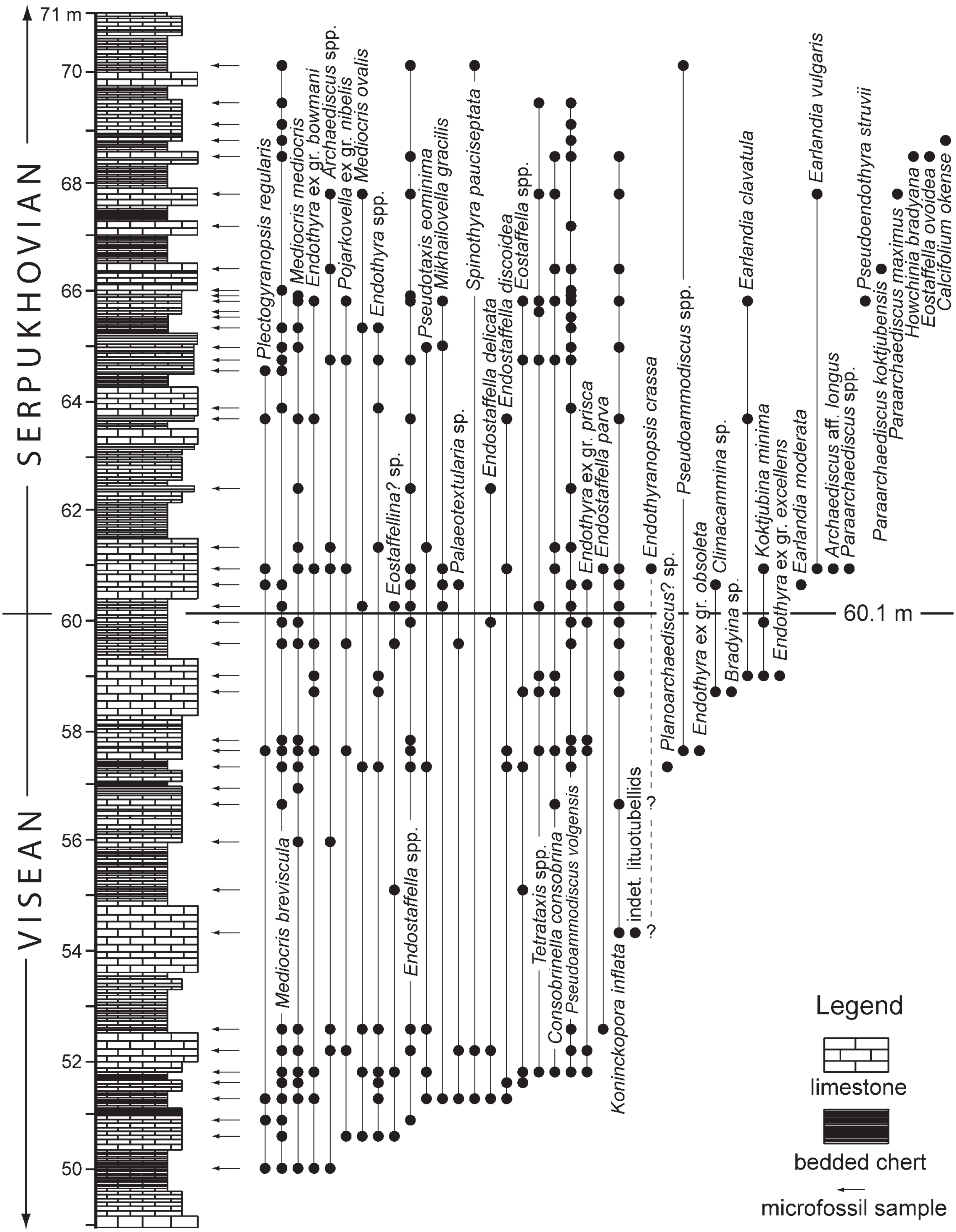

FIGURE 4—Columnar stratigraphic section and calcareous microfossil occurrences at Nashui section.

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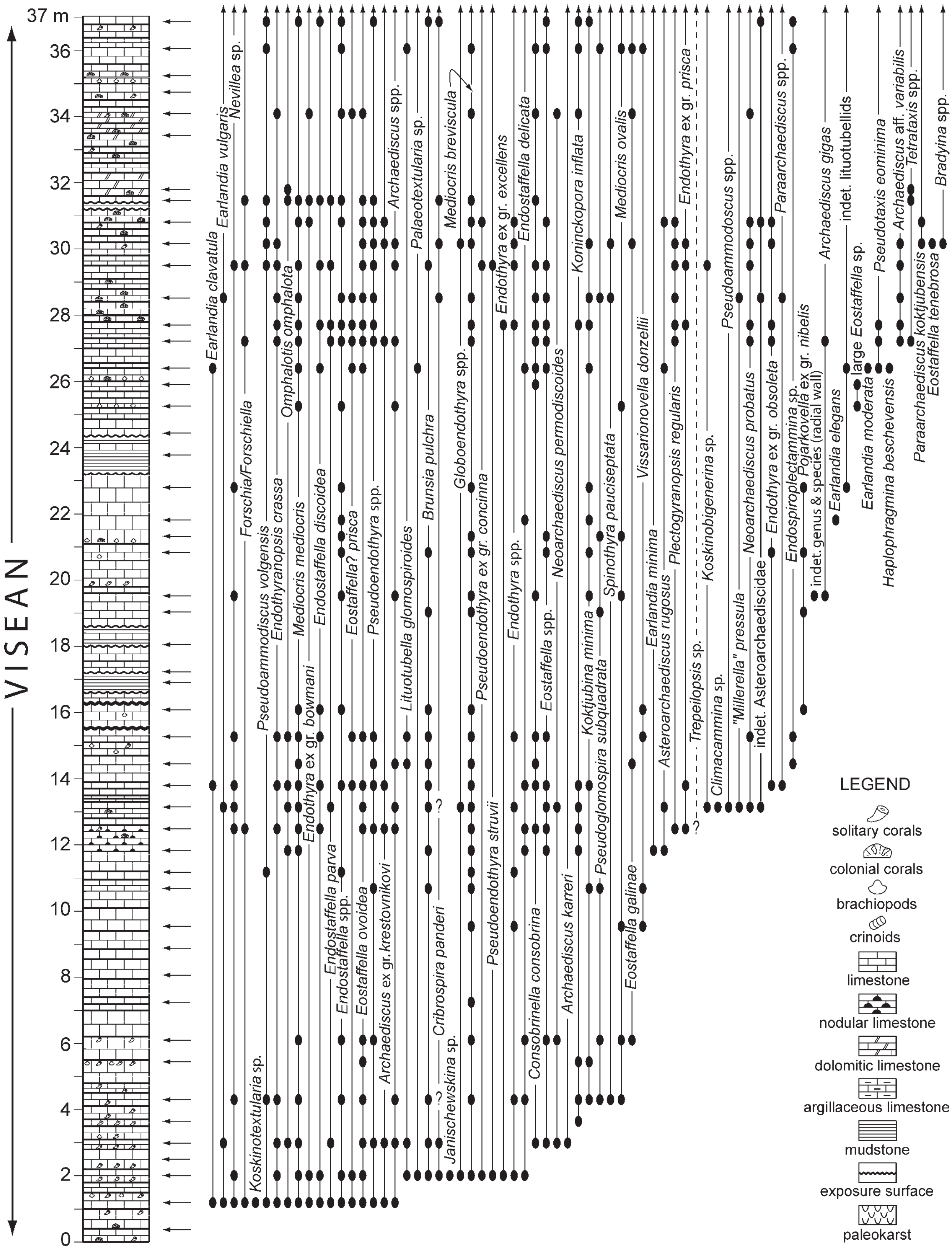

FIGURE 5—Columnar stratigraphic section and calcareous microfossil occurrences at Yashui section.

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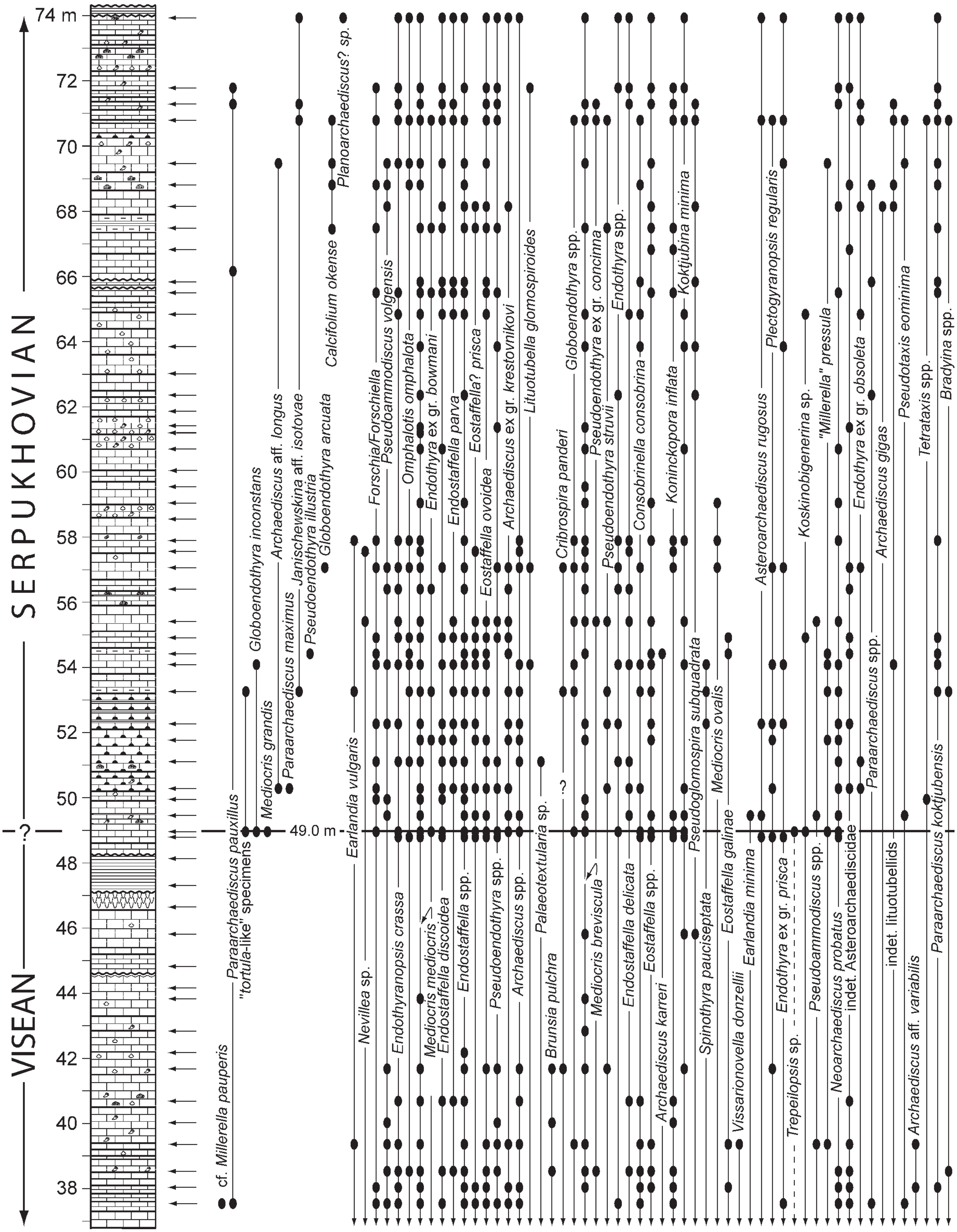

FIGURE 5—Continued.

