

# The biostratigraphic importance of conchostracans in the continental Triassic of the northern hemisphere

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**Abstract:** Conchostracans or clam shrimp (order Conchostraca Sars) are arthropods with a carapace consisting of two chitinous lateral valves. Triassic conchostracans range in size from 2 to 12.5 mm long and are common in deposits that formed in fresh water lakes, isolated ponds and brackish areas. Their dessication- and freeze-resistant eggs can be dispersed by wind over long distances. Therefore many conchostracan species are distributed throughout the entire northern hemisphere. In the Late Permian to Middle Triassic interval, several of these forms are also found in Gondwana. Many wide-ranging conchostracan species have short stratigraphic ranges, making them excellent guide forms for subdivision of Triassic time and for long-range correlations. The stratigraphic resolution that can be achieved with conchostracan zones is often as high as for ammonoid and conodont zones found in pelagic marine deposits. This makes conchostracans the most useful group available for biostratigraphic subdivision and correlation in continental lake deposits. Upper Triassic Gondwanan conchostracan faunas are different from conchostracan faunas of the northern hemisphere. In the Norian, some slight provincialism can be observed even within the northern hemisphere. For example, the Sevatian *Redondestheria* seems to be restricted to North America and *Acadiestheriella* n. gen. so far has been found only in the Sevatian deposits from the Fundy Basin of southeastern Canada. Here we establish a conchostracan zonation for the Changhsingian (Late Permian) to Hettangian (Early Jurassic) of the northern hemisphere that, for the most part, is very well correlated with the marine scale. This zonation is especially robust for the Changhsingian to early Anisian, late Ladinian to Cordevolian and Rhaetian to Hettangian intervals. For most of the Middle and Upper Triassic, this zonation is still preliminary. Five new genera, six new species and a new subspecies of conchostracans are described that are stratigraphically important.

Half of the eight stage boundaries of the Triassic have been defined by a bio-event within a marine Global Stratotype and Point (GSSP) locality, and these definitions have been accepted by both the International Subcommission on Triassic Stratigraphy and the International Commission on Stratigraphy. The remaining four stage boundaries are nearing final definition. In the Lower Triassic, both the base of the Induan (priority: Brahmanian) Stage (= base of Triassic) and the base of the next younger Olenekian Stage have been firmly defined. In the Middle Triassic, there is wide agreement that the defining species for the base of the Anisian Stage should be *Chiosella timorensis* in the GSSP candidate site at Desli Caira (Romania), but there has not yet been a formal vote on this. The base of the overlying Ladinian Stage, however, has been firmly defined. In the Upper Triassic, the base of the Carnian has been firmly likewise defined, but there is not yet a final definition for the boundaries of the overlying Norian and Rhaetian stages. A consensus has not been reached on a defining species for the base of the

Norian or its GSSP locality, but all of the different proposals under consideration do at least fall within a rather narrow stratigraphic interval. For the base of the Rhaetian, *Misikella posthernsteini* Kozur & Mock has been chosen as the defining species by the International Working Group on the Rhaetian stage, and the GSSP candidate locality at Steinbergkogel (Austria) has been studied in detail by a group under the leadership of L. Krystyn (Vienna) and presented to the participants of the International Conference on 'Upper Triassic Subdivisions, Zonations and Events' in Bad Goisern in the autumn of 2008. The base of the overlying Hettangian stage (= base of the Jurassic) has been defined (so far only by a working group) as the FAD (First Appearance Datum) of *Psiloceras spelae* Guex, Taylor, Rakus & Bucher.

The final definition of the Triassic stages within marine GSSP sections will be completed in the near future, but more than 50% of known Triassic rocks are of continental origin. Therefore, the main task of Triassic stratigraphers in the future will be subdividing and correlating terrestrial strata, both between

continents and to the international scale as defined in marine, mainly pelagic successions. Currently, lithostratigraphic subdivisions and correlations are used primarily in Triassic continental basins, and this generally works well within a basin that has numerous well-exposed outcrops in the basin center. These lithostratigraphic units, however, are difficult to correlate on a global scale with other continental successions, and it is still more difficult to correlate them with marine successions. Correlations have been attempted between these deposits by use of different fossil groups, by magnetostratigraphy, and by stratigraphic evaluation of carbon isotope trends. Among fossil groups, the most suitable are sporomorphs, conchostracans, terrestrial vertebrates and, to a minor degree, also megaplants, charophytes, ostracods, fresh water bivalves, fish remains, tetrapod footprints and arthropod trails.

Conchostracans have the highest biostratigraphic resolution power of all Triassic continental fossils, and in some intervals their resolution is as high as that of ammonoids and conodonts in pelagic marine beds. They have the widest distribution of identical species in both low and high latitudes, have the lowest level of endemism, and the lowest correspondence to palaeolatitudes (palaeo-provinciality) of all investigated Triassic continental fossils. Additionally, they can be found in a variety of facies including grey, black, green and red beds. Their potential for correlation with marine facies is high because they are not only common in fresh water deposits, but they also can be found in brackish deposits, deltaic marginal marine beds and on some bedding planes or in brackish intervals of very shallow marine deposits such as the Werfen facies in the Balaton Highland of west-central Hungary. In the present paper, a conchostracan zonation for the Triassic northern hemisphere is presented. In the Lower Triassic (and partly also in the Middle Triassic) many of the northern hemisphere guide forms also occur in parts of Gondwana (India, central, eastern, western and northern Africa, and South America). In the Upper Triassic, however, the Gondwanan and northern hemisphere conchostracan faunas are different.

### **General character, preservation and palaeoecology of fossil conchostracans**

Conchostracans or clam shrimp (order Conchostraca Sars) are Arthropoda of the Class Branchiopoda Latreille. They have a short, laterally-compressed body enclosed in a carapace consisting of two lateral valves. As the animal grows, it enlarges its carapace by adding bands of new shell material (called growth bands) that can be distinguished from older growth bands by a narrow line

(growth line) that marks the boundary between adjacent growth bands. The carapace typically has a chitinous composition and can range from 2–42 mm long, though among Triassic forms the range is 2–12.5 mm and usually 3–10 mm. The frequent preservation of the carapace as phosphatized shells indicates that there is, at least in some fossil groups, a low calcium phosphate content as well. Well-preserved fossil shells show a structure of several layers (Kozur 1982).

In the suborder Spinicaudata Linder, 1945, to which all Triassic conchostracans belong (see the next section), the shells have a very small to large umbonal area without growth lines and a generally (much) larger part with growth lines. Vertical radial ribs may be present that may bear nodes or short spines at the intersection points with the growth lines. The umbonal area is smooth or bears one, or rarely two or three, often elongate nodes. Exceptionally, the umbonal node is transformed into a long, hollow spine. Additional spines may be present along the dorsal and posterodorsal margins. The space between the growth lines is smooth, punctate, reticulate or has radial lirae or anastomosing lirae.

Usually only the carapace is preserved, but exceptionally even the body can be discerned. Often only prints of the valves are preserved, but these can be identified just as well as preserved valves. The preserved chitinous shells and their prints are most often strongly deformed in fine-grained sediments (claystones, sometimes in limestones). Such forms with shell deformation were often regarded as distinct species or even genera, but they are only variants of undeformed species as demonstrated by Kozur (1983), Kozur & Seidel (1983*a*) and Goretzki (2003) for Lower Triassic conchostracans. For this reason, the exact stratigraphic range and regional distribution of fossil conchostracans requires modern studies of continuous conchostracan-bearing sections with different modes of preservation, and older publications must be evaluated with caution.

Phosphatized carapaces are often undeformed. In limestones, conchostracan shells usually are also undeformed. In somewhat coarser-grained sediments (siltstones, fine-grained sandstones), the conchostracans are mostly undeformed, but finer details of the sculpture and above all the microsculpture in the space between the growth lines are not preserved. The best approach, where possible, is to study conchostracans both from claystones, shales or micritic limestones (for the microsculpture) and from siltstones or fine-grained sandstones for the undeformed outline of the carapace. Fresh-water limestones with conchostracans are rather rare, but they often contain the best-preserved fossil conchostracans (e.g. at Dalongkou in the conchostracan-rich 'Sesame cake beds').

The main habitats of living and fossil conchostracans are temporary, alkaline inland ponds and small temporary fresh-water lakes. They also can occur, however, in flood-plain pools, coastal flood-plains, coastal salt flats, and (in the case of some species) in brackish water estuarine facies or in deltaic plains with variable salt content (Webb 1979).

Conchostracan eggs can withstand long desiccation and, in many species, also tolerate long periods of freezing. These desiccation- and freeze-resistant eggs can be dispersed by wind and water over long distances. The life cycle from hatching to sexual maturity is very short, lasting only 5–23 days in modern species (Webb 1979). Therefore, conchostracans can occupy, even in semiarid and arid areas, small temporary lakes and ponds that exist for only a short time and are not necessarily even present every year.

### Classification of conchostracans

A robust classification of fossil and even living conchostracans (clam shrimp) has not yet been established. The order Conchostraca Sars, 1867 is often regarded as paraphyletic or polyphyletic and has been replaced by some workers with the orders or suborders Spinicaudata Linder, 1945 and Laevicaudata Linder, 1945, so the phyletic status of both the Conchostraca and the Spinicaudata (to which most of the living Conchostraca and nearly all fossil Conchostraca belong) remains uncertain. Sometimes the Cyclestherida Sars, 1899 are separated from the Spinicaudata as an independent order or suborder, and the Spinicaudata, Laevicaudata and Cyclestheriida are partly regarded as orders or suborders of the superorder Diplostraca Gerstaecker, 1866; this classification completely eliminates the order Conchostraca. In the present paper, we regard the superorder Diplostraca as containing the orders Conchostraca Sars, 1867 and Cladocera Latreille, 1829 (the latter commonly called 'water fleas'). According to Olesen (1998), the monophyletic character of the Diplostraca is generally accepted. Therefore the monophyletic character of the Conchostraca only needs to be discussed briefly.

The fossil record does not support a polyphyletic origin for the Conchostraca. Palaeozoic Conchostraca all belong to the Spinicaudata, and they do not show any indication of convergence toward different other branchiopod Crustacea, but rather are a fairly uniform group that is morphologically very similar to extant Spinicaudata. Even preserved soft parts, known only from a few fossil taxa, show no clear differences from living Spinicaudata. In the Permian and Triassic, all morphological transitions of the carapace outline can be observed between

forerunners of Cyzicidae among the Spinicaudata to Cyclestheriidae Sars, 1899. They are mostly thick-shelled genera that contain both species with a circular and an oval carapace outline, such as *Magniestheria truempyi* (Kozur & Seidel) with a circular shell outline in females and *Magniestheria mangaliensis* (Jones) with an oval outline. It is not until the Norian that two species appear in the Germanic Basin and in the Culpeper Basin of Virginia (USA) which are thin-shelled forms with a circular carapace outline. These species, representing an as yet undescribed genus, are the oldest examples of the Cyclestheriidae. In their shell morphology, the Cyclestheriidae have never diverged far from other Spinicaudata and should be regarded as a family of this suborder.

The Mesozoic Conchostraca are mainly Spinicaudata, though a few members of the Cyclestheriidae occur among them. The oldest species referable to the Laevicaudata have been reported from the Cretaceous (Tasch 1969), but it is only in the Eocene that typical fossil forms of the Laevicaudata appear (Shen *et al.* 2006). Thus, the fossil record supports the idea that the Conchostraca are a monophyletic group, and nearly all known Palaeozoic and Mesozoic Conchostraca are referable to the suborder Spinicaudata. The Cyclestheriidae seemingly evolved during the Late Triassic from the Spinicaudata. The position of the Laevicaudata cannot be evaluated from the fossil record, because they have not been found among Palaeozoic and pre-Cretaceous Mesozoic Conchostraca, and even in Cretaceous and younger beds they are rare. For this reason, we are concerned here only with the order Conchostraca and the suborder Spinicaudata.