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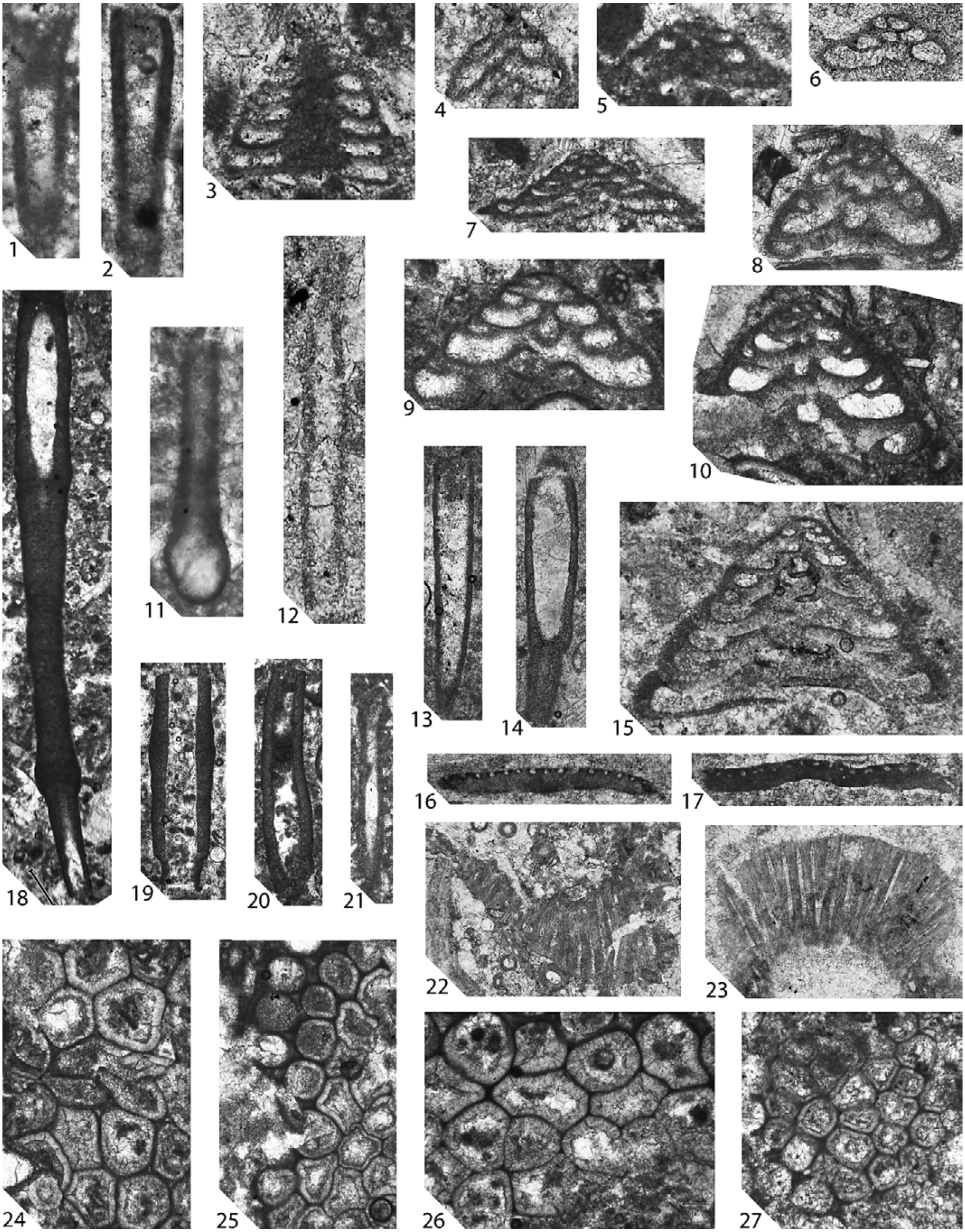

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excursion to Guizhou Province following the 11th Congress enabled non-Chinese geologists to visit the Nashui site for the first time. Ever since then the Nashui site has been recognized by international specialists as a key reference section for rocks of Carboniferous and early Permian age. A proprietary report on foraminifers and calcareous algae from the Upper Mississippian and Lower Pennsylvanian interval at Nashui was prepared for the former Amoco Production Company by Brenckle and Rui (1990).

Interest in Nashui as a potential GSSP for the Visean–Serpukhovian boundary heightened in 2003, coincident with the publication of a more detailed account of the site's microfossils (Wang and Qi, 2003). Specialists with the Nanjing Institute of Geology and Palaeontology intensified their research on all aspects of the Nashui section in preparation for a field excursion following the 16th International Congress on the Carboniferous and Permian, held in Nanjing in 2007. Qi et al. (2009) published the first proposal for adopting Nashui as the GSSP for the base of the Serpukhovian Stage. Other important papers dealing primarily with conodonts from the Nashui section include those by Qi and Wang (2005), Wang and Qi (2007), and Wang et al. (2008). Most recently, members of the SCCS visited the Nashui section in connection with a meeting and field excursion organized by specialists with the Nanjing Institute of Geology and Palaeontology. In the SCCS field guidebook, Qi et al. (2010) summarized the conodont biostratigraphy of the Visean–Serpukhovian boundary interval and illustrated conodont specimens in 19 plates.

Forty-four samples for foraminifers were collected from the Visean–Serpukhovian boundary interval at Nashui, from 50 m to 70.15 m above the base of the section. Foraminiferal specimens from this interval include at least 34 species in 23 genera (Figs. 4, 6–15). Qi et al. (2010) identified the lowest occurrence of *Lochriea ziegleri* at 60.1 m (=17.94 m according to the 2008 measurements) (Fig. 2). This level is firmly established on the basis of stratigraphically continuous, centimeter-scale sampling conducted over the course of several years.

Limestones at the Yashui section were deposited in a platform interior environment in which biologic productivity was high. Most beds are richly fossiliferous. Pervasive lime mud, calcispheres, and a variety of skeletal calcareous algae suggest a relatively quiet setting within the euphotic zone. The section is punctuated by a number of unconformities with associated paleosols and vadose solution features (Fig. 3). Foraminifers, corals, and brachiopods from the Yashui section were first reported by Wu (1987), also in connection with the field excursion to Guizhou Province following the 11th International Congress on Carboniferous Stratigraphy and Geology. Wu (2008) and Wu et al. (2009) published further accounts of foraminifers from the Visean–Serpukhovian boundary interval at Yashui, but only a few specimens were illustrated. Most recently, Hance et al. (2011) published a short description of the Yashui section along with calcareous foraminifers illustrated in three plates. The authors assigned the entire sampled portion of the Yashui section to their Mississippian Foraminifer Zone 15 (MFZ15–*Janischewskina* Zone), which they equated with the RC8 coral zone and interpreted as latest Visean in age. According to the zonation outlined in Hance et al. (2011), *Janischewskina* aff. *delicata* (Malakhova, 1956) occurs in the upper part of MFZ15, and a single specimen of *J.* aff. *delicata* was reported from the Yashui section. Observations in the Moscow Basin and on the eastern slope of South Urals, reviewed in the following section, make it clear that the appearance of *J. delicata* falls at or very near the base of the Serpukhovian as redefined on the evolutionary origin of *L. ziegleri*. Therefore, the upper part of MFZ15 must be early Serpukhovian in age. The Yashui columnar section depicted by Hance et al. (2011) is highly schematic, however, and so it is not possible to precisely relate it to our section or those in Wu (2008) and Wu et al. (2009).

Foraminiferal occurrences at Yashui are reported here on the basis of 106 samples taken from the lower 74 m of the section. They include at least 69 species in 42 genera (Figs. 5–15). Conodonts are exceedingly rare in the Yashui section. Only a single specimen has been recovered from more than 100 acid residues. Accordingly, there is no independent conodont evidence for constraining the foraminiferally-recognized boundary position.

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FIGURE 6—*1*, *2*, *Earlandia moderata* (Malakhova, 1954), longitudinal sections, ×100: *1*, Nashui 60.6 m (153184); *2*, Yashui 26.4 m (153245); *3*, *Howchinia bradyana* (Howchin, 1888), axial section, ×100, Nashui 68.47 m (153203); *4–6*, *Pseudotaxis eominima* (Rauser-Chernousova, 1948b) (possible senior synonym of *Endotaxis brazhnikovae* [Bogush and Yuferev, 1966]), variably oblique axial sections, ×100: *4*, Nashui 57.3 m (153176); *5*, Nashui 51.25 m (153165); *6*, Yashui 70.8 m (153300); *7–10*, *15*, *Tetrataxis* spp., variably oblique axial sections, ×50: *7*, Nashui 65 + 1.0 m (153196); *8*, Yashui 31.5 m (153252); *9*, Yashui 50 m (153271); *10*, Yashui 50 m (153271); *15*, Yashui 70.8 m (153300); *11, 12*, *Earlandia minima* (Birina, 1948), longitudinal sections, ×200: *11*, Yashui 49.45 m (153270); *12*, Yashui 11.75 m (153229); *13*, *14*, *Earlandia clavatula* (Howchin, 1888), longitudinal sections, ×50: *13*, Yashui 26.4 m (153245); *14*, Yashui 1.2 m (153218); *16*, *17*, *22*, *23*, *Calcifolium okense* Shvetsov and Birina, 1935, ×50; *16*, transverse section, Yashui 70.8 m (153300); *17*, transverse section, Yashui 69.55 m (153299); *22*, parallel section, Yashui 68.72 m (153298); *23*, parallel section, Yashui 67.5 m (153296); *18–20*, *Earlandia vulgaris* (Rauser-Chernousova and Reitlinger in Rauser-Chernousova and Fursenko, 1937), longitudinal sections, ×20.; *18*, Yashui 26.4 m (153245); *19*, Yashui 26.4 m (153245); *20*, Yashui 53.2 m (153276); *21*, *Earlandia elegans* (Rauser-Chernousova and Reitlinger in Rauser-Chernousova and Fursenko, 1937), longitudinal section, ×100, Yashui 21.9 m (153240); *24–27*, *Koninckopora inflata* (de Koninck, 1842), tangential sections, ×50; *24*, Yashui 49.45 m (153270); *25*, Yashui 12.5 m (153230); *26*, Yashui 28.5 m (153248); *27*, Nashui 60.95 m (153185).

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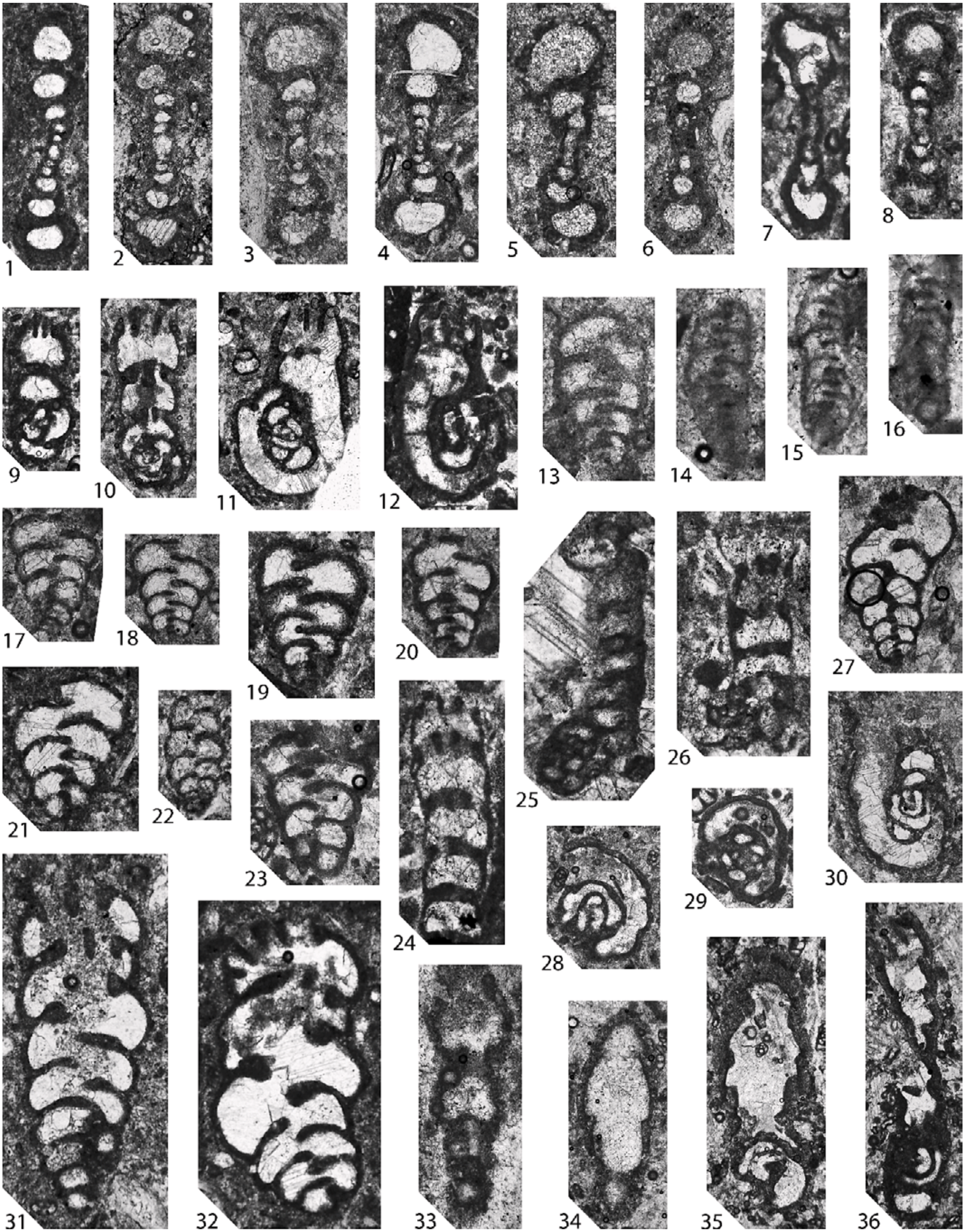
FIGURE 7—*1–8,* indet. *Forschia* or *Forschiella* spp., axial sections ×50: *1*, Yashui 54 m (153277); *2*, Yashui 71.75 m (153302); *3*, Yashui 37.45 m (153257); *4*, Yashui 37.45 m (153257); *5*, Yashui 29.6 m (153249); *6*, Yashui 65.5 m (153293); *7*, Yashui 57.9 m (153284); *8*, Yashui 57 m (153282); *9*, *10*, *Nevillea* sp., partial longitudinal sections through uniserial portion of test, ×25: *9*, Yashui 2.0 m (153219); *10*, Yashui 13.7 m (153232); *11*, *12*, *28–30*, *34–36*, *Lituotubella glomospiroides* Rauser-Chernousova, 1948a, variably oblique and tangential sections, ×25: *11*, Yashui 2.0 m (153219); *12*, Yashui 15.15 m (153234); *28*, Yashui 2.0 m (153219); *29*, Yashui 15.15 m (153234); *30*, Yashui 57 m (153282); *34*, Yashui 2.0 m (153219); *35*, Yashui 3.0 m (153220); *36*, Yashui 36 m (153255); *13–16*, *Endospiroplectammina* sp., partial longitudinal sections, ×100: *13*, Yashui 36 m (153255); *14*, Yashui 36.95 m (153256); *15*, Yashui 14.45 m (153233); *16*, Yashui 15.15 m (153234); *17–23*, *Consobrinella consobrina* (Lipina, 1948), longitudinal sections, ×50: *17*, Yashui 38.5 m (153259); *18*, Yashui 50.35 m (153272); *19*, Yashui 53.2 m (153276); *20*, Yashui 13.7 m (153232); *21*, Yashui 57 m (153282); *22*, Nashui 57.6 m (153209); *23*, Yashui 15.15 m (153234); *24–26*, *Mikhailovella gracilis* (Rauser-Chernousova, 1948a), incomplete longitudinal sections through uniserial portion of test, ×50: *24*, Nashui 51.25 m (153165); *25*, Nashui 65 m (153192); *26*, Nashui 60.95 m (153185); *27*, *Koskinotextularia* sp., incomplete longitudinal section showing cribrate terminal aperture, ×50, Yashui 1.2 m (153218); *31–32*, *Koskinobigenerina* sp., partial longitudinal sections, ×50: *31*, Yashui 64.8 m (153292); *32*, Yashui 49 m (153269); *33*, *Haplophragmina beschevensis* (Brazhnikova *in* Brazhnikova et al., 1967), ×50, oblique section through uniserial portion of test, Yashui 26.4 m (153245).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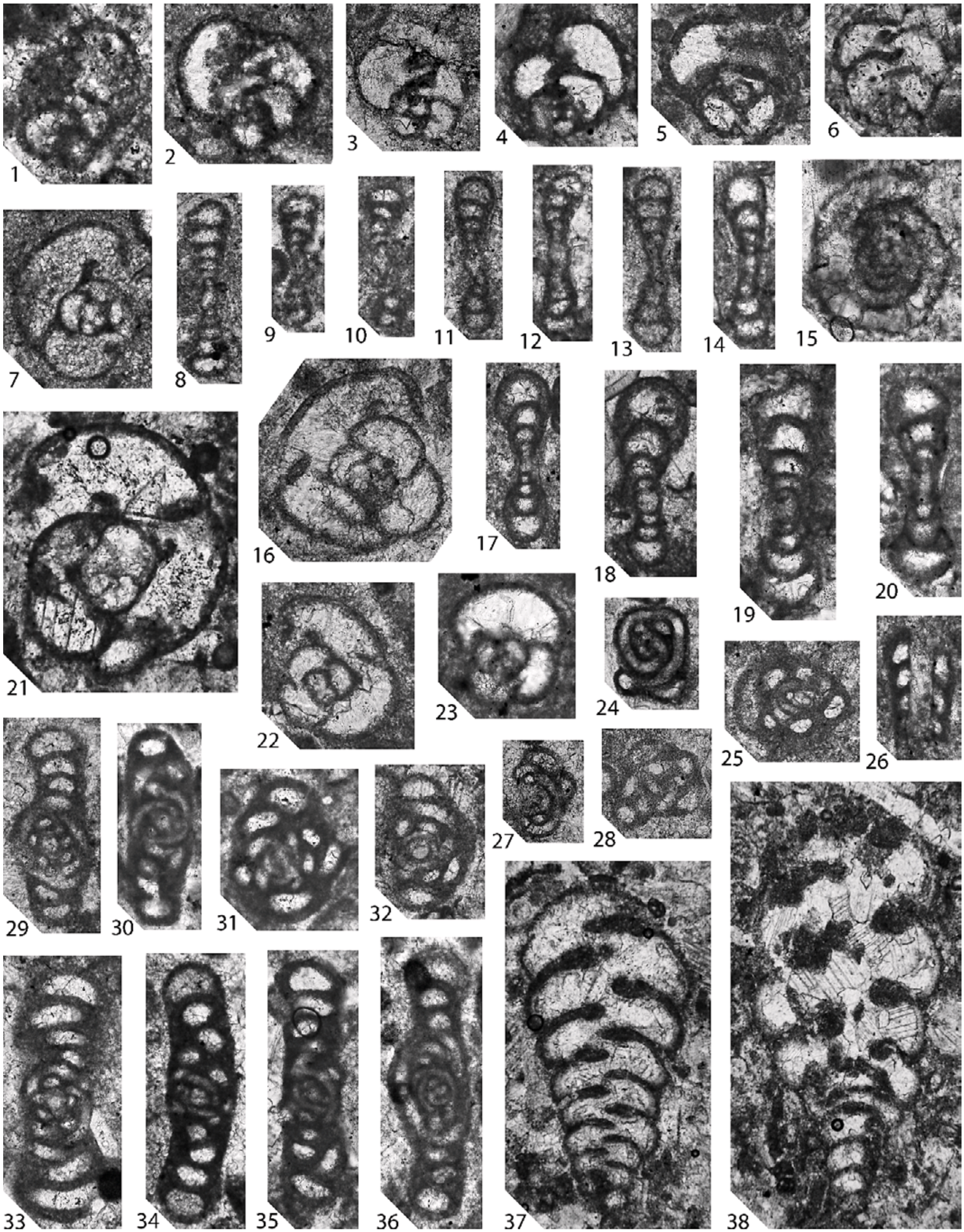
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FORAMINIFERAL CHARACTERIZATION OF THE VISEAN–SERPUKHOVIAN BOUNDARY

Skompski et al. (1995) first suggested that global correlation of a level at or near the base of the Western European Namurian Stage might be possible using the appearance of the conodont *Lochriea ziegleri* in evolutionary continuity with its ancestor *L. nodosa*. In 2003, the International Commission on Stratigraphy and the International Union of Geological Sciences ratified a formal subdivision of the Carboniferous System in which the name Serpukhovian supplanted Namurian for the interval above the Visean Stage and below the Mid-Carboniferous boundary (i.e., base of Bashkirian Stage) (Heckel, 2004). In the years since 2003, the Visean–Serpukhovian boundary Task Group evaluated several alternative biostratigraphic indices for characterizing the base of the Serpukhovian. The Task Group now strongly favors the appearance of *L. ziegleri* for marking the boundary, especially in light of multidisciplinary work indicating minimal diachroniety of this event (Richards, 2010). In contrast, there is no widespread agreement on foraminiferal characterization of the Visean–Serpukhovian boundary. It is informative therefore to review foraminiferal successions across this boundary at important reference sections in the type area of the Serpukhovian Stage (Moscow Basin), elsewhere in Russia and in cratonic North America. This review includes multiple references to taxonomically and nomenclaturally controversial specimens identified as "*Millerella tortula*" Zeller, 1953. It is necessary to clarify our concepts of these specimens and their biostratigraphic significance before proceeding with the review.

"Millerella tortula" *and similar forms*.—*Millerella tortula* was described by Zeller (1953) from the type section of the Glen Dean limestone in Breckinridge County, Kentucky. The Glen Dean limestone occurs in the middle of the Chesterian regional stage of the North American chronostratigraphic scheme and its age is now regarded as early but not earliest Serpukhovian. Brenckle (1991) used the appearances of *M. tortula* and morphologically similar *M. designata* Zeller (1953) to define his "Horizon 6," a biostratigraphic level widely recognizable in the midcontinent, southeastern U.S., Texas, and throughout the Cordillera including western Canada and Alaska. *Millerella tortula* is broadly rounded in axial section, mostly involute and markedly umbilicate. The coiling is initially skewed or planispiral and then mostly planispiral, with the planispiral whorls outnumbering skewed coils. The outer volution has 10–13 chambers separated by more or less straight septa that are perpendicular to the outer wall. The wall is layered with a continuous floor deposit and pseudochomata. Although the holotype and most of the paratypes fit this description, Zeller (1953) included in *M. tortula* a few other specimens that might best be placed in other species, a circumstance that created the potential for taxonomic confusion.

Gibshman (2003), Gibshman and Baranova (2007), and Gibshman et al. (2009) illustrated specimens as "*Millerella*" *tortula* from the Moscow Basin at or near the level of the redefined Visean–Serpukhovian boundary. The Moscow Basin specimens differ from the types of *M. tortula* in being more angular, more evolute, narrower, and less umbilicate with a higher number of skew volutions. It is our contention, and that of P. L. Brenckle (personal commun., 2011), that these specimens are taxonomically distinct from bona fide *M. tortula*.

In the present work we encountered specimens (Fig. 14) that are remarkably similar to those from the Visean–Serpukhovian boundary interval in the Moscow Basin, indicating that the form was geographically widespread and potentially biostratigraphically useful. Given that there is no formal name for these specimens, and given that they are older and morphologically distinct from bona fide *M. tortula*, we refer to them informally as "*tortula*-like."