Because soft parts of conchostracans are found only rarely, the taxonomy of fossil conchostracans is entirely based on features of the carapace. Size, outline, convexity of carapace, number and width of growth bands, position and size of the free umbonal area (without growth lines), sculpture, and microsculpture are all important for establishing the taxonomy of fossil conchostracans. In combination with other features, the maximum size of adult conchostracans sometimes can be used to separate taxa that belong to small and large Triassic species. This is possible because the smallest Triassic species are only 2–3 mm long, whereas the largest species are 8–12.5 mm long. In several Triassic lineages, a clear increase in size can be observed over time, often even within a single species lineage. Thus, the latest Brahmanian (latest Induan) to basal Olenekian species *Magniestheria subcircularis* is only 3–5.2 mm long (mostly around 3.5 mm), but the succeeding lower Smithian *M. truempyi* Kozur & Seidel can be up to 10 mm (5.2–10 mm) long. The late Spathian to Aegean *Euestheria albertii mahlerselli* Kozur & Lepper

is only 2.4–3.3 mm long, but the succeeding subspecies *Euestheria albertii albertii* (Voltz) from the basal Bithynian is larger (around 4 mm long) and becomes still larger in the lower Bithynian Grès à Voltzia where it can be up to 5 mm long. Finally, in the upper Bithynian Holbrook Member of the Moenkopi Formation, it can be up to 6–6.3 mm long (Kozur, Lucas & Morales, in prep.). Similar phylogenetic increases of size can be observed in the Upper Triassic genus *Shipingia*, where the largest *S. olseni* Kozur & Weems (up to 12.5 mm) occur immediately before its extinction at or near the end of the late Sevatian.

The outline of the carapace (including its length/height [l/h] ratio) is always an important taxonomic characteristic at lower taxonomic levels, but species with the same outline can belong to different lineages. Particularly important is the presence or absence of a straight dorsal margin, with or without distinct antero-dorsal and postero-dorsal corners. The height, degree and shape of rounding along the anterior and posterior margins are also important taxonomic characteristics. The l/h ratio may be different in females and males of the same species. Some special features of the outline, such as an incision in the upper part of the anterior margin, surrounded by an elevation, may be restricted to only one genus, for example, the Sevatian genus *Redondestheria* Kozur, Weems & Lucas (in Kozur & Weems 2005), but other similar features may be taxonomically important yet present in different lineages (e.g. a slight concave incision immediately below the straight dorsal margin in the upper part of the posterior margin, which in the Triassic is known in *Falsisca* Novozhilov, *Dictyonatella* Kozur, some *Vertexia* Ljutkevitch, and in *Eosolimnadiopsis gallegoi* Kozur). The outline of conchostracan shells can be strongly altered by plastic deformation, and this is common in claystones. Such deformation leads all too often to the creation of numerous synonymous taxa that simply represent different preservation of a single species.

The convexity of the carapace is sometimes important for supraspecific taxonomy, but generally it is not important for separation of species within the same genus. This characteristic can be accurately evaluated only in undeformed specimens that occur in somewhat coarser sediments such as siltstones, fine sandstones, or occasionally limestones. With some experience, carapace convexity can be reconstructed from flattened specimens. In species with strong carapace convexity, the umbonal area generally overreaches the dorsal margin, especially if the specimens are flattened.

The number and width of growth bands in some species are rather constant and characteristic for that species. In other species, they are highly variable

and represent only intraspecific variation. For example, the late Ladinian to early Carnian *Euestheria minuta* (von Zieten) consistently has 10–20 growth lines and thereby can be readily distinguished from the somewhat younger early Carnian *E. winterpockensis* (Bock), which has 19–46 growth lines. *E. winterpockensis* evolved from *E. minuta* by greatly increasing the number of growth lines (Kozur & Weems 2007), and this can be documented by the presence of transitional forms where there is a slight stratigraphic overlap in the occurrence of these two forms. The reverse trend is seen within the genus *Laxitextella*, where the stratigraphically oldest species *L. multireticulata* (Reible) has numerous and narrow growth lines, but the stratigraphically youngest species *L. freybergi* Kelber & Kozur has only a few very broad growth bands. In contrast, specimens of *Magniestheria mangaliensis* (Jones) have anywhere from 14–36 growth lines, yet there is no trend over time toward either an increase or decrease in the number of growth lines which can be used to distinguish different taxa.

Radial ribs or radially-arrayed lines of nodes also are important taxonomic features. Their presence or absence is a family level characteristic, but the number of radial ribs or the number of radial lines of nodes may constitute a generic character, a specific character or (in certain cases) only an intraspecific feature. Nodes generally develop where radial ribs intersect with growth lines. During evolution within a lineage, however, the radial ribs may disappear between the nodes leaving only the radial lines of nodes visible on the growth lines. In some advanced forms, the nodes may shift their position to the middle of the growth bands. The length of radial ribs or radially arranged lines of nodes are important for separation of species, but small variations in this trait are only an intraspecific feature. Whether radial ribs are obvious or rather subtle is an intraspecific feature. Generally, the stronger the node elevations are at the growth lines, the weaker the radial ribs are and vice versa. Presence or absence of spines at the dorsal margin and/or at the postero-dorsal corner of the carapace is an important characteristic for separating genera within the Vertexiidae, but these fragile features often are not preserved. Only the posterodorsal spine is robust enough to be usually preserved. The length of this posterodorsal spine can have taxonomic importance.

Position, size and sculpture of the free umbonal area (which lacks growth lines) is a very important feature for separating species, genera and even families. However, the entire ontogenetic growth series within a species must be considered. The small juvenile stages have a relatively larger free umbonal area than adults of the same species in

relation to the length and height of the carapace, because during growth more and more growth bands are added after the first few have formed around the free umbonal area. Simple nodes, elongated nodes, ribs or spines occur on the free umbonal area in many species, and these are also taxonomically important. These features mostly represent generic or familial characters, but in some genera their form and size distinguish different species. Hollow spines are only rarely preserved, because they stand vertically or obliquely on the free umbonal area. Therefore they only can be preserved as spines if they are squeezed onto the plane of the carapace, either in the umbonal area or beyond its dorsal margin. This means that they are much more frequently preserved on strongly deformed specimens than they are on undeformed specimens. Normally only the sediment fill within the basal part of a spine is preserved, which looks like a cone or conical node (Kozur 1983). This has resulted in different genera being established for different preservations of umbonal spines (Kozur & Seidel 1983a).

Another important taxonomic feature is microsculpture, if present. Most Lower Triassic conchostracans lack or have only very indistinct microsculpture, though as a group they include the widest array of species with distinct macrosculpture (e.g. umbonal spines, spines on the dorsal margin, radial ribs). In the Middle Triassic, several forms appear that have a distinct microsculpture, but species without microsculpture still are common. By the Upper Triassic, the number of taxa with distinct microsculpture exceeds the number of species without microsculpture or with only very weak microsculpture, and the differences in microsculpture can be used to separate genera and species.

Most common is a reticulation pattern on the external surface of the carapace. The polygons may be small to large and are a useful feature for distinguishing species. The arrangement of polygons also can be different, being arrayed in vertical or oblique lines (e.g. *Shipingia hebaozhaiensis* Shen) or lying parallel to the growth lines (e.g. *S. olseni* Kozur & Weems). Again, this is a useful feature to separate species. Often the microsculpture is arranged in radial lirae, a feature which also can be used to distinguish genera and species. These densely spaced radial lirae may occur in straight and parallel, irregularly curved, or anastomosing patterns, and such differences also can be used to separate species. Different types of microsculpture can be combined in a single species, for example, radial lirae may be developed on marginal growth bands, but reticulation is present on the inner growth bands and on the free umbonal area. Other types of microsculpture are a pitted surface or tiny, densely spaced nodes on the growth lines. These often represent the base of spines or hairs

on the growth lines (growth line setae) that usually are not preserved (e.g. Shen 2003; Shen & Zhu 1990). All of these different types of microsculpture, including combinations of them, can be used to separate species or sometimes genera.

### **Importance of conchostracans for the biostratigraphic subdivision and correlation of the continental Triassic**

In the Triassic, conchostracans are very common in sediments that formed in terrestrial and brackish environments. In brackish intercalations of marine beds (e.g. in the Werfen Beds of the Tethys and brackish intercalations of ammonoid-bearing beds in northeastern Siberia) these occurrences can be correlated accurately with the marine timescale by identification of associated conodonts, bivalves and sometimes ammonoids.

Radially ribbed conchostracans (e.g. *Estheriella*, *Lioleatina*) and spined conchostracans (e.g. *Cornia*, *Molinestheria* and *Vertexia*) are common during the Early Triassic. These are distinctive, short-ranging excellent guide forms that have a very widespread northern hemisphere-Gondwana distribution, especially during the Gandarian (junior synonym = Dienerian). The Gandarian was established by Mojsisovics *et al.* (1895) as the upper substage of the Brahmanian. It was well defined by the ammonoid faunas of the Lower Ceratite Limestone and Ceratite Marls of the Salt Range, Pakistan. Seventy years later Tozer (1965) established the Dienerian Stage for the same stratigraphic interval, and nobody has ever doubted that both units comprise the same time interval. We prefer to use the Gandarian Substage, partly for reasons of priority but also because the Dienerian was established in a lower diversity high latitude environment while the Gandarian was established in a low latitude environment that was much more favourable for defining an international stage or substage boundary.

The conchostracan zonation that has been established for Early Triassic continental deposits (Kozur & Seidel 1983a, b; Kozur 1993b, 1999a, b; Kozur & Weems 2007) is just as detailed as the ammonoid and conodont zonations established in pelagic marine deposits. During the Upper Triassic, forms with distinct microsculpture became dominant, and a number of these are also short-ranging species with very wide regional distribution. Conchostracans are quite possibly the best available fossil group for establishing detailed Triassic continental biostratigraphy that is cross-correlative with the standard marine timescale. This assertion is based on:

- The general abundance of conchostracan specimens in many continental to marginal marine settings.

- The high percentage of specimens that represent short-ranging species.
- The fact that conchostracans produce desiccation- and freeze-resistant eggs that are spread by wind, which allows them to occupy even isolated and temporary bodies of fresh to brackish water over broad geographical areas.
- The resultant widespread occurrence of short-ranging species over nearly all of the northern hemisphere and also over parts of Gondwana.
- The occurrence of some species in brackish-estuarine and deltaic environments, or in brackish intercalations between marine environments that contain conodonts and other marine guide forms, allowing cross-correlation with the marine timescale.
- The presence of many species of conchostracans in markedly different climatic zones, ranging from high latitudes to low latitudes.

The wind-transport of desiccation-resistant conchostracan eggs, in combination with their short life-cycle between hatching from eggs until sexual maturity, explains the very wide, transcontinental distribution of many fossil conchostracan species. Thus, the easily recognizable, short-ranging spined *Cornia germari* (Beyrich) can be found in the upper Gandarian (= upper Dienerian) of Greenland, the Germanic Basin, the Russian Platform, northern Urals, Pricaspian depression, Timan (northern Russia), Jakutia (northeastern Siberia), Sinkiang (Xinjiang, China), India, Gabon (Africa) and Australia. Additionally, it occurs in Hungary in brackish intercalations between conodont-bearing marine strata of the Werfen Beds (Kozur & Mock 1993), in Greenland and Jakutia (Russia) in brackish beds and brackish intercalations between marine beds, and in Jakutia with ammonoids. Other short-ranging species, for example, the radially ribbed *Esteriella costata* Weiss and *E. nodosocostata* (Giebel), have a regional distribution ranging from the Germanic Basin, across the Russian Platform and Gondwanan India to Angola. *Magniestheria mangaliensis* (Jones) occurs throughout the Lower Triassic of Eurasia (including brackish intercalations between marine strata of the Werfen Beds of the Tethys; Kozur & Mock 1993) and also in Gondwanan India and Angola. These few examples serve to show that, among Triassic Conchostraca, there are a number of short-ranging guide-forms that occur both in the northern hemisphere and in Gondwana.

Endemism is not a serious problem for establishing a comprehensive latest Permian through early Hettangian conchostracan zonation scheme. As conchostracans have drought and freeze-resistant eggs that are distributed readily by wind, widely scattered ponds in an arid area may have the same conchostracan fauna. Generally, conchostracans have a very

large regional distribution. The Late Permian low and high northern latitudes have a very similar fauna, and individual species of the family Leaiidae have been reported both from very high northern palaeolatitudes of northern Siberia and from high southern palaeolatitudes of southeastern Australia. The same species of Latest Permian and Early Triassic conchostracans often occur in Greenland, the Germanic Basin, the Russian Platform, Siberia, China, Gondwanan India and central and eastern Africa. Up to the late Ladinian, guide forms of the northern latitudes also have been found in parts of Gondwana. For example, *Euestheria minuta* (von Zieten) is present throughout the entire northern hemisphere and in Argentina as well.