Russian sections.—The Serpukhovian Stage was proposed by Nikitin (1890) on the basis of outcrops in the southern Moscow Basin. Nikitin did not designate a type section, but he mentioned several typical localities by name. Of these, only Zaborie Quarry still exists and has become the Serpukhovian lectostratotype (Gibshman et al., 2009). Exposures in the quarry have deteriorated, however, and the site has been used for waste disposal at least since 1998. A more complete exposure of equivalent rocks occurs at Novogurovsky Quarry approximately 50 km south of Zaborie. Novogurovsky Quarry is now regarded as the hypostratotype of the Serpukhovian Stage. The succession of foraminifers across the Visean–Serpukhovian boundary at Zaborie Quarry was documented by Gibshman (2001, 2003) and Kabanov et al. (2009). Gibshman et al. (2009) documented foraminifers, conodonts, and other fossils from Novogurovsky. Makhlina et al. (1993) compiled the stratigraphic ranges of foraminifers and other fossils from lower Carboniferous rocks throughout the Moscow Basin and adjacent Voronezh Anticlise.

Lowest Serpukhovian rocks in the southern Moscow Basin are assigned to the *Pseudoendothyra globosa* Zone of the General Carboniferous Stratigraphic Scale of Russia (Makhlina et al.,

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FIGURE 8—*1–6*, *Koktjubina minima* (Vdovenko, 1962), variably tangential axial sections, ×100: *1*, Nashui 60.95 m (153185); *2*, Yashui 27.75 m (153247); *3*, Yashui 74 m (153303); *4*, Yashui 54 m (153277); *5*, Yashui 60.7 m (153287); *6*, Yashui 4.2 m (153222); *7*, *16*, *21–23*, *Spinothyra pauciseptata* (Rauser-Chernousova, 1948d), tangential sagittal sections, ×100: *7*, Yashui 30.2 m (Cat.no. 153250); *16*, Yashui 28.5 m (153248); *21*, Yashui 4.2 m (153222); *22*, Yashui 52.3 m (153275); *23*, Yashui 54.3 m (153278); *8–15*, *Pseudoammodiscus volgensis* (Rauser-Chernousova, 1948c), ×100: *8*, axial section, Yashui 30.8 m (153251); *9*, axial section, Nashui 65 + 1.0 m (153196); *10*, axial section, Yashui 19.55 m (153237); *11*, axial section, Yashui 36.95 m (153256); *12*, axial section, Yashui 41.6 m (153263); *13*, axial section, Yashui 36.95 m (153256); *14*, axial section, Yashui 49.45 m (153270); *15*, sagittal section, Nashui 66.35 m (153199); *17–20*, *Pseudoammodiscus* sp., axial sections, ×100; *17*, Yashui 55.4 m (153280); *18*, Yashui 39.4 m (153260); *19*, Yashui 39.4 m (153260); *20*, Yashui 49.45 m (153270); *24*, *25*, *27*, *28*, *31*, *32*, *Pseudoglomospira subquadrata* (Potievskaya and Vakarchuk in Brazhnikova et al., 1967), variably oblique sections, ×100: *24*, Yashui 28.5 m (153248); *25*, Yashui 19 m (153236); *27*, Yashui 70.8 m (153300); *28*, Yashui 45.8 m (153267); *31*, Yashui 21.4 m (153239); *32*, Yashui 4.2 m (153222); *26*, *Trepeilopsis* sp., ×100, Yashui 49 m (153269); *29*, *30*, *33–36*, *Brunsia pulchra* Mikhailov, 1939, axial sections, ×100: *29*, Yashui 16.06 m (153235); *30*, Yashui 15.15 m (153234); *33*, Yashui 20.9 m (153238); *34*, Yashui 29.6 m (153249); *35*, Yashui 13.7 m (153232); *36*, Yashui 36.95 m (153256); *37*, *Palaeotextularia* sp., longitudinal section, ×50, Yashui 2.0 m (153219); *38*, *Climacammina* sp., tangential longitudinal section, ×50, Yashui 13.2 m (153278).

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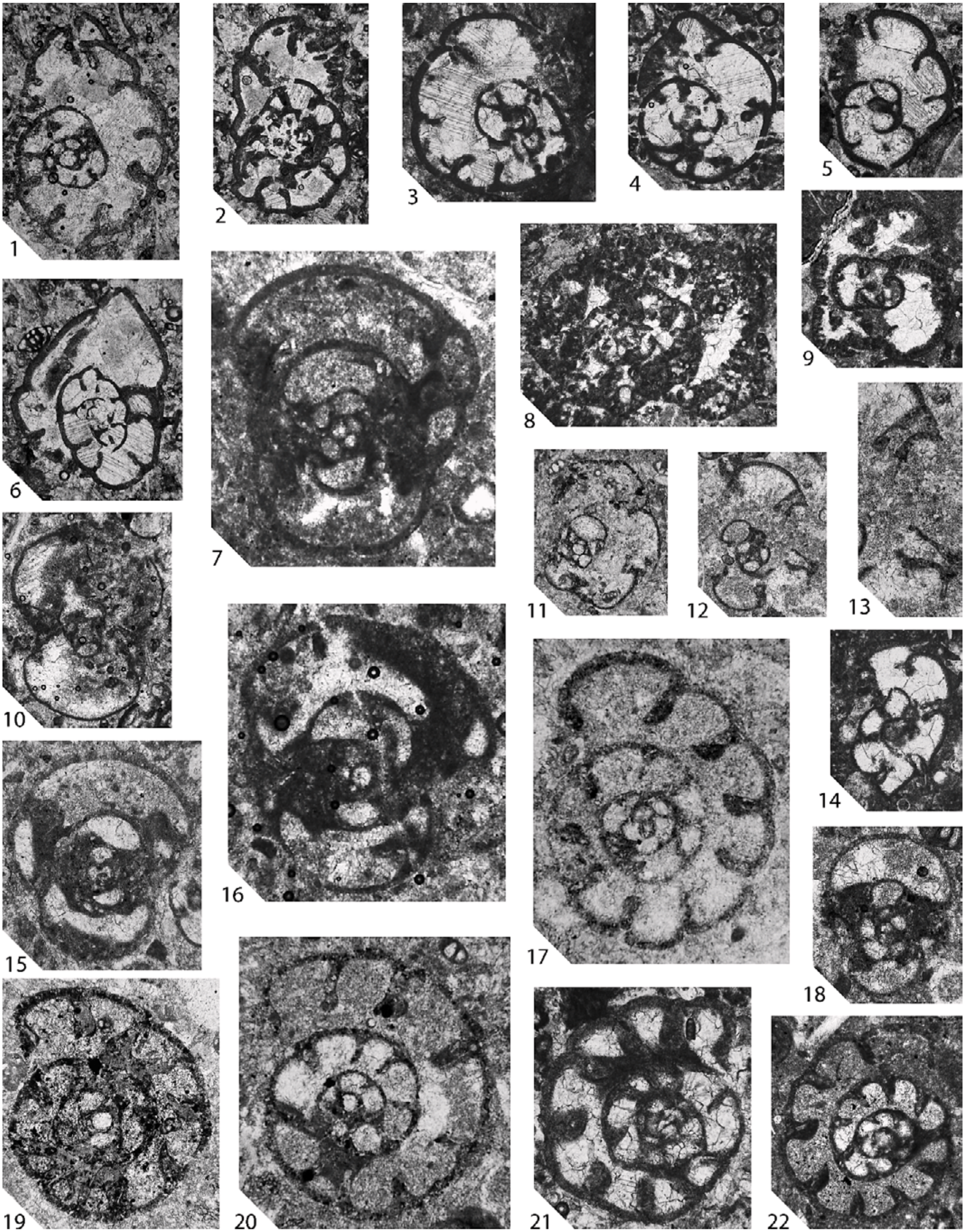
FIGURE 9—*1–6*, *Cribrospira panderi* Möller, 1878, variably tangential sagittal sections, ×25: *1*, Yashui 3.0 m (153220); *2*, Yashui 3.0 m (153220); *3*, Yashui 57 m (153282); *4*, Yashui 36.95 m (153256); *5*, Yashui 31.5 m (153252); *6*, Yashui 3.0 m (153220); 7, *15–22*, *Endothyranopsis crassa* Brady, 1870 emend. Cummings, 1955, ×50: *7*, axial section, Yashui 49 m (153269); *15*, axial section, Yashui 65.5 m (153293); *16*, axial section, Yashui 2.0 m (153219); *17*, sagittal section, Yashui 71.75 m (153302); *18*, axial section, Yashui 69.55 m (153299); *19*, sagittal section, Yashui 71.3 m (153301); *20*, sagittal section, Yashui 71.3 m (153301); *21*, sagittal section, Yashui 40.6 m (153262); *22*, sagittal section, Yashui 27.75 m (153247); *8*, *9*, *Bradyina* spp., oblique sections through crushed specimens, ×20; 8, Yashui 38.5 m (153259); 9, Yashui 30.2 m (153250); *10*, *Janischewskina* sp., near axial section, ×25, Yashui 2.0 m (153219); *11–14*, *Janischewskina* aff. *isotovae* Lebedeva *in* Grozdilova et al., 1975, sagittal and near sagittal sections: *11*, Yashui 74 m (153303), ×25; *12*, Yashui 70.8 m (153300), ×25; *13*, enlarged view of *12* showing characteristic double septa, ×50; *14*, Yashui 53.2 m (153276), ×25.



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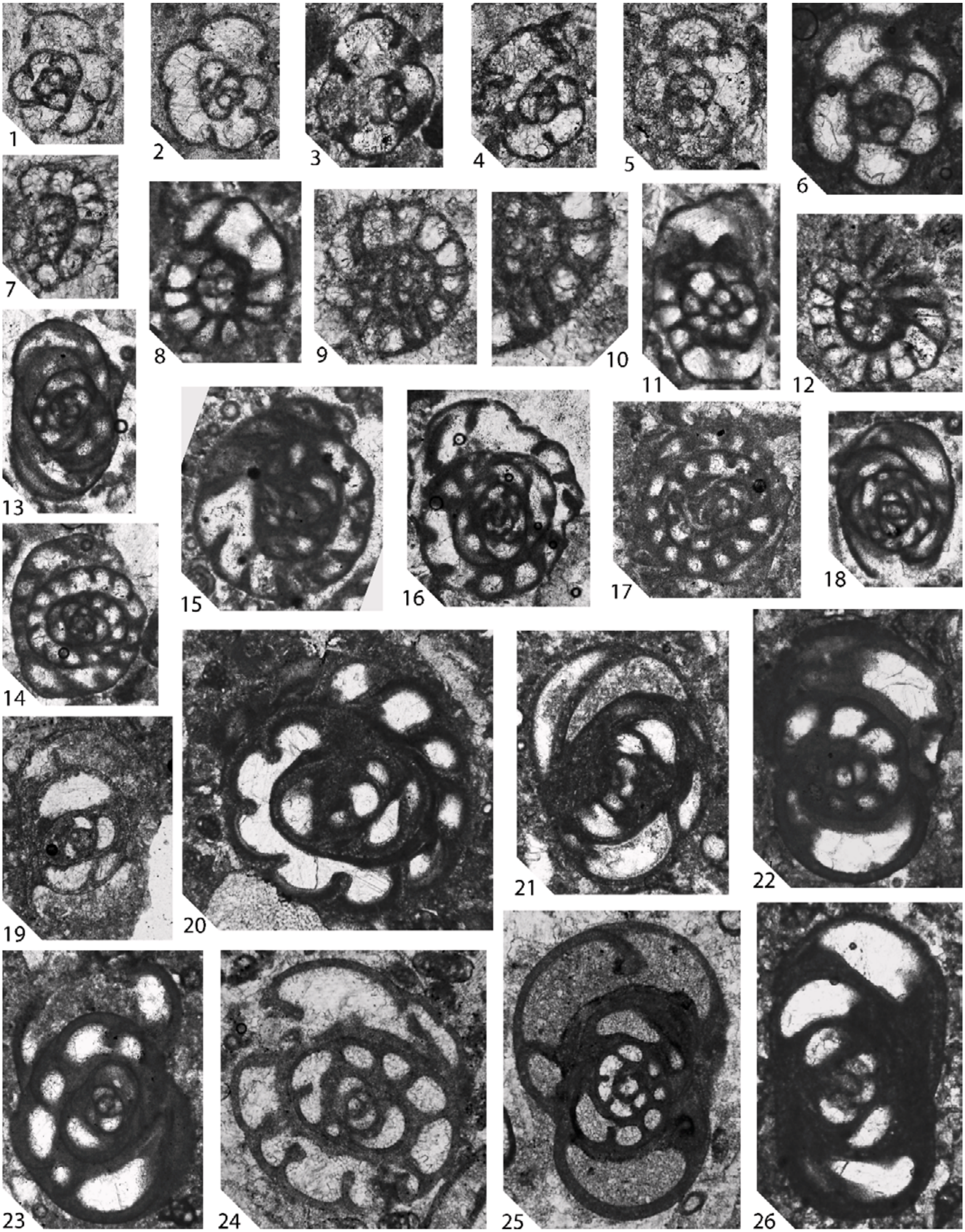

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1993; Kulagina and Gibshman, 2002, 2005; Kulagina et al., 2003). According to Gibshman et al. (2009), however, the zonal index is very rare in the Moscow Basin and so appearances of other species are more useful locally for marking the base of the Serpukhovian. The appearance of "*tortula*-like" specimens coincides precisely with that of *L. ziegleri* at Novogurovsky Quarry, whereas they occur one bed higher than that of *L. ziegleri* at Zaborie Quarry. The appearance of *Janischewskina delicata* (Malakhova, 1956) coincides with that of "*tortula*-like" specimens at Novogurovsky Quarry. *Janischewskina* cf. *delicata* locally appears one bed higher than "*tortula*-like" specimens at Zaborie Quarry (Kabanov et al., 2009). The appearance of *Asteroarchaediscus postrugosus* (Reitlinger, 1949) falls at this same level at Zaborie Quarry, but several beds higher at Novogurovsky Quarry. At Novogurovsky Quarry the boundary level also contains the local appearances of *Endothyra phrissa* (Zeller, 1953), *Planoendothyra* sp. and *Rectoendothyra* sp. The local appearances of *Omphalotis samarica* (Rauser-Chernousova, 1948d) and *Mikhailovella gracilis* (Rauser-Chernousova, 1948a) fall immediately below the boundary, whereas appearances of *Endostaffella asymmetrica* Rozovskaya, 1963, *Janischewskina typica* Mikhailov, 1939, *Bradyina* ex gr. *cribrostomata* Rauser-Chernousova and Reitlinger in Rauser-Chernousova and Fursenko, 1937 and *Eostaffella mirifica* Brazhnikova in Brazhnikova et al., 1967 occur immediately above it. At Zaborie Quarry the appearances of *E. mirifica*, *E. ovoidea* (Rauser-Chernousova, 1948b), *Pseudoendothya globosa* Rozovskaya, 1963, and *Endotaxis brazhnikovae* (Bogush and Yuferev, 1966) occur within 2.5 m above the boundary level.

Alekseev et al. (2004) noted that the Visean–Serpukhovian boundary in the Moscow Basin is marked by an erosional unconformity that resulted from a major drop in sea-level. Detailed sedimentologic analysis at both Zaborie and Novogurovsky quarries revealed that multiple discontinuities punctuate the upper Visean–lower Serpukhovian succession. At both quarries the biostratigraphically identified stadial boundary immediately overlies exposure profiles characterized by root traces and vadose solution features (Gibshman et al., 2009; Kabanov et al., 2009). The biostratigraphically identified boundary coincides with the base of the Tarusian Horizon (or regional substage) at Zaborie Quarry, whereas at Novogurovsky Quarry it falls within the upper Venevian Horizon approximately 2.6 m below the base of the Tarusian. According to Gibshman et al. (2009), the basal Tarusian exposure surface at Zaborie Quarry correlates to an exposure surface at Novogurovsky that is ~3.5 m above the appearance of *L. ziegleri*. If correct, this implies that lowest Serpukhovian rocks at Zaborie Quarry have been erosionally removed and the local appearance of *L. ziegleri* there is stratigraphically perched so that it does not represent an evolutionary first appearance.

Additional, informative foraminiferal successions across the Visean–Serpukhovian boundary have been documented in the eastern subregion of the South Urals. At the shallow-water Bolshoi Kizil section uppermost Visean rocks are assigned to the *Eostaffella tenebrosa* Zone and basal Serpukhovian rocks to the *Eolasiodiscus donbassicus-Asteroarchaediscus postrugosus* Zone (Kulagina and Gibshman, 2002; Kulagina et al., 2002, 2003, 2012). We are not aware of conodonts reported from this locality. Rather, the boundary at Bolshoi Kizil is placed at the joint appearances of *E. donbassicus* Reitlinger, 1956, *A. postrugosus* and *Janischewskina delicata*. This level (base of bed 7) coincides also with the local appearance of *Neoarchaediscus probatus* (Reitlinger, 1950). The local appearances of *Howchinia bradyana* (Howchin, 1888) and *Biseriella parva* (Chernysheva, 1948) occur immediately below the boundary. Several notable species appear locally immediately above the boundary, including *Endotaxis brazhnikovae* [=*Pseudotaxis eominima* (Rauser-Chernousova, 1948b) herein], *Pseudoglomospira* sp., *Monotaxinoides gracilis* (Dain in Reitlinger, 1956), and *M. subplanus* (Brazhnikova and Yartseva, 1956).

The Khudolaz River section is another shallow-water reference for the Visean–Serpukhovian boundary on the eastern slope of the South Urals. Foraminifers, calcareous algae and brachiopods from this section were documented recently by Stepanova and Kucheva (2009) and Kulagina et al. (2012). Those authors did not report conodont occurrences, and so it is unclear whether or not the Visean–Serpukhovian boundary at Khudolaz River coincides with the appearance of *L. ziegleri*. Operationally, they placed the boundary at the base of bed 31 at the joint appearances of the foraminifers *Janischewskina delicata* and *Eolasiodiscus donbassicus*. This level also marks the local appearances of *Haplophragmina* ex gr. *anomalis* (Vdovenko, 1962), *H. beschevensis* (Brazhnikova in Brazhnikova et al., 1967) and *Paracaligelloides*(?) *serpuchoviensis* Brazhnikova in Brazhnikova and Vdovenko, 1983. The appearance of *Asteroarchaediscus postrugosus* was reported by Stepanova and Kucheva (2009) more

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FIGURE *10*—*1–6*, *Plectogyranopsis regularis* (Rauser-Chernousova, 1948d), sagittal and tangential sagittal sections, ×50: *1*, Yashui 70.8 m (153300); *2*, Yashui 30.8 m (153251); *3*, Nashui 60.95 m (153185); *4*, *5*, Nashui 63.7 m (153188); *6*, Yashui 12.5 m (153230); *7–12*, *Pojarkovella* ex gr. *nibelis* (Durkina, 1959): *7*, oblique sagittal section, ×100, Nashui 57.6 m (153177); *8*, oblique, tangential sagittal section, ×100, Yashui 22.8 m (153241); *9*, oblique, tangential sagittal section, ×100, Nashui 57.6 m (153209); *10*, enlarged view of *9* showing differentiated wall, ×150; *11*, oblique, tangential axial section, ×100, Yashui 22.8 m (153241); *12*, oblique, tangential sagittal section, ×60, Nashui 60.95 m (153185); *13–18*, *Vissarionovella donzellii* Cózar and Vachard, 2001, ×50; *13*, near axial section, Yashui 15.15 m (153234); *14*, sagittal section, Yashui 15.15 m (153234); *15*, tangential sagittal section, Yashui 16.08 m (153235); *16*, sagittal section, Yashui 15.15 m (153234); *17*, tangential sagittal section, Yashui 9.45 m (153226); *18*, near axial section, Yashui 15.15 m (153234); *19*, *Globoendothyra arcuata* (Grozdilova and Lebedeva, 1954), tangential axial section, ×40, Yashui 57 m (153282); *20*, *21*, *Globoendothyra inconstans* (Grozdilova and Lebedeva, 1954), ×40: *20*, tangential sagittal section, Yashui 54 m (153277); *21*, oblique, tangential axial section, Yashui 49 m (153269); *22–26*, *Omphalotis omphalota* (Rauser-Chernousova and Reitlinger in Rauser-Chernousova et al., 1936), ×50: *22*, oblique axial section, Yashui 53.2 m (153276); *23*, oblique section, Yashui 53.2 m (153276); *24*, sagittal section, Yashui 31.5 m (153252); *25*, oblique section, Yashui 70.8 m (153300); *26*, near axial section, Yashui 57.9 m (153284).