This very wide distribution of many species of conchostracans in both in the northern hemisphere and across large parts of Gondwana ended during the Carnian. Upper Triassic conchostracans of Argentina, Brazil and Chile are very different from the conchostracan faunas of the northern hemisphere, and only in northwestern Africa do the same conchostracans occur as in the northern hemisphere. As this part of Gondwana in the Late Triassic was directly adjacent to the eastern United States and Canada, and also close to southwestern Europe, it is not surprising that its conchostracan fauna was much the same as that of the northern hemisphere. Within the northern hemisphere, many genera and species of Upper Triassic conchostracans are widely distributed. For example, the middle Norian species *S. hebaozhaiensis* can be found from China through the Germanic Basin, northwestern Africa (Morocco), and the eastern United States all the way to the southwestern United States.

By the Tuvanian and Norian, some endemism within the northern hemisphere can be observed. The conchostracan faunas of the southern Newark Supergroup basins and of the southwestern United States, which were at similar equatorial palaeolatitudes (0–5°N), are much more diverse, with dominant species that either do not occur farther north or occur there only very rarely. The biozonal guide forms of the northern Newark Supergroup basins and the Germanic Basin are present in these equatorial faunas, but often they also are rather rare. Thus, with adequate collecting, there are no serious problems with correlating the conchostracan faunas of these two areas, even though the overall complexion of their faunas is distinctly different.

By the late Norian, endemism becomes even more pronounced. For example, the genus *Redondestheria* Kozur, Weems & Lucas, which is common both in the eastern and southwestern United States, is absent in the Germanic Basin and China. Similarly, *Acadiestheriella cameroni* n. gen. n. sp. is restricted to the upper Norian of the Fundy Basin, and there to a single level.

However, there is a forerunner of this form in the Middle Triassic of the Germanic Basin, which is known from one specimen from the lower Anisian (Gall 1971) and one specimen from the upper Ladinian (Warth 1969). Thus, it is quite possible that *A. cameroni* has a much wider distribution than currently known, because it may be an extraordinarily rare form that had a very exceptional bloom within a single upper Norian horizon of the Fundy Basin. With the extinction of all known large species of conchostracans at the end of the Norian, the surviving small species again show a nearly ubiquitous distribution throughout the northern hemisphere.

## Previous work

### *North America and Europe*

Many groups of Triassic microfossils, today considered to be of exceptional stratigraphic importance, were in the 19th century either unknown (e.g. conodonts, holothurian sclerites, scolecodonts, charophytes, sporomorphs) or poorly known (e.g. foraminifers, ostracods, radiolarians). At most, somewhere between 1–5% of the presently known species of these groups were described in the 19th century. Triassic conchostracans, with a shell size range of 2–12.5 mm, lay at the boundary between microfossils and macrofossils, and in the second half of the 19th century they were relatively well known compared with the true microfossils of the Triassic. Depending on the stage, about 10–20% of the presently known and valid Triassic conchostracan species of Europe and North America were described in the 19th century.

Investigation of Triassic conchostracans began in the 19th century in the Germanic Basin of Germany (von Zieten 1833; Beyrich 1857; Giebel 1857; Jones 1862, 1863; Sandberger 1871; Weiss 1875), in France (Voltz 1835), in Great Britain (Jones 1862, 1863, 1890, 1891; Jones & Woodward 1894), and in the Newark Supergroup of the eastern United States (Emmons 1856, 1857, 1863; Lea 1856; Jones 1890, 1891). After this initial flurry of research, a long interval followed in all of these regions during which only a few new Triassic conchostracan species were described. These rare contributions include investigations by Picard (1911); Schmidt (1928); Raymond (1946); Defretin (1950), and Defretin-Lefranc (1963) for the Germanic Basin. In the Germanic Basin, modern work on Triassic conchostracans began with Reible (1959, 1962) and Warth (1969). Since that time, a number of modern papers concerning Triassic conchostracans and Triassic conchostracan stratigraphy in the Germanic Basin have been published (e.g. Alexandrowicz & Slupczynski 1971; Battarel &

Guérin-Franiatte 1971; Gall 1971, 1976; Kozur 1974, 1979, 1980, 1982, 1983, 1989, 1993a, b; Kozur & Seidel 1981, 1983a, b, c; Martens 1983, 2005; Kozur *et al.* 1993; Olempska 2004; Kozur & Weems 2006, 2007; Seegis 1997; Ptaszyński & Niedźwiedzki 2004, 2005, 2006a, b; Korte *et al.* 2007; Kozur & Hauschke 2008).

The taxonomy of Lower Triassic and lower Anisian conchostracans has been revised and an uppermost Permian to lower Anisian conchostracan biostratigraphy established (Docker *et al.* 1980; Kozur & Seidel 1983a, b, c; Mader 1984; Kozur 1993b, 1999a, b; Kozur *et al.* 1993; Ptaszyński & Niedźwiedzki 2004, 2005, 2006a, b; Kozur & Weems 2006, 2007; Kozur & Hauschke 2008) that has been correlated with palaeomagnetic succession, carbon isotope excursions, and Milankovitch cyclicity (Bachmann & Kozur 2004; Korte & Kozur 2005; Kozur & Weems 2006, 2007; Korte *et al.* 2007; Kozur & Hauschke 2008). In contrast, little work has been done on the taxonomy of Upper Triassic conchostracans of the Germanic Basin since Reible (1962) and Warth (1969). From the late 1960s until 2006, only two new genera, two new species, and one new subspecies were established from the Carnian of the Germanic Basin (Kozur 1982; Geyer 1987; Olempska 2004). Otherwise, Upper Triassic conchostracans only have been mentioned or illustrated (e.g. Hopf & Martens 1992; Reimann & Schmidt-Kaler 2002), or else described in open nomenclature (Seegis 1997). Recently, Kozur & Weems (2007; Appendix 1) described three new index species from the Tuvalian of the Germanic Basin. In the Arctic region, conchostracans have been reported from the Gandarian (Dienerian) of eastern Greenland (Defretin-Lefranc *et al.* 1969; Kozur & Seidel 1983a, b), where *Cornia germari* occurs.

The other classic region for early conchostracan research in the 19th century was the Upper Triassic to Lower Jurassic Newark Supergroup rift basins in eastern North America. Following the paper on this region by Jones (1891), however, only a few conchostracans were studied or described (Wanner 1926; Bock 1946; Raymond 1946). The first modern description of Upper Triassic conchostracans from the Newark Supergroup was by Bock (1953a), who shortly thereafter also published a brief taxonomic revision that replaced the generic name *Howellites* Bock, 1953 with *Howellisaura* Bock, 1953 because of homonymy (Bock 1953b). Other authors since 1953 occasionally have noted occurrences of conchostracans in the Newark Supergroup, but they either did not attempt any taxonomic designations or else used 'wastebasket' names (such as *Cyzicus* sp.) to describe them. In a few cases small photographs were shown, with insufficient magnification for accurate taxonomic determination, or else

drawings were presented (e.g. Gore 1986; Olsen 1988).

After Bock's work, the detailed study of Newark Supergroup conchostracans and their taxonomy languished until the work of Kozur and Weems (2005, 2006, 2007). Kozur & Weems (2005) described the upper Alaunian to lower Hettangian conchostracans of the Culpeper and Newark basins and established the first conchostracan zonation for that time interval. Kozur & Weems (2007) soon after presented an early Carnian to early Hettangian conchostracan zonation for the entirety of the Newark Supergroup and the Germanic Basin, the latter well correlated with the marine scale. The Germanic Basin and the Newark Supergroup of eastern North America have many Upper Triassic conchostracan species in common that occur in the same order of succession, but a great many other species in the Newark are undescribed or in need of major revision. Most of the new species occur in the southernmost rift basins (e.g. in the Durham and Sanford sub-basins of the Deep River Basin and in the Dan River–Danville Basin) which had palaeolatitudes around 0–5°N. This equatorial fauna is more diverse than the conchostracan fauna found in the northern rift basins (e.g. in the Fundy, Hartford, and Newark basins) which had palaeolatitudes around 10–15°N. Even in these more northerly basins, several new species are yet to be described. This will be done mainly in forthcoming papers, and only a few new taxa of exceptional stratigraphic importance will be described in the present paper.

Rich conchostracan faunas have been found in the southwestern United States (Texas, New Mexico, Arizona, and Utah). Spathian and lower Anisian conchostracans from Arizona will be described by Kozur, Lucas & Morales (in prep.). They are identical with the conchostracans of this age from the Germanic Basin. In contrast, very few of the Late Triassic conchostracans from this region have been described. These include *Anyuanestheria wingatella* (Tasch) from the Adamanian (late early Tuvanian to middle Tuvanian) 'Lake Ciniza' facies of the Bluewater Creek Formation, New Mexico (Tasch 1978), and *Redondestheria novomexicoensis* Kozur, Weems & Lucas and *Shipingia olseni* Kozur & Weems, both from the uppermost Sevatian part of the Redonda Formation, New Mexico (Kozur & Weems 2005, 2007).

### Asia

Unlike in Middle and Western Europe and the eastern United States, where few studies were conducted on conchostracans during the first two-thirds of the twentieth century, comprehensive work was being done then on Triassic conchostracans in the Russian part of the former Soviet Union on the

Russian Platform, in the Pricaspian Basin, and in Mangyshlak and Siberia. There, mainly Lower Triassic and lower Anisian conchostracans were described, which generally were the same as those from the Germanic Buntsandstein (e.g. Chernyshev 1934; Lyutkevich 1938; Novozhilov 1946, 1958, 1959, 1960, 1966, 1970, 1976; Novojilov [Novozhilov] 1958*a, b, c, d*; Novozhilov & Kapelka 1960, 1968; Zaspelova 1961, 1965, 1973; Molin 1965*a, b*, 1966, 1968, 1975; Molin & Novozhilov 1965; Defretin-Lefranc 1965; Budanov & Molin 1966; Blom 1969, 1974; Lopato 1972; Menner & Lipatova 1972; Kozur *et al.* 1983; Lipatova & Lopato 1985; Tuzhikova 1985; Sadovnikov & Orlova 1990, 1993, 1994; Sadovnikov 1997, 2008; Orlova 1999). In the Lower Triassic and lower Anisian, nearly the same fauna is present in the Germanic Basin and in Russia. Despite this, three to five times as many species were described from Russia. This is strictly a taxonomic issue, however, because for most species several synonymous species were erected that were based on different modes of preservation or on deformed specimens (Kozur 1982; Goretzki 2003). In Russia, 10–15, or even more, conchostracan species were often described from a single bedding plane, sometimes even from a single bedding plane within the small area of a borehole, and these on occasion were placed into more than 10 genera. It is highly unlikely that this many species of conchostracans would ever occur at a single horizon, for this is far more than have been demonstrated from a single locality anywhere else in the world. For example, in modern populations of one pond or temporary lake, or even on single bedding planes of Triassic lake deposits, usually one, two or at most three species can be observed (Kozur 1983).

Even species with very strong and characteristic sculpture were assigned to numerous different species and genera. For example *Cornia germari* (Beyrich), with its large, hollow umbonal spine, was assigned to 11 different genera and 21 different species. An additional nine species, assigned to *Cornia* and one other genus, also questionably belong to *Cornia germari* as shown by Kozur (1982) and Kozur & Seidel (1983*a*). Most or all of the latter forms probably belong to this species, but the type material has not been available for study, and the original descriptions and illustrations are inadequate to confirm or reject this synonymy. Investigations of Lower Triassic conchostracans from the Russian Platform by Kozur have shown that the same species with the same ranges occur there as in the Germanic Basin and that the number of species represented is similar. The presence of numerous synonyms among the conchostracans described from Russia also was confirmed by Goretzki (2003), who presented examples where



synonymous species, assigned to different genera, occurred on a single bedding plane of one slab.

Additionally, he demonstrated that many drawings of holotypes by Novozhilov do not accurately portray the characteristics of the species being described. Even so, the above mentioned papers by Novozhilov and Molin mark an important step in the research of Triassic conchostracans, because they demonstrated for the first time that conchostracans actually are widespread and even common in continental beds that until then had been regarded as sparsely fossiliferous or barren of fossils and because they highlighted the stratigraphic importance of Middle Permian to lower Anisian conchostracans. Since these earlier studies, conchostracans also have been reported from continental and brackish water sediments between, above or below marine sediments of the Arctic, for example, in the lowermost Triassic of northeastern Siberia or in late Olenekian (Spathian) sediments from the coastal region of the Laptev Sea in northern Siberia, close to the Olenekian type area (Molin & Novozhilov 1965).