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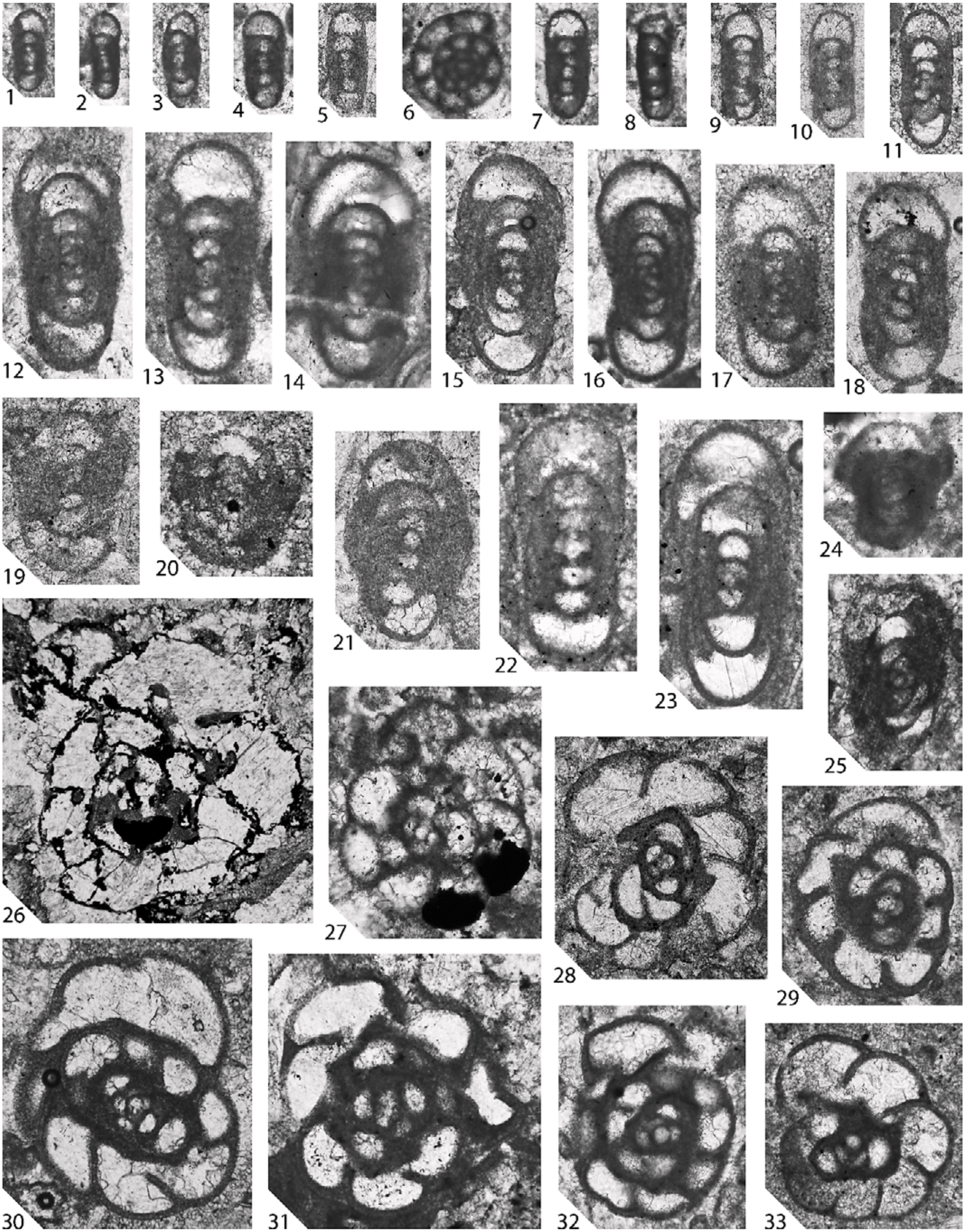
FIGURE *11*—*1–11*, *Mediocris breviscula* (Ganelina, 1951): *1*, axial section, Yashui 30.8 m (153251); *2*, axial section, Nashui 63 + 1.65 m (153189); *3*, axial section, Yashui 30.8 m (153251); *4*, axial section, Yashui 16.08 m (153235); *5*, axial section, Yashui 38.5 m (153259); *6*, sagittal section, Yashui 57.6 m (153283); *7*, axial section, Yashui 43.75 m (153266); *8*, axial section, Yashui 57.9 m (153284); *9*, axial section, Yashui 69.55 m (153299); *10*, axial section, Yashui 31.5 m (153252); *11*, axial section, Yashui 64.8 m (153292); *12–18*, *Mediocris mediocris* (Vissarionova, 1948), axial and near axial sections: *12*, Yashui 4.2 m (153222); *13*, Yashui 49 m (153269); *14*, Yashui 57.6 m (153283); *15*, Yashui 3.0 m (153220); *16*, Yashui 15.15 m (153234); *17*, Yashui 52.3 m (153275); *18*, Yashui 64.8 m (153292); *19–21*, *24*, *25*, *Mediocris ovalis* (Vissarionova, 1948), near axial sections: *19*, Nashui 51.9 m (153167); *20*, Nashui 50.65 m (153162); *21*, Yashui 19.55 m (153237); *24*, Nashui 65.4 m (153193); *25*, Nashui 52.65 m (153170); *22*, *23*, *Mediocris grandis* Bogush and Yuferev, 1962, axial sections, Yashui 49 m (153269); *26*, *Endothyra* ex gr. *excellens* (Zeller, 1953), near sagittal section, Nashui 59 m (153211); *27–29*, *32*, *33*, *Endothyra* ex gr. *obsoleta* Rauser-Chernousova, 1948d, sagittal and near sagittal sections: *27*, Nashui 57.6 m (153209); *28*, Yashui 74 m (153303); *29*, Yashui 30.8 m (153251); *32*, Yashui 50.35 m (153272); *33*, Yashui 27.75 m (153247); *30*, *31*, *Endothyra* ex gr. *bowmani* Phillips, 1846 emend. Brady, 1876 emend. China, 1965, near sagittal sections; *30*, Yashui 1.2 m (153218); *31*, Yashui 34.15 m (153254). All ×100.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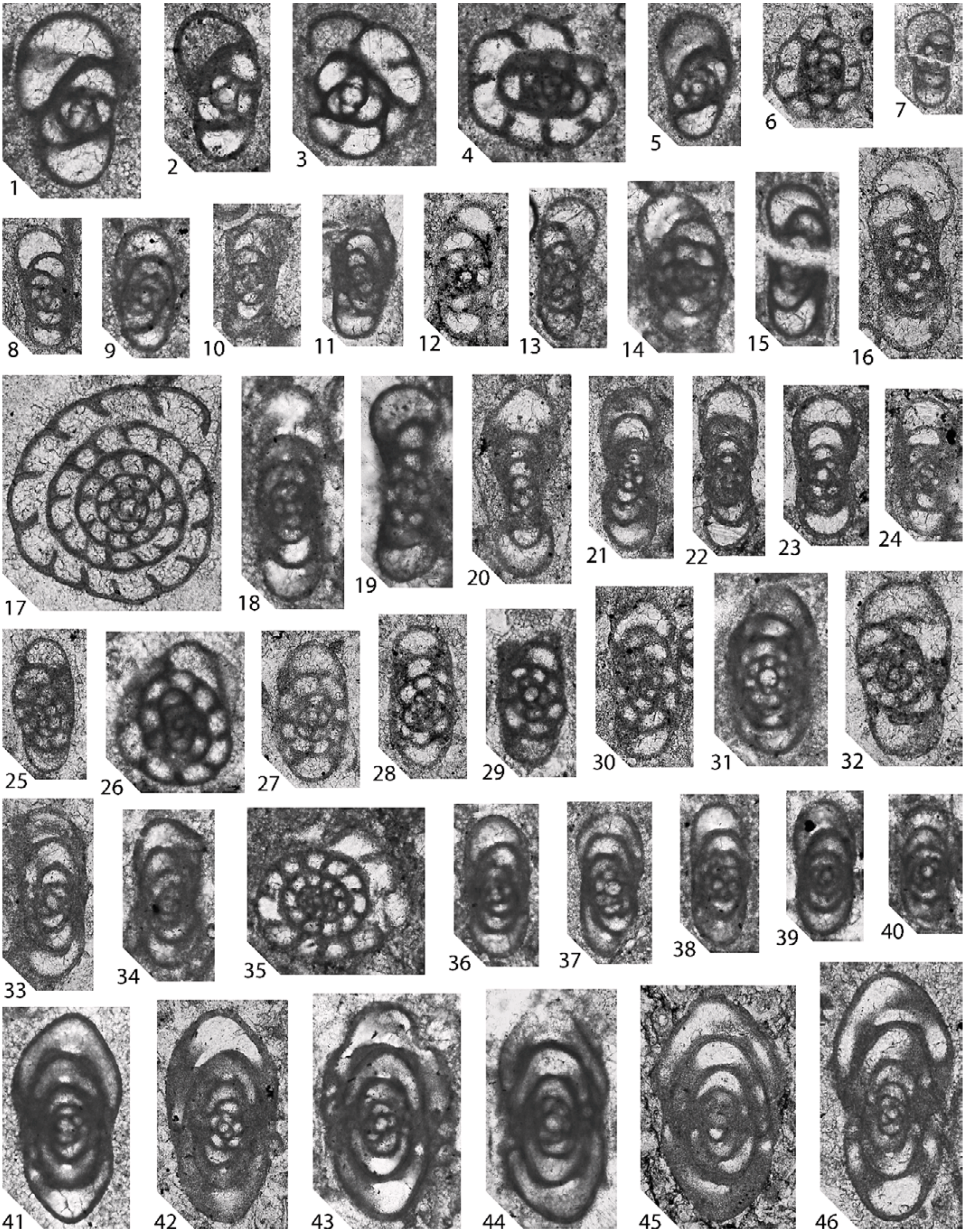

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than 250 m above the boundary in rocks assigned to the lower part of the upper Serpukhovian Substage.

The Verkhnyaya Kardailovka section, also in the eastern part of the South Urals, comprises relatively condensed, deep-water cephalopod facies quite distinct from the shallow-water facies at both Bolshoi Kizil and Khudolaz. Verkhnyaya Kardailovka was proposed as a GSSP candidate for the Visean–Serpukhovian boundary by Pazukhin and Goroshanina (2002; see also Pazukhin et al., 2009; Nikolaeva et al., 2002, 2009). The boundary there is recognizable on the appearance of *L. ziegleri* in the *L. nodosa*–*L. ziegleri* chronocline with transitional forms. In terms of foraminiferal biostratigraphy, uppermost Visean strata are referred to as "beds with *Endostaffella asymmetrica*" and lower Serpukhovian strata are assigned to the *Eolasiodiscus donbassicus* Zone. There are no foraminiferal appearances exactly coincident with the base of the Serpukhovian at Verkhnyaya Kardailovka. Rather, *Eolasiodiscus muradymicus* Kulagina in Kulagina et al., 1992 appears approximately 1.4 m above the boundary, and the local appearances *Planospirodiscus* spp., *Monotaxinoides* sp., *Neoarchaediscus* aff. *probatus*, *Asteroarchaediscus postrugosus*, and *Howchinia gibba* (Möller, 1879) occur at 7 m above the boundary (Kulagina et al., 2012).

United States.—The Visean–Serpukhovian boundary is contained within the Chesterian regional stage of the North American chronostratigraphic scheme. Foraminiferal successions in Chesterian strata in their type area in the Mississippi River Valley have been summerized by Baxter and Brenckle (1982) and Lane and Brenckle (2005). The latter authors tentatively equated the Visean–Serpukhovian boundary with the base of the Menard limestone of the type Chesterian stratal succession. The base of the Menard Limestone coincides with the base of the *Cavusgnathus naviculus* conodont zone, and it is marked also by the appearances of several foraminifers including *Brenckleina rugosa* (Brazhnikova, 1964), *Eosigmoilina robertsoni* (Brady, 1876) *Endothyra excellens* (Zeller, 1953) and *Millerella designata* (Zeller, 1953). Lane and Brenckle (2005) reported the lowest occurrence of bona fide *M. tortula* in the Menard limestone, but the type specimens come from the Glen Dean limestone, several formations lower in the Chesterian succession. Placement of the Visean–Serpukhovian boundary at the base of the Menard limestone is problematic given that the appearance of *B. rugosa* falls at the base of, or within, the upper Serpukhovian Substage in the Moscow Basin, Donets Basin and elsewhere in the former Soviet Union (Aisenverg et al., 1979, 1983).

More recently Kulagina et al. (2008) correlated the Visean–Serpukhovian boundary with the Beech Creek Limestone of the type Chesterian succession, a level considerably lower than the Menard Limestone. They based this correlation on occurrences in the Beech Creek Limestone of *Asteroarchaediscus postrugosus* and "*Millerella*" *tortula*. The latter occurrence was documented by a single illustrated specimen. Additional specimens are needed to determine if the taxon is bona fide *M. tortula* or the "*tortula*-like" form known in Eurasia. The Beech Creek foraminiferal assemblage also contains other "*Millerella*" spp., *Endostaffella discoidea* (Girty, 1915), *Loeblichia* sp., *Asteroarchaediscus rugosus* (Rauser-Chernousova, 1948b), and *A. parvus* (Rauser-Chernousova, 1948e). Independently, Browne and Pohl (1973) and Browne et al. (1977) documented occurrences of *A. postrugosus* and *Eolasiodiscus donbassicus* (illustrated as *Monotaxinoides* sp.) in the so-called Fraileys Facies in Kentucky, which they regarded as correlative with the Beech Creek Limestone. Insofar as certain Russian specialists consider *Eolasiodiscus donbassicus* a useful marker for the base of the Serpukhovian, this might be another indication that the Beech Creek Limestone is early Serpukhovian in age. P. L. Brenckle (personal commun., 2010, 2011) accepts the revised correlation by Kulagina et al. (2008) and he considers the appearance of *A. postrugosus* a potentially viable foraminiferal index to the base of the Serpukhovian.

In summary, combined evidence from the type area of the Serpukhovian Stage, the Urals and cratonic North America shows that the base of the Serpukhovian, as redefined on the evolutionary origin of *L. ziegleri*, can be recognized, or closely approximated, by the appearances of *Asteroarchaediscus postrugosus*, *Eolasiodiscus donbassicus*, and *Janischewskina delicata*. Specimens herein referred to as "*tortula*-like" make their appearance at or near the redefined boundary in the Moscow Basin and possibly in the midcontinental U.S. They are potentially useful biostratigraphic markers, but taxonomic and nomenclatural issues still await resolution.