Comprehensive taxonomic work on Upper Triassic and Liassic (Lower Jurassic) conchostracans has been undertaken in Asia, and in China there also has been work done on Lower and Middle Triassic conchostracans (e.g. Mansuy 1912*a, b*; Chi 1931; Kobayashi 1951, 1952, 1954, 1973, 1975, 1984; Chen 1974, 1982; Chang *et al.* 1976; Chen & Shen 1980, 1985; Liu 1982, 1987*a, b, c*, 1988*a, b*, 1989, 1990, 1994; Liu *et al.* 1990; Shen 1985, 2003; Li & Shen 1995). Many of these species have very widespread distributions, because they also are found in the Germanic Basin and in the Newark Supergroup.

### *Gondwana*

The study of Triassic conchostracans from Gondwana also began early with the work of Jones (1862). Today, conchostracans are known from all parts of Gondwana: southern, eastern, central and north-western Africa, Antarctica, Australia, northern India, and South America (e.g. Jones 1862, 1897; Newton 1910; Leriche 1913, 1914, 1932; Janensch 1927; Mitchell 1927; Marlière 1948, 1950; Teixeira 1950*a, b*, 1951; Defretin & Fauvelet 1951; Bock 1953*a*; Defretin 1953, 1958; Defretin-Lefrance 1967; Kato 1971; Cockbain 1974; Ghosh & Shah 1978; Tasch & Jones 1978; Ghosh 1983; Herbst & Ferrando 1985; Tasch 1987; Ghosh *et al.* 1988; Gallego 1992, 1996, 1998, 1999*a, b*, 2001*a, b*, 2005; Gallego & Covacevich 1998; Shen *et al.* 2001, 2002; Gallego *et al.* 2005, 2009; Shen 2006). Tasch (1987) published a monograph about the fossil conchostracans of Gondwana, including the Triassic forms. Even in central

Gondwana (Madagascar), where marine beds are very rare, Shen *et al.* (2002) recently described *Magniestheria truempyi* (Kozur & Seidel) from beds immediately below the second ammonoid zone of the Olenekian, thereby establishing an early Smithian age for this species.

Among Gondwanan conchostracans, the best known and described are the Middle and especially the Late Triassic conchostracans from South America. In general, the correlation of Gondwanan conchostracan faunas with the international marine timescale is not very precise. In the Lower Triassic and known parts of the Middle Triassic in large parts of Gondwana (northern India, central, eastern and northern Africa, South America), conchostracan faunas are present that are very similar to those found in the northern hemisphere. In the Upper Triassic, however, the conchostracan faunas of Gondwana are rather different from those found in the northern hemisphere. Only in north-western Africa (Morocco) are the same Upper Triassic conchostracans present as in the northern hemisphere. The conchostracan faunas of Australia and Antarctica are, so far as is known, different throughout the entire Triassic from the contemporaneous faunas in the northern hemisphere, though a few taxa are probably identical at the generic level (e.g. *Anyuanestheria* probably = *Menucoestheria*). Except where the same zones are present in both parts of Gondwana and the northern hemisphere, the Gondwanan conchostracan faunas will not be discussed in the present paper.

### *Tethys*

Some Triassic conchostracans have been described from the Tethys in Europe, Indochina, and from the margin of Panthalassa in Japan and Korea (Mansuy 1912*a, b*; Kobayashi 1951, 1952, 1954, 1973, 1975, 1984; Vadász 1952; Nagy 1959, 1960, 1968; Tintori *et al.* 1985; Kozur 1987, 1999*a, b*; Tintori 1990; Tintori & Brambilla 1991; Kozur & Mock 1993). These have been extremely important for correlating continental deposits with the well-established marine geologic timescale (Kozur 1999; Kozur & Mock 1993). They can occur in markedly different settings. They can be found in predominantly continental beds within the Tethys, such as in the Mecsek Mountains of Hungary or in Thailand. Often they occur in continental to brackish intercalations between marine beds, as in the westernmost Southern Alps, Japan and parts of Indochina. Occasionally they occur on single bedding planes or within a longer interval in very shallow water deposits that had variable salt content, such as in the Werfen Group of Hungary and in the Southern Alps. These occurrences may represent a temporary lowering of the salt content

in the local depositional environment. Specific bedding planes with numerous conchostracans do not contain marine fossils, though marine fossils may be common in the immediately underlying and overlying beds. For example, bedding planes with *Cornia germari* (Beyrich) occur between immediately overlying and underlying beds that contain the marine bivalve *Claraia aurita* (Hauer) in the Werfen Beds of Hungary (Kozur & Mock 1993). As the Werfen Beds contain most of the conchostracan zones from the basal Triassic up to the middle Spathian, this has been a great help in correlating marine biozones with terrestrial conchostracan biozones throughout this stratigraphic interval.

### Investigated regions

We have studied private conchostracan collections from: the Upper Permian to basal Triassic of Dalongkou and Xialongkou (Sinkiang = Xinjiang, NW China); the uppermost Permian to lowermost Hettangian of the Germanic Basin from northern, central and southern Germany, England, and southeast and southern Poland (Holy Cross Mountains, Upper Silesia); the Tethyan Triassic of the Balaton Highland (including boreholes), Mecsek Mountains (both Hungary), Werfen Beds of the Southern Alps and lower Carnian of westernmost Southern Alps (both Italy); Lower Triassic of Libya, Upper Triassic of Morocco; the Carnian to Hettangian of the Newark Supergroup basins in the eastern United States; the late Ladinian to Norian of the Fundy Basin in southeastern Canada; and the late Olenekian, early Anisian, and Carnian to Hettangian of the southwestern United States (Utah, Arizona, New Mexico, Texas); Middle and Upper Triassic of Argentina. From many of these areas we also have investigated material from museum collections, specifically the Naturkunde Museum (Stuttgart), the Institut für Geologische Wissenschaften at Martin-Luther-Universität (Halle), the Yale-Peabody Museum (New Haven), the Academy of Natural Science (Philadelphia), the United States National Museum (Washington), the North Carolina Museum of Natural Sciences (Raleigh), the Texas Tech Museum (Lubbock), the New Mexico Museum of Natural History and Science (Albuquerque), and the Museum of Northern Arizona (Flagstaff).

#### *Dalongkou (Xinjiang, NW China)*

During the Sino-American National Geographic Society project in Dalongkou (1996), in which H. W. Kozur took part, the stratigraphic section on the southern limb of the Dalongkou anticline was measured in detail by Dr. Spencer Lucas (New

Mexico Museum of Natural History and Science, Albuquerque), and sampled for conchostracans by Kozur. The measured section by Lucas is used here because all fossil data (not only conchostracan data) were correlated in the field with his cumulative section (recorded both in metres above the base of the Guodikeng Formation and metres below the top of the Guodikeng Formation). Additionally, both the distance between the FAD (First Appearance Datum) and LOD (Last Occurrence Datum) of important fossils and the thickness of conchostracan zones were noted. These measurements are distinctly different from an earlier Chinese measured section, but only slightly different from the measured section of Metcalfe *et al.* (2009), which unfortunately shows only the metres above the base or below the top of the Guodikeng Formation and not the distances between bioevents. According to the measured section of Lucas, the Guodikeng Formation is 234.7 m thick, while the section measured by Metcalfe *et al.* (2009) is 229.8 m, a difference of only about 2%. Using the measurements of Lucas, important data concerning the observed faunal changes and their distance from the Permian–Triassic boundary (PTB) were documented by Kozur (1998*a, b*), and the position of important bioevents was given in metres above the base of the Guodikeng Formation (Fig. 1). Unfortunately, all material that was obtained during the project (all palaeomagnetic samples and all conchostracan samples) was confiscated at the end of field work and, after 13 years, remains unavailable for study.

All large or distinctly sculptured conchostracans (*Bipemphigus*, *Falsisca*, *Megasitum*, *Trimpemphigus*) were identified by H. W. Kozur in the field, mostly to species level by a pocket-lens, and their range was correlated with the detailed measured section made by S. G. Lucas. Smaller conchostracan genera (even those with distinct sculpture such as *Tripemphigus*) and genera not described at that time (e.g. species of *Megasitum*) could be identified in the field only to genus level or to species groups. From the *F. eotriassica* Zone (described below) of the uppermost Zechstein upward, the conchostracan succession of Dalongkou is identical with the succession found in the Germanic Basin. Below this level, no conchostracans are present in the upper Zechstein of the Germanic Basin, but the conchostracan succession of Dalongkou coincides at the generic level and mostly even at the species level with the conchostracan succession in the Tunguska Basin in Siberia.

From this study of conchostracan ranges done during 1996 field work in Dalongkou, not only could the base of the Triassic be very precisely defined by conchostracans (Kozur 1998*a, b*), but it also could be shown that the base of the Triassic is not close to the FAD of *Lystrosaurus*, as generally



the nine-metre difference represents only a very short time interval. Thus when conchostracans are not present, the LOD of *Dicynodon* can be used as a proxy for recognizing the Permian–Triassic boundary, as in South Africa.

The first occurrence of *Lystrosaurus* at Dalongkou is not the FAD of this genus, but rather its local FOD (First Occurrence Datum) at Dalongkou. It occurs there within the *F. eotriassica* Zone, in the long normal interval that straddles the Permian–Triassic boundary (palaeomagnetic chron 'In.In' in Bachmann & Kozur 2004). In South Africa, *Lystrosaurus* begins in the short reversed interval (palaeomagnetic chron 'Or' in Bachmann & Kozur 2004) immediately below this long interval (Ward *et al.* 2005). Sediments representing this short reversed interval have not been found at Dalongkou, either because they were removed by local erosion that created a short gap (occasionally present in sub-aerial sediments and actually documented in some levels of the upper Guodikeng Formation) or else because they were not sampled. A combination of erosional thinning and lack of sampling of the thinned interval also is possible. In this critical interval, the section consists almost exclusively of mudstones, which were not sampled by Metcalfe *et al.* (2009). Metcalfe *et al.* (2009) have suggested that a short reversed horizon in the lowermost Guodikeng Formation and upper Wutonggou Formation corresponds to the short reversed interval that lies immediately below the long normal interval straddling the Permian–Triassic boundary. This view, however, contradicts all available biostratigraphic data. The basal Guodikeng and upper Wutonggou formations have conchostracan faunas with species that occur well below the top of the characteristic *Bipemphigus*–*Megasitum*–*Trimphemphigus* conchostracan fauna, but the short reversed horizon just below the Permian–Triassic boundary lies well above this fauna in an interval where these three characteristic genera are no longer present and the *Falsisca* species also are different. In the Germanic Basin, it can be shown that the top of this reversed interval lies in the lowermost *F. eotriassica* Zone, which begins in the Dalongkou section more than 100 m above the top of the short reversed interval documented by Metcalfe *et al.* (2009). The uppermost Permian short reversed interval often contains tuff fallout (as in the Nedubrovo Formation northeast of Moscow) or common volcanic microsphaerules (as in the lower Fulda Formation of Germany) and yields sporomorphs of the *Triquitrites proratus* Zone together with megaspores of *Otynisporites eotriassicus* Fuglewicz. *O. eotriassicus* is common in the upper Guodikeng Formation, but completely absent throughout the lower half of this formation (Metcalfe *et al.* 2009). As the top of the short reversed interval lies about 100 m below the first

appearance of *O. eotriassicus*, the palynological data and the conchostracan data are in agreement that the reversed horizon in the lowermost Guodikeng Formation and in the upper Wutonggou Formation are well below (and thus not correlative with) the short reversed horizon immediately below the long normal palaeomagnetic zone that straddles the Permian–Triassic boundary.

The reversed horizon that ends within the lowermost Guodikeng Formation corresponds to a reversed interval found in the uppermost Zechstein 3 and Zechstein 4, as shown by Szurlies (2007). This conclusion is supported by the Milankovitch cyclicity pattern. The Guodikeng Formation includes four readily recognizable short eccentricity cycles with five readily recognisable precession cycles. Thus, the Guodikeng Formation represents about 400,000 years of time, which means that the upper limit of the reversed horizon in the upper Wutonggou and basal Guodikeng formations must have been about 400,000 years before the end of Guodikeng Formation deposition and more than 350,000 years before the beginning of the *F. verchovjanica* Zone (= base of the Triassic). In the Germanic Basin, the top of the latest Permian short reversed palaeomagnetic interval lies about 200,000 years below the beginning of the Triassic (Bachmann & Kozur 2004) and, in the conodont-dated beds of central and northwestern Iran and in the Southern Alps, the top of the short reversed interval also occurred about 200,000 years before the beginning of the Triassic (Kozur 2007).