VISEAN–SERPUKHOVIAN BOUNDARY IN SOUTHERN GUIZHOU

Nashui section.—Foraminifers at the Nashui section are relatively rare and poorly preserved. Many specimens are recrystallized and (or) deformed as a consequence of low-grade metamorphism. Most or all were transported downslope from their platform habitat so we cannot rule out the possibility of minor stratigraphic reworking. The association is dominated by *Mediocris breviscula* (Ganelina, 1951), *M. mediocris* (Vissarionova, 1948), *Endostaffella* spp., *Consobrinella consobrina* (Lipina, 1948), and *Pseudoammodiscus volgensis* (Rauser-Chernousova, 1948c). Fragmentary specimens of the calcareous alga *Koninckopora inflata* (de Koninck, 1842) also occur in many samples. With one exception, the assemblage comprises mostly long-ranging taxa of generalized late Visean–early Serpukhovian aspect. The possible exception is the occurrence at 68.8 m (~8.7 m above the appearance of *L. ziegleri*) of the calcareous alga *Calcifolium okense* Shvetsov and Birina, 1935. Until recently this species was known only from western Tethys, with its easternmost Asian occurrence being in Tadjikhistan (Mamet, 1991). Brenckle (2004) did not observe this form among the diverse algae recovered from upper, but not uppermost Visean rocks in the Tarim Basin of western China. Mamet and Zhu (2005) later documented it from the uppermost Visean and

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FIGURE 12—*1–7*, *Endothyra* ex gr. *prisca* Rauser-Chernousova and Reitlinger in Rauser-Chernousova et al., 1936: *1*, axial section, Yashui 29.6 m (153249); *2*, axial section, Yashui 27.75 m (153247); *3*, sagittal section, Yashui 27.75 m (153247); *4*, sagittal section, Yashui 30.2 m (153250); *5*, axial section, Yashui 52.3 m (153275); *6*, sagittal section, Yashui 70.8 m (153300); *7*, axial section, Yashui 63.85 m (153291); *8–16*, *Endostaffella delicata* Rozovskaya, 1963, axial and near axial sections: *8*, Yashui 64.8 m (153292); *9*, Yashui 50.35 m (153272); *10*, Yashui 6.1 m (153224); *11*, Yashui 40.6 m (153262); *12*, Yashui 71.3 m (153301); *13*, Yashui 26.4 m (153245); *14*, Yashui 13.7 m (153232); *15*, Yashui 57.6 m (153283); *16*, Yashui 71.3 m (153301); *17–24*, *Endostaffella discoidea* (Girty, 1915): *17*, sagittal section, Yashui 31.5 m (153252); *18*, axial section, Yashui 54 m (153277); *19*, axial section, Nashui 60.95 m (153185); *20*, axial section, Yashui 65.5 m (153293); *21*, axial section, Yashui 64.8 m (153292); *22*, axial section, Yashui 71.75 m (153302); *23*, axial section, Yashui 65.5 m (153293); *24*, axial section, Yashui 74 m (153303); *25–32*, *Endostaffella parva* (Möller, 1879): *25*, axial section, Yashui 70.8 m (153300); *26*, sagittal section, Yashui 29.6 m (153249); *27*, axial section, Yashui 70.8 m (153300); *28*, axial section, Yashui 71.3 m (153301); *29*, axial section, Yashui 51.85 m (153274); *30*, axial section, Yashui 52.3 m (153275); *31*, axial section, Yashui 51 m (153273); *32*, axial section, Yashui 70.8 m (153300); *33–40*, *Eostaffella*? *prisca* (Rauser-Chernousova, 1948b): *33*, axial section, Yashui 37.45 m (153257); *34*, axial section, Yashui 50.35 m (153272); *35*, sagittal section, Yashui 51.85 m (153274); *36*, axial section, Yashui 54.85 m (153279); *37*, axial section, Yashui 51.85 m (153274); *38*, axial section, Yashui 54.85 m (153279); *39*, axial section, Yashui 50.35 m (153272); *40*, axial section, Yashui 54 m (153277); *41–46*, *Eostaffella ovoidea* (Rauser-Chernousova, 1948b), axial sections: *41*, Yashui 29.6 m (153249); *42*, Yashui 74 m (153303); *43*, Yashui 38 m (153258); *44*, Yashui 50 m (153271); *45*, Yashui 71.75 m (153302); *46*, Yashui 1.2 m (153218). All ×100.

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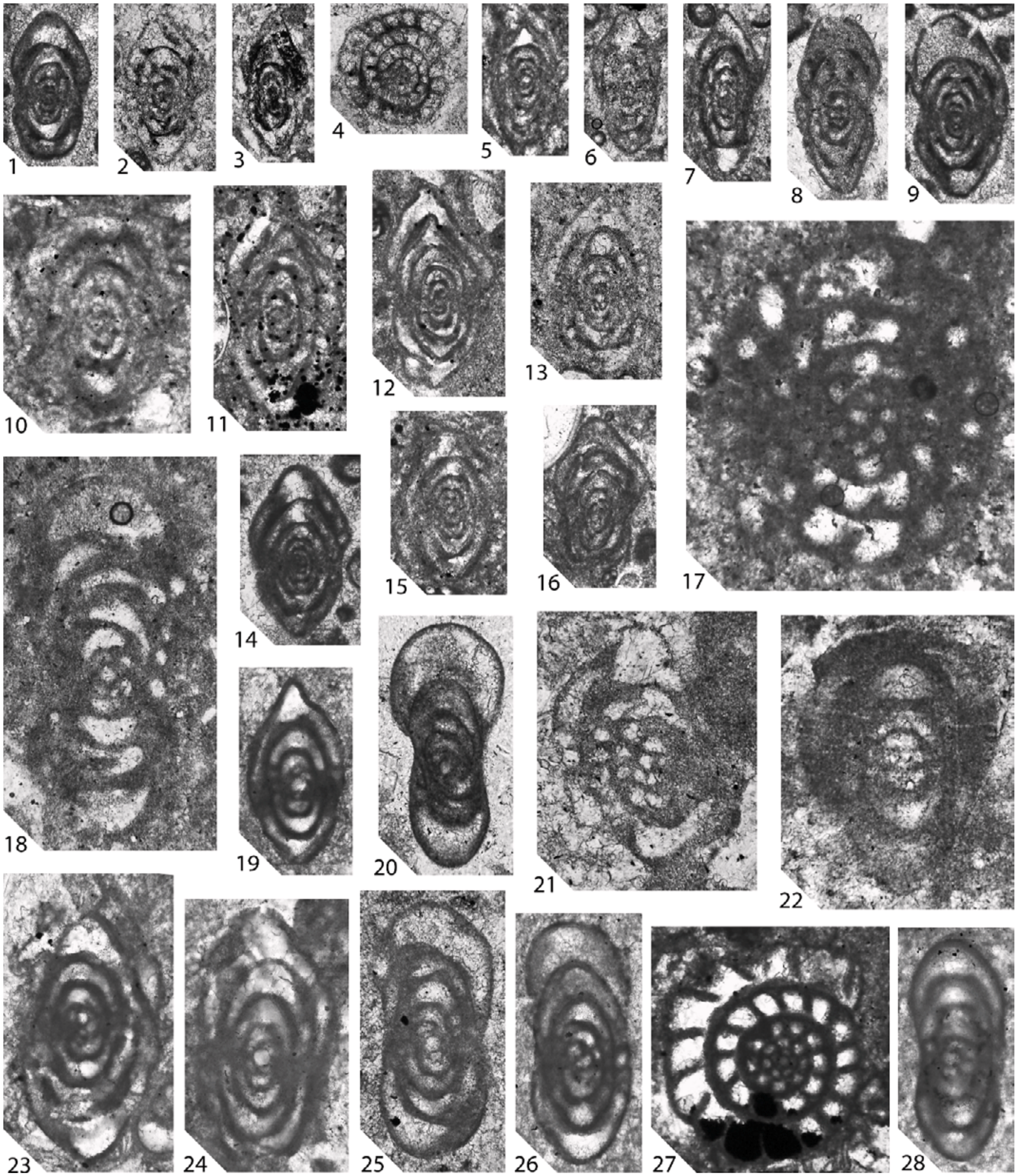

FIGURE 13—*1–9*, *Pseudoendothyra* ex gr. *concinna* (Shlykova, 1951), ×50: *1*, axial section, Yashui 29.6 m (153249); *2*, near axial section, Yashui 70.8 m (153300); *3*, near axial section, Yashui 74 m (153303); *4*, near sagittal section, Yashui 70.8 m (153300); *5*, axial section, Yashui 55.4 m (153280); *6*, axial section, Yashui 2.0 m (153219); *7*, near axial section, Yashui 30.8 m (153251); *8*, near axial section, Yashui 70.8 m (153300); *9*, axial section, Yashui 29.6 m (153249); *10*, *Pseudoendothyra illustria* (Vissarionova, 1948), near axial section, Yashui 54.3 m (153278), ×100; *11–16*, *Pseudoendothyra struvii* (Möller, 1879), axial and near axial sections, ×50: *11*, Yashui 55.4 m (153280); *12*, Yashui 52.3 m (153275); *13*, Yashui 67.5 m (153296); *14*, Yashui 29.6 m (153249); *15*, Yashui 55.4 m (153280); *16*, Yashui 41.6 m (153263); *17*, *18*, large *Eostaffella* sp., ×100: *17*, near sagittal section, Yashui 25.85 m (153244); *18*, near axial section, Yashui 25.15 m (153243); *19*, *Eostaffella tenebrosa* Vissarionova, 1948, axial section of juvenile specimen, Yashui 30.2 m (153250), ×100; *20*, cf. *Millerella pauperis* Durkina, 1959, axial section, Yashui 37.45 m (153257), ×100; *21*, *22*, *Eostaffellina*? sp., oblique, tangential sections, ×100: *21*, Nashui 50.65 m (153163); *22*, Nashui 55.1 m (153172); *23*, *24*, *Eostaffella galinae* Ganelina, 1956, axial sections, ×100: *23*, Yashui 54.85 m (153279); *24*, Yashui 14.45 m (153233); *25–28*, “*Millerella*” *pressula* Ganelina, 1951, ×100: *25*, axial section,Yashui 69.55 m (153299); *26*, axial section,Yashui 54 m (153277); *27*, sagittal section, Yashui 54.3 m (153278); *28*, axial section, Yashui 53.2 m (153276).

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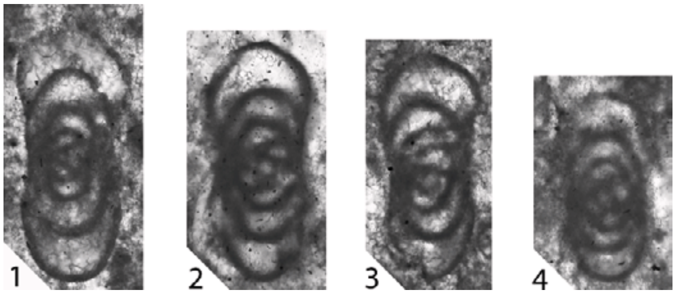

FIGURE *14*—*1–4*, "*tortula*"-like specimens, axial sections, ×100: *1*, Yashui 49 m (153269); *2*, Yashui 53.2 m (153306); *3*, Yashui 49 m (153269); *4*, Yashui 53.2 m (153305).

Serpukhovian of the Tarim Basin and reported other, undated occurrences in Guangxi Province of southern China. The present findings, both at Nashui and in the upper part of the section at Yashui, suggest that *C. okense* appeared in Guizhou slightly pursuant to the Visean–Serpukhovian boundary.

Yashui section.—Platform facies of the Yashui section contain extremely abundant, diverse and well preserved foraminifers, in stark contrast to the sparse fauna at Nashui. The lower part of the section, up to about 40 m above the base, yields a typical late Visean association of eostaffellids, endothyrids, archaediscids, earlandiids, pseudoendothyrids, endothyranopsids, and a number of large taxa with variably granular wall structure (indeterminate *Forschia* or *Forschiella*, *Nevillea* sp., *Lituotubella glomospiroides* Rauser-Chernousova, 1948a, palaeotextulariids and allied forms). Within this association, the highest observed occurrence of *Brunsia pulchra* Mikhailov, 1939 is at 41.6 m and that of *Vissarionovella donzellii* Cózar and Vachard, 2001 is at 39.4 m. Although we are not aware of *B. pulchra* in rocks of unquestioned Serpukhovian age, *V. donzellii* has been observed in lower Serpukhovian rocks in the North Caspian Basin (P. L. Brenckle, personal commun., 2011).

The lowest occurrence of a potential Serpukhovian marker is that of rare "*tortula*-like" specimens at 49 m. Additional rare individuals occur at 53.2 m. Unfortunately, the interval above 41.6 m and below 48.9 m is mostly barren of foraminifers, a circumstance that complicates placement of the Visean–Serpukhovian boundary. Some of the rocks in this interval are diagenetically altered. Beds between 43 m and 45 m are micritic with irregular vadose solution tubes and channels filled by oosparite. A bed of carbonate nodules that resemble oncolites or lithorelicts occurs immediately below 47.3 m. The top of this bed is a dissolution surface with well developed rundkarren, and it is overlain by a greenish-grey paleosol. The paleosol, in turn, is followed by another nodular limestone with lithorelicts or oncolites at 50.9 m to 51.1 m (Fig. 3).