Previous descriptions of conchostracans from Dalongkou (Liu 1987, 1989) are rather difficult to evaluate because the taxonomy used is partly outdated. Important genera are assigned to other unrelated genera, such as the Permian genus *Megasitum* Novozhilov, which is assigned to the Gandarian (Dienerian) genus *Cornia* Lyutkevich. For other genera, such as *Tripemphigus* Novozhilov 1965, a junior synonym *Trinodus* Liu 1987 was established. *Falsisca* cf. *F. kanandaensis* Novozhilov (*sensu* Liu 1989) belongs to *Falsisca turaica* (Novozhilov, in Molin & Novozhilov 1965), and *Falsisca beijiangensis* Liu, 1987 is a junior synonym of *F. zavjalovi* (Novozhilov 1970).

In addition to the southern limb of the Dalongkou anticline, the northern limb of the anticline also was studied but not sampled in great detail. The conchostracan succession was found to be the same, and the so-called 'Sesame cake beds' (limestones with very well-preserved conchostracans of the *Beijianglimnadia*–*Bipemphigus*–*Falsisca*–*Polygrapta*–*Tripemphigus* fauna) are exceptionally well developed there. In the Xiaolongkou section, we mainly studied the c. 300 m-thick Lower Triassic Jiucaiyan Formation to determine the relationship between the LOD of *Lystrosaurus* and *Falsisca*. About 200 m above the base of the

Jiucaiyan Formation, there is a whitish sandstone that has in its upper part a thin intercalation of greenish-grey shale. The highest occurrence of *Falsisca* in the Xiaolongkou section is in these beds. By comparison to other sections, this interval is the highest possible LOD for *Lystrosaurus*. Thus, *Falsisca* seems to have the same uppermost range as the tetrapod *Lystrosaurus*, which does not occur above the Gangetian (upper Griesbachian).

The base of the Gangetian was excellently defined in Mojsisovics *et al.* (1895) as the base of the *Otoceras woodwardi* Zone s.l. (including the *Otoceras fissisellatum* fauna) and was included as the lower substage of the Brahmanian Stage in the Himalayas. This level corresponds to the FAD of *Hindeodus parvus*, which marks the base of the Triassic. The Griesbachian was established as a stage 70 years later on Axel Heiberg Island, Arctic Canada by Tozer (1965) and its base was defined by the base of the *Otoceras concavum* Zone. The lower Griesbachian is older than the FAD of *H. parvus*, and the second ammonoid zone of the Griesbachian has a Permian conodont fauna (e.g. Kozur 2007). Therefore, we use here and in the following sections the Brahmanian stage and the Gangetian substage in its original definition, because use of the Griesbachian substage would improperly put the lowermost substage of the Triassic partly in the Upper Permian and partly in the Lower Triassic.

### Germanic Basin

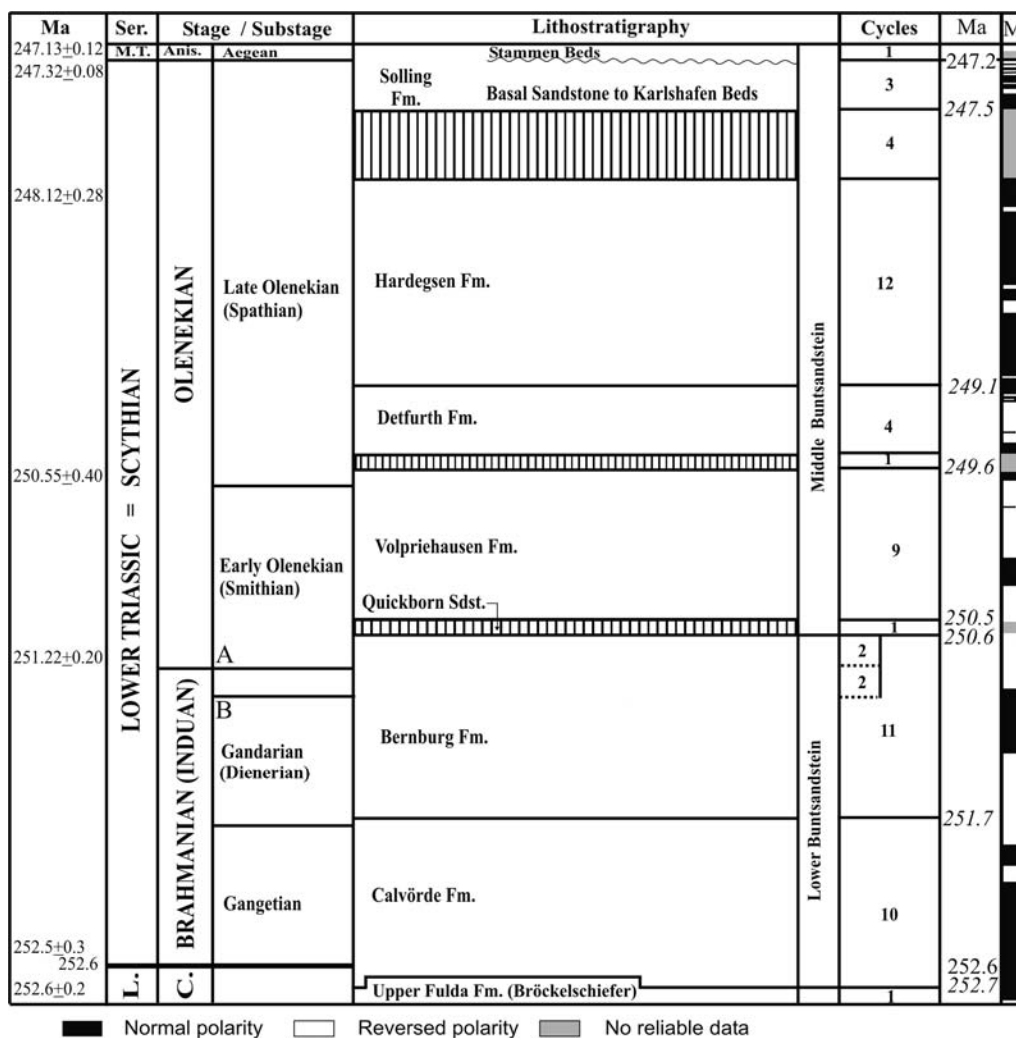
During the Triassic, the Germanic Basin (Central European Basin) was a large depocentre that extended (west to east) from England through the North Sea, the Netherlands, and northern and central Germany to eastern Poland and (north to south) from southwestern Sweden and Denmark through northern, central and western Germany, eastern France, and southern Germany to non-Alpine Switzerland and southeastern France. Depending on the position of sea level at any given time and the regional climate, very different sedimentation regimes were present in the basin, ranging from fluvial in the marginal areas (and sometimes also in the central parts of the basin, e.g. parts of the Schilfsandstein) to lacustrine, brackish, marine, or hypersaline (with large volumes of gypsum and halite) in the central part of the basin. Large flood plains and hypersaline flats also were present during some parts of the Triassic.

The strata within the Germanic Basin are divided into three groups; from the base, they are the Buntsandstein Group, the Muschelkalk Group, and the Keuper Group (Bachmann & Kozur 2004). It is this three-fold division that gave the Triassic System its name (von Alberti 1834). The Buntsandstein ranges in age from latest Permian to early Anisian, and mostly consists of continental deposits

together with early Anisian marine to hypersaline facies. The Muschelkalk ranges in age from early Anisian through late Ladinian and consists of marine to hypersaline facies. The Keuper ranges in age from late Ladinian through Rhaetian and consists of continental and hypersaline deposits interbedded with subordinate marine facies.

During deposition of the Lower and Middle Buntsandstein, there was a weak marine influence that originated from the northwest through a connection to the Boreal Sea. This connection allowed slightly brackish depositional environments to develop, especially during Olenekian time. During the Middle and Upper Triassic, connections to the Tethys in the south were present through gateways in the east to the Dobrogea–Küre Ocean, to the northern shelf of the Meliata Ocean through the Eastern Carpathian and Upper Silesian gates, and through gateways in the S–SW to the northwestern shelf of the Meliata Ocean through the Alemannic Gate (in the present Alpenrhein depression) and to the Westmediterranean Sea in southeastern France through the Burgundian Gate. The occurrence of these thin marine intervals in the Germanic Basin allows correlation of its conchostracan-bearing continental beds to nearby marine sections in the Tethys region (e.g. Kozur 1972, 1975, 1999a, b, 2005; Brack *et al.* 1999; Bachmann & Kozur 2004; Kozur *et al.* 1993; Kozur & Mock 1993; Urlichs & Tichy 2000; Kozur & Bachmann 2005, 2006, 2008b). Each marine interval is well mapped and contains a stratigraphically useful marine fauna. Sporomorphs also have yielded important data for correlating in detail the Germanic Triassic with the international marine timescale (e.g. Schulz 1967, 1996; Scheuring 1970; Lund 1977; Orłowska-Zwolinska 1983; Heunisch 1996, 2005; Fialkowska-Mader 1999; W. Wille, Mössingen, pers. comm.). In central and northern Germany, the conchostracan-rich Lower and Middle Buntsandstein mid-basin facies (uppermost Permian to lowermost Anisian) are well correlated across the central Germanic Basin and with the international scale as summarized in Bachmann & Kozur (2004) and in Kozur & Bachmann (2005, 2006, 2008b) (see Figs 2 & 3). Correlation with fluvial marginal facies in the southern Germanic Basin has been more difficult, because no conchostracans have been found there.

The correlation of the Germanic Lower Triassic with the international marine timescale has been well established. Differences in results between the various correlation methods do not exceed two or at most three short eccentricity cycles, a very low level of discrepancy for correlation of continental sequences with the international marine scale. Only the Olenekian–Anisian boundary within the Germanic Basin is controversial. Nawrocki & Szulc (2000) placed the base of the Anisian within the lower Jena Formation of the lowermost



**Fig. 2.** Formations of the Lower and Middle Buntsandstein (Lower Triassic) and their correlation with the international marine timescale, their numeric ages, Milankovitch cyclicity and palaeomagnetic normal and reversed intervals (slightly modified from Kozur & Bachmann 2008b). Palaeomagnetic intervals and Milankovitch cyclicity after Szurlies (2007), but with 11 cycles shown in the Bernburg Formation. Left column: Compiled new radiometric ages from the marine Lower Triassic after Galfetti *et al.* (2007); Lehmann *et al.* (2006); Mundil *et al.* (2004) and Ovtcharova *et al.* (2006). Right column: Extrapolated numerical ages for the Germanic Triassic in italic script; age of the base of the Triassic and the Anisian in normal script. **A**, Biostratigraphically correlated base of the Olenekian after Kozur & Seidel (1983), Kozur (1993, 1999a) and Kozur & Weems (2007); **B**, Olenekian base from palaeomagnetic correlation (Bachmann & Kozur 2004; Szurlies 2007). L., Lopingian Series; C., Changhsingian Stage.

Muschelkalk close to the base of Middle Triassic as originally chosen by von Alberti (1834). Brugman (1986) placed the Olenekian–Anisian boundary within the upper part of the Solling Formation in the Buntsandstein based on the FAD of the sporomorph *Hexasaccites thiergartii* (Mädler) Kozur. Bachmann & Kozur (2004) and Kozur & Bachman (2005, 2006, 2008b) placed the base of

the Anisian at the base of the Stammen Beds within the upper Solling Formation (Fig. 2). Hounslow *et al.* (2007) and Szurlies (2007) also placed the base of the Anisian within the Solling Formation using correlation of magnetic reversals to the marine record, but their boundary is slightly lower than that of Bachmann & Kozur (2004) and Kozur & Bachmann (2005, 2006, 2008b) because they

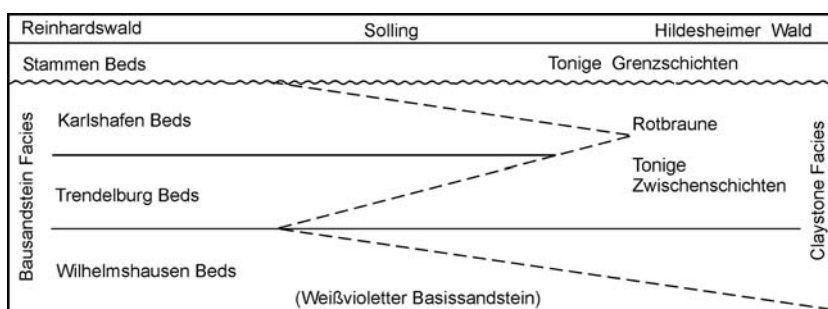


Fig. 3. Subdivisions of the Solling Formation in the Solling Mountains region (northwestern Germany). Wavy line represents a widespread unconformity of short duration within the Solling Formation.

placed the marine section base of the Anisian at a magnetic reversal slightly lower than the FAD of the conodont *Chiosella timorensis* rather than at its FAD. As the location of the base of the Anisian in the Germanic Basin falls within the upper Solling Formation, as determined by palynomorphs, conchostracans and palaeomagnetism, this correlation now seems to be well founded and is not likely to change to any great degree in future investigations. Therefore, we use this boundary.

Only a few new results can be added to the synthesis of Middle Triassic stratigraphic subdivisions, correlation with the international marine timescale, numeric ages and cyclicity sequence published by Bachmann & Kozur (2004) and Kozur & Bachmann (2005, 2006). The  $244.60 \pm 0.36$  Ma age determination for the *Balatonites shoshoensis* Zone (Ovtcharova *et al.* 2006) has been cited by Kozur & Bachmann (2008b), and it fits well with the data shown in Bachmann & Kozur (2004) and Kozur & Bachmann (2005, 2006). Similarly, the  $246.83 \pm 0.31$  Ma age determination for the *Platycuccoceras* beds Ovtcharova *et al.* (2006) fits well into the scheme proposed in Bachmann & Kozur (2004) and later papers by these authors. These new data are shown together with earlier data in Figure 4. The *Platycuccoceras* Beds correspond to the middle Bithynian. From a similar level Lehrmann *et al.* (2006) reported a  $246.77 \pm 0.13$  Ma age determination, described in more detail later by Galfetti *et al.* (2007). The age of the stratigraphic horizon from which this date was determined is not clear, because the conodont species *Chiosella gondolelloides* (Bender) and *Nicoraella kockeli* (Tatge) both are reported from this locality but they are not known to co-occur anywhere else. Most probably *N. germanica* (Kozur) is the species that is present instead of *N. kockeli*, together with a form transitional between *C. gondolelloides* to *N. germanicus*. Such a fauna is known to occur in Pietra dei Saracini in the Sosio Valley (western Sicily, Italy) in the lower to middle Bithynian.

It is within the Norian and Rhaetian parts of the Keuper that the largest remaining problems exist with the lithostratigraphic subdivisions of the sequence and their correlation within the Germanic Basin and with the international marine timescale. This is due to unclear stratigraphic definitions, mis-correlations, and because it is unclear exactly how many disconformities are present in the sequence and whether they are local or regional in nature. As is common in continental sequences, the continental sequences within the Germanic Basin include stratigraphic gaps at various horizons. In the Buntsandstein, these gaps have been recognized for a long time and often have been used as the boundaries between formations, though some are present within a formation (e.g. the intra-Solling unconformity below the Stammen Beds). In the Keuper, unconformities for a long time either remained undiscovered or were disregarded. Beutler has in several papers drawn attention to the numerous unconformities within the Keuper and has summarized his results in Deutsche Stratigraphische Kommission (2005). All unconformities are named as disconformities, but a few actually occur only locally and are erosional surfaces at the base of fluvial sandstone bodies (e.g. within the Schilfsandstein), a few others are paraconformities, and some reflect a sharp change in facies (e.g. a depositional shift from marine to limnic or to very slightly brackish depositional environments) that was incorrectly interpreted as a disconformity (such as the transition between the middle Rhaetian Contorta Beds and the Triletes Beds). Except for the unconformity at the base of the Schilfsandstein (Stuttgart Formation), which is a basin-wide unconformity caused by a very pronounced sea-level lowstand, other verifiable unconformities within the Keuper only occur at the basin margin or on swells within the basin. In the centre of the basin, these disconformities are either missing or only represented by subtle paraconformities.

Ma		Stage / Substage	Lithostratigraphy		Cycles	
237.0	MIDDLE TRIASSIC	LADINIAN	Grabfeld Fm. (Lower Gypsum Keuper) without "Estheria" Beds	Middle Keuper	1 9	
<b>238 +0.4/-0.7</b> <i>237.9 +1.0/-0.7</i>			Longobardian	Erfurt Fm. (Lettenkeuper)	Lower Keuper	8
<b>238.8 +0.5/-0.2</b> <i>239.0</i>						2
		Fassanian	Meißner Fm.	Upper Muschelkalk	28	
240.5		ANISIAN	CB	Meißner Fm.	Upper Muschelkalk	21
<b>241.2 ± 0.8</b>			Spinosus Zone			
			Illyrian	TB 10, base of <i>Compressus</i> Zone Trochitenkalk Fm.		12
				Diemel Fm.		1
				Heilbronn Fm.	M. M.	7
				Karlstadt Fm.		1
<b>244.6 ± 0.36</b>			Pelsonian	Schaumkalk Member	Lower Muschelkalk	3 9 21
			TB			
			Jena Fm.			
		Bithynian	OB	Lower Muschelkalk	9	
<b>246.83 ± 0.31</b>		DGB	Upper Buntsandst.	2 9 11		
	Aegean	Röt Fm.				
247.2		Stammen Beds of Solling Fm.				

**Fig. 4.** Lithostratigraphic subdivisions of the Germanic Middle Triassic and their correlation with the international marine timescale, Milankovitch cycles (short eccentricity cycles) and numeric ages. Slightly modified from Kozur & Bachmann (2008b). OB, Oolithbänke; TB, Terebratelbänke; CB, Cycloidesbank; MM., Middle Muschelkalk. Numeric ages in bold script are compiled measured radiometric data from the Tethys; numeric ages in italic script are calculated numeric ages for the base of the Anisian, Ladinian and Carnian stages, as well as for the Longobardian substage. DGB, Dolomitische Grenzbank which has the LO of *Costatoria costata* (Zenker) and the FAD of *Myophoria vulgaris* (von Schlotheim).

The largest single problem has been determining the age of the Trossingen Formation (better known as the Knollenmergel or Feuerletten), which contains the famous *Plateosaurus* site at Trossingen. Originally, the Knollenmergel strata were placed below

the Malschenberg Sandstone, formerly called the Bonebed- or Rhaetsandstein. Etzold & Schweizer (*in* Deutsche Stratigraphische Kommission 2005) recently have correlated the Malschenberg Sandstone with the '4. Stubensandstein' (s4) of the



Kraichgau region. Seegis (report to the Keuper Group of the Deutsche Stratigraphische Kommission, 2004 and pers. comm. to H. W. Kozur 2008) has found the lower Rhaetian ostracod species *Rhombocythere wicheri* (Anderson) in the 's4' of the Kraichgau region, which would seem to confirm the correlation of Etzold & Franz (2005) because they also reported *R. wicheri* from the Malschenberg Sandstone in the borehole Malschenberg 1. Therefore, the 's4' unit, as mapped in the Kraichgau region, can be re-assigned to the Malschenberg Sandstone, and its age can be established as early Rhaetian as in the borehole Malschenberg 1, where not only *R. wicheri* indicates an early Rhaetian age for the Malschenberg Sandstone but also early Rhaetian sporomorphs are present (Heunisch 1996).

Correlation of the Malschenberg Sandstone with the '4. Stubensandstein' of the Löwenstein area, however, is not supported by any palynological or palaeontological data. In the Löwenstein area, the Knollenmergel lies above strata assigned to '4. Stubensandstein,' which was correlated with minimal supporting data to the lower Rhaetian Malschenberg Sandstone. This correlation required that the Knollenmergel there had to be younger than the Malschenberg Sandstone, which would place it in the upper part of the lower Rhaetian. For this reason, the Knollenmergel either was placed in an exceptionally high stratigraphic level (and the strata below the Malschenberg Sandstone assigned to the 'Hangendletten 3' above the '3. Stubensandstein' instead of to the Knollenmergel) or else these strata were assigned to a lower Knollenmergel (to distinguish them from the 'Knollenmergel' above the '4. Stubensandstein,' which was therefore called 'upper Knollenmergel'). Etzold & Schweizer (in Deutsche Stratigraphische Kommission 2005) demonstrated that the Trossingen Formation (type Knollenmergel) in its type section begins above the 'Stubensandstein 2.3.' Thus, the oldest part of the type Trossingen Formation (Knollenmergel) corresponds to the 'Hangendletten 2' of the Stubensandstein. In the borehole Malschenberg 1, located in the immediately overlying basal part of the '3. Stubensandstein,' there is a conchostracan fauna with *Shipingia mcdonaldi* n. sp. and *Norestheria* n. sp., both of which indicate a middle Norian age for this fauna. Therefore, the lowermost part of the Trossingen Formation is middle Norian.

A distinct climate change occurred between the Norian and Rhaetian. The lower Rhaetian reflects a much wetter climate than was present in the Norian, so lower Rhaetian sediments are often grey and contain plant detritus. This makes it very improbable that the Knollenmergel strata could range from the higher part of the middle Norian all the way up to the upper part of the lower Rhaetian

without reflecting this climatic trend. This problem has caused Kozur and Andreas Etzold (Emmendingen) to investigate the age of the Knollenmergel and related problems in detail. In a personal communication to Etzold, Wolfgang Wille (Mössingen) has stated that the sporomorph association of the '4. Stubensandstein' does not correspond to the lower Rhaetian association of the Malschenberg Sandstone, but rather to the (Norian) sporomorph association of the '3. Stubensandstein.' This clearly shows that the '4. Stubensandstein' of the Löwenstein area has been incorrectly assigned to that unit and instead is older than the Malschenberg Sandstone and older than the lower Rhaetian. This important result of Wille's research indicates that Knollenmergel strata do not occur above the level of the lower Rhaetian Malschenberg Sandstone, but rather lie below this level. Thus, the lowermost part of the Trossingen Formation (Knollenmergel) is middle Norian in age, the Trossingen Formation lies below the lower Rhaetian Malschenberg Sandstone as previously believed, and most of the Trossingen Formation is Sevatian in age. *Plateosaurus* has not been found as low as the middle Norian part of the Knollenmergel at Trossingen, so therefore this famous dinosaur occurs in the Sevatian part of the Trossingen Formation at Trossingen. This is also true for the *Plateosaurus* occurrence at Halberstadt (Jaekel 1914; Sander 1992, 1999).

In Hallau (Switzerland), below marine Hettangian beds that are at most 2 m thick, there are other beds that begin with a thick compact Steinmergel and are overlain by greenish grey marls with thin dark layers that contain plant detritus. These wet-climate beds are surely younger than the typical reddish Knollenmergel beds, which lack dark layers with plant detritus. However, according to palynologic investigations by Achilles & Schlatter (1986), they are also older than Rhaetian (older than the Malschenberg Sandstone). Therefore, this interval seems to represent a sequence that in most areas was erosionally removed between the Knollenmergel and overlying middle Rhaetian or marine Hettangian beds.

The Rhaetian Exter Formation *sensu* Beutler (in Deutsche Stratigraphische Kommission, Menning *et al.* 2005) is not a very convincing stratigraphic unit. Duchrow (1984) originally introduced this name as the Exter Group and divided it into three formations: the lower Rhaetian brackish Rinteln Formation, overlain unconformably by the middle Rhaetian marine Oeynhausien Formation, in turn overlain by the upper Rhaetian to earliest Hettangian fresh water to slightly brackish Valbruch Formation. This subdivision still seems logical. As this problem remains to be discussed by Bachmann & Kozur (in prep.), we continue use of the 'Exter Formation' for now.

Only a few new biostratigraphic data points have been added to the Upper Triassic framework of the Germanic Basin since Bachmann & Kozur (2004). One new result is that the ostracod *Simeonella nostorica* Monostori has been reported from the Lehrberg Beds of the Weser Formation. This species is common in the marine lower Tuvallian of Hungary and in the marine lower Tuvallian of Austria. In Hungary, it occurs also in slightly hypersaline marine beds. Seegis (1997) illustrated well-preserved material of this species, but incorrectly assigned it to the late Julian species *Simeonella brotzenorum alpina* Bunza & Kozur, which is morphologically distinct. Other new biostratigraphic data in the Norian, Rhaetian and basal Hettangian are discussed below, under the relevant conchostracan zones.