Specimens of *Janischewskina* aff. *isotovae* Lebedeva in Grozdilova et al., 1975 first appear at 53.2 m and continue sporadically up to the highest sample at 74 m. These specimens resemble *J. delicata* in size and general morphology, but differ from the latter in their much thinner walls. The single type specimen of *J. isotovae* comes from the upper Visean (C_1v_3) Ladeininskiy Horizon of the Urals.

A single specimen of *Pseudoendothyra illustria* (Vissarionova, 1948) was recovered from the sample at 54.3 m. This species is similar to and possibly a senior synonym of *P. globosa*, the zonal index to the basal Serpukhovian in the General Carboniferous Stratigraphic Scale of Russia. We do not attach biostratigraphic significance to the present occurrence, however, given that the type specimens of *P. illustria* are from the middle Visean.

Wu et al. (2009) placed the base of the Serpukhovian in their bed 428, which falls approximately 49 m above the base of our measured section, coincident with our first observed occurrence of "*tortula*-like" specimens. They recognized the stadial boundary on the appearances of "*Millerella*" *pressula* Ganelina, 1951 and *Spinothyra* n. sp., and reported the appearance of *Asteroarchaediscus postrugosus* in bed 429, less than one meter higher. Although we agree with Wu et al. (2009) on the approximate position of the Visean–Serpukhovian boundary, we failed to verify a number of their reported foraminiferal occurrences. For example, we observed multiple occurrences of "*M.*" *pressula* beginning as low as 13.2 m and continuing nearly to the top of the section. This species was described originally from the Aleksinsky Horizon (lower part of upper Visean) in European Russia. Secondly, we see no taxonomic distinction between *Spinothyra pauciseptata* (Rauser-Chernousova, 1948d) and *S.* n. sp. and use the former epithet for all locally recovered specimens in the genus. Our *S. pauciseptata* specimens range from 4.2 m to 54.3 m. Finally, despite photographing and identifying more than 3,000 individual foraminifers from the Yashui section, we found no specimens assignable to *A. postrugosus*. Wu Xianghe allowed us to examine his collections in November, 2010, prior to the Nanjing meeting of the SCCS. Specimens he identified as *A. postrugosus* are referrable to *Neoarchaediscus probatus* in our opinion. Our collections yielded abundant *N. probatus* from 13.2 m to the top of the section,

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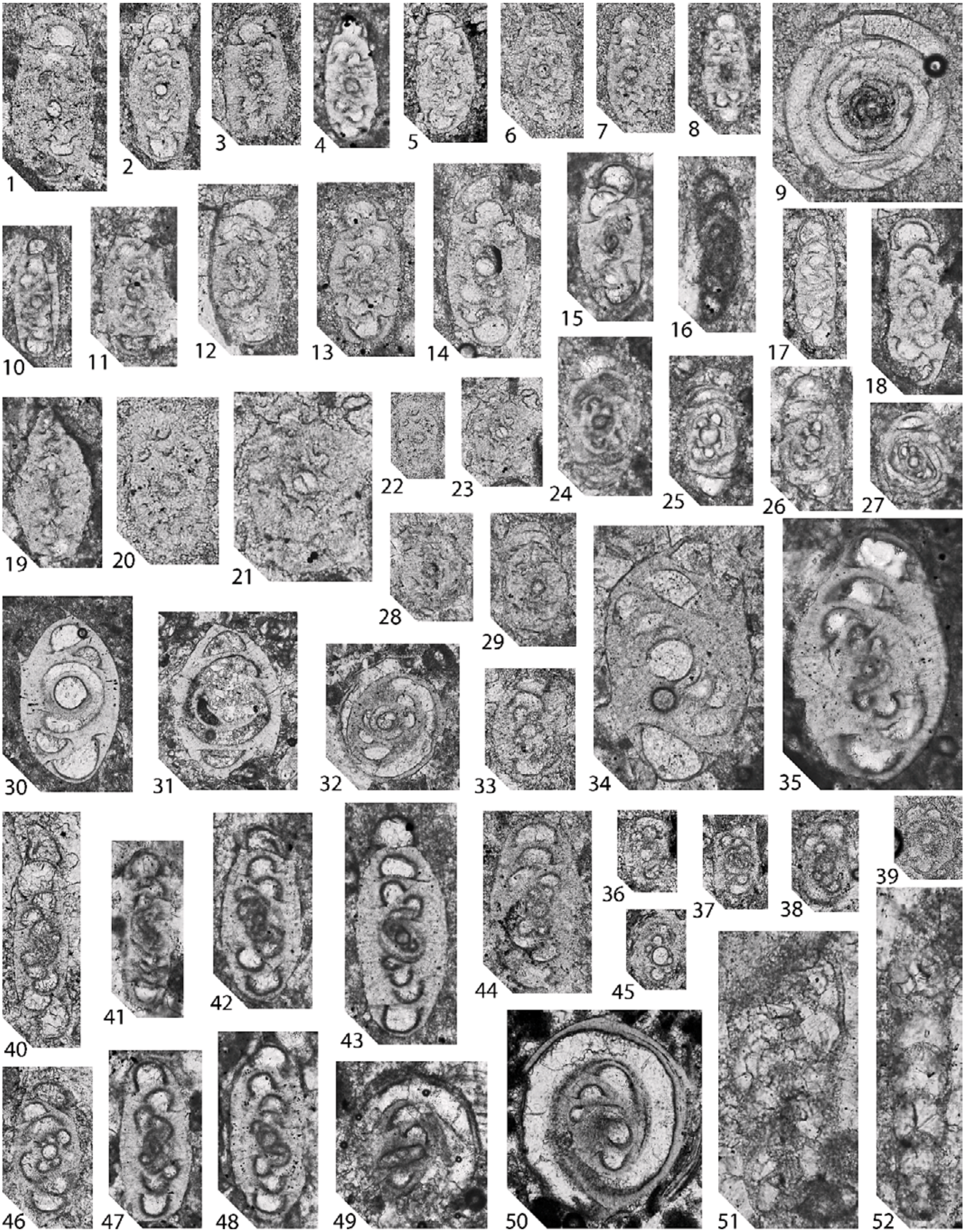
FIGURE *15*—*1–8*, *Neoarchaediscus probatus* (Reitlinger, 1950), axial sections, ×100: *1*, Yashui 60.7 m (153287); *2*, Yashui 74 m (153303); *3*, Yashui 48.9 m (153268); *4*, Yashui 55.4 m (153280); *5*, Yashui 71.75 m (153302); *6*, Yashui 51 m (153273); *7*, Yashui 51.85 m (153274); *8*, Yashui 30.2 m (153250); *9–15*, *Archaediscus* ex gr. *krestovnikovi* Rauser-Chernousova, 1948b, ×100: *9*, sagittal section, Yashui 1.2 m (153218); *10*, axial section, Yashui 51.85 m (153274); *11*, axial section, Yashui 50.35 m (153272); *12*, axial section, Yashui 1.2 m (153218); *13*, axial section, Yashui 50.35 m (153272); *14*, axial section, Yashui 37.45 m (153257); *15*, axial section, Yashui 49.45 m (153270); *16*, *Planoarchaediscus*? sp., tangential axial section, Nashui 57.3 m (153176), ×100; *17*, *18*, *Archaediscus* aff. *longus* Potievs'ka, 1958, axial sections, ×100: *17*, Yashui 69.55 m (153299); *18*, Yashui 50.35 m (153272); *19*, *Neoarchaediscus permodiscoides* (Reitlinger, 1950), near axial section, Yashui 34.15 m (153254), ×100; *20–23*, *28*, *29*, *Asteroarchaediscus rugosus* (Rauser-Chernousova, 1948b), oblique axial sections in which axial width is exaggerated: *20*, *22*, Yashui 48.9 m (153268), ×200 and ×100, respectively; *21*, *23*, Yashui 70.8 m (153300), ×200 and ×100, respectively; *28*, Yashui 74 m (153303), ×100; *29*, Yashui 13.2 m (153231), ×100; *24–27*, *Archaediscus* aff. *variabilis* Reitlinger, 1950, ×100: *24*, axial section, Yashui 29.6 m (153249); *25*, axial section, Yashui 30.2 m (153250); *26*, axial section, Yashui 38 m (153258); *27*, oblique sagittal section, Yashui 27.75 m (153247); *30–32*, *Archaediscus gigas* Rauser-Chernousova, 1948e, ×50: *30*, axial section, Yashui 27.2 m (153246); *31*, oblique, tangential section, Yashui 68.05 m (153297); *32*, sagittal section, Yashui 19.55 m (153237); *33*, *36–39*, *45*, *Paraarchaediscus pauxillus* (Shlykova, 1951), axial and near axial sections, ×100: *33*, Yashui 71.3 m (153301); *36*, Yashui 65.9 m (153294); *37*, Yashui 71.75 m (153302); *38*, Yashui 37.45 m (153257); *39*, Yashui 37.45 m (153257); *45*, Yashui 71.75 m (153302); *34*, *35*, *Archaediscus karreri* Brady, 1873, axial sections, ×100: *34*, Yashui 3.0 m (153220); *35*, Yashui 54.3 m (153278); *40*, *41*, *Paraarchaediscus* aff. *stilus* (Grozdilova and Lebedeva in Grozdilova, 1953), near axial sections, ×100: *40*, Yashui 68.05 m (153297); *41*, Yashui 13.7 m (153232); *42–44*, *46–48*, *Paraarchaediscus koktjubensis* (Rauser-Chernousova, 1948b), axial sections, ×100: *42*, Yashui 54 m (153277); *43*, Yashui 54 m (153277); *44*, Yashui 74 m (153303); *46*, Yashui 74 m (153303); *47*, Yashui 54 m (153277); *48*, Yashui 54.3 m (153278); *49*, *50*, *Paraarchaediscus maximus* (Grozdilova and Lebedeva, 1954), tangential, sagittal sections, ×50: *49*, Nashui 67.8 m (153201); *50*, Yashui 50.35 m (153272); *51–52*, indet. genus and species (biserial, hyaline-radial form), frontal and lateral longitudinal sections, both from Yashui 19.55 m (153237), ×200.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indicating that this species is of no value in marking the stadial boundary.

CONCLUSIONS

The Visean–Serpukhovian boundary is placed at 60.1 m above the base of the relatively deep-water Nashui section at the appearance of *Lochriea ziegleri* in evolutionary continuity with its ancestor, *L. nodosa*. The association of foraminifers from a ~20 meter interval centered about this boundary lacks age-diagnostic species, but contains ones whose previously established ranges were known to extend from the upper Visean into the lower Serpukhovian. Conodonts do not allow direct correlation from the Nashui section to the shallow-water Yashui section because of their paucity in platform interior limestones. Instead, the stadial boundary at Yashui is identified provisionally at 49 m above the base of the section on the appearance of "*tortula*-like" specimens whose first occurrence in the Serpukhovian hypostratotype (Novogurovsky Quarry, Moscow Basin) coincides precisely with that of *L. ziegleri*. Curiously, *Asteroarchaediscus postrugosus* and *Eolasiodiscus donbassicus*, reliable Serpukhovian markers elsewhere in Eurasia and North America, have not yet been observed at Yashui. Beds immediately beneath the appearance of "*tortula*-like" specimens are altered limestones associated with subaerial exposure profiles and they are nearly barren of foraminifers.

The Nashui section is one of two leading candidates for the basal Serpukhovian GSSP. The Yashui section contains abundant foraminifers but is not a suitable auxillary GSSP because of multiple subaerial exposure surfaces and the absence of definitive basal Serpukhovian markers. Together, however, the two sections allow detailed micropaleontologic characterization of the Visean–Serpukhovian boundary in southern Guizhou.

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