The Triassic–Jurassic boundary in the Germanic Basin also is problematic. Generally, it is drawn where the fresh water to slightly brackish *Triletes* beds are directly overlain by marine ammonoid-bearing Hettangian beds. However, the lowest ammonoid occurrences in these beds generally are specimens of *Psiloceras psilonotum* (Quenstadt), which is probably a junior synonym of *P. sampsoni* (Portlock). This species is not known to occur as low as the base of the *P. planorbis* Zone, but rather first appears in the higher part of this zone. Although not yet officially defined, the proposed base of the Jurassic lies still lower than the *P. planorbis* Zone at the base of the *P. spelae* Zone. Marine beds in northern Germany below the Pylonotum Beds, generally without ammonoids, have been assumed to correlate with the ‘pre-*planorbis* beds,’ but in the central part of the Germanic Basin these beds probably are no older than the lower *P. planorbis* Zone. In western England (e.g. St. Audries Bay), the Rhaetian–Hettangian boundary is within marine beds, but even so diagnostic ammonoids of the *P. spelae* Zone are missing. In the central Germanic Basin, the fresh water to slightly brackish *Triletes* beds probably straddle the Triassic–Jurassic boundary. The exact position of this boundary is now under study in the temporary outcrop at the A4 highway at Moseberg in the western Thuringian Basin. The sporomorphs from this locality are being investigated by the Utrecht group (Kuerschner, Bonis) and values for  $\delta C_{org}$  are being evaluated by Kraus, Korte, Bachmann & Kozur. The initial negative carbon isotope excursion just below the base of the Jurassic probably lies somewhat below the Red Levallois Clays, which for the first time have been recognised in western Thuringia. This same level in France contains the monospecific *Euestheria brodieana* fauna, which is characteristic of the upper Rhaetian. At Moseberg, this level has not yielded conchostracans, but immediately below this level the monospecific *E. brodieana* fauna does occur.

The sporomorph and carbon isotope investigations will show whether the Red Levallois Clays correspond to the similarly red Schattwald Beds in the proposed GSSP for the base of the Hettangian at Kuhjoch, in the Northern Alps. If this proves to be the case, then the top of the Red Levallois Clays would represent the most practical mapping horizon for the continental Triassic–Jurassic boundary in the Germanic Basin because the FAD of *P. spelae* Guex, Taylor, Rakus & Bucher is immediately above the Schattwald beds. The beginning of the marine *P. sampsoni* beds in the Moseberg section is much higher than the Red Levallois Clays in this section. This indicates that the Liassic marine flooding of the Germanic Basin did not begin until well after the beginning of the Jurassic. No unconformity can be recognised above the Red Levallois Clays in the Moseberg section, so the unconformity D8 probably is not present either in the western Thuringian Basin or in northern Germany.

Conchostracans occur regionally and stratigraphically in various parts of the Germanic Basin. In the uppermost Permian to middle Spathian interval, they are common throughout the basin centre in northern and central Germany and in Poland, and can be found there nearly in every outcrop of shales and siltstones from the Calvörde Formation up through the Hardegsen Formation. Only in the upper Calvörde Formation is there an interval in which the dry Zechstein climate returned, producing hypersaline lake and sabkha deposits but no fresh water lake or pond deposits. During this time interval, conchostracans seem to have totally disappeared from the Germanic Basin, because in the uppermost Calvörde Formation a new immigrant fauna appears that is unrelated to the fauna below the arid interval. Throughout other intervals in the Lower Triassic, even in the marginal, mainly sandy facies of lake deposits in central Germany, conchostracans are common in shaly and silty intercalations, such as in the Großwangen region south of Halle. Sometimes conchostracans can even occur in sandstones, such as *Estheriella* species, that are found around Bad Salzungen in southern Thuringia. Conchostracans also are rather common in marginal facies in southeastern Poland (e.g. Holy Cross Mountains, Ptaszyński & Niedźwiedzki 2004, 2005, 2006a, b). In marginal facies in England, Lower Triassic conchostracans are very rare but still present. Surprisingly, no conchostracans have been reported from the predominantly fluvial Lower Triassic strata of Southern Germany, not even from shaly intercalations, and personal small-scale sampling for them so far has not been successful.

In the upper Spathian to lowermost Anisian Solling Formation, rich conchostracan faunas are found in surface outcrops only in northwestern

Germany, where rich conchostracan faunas can be found throughout most of the Solling Formation in the Solling Mountains. In the uppermost part of the Solling Formation (lowermost Anisian Stammen Member in the Solling type area) and the correlative Thuringian *Chirotherium* Sandstone, conchostracans are rather rare but do occur in Thuringia (Kozur & Seidel 1983a) and in the northern part of southern Germany (Kozur *et al.* 1993). In the lower Anisian Upper Buntsandstein (Röt), the eastern Germanic Basin and the basin centre in the northern Germanic Basin had marine and hypersaline environments that were not suitable for conchostracans, but conchostracans of this age can be found in the northern part of southern Germany, western Germany, and eastern France.

In the lowermost part of the Muschelkalk, conchostracans occur in the western marginal facies (Lorraine, France). The largest part of the Muschelkalk, however, formed in marine or (in the Middle Muschelkalk) in hypersaline environments and therefore does not contain conchostracans. However, in the Longobardian part of the Upper Muschelkalk, above the Cycloidesbank, conchostracans are locally common in shales found between the ammonoid-rich limestones and marls. These shales also have a brackish ostracod fauna with abundant *Pulviella teres* (von Seebach). The associated conchostracan fauna is very monotonous, consisting mainly of *Euestheria minuta* (von Zieten) and sometimes also *Euestheria franconica* (Reible).

A rich conchostracan fauna also can be found in the predominantly brackish Longobardian Erfurt Formation (Lower Keuper). Here also, *E. minuta* is almost always the only species present, though one specimen of *Liroleaia* n. sp. was found by Warth (1969). In contrast, conchostracans are very rare in the mainly hypersaline Longobardian part of the Grabfeld Formation (Lower Gypsum Keuper) below the Cordevolian 'Estheria' Beds. Where conchostracans do occur, the typical Longobardian monospecific *Euestheria minuta* fauna is found.

Rich conchostracan faunas occur in the 'Estheria' Beds of the upper Grabfeld Formation. The sporomorphs *Patinasporites densus* Leschik and *Vallasporites ignacii* Leschik have their lowest occurrences in the Germanic Basin in the basal 'Estheria' Beds, and their FAD lies close to the base of the Carnian at the GSSP Stuores Wiesen locality in the Southern Alps (Italy). Therefore, the base of the 'Estheria' Beds coincides with the base of the Carnian. As the FAD of *Laxitextella multireticulata* (Reible) also lies at the base of the 'Estheria' Beds, it is an excellent proxy for locating the base of the Carnian. Transitional forms between this species and *L. laxitexta* (Sandberger) occur in the westernmost part of the Southern Alps within the Cordevolian (Kozur & Mock 1993). In the

middle 'Estheria' Beds, the late Cordevolian conchostracan fauna characteristic of the *Laxitextella laxitexta* Zone occurs, which includes the first appearance of the genus *Gregoriusella* n. gen. From this level, *Gregoriusella* occurs upward into the lowermost Rhaetian. Rich conchostracan faunas also are found in the Basisschichten (Osterhagen Horizon) of the Schilfsandstein. The preservation of the recovered conchostracan is poor, however, though *Laxitextella* of the *L. laxitexta* group and *Gregoriusella* of the *G. fimbriata* group definitely are present. Rich conchostracan faunas occur also in lacustrine strata of the lower Schilfsandstein between the top of the Basisschichten and the Gaildorf Horizon. They are well-preserved but have not been studied yet in any detail. Several species belonging to the *L. laxitexta* group, however, definitely are present. A rich and diverse conchostracan fauna occurs also in the Gaildorf Horizon at the base of the upper Schilfsandstein. This fauna consists partly of new species of the *L. laxitexta* group, and also includes transitional forms between *Laxitextella* and *Anyuanestheria*, as well as *Palaeolimnadia* n. sp. The rich conchostracan fauna of the Schilfsandstein remains to be described.

During the Tuvallian, the distribution of conchostracans in the Germanic Basin became very restricted. Before the Tuvallian they occurred throughout the entire Germanic Basin, but in the Tuvallian they are absent in the hypersaline central parts of the basin and also in the fluvial deposits that formed within a narrow marginal belt around the basin centre. During the Tuvallian, they only occur in those marginal areas where fluvial fresh water input changed a spatially restricted marginal region of hypersaline marine environments into brackish water environments. Such environments have been found in some marginal areas around the inverse estuary of the basal Tuvallian Dolomie de Beaumont (e.g. at Stuttgart, Hausmannstrasse 44, which has a rich conchostracan fauna, Kozur & Weems 2007); and in eastern France in the Hombourg-Buange D 978 road cut, region Thionville (Bourquin & Durand 2006), or in larger fresh water lake to brackish areas around the hypersaline marine ingression of the Lehrberg beds in the eastern Germanic Basin of Poland (e.g. in Krasiejów, Upper Silesia) or in southern Germany (Seegis 1997). Conchostracans also occur in fresh water pond deposits close to rivers that terminated in hypersaline flats, as in the Coburg Sandstein (Hassberge Formation, upper Tuvallian; Fig. 5) of the Hassberge and Steigerwald regions of Franconia (northern Bavaria). The only conchostracan occurrences from the Coburg Sandstein in the Germanic Basin are (Kelber, pers. comm.): (1) Coburg Sandstein quarry just east of Passmühle in the Ebelsbach

Ma	Stage	Substage	Lithostratigraphy				
201.5	Rhaetian		Triletes Clay	Triletes Beds	Reddish Levallois Clays		
			Tübingen Sdst.	Contorta Clay	U. Contorta Clay Hauptsandstein L. Contorta Clay		
206	Norian	Sevastian	Trossingen Fm (Knollenmergel)	Malschenberg Sandstone	Postera Sandstone		
		Alaunian	4	1. - 4. Stubensandstein + 1. - 4. Hangendletten	Arnstadt Fm no or very rare Steinmergel	lower and middle Postera Beds	
		Lower Norian ("Lacian")	Löwenstein Formation		3	Arnstadt Formation (with common Steinmergel)	
225 ± 3 226	Carnian	Tuvalian	Mainhardt Fm (Heldburggips / OBM, pars)		Heldburggips	Weser Formation (Upper Gypsum Keuper)	
227.8 ± 0.3*			Hasberge Fm (Coburg Sandst., Blasensandst.)	Lehrberg Beds	Lehrberg Beds		
230.91 ± 0.33		Julian	Steigerwald Formation	Lehrberg Beds Rote Wand	Rote Wand		
			Stuttgart Formation (Schilfsandstein)				
237		Cordevolian	upper Grabfeld Formation ("Estheria" Beds)				

**Fig. 5.** Lithostratigraphic subdivisions of the Germanic Upper Triassic and their correlation with the international marine timescale and numeric ages. Modified after Kozur & Bachmann (2008b). Date with an asterisk [\*] is  $^{40}\text{Ar}/^{39}\text{Ar}$  data from the Adamanian of Ischigualasto, Argentina (Rogers *et al.* 1993), corresponding to a middle to late Tuvalian level between the Lehrberg Beds and the top of the Weser Formation. The  $230.91 \pm 0.33$  Ma date of Furin *et al.* (2006) is from the basal *Carnepigondolella zoeae* Zone, a level somewhat older than the Lehrberg Beds of the Weser Formation. The  $225 \pm 3$  Ma date (Gehrels *et al.* 1986, 1987) is from volcanics in the lower Norian *E. quadrata* Zone in SE Alaska. The 201.5 Ma date for the Triassic–Jurassic boundary is based on a biostratigraphic re-dating (Kozur & Weems 2007) as latest Rhaetian of the lower lava flow of the CAMP volcanics in the Newark Supergroup, and on radiometric data from a well-dated Rhaetian–Hettangian boundary section in Peru by Schaltegger *et al.* (2008). Calculated numeric ages for the base of the Carnian, Norian and Rhaetian stages are in italic script. Wavy line in the upper Arnstadt Formation represents an unconformity of short duration underlain by pedogenic sediments. Wavy line below the Contorta Beds represents an unconformity of short duration, especially where the Lower Contorta Clay is missing. 2.3, 3, 4, Stratigraphic position of the Stubensandstein subdivisions designated as Stubensandstein 2.3, Stubensandstein 3 and Stubensandstein 4; OBM, Obere Bunte Mergel; U., Upper; L., Lower.

valley, the enlarged quarry Fränkische Schleifsteinwerke GmbH (the former quarry Ankenbrand):  $50^{\circ}00'56.19''$  N;  $10^{\circ}40'55.52''$  E.; (2) Coburg Sandstein quarry Vetter, southeast of Eltmann:  $49^{\circ}57'37.74''$  N;  $10^{\circ}40'22.80''$  E (Reimann & Schmidt-Kaler 2002); and (3) Coburg Sandstein quarry at the Steinberg northwest of Obersteinbach:  $49^{\circ}54'31.07''$  N;  $10^{\circ}31'15.52''$  E (Reimann & Schmidt-Kaler 2002). Conchostracans occur in a

similar geological setting in the Heldburggipsmergel Member of the uppermost Weser Formation (borehole Groß-Schönebeck-1 at 778 m, northern Germany) and in the Weser Formation at the Schwanberg at Iphofen (Franconia, northern Bavaria). The occurrence in the Groß-Schönebeck-1 borehole is the only occurrence of conchostracans in the Weser Formation of northern Germany. According to Gerhard Beutler (pers. comm.), in this region

a significant fresh water influx prevented the accumulation of gypsum in the Heldburgipsmergel Member of the Weser Formation, which accords well with the occurrence of conchostracans in this region.

In the Norian and Rhaetian conchostracans again are found throughout the entire Germanic Basin, though at most localities they are rare. They are common only in a few levels, especially in the lower and middle Arnstadt Formation. In the upper Arnstadt Formation, they have been found only in northern Germany. Lower Rhaetian conchostracans have been found in boreholes in northern Germany, and also occur rarely in the western Thuringian Basin (e.g. the outcrop at the A 4 highway, 800 m west-northwest of Moseberg west of Eisenach) and in southern Poland (at Lipie, Upper Silesia). The upper Rhaetian monospecific *Euestheria brodieana* fauna is much more widely distributed and is found in England (Lilstock Formation), in northern Germany, in the Moseberg section in the western Thuringian Basin, and occasionally mentioned but not yet figured in southern Germany. Especially interesting is the occurrence of the monospecific *E. brodieana* fauna in the Red Levallois Clays at the very top of the Rhaetian section in eastern France (Battarel & Guérin-Franiatte 1971). This occurrence indicates that the genus *Bulbilimnadia*, common in the early Hettangian, was not present yet in the latest Rhaetian.

Conchostracans from continental basal Hettangian (correlative to the marine *P. spelae* Chron) deposits in the Germanic Basin so far have been found only in the lower Hettangian Sołtyków exposure, Holy Cross Mountains, Poland (Pieńkowski 2004; Pieńkowski & Niedźwiedzki 2009). SEM photographs and data detailing the age of this sequence, sent to us by Drs Grzegorz Pieńkowski and Grzegorz Niedźwiedzki (Warsaw), show that this fauna contains *Bulbilimnadia killianorum* Kozur, Weems & Lucas n. sp. This oldest Hettangian species also is found in the Culpeper Basin of Virginia (eastern United States) and in the upper Whitmore Point Member of the Moenave Formation in the St. George-Zion area of Utah and northern Arizona (western United States).

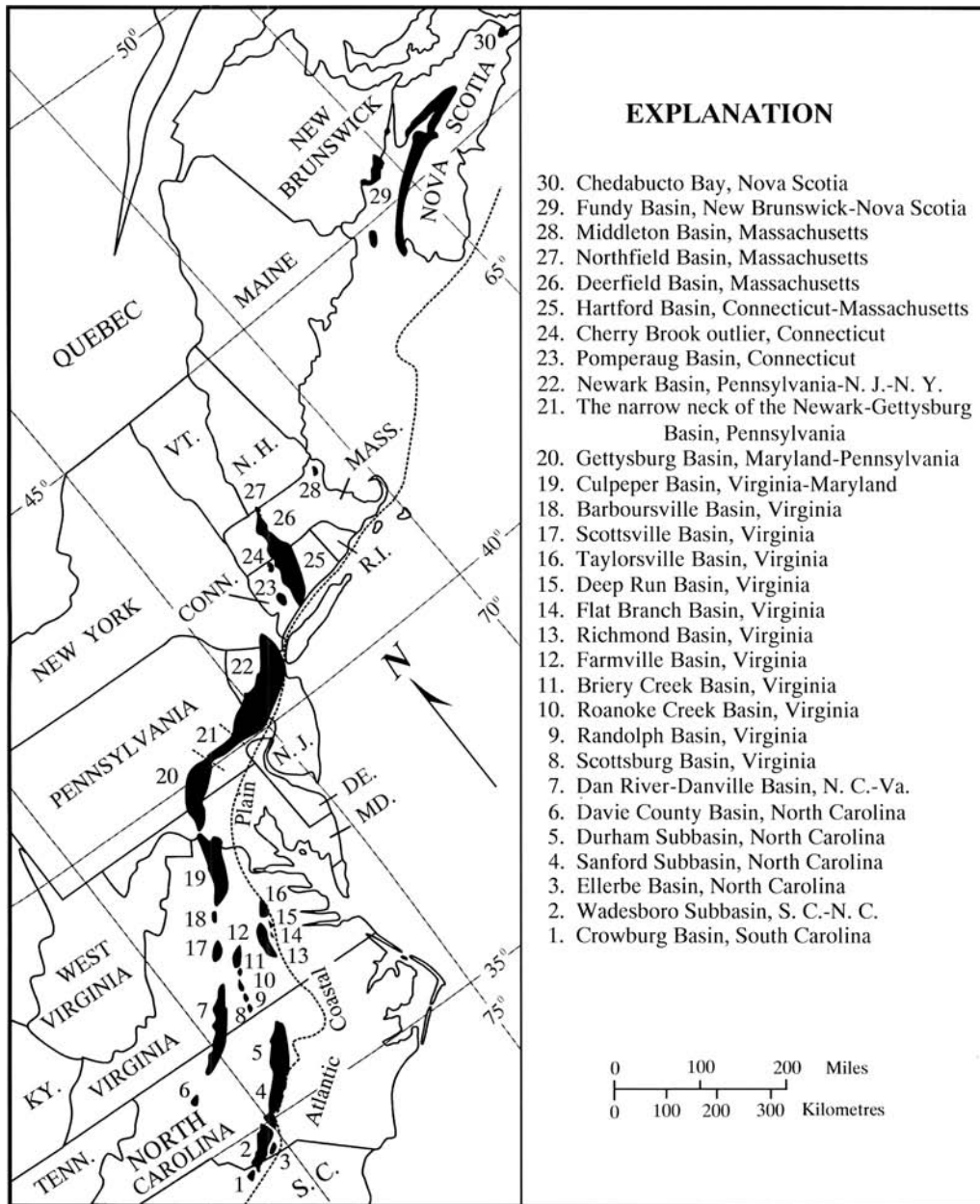
#### *Newark Supergroup rift basins*

The Newark Supergroup includes all strata and volcanic flows and tuffs deposited in 30 tectonic basins that filled mostly during the Late Triassic and earliest Jurassic in what is now the eastern United States and eastern Canada (Fig. 6). A comprehensive bibliography of much of the earlier literature concerning the Newark Supergroup is in Margolis *et al.* (1986), and Newark Supergroup stratigraphic nomenclature has been summarized thoroughly by

Luttrell (1989), including history of units, age of units, and location of type sections or areas. Since the summary of Luttrell, the only regional studies that have been conducted are by Weems & Olsen (1997) and Fail (2003). The stratigraphic nomenclature for formations and members followed here is that used by Luttrell (1989) and slightly modified by Weems & Olsen (1997).

Prior to the work of Weems & Olsen (1997), group names were established for individual basins, creating an unnecessarily complex stratigraphic nomenclature. Weems & Olsen (1997) chose instead to define only three regionally recognizable groups within the Newark Supergroup based on the common tectonic framework of the supergroup. These are the Chatham Group, which includes the pre-CAMP (Central Atlantic Magmatic Province) sedimentary sequence, the Meriden Group, which includes the CAMP volcanics and interbedded sedimentary sequences, and the Agawam Group, which includes the post-CAMP sedimentary sequence (Fig. 7).

Within the Chatham Group, Olsen (1997) recognized a regionally extensive unconformity that separated his tectonostratigraphic sequence TS II from sequence TS III. Kozur & Weems (2007) have confirmed the presence of this unconformity, because the youngest dated strata beneath this unconformity are early Cordevolian in age and the oldest dated strata overlying this unconformity are late Julian. This unconformity therefore encompasses some or perhaps all of late Cordevolian (late early Carnian) through early Julian (early middle Carnian) time. All strata in the small and shallow Scottsburg, Randolph, Roanoke Creek, Briery Creek, Flat Branch, and Deep Creek basins lie below this unconformity, and the basal strata of the Farmville (basal sandstone and overlying unnamed coal-bearing shale-rich unit), Richmond (Tuckahoe Formation and Vinita Shale), Taylorsville (Stagg Creek and Falling Creek formations), and Gettysburg basins (basal beds here informally named 'Irishtown beds') also are below this unconformity. The basal units of the Culpeper Basin (Seneca Creek Conglomerate, Reston Conglomerate, and Rapidan Member of the Manassas Sandstone) also probably lie below this unconformity, but definitive fossil evidence bracketing the age of the unconformity above these units is lacking. In the Newark Basin, Olsen & Rainforth (2003, fig. 4) have placed an unconformity between the Cutalossa and Prallsville members of the Stockton Formation. This also may represent the regional unconformity between TS II and TS III, and we also have noted that the Solebury Member of the Stockton Formation (which lies directly beneath the Prallsville Member) possibly belongs below this unconformity because of the occurrence there of an unusual amphibian not found



**Fig. 6.** Map showing the names and distribution of basins comprising the Newark Supergroup in the eastern United States and eastern Canada. Basins are numbered from south to north. Basin numbers match basin column numbers in Figures 8 through 10.

anywhere above the TS II–TS III unconformity (Kozur & Weems 2007). Definitive conchostracan or other evidence for this conclusion, however, is lacking.

Throughout the Newark Supergroup, Kozur & Weems (2005, 2007) have recognized a second

major stratigraphic unconformity, possibly as much as four or five million years in duration, which encompasses latest Norian and all but latest Rhaetian time (Fig. 7). This unconformity is located at the boundary between tectonostratigraphic sequences TS III and TS IV of Olsen (1997).

Age (Ma)	Period	Stage	Substage	Fauna-chron	Super-group	Group	Defining Character
201.5	LOWER JURASSIC (part)	Sinemurian		Dawan	NEWARK SUPERGROUP		Hiatus
		Hettangian		Wassonian		Agawam Group	Post - CAMP deposition
	UPPER TRIASSIC	Rhaetian		Apachean		Meriden Group	CAMP basalt flows + sediments
		Norian	Sevatian	Revueltian		Chatham Group	Pre-CAMP deposition Hiatus
			Alaunian				Pre-CAMP deposition
			Lacian				
		Carnian	Tuvalian	Adamanian		Hiatus	
			Julian	Otischalkian			
			Cordevolian	Pre-CAMP deposition			
		MIDDLE TRIASSIC	Ladinian			Berdyankian	
	Anisian			Perovkan			Lower Economy beds
	LOWER TRIASSIC	Olenekian		Nonesian			Hiatus
		Induan		Lootsbergian			

Fig. 7. Graphic representation of the age ranges of the groups within the Newark Supergroup. Stratigraphy after Weems & Olsen (1997). CAMP is an acronym for Central Atlantic Magmatic Province.

Although Olsen did not recognize an unconformity at this boundary, he did note 'sediments interbedded and overlying the basalts typically have much higher sedimentation rates than underlying sequences. . .'. As the TS I–TS II and TS II–TS III boundaries are both marked by significant unconformities (Olsen 1997), and as there is a sudden major increase in the rate of deposition with the beginning of sequence TS IV as described above, it is not surprising to find that an unconformity also marks the TS III–TS IV boundary. In most basins, modern erosional rubble from the basal lava flows has

obscured this contact. However, in the exposure near Old Wife Rock in the Fundy Basin of Nova Scotia, this low angle unconformity is prominently exposed at the top of a thick whitish paleosol that formed during the interval of nondeposition before the accumulation of the North Mountain Basalt (shown on the cover of Olsen *et al.* 1989). An angular unconformity also has been recognized in the Deerfield Basin between the Upper Triassic Sugarloaf Arkose and the Lower Jurassic Fall River beds (Hubert & Dutcher 1999), and it also is inferentially present in at least the northern Hartford

Basin because the basal Talcott Basalt is missing there as it is in the Deerfield Basin to the north (lost within this unconformity). In the Newark and Culpeper basins, the extremely condensed Rhaetian section indicates that an unconformity is present, but sufficient outcrops to demonstrate this conclusively have not been found.

The stratigraphy of those basins that have produced conchostracans is briefly summarized below. Numbers refer to the basin number designations that are used in Figures 6, 8–10. We have made some fairly significant changes in interpretation since Kozur & Weems (2007), and these are discussed below.

#### *Sanford and Durham Sub-basins of the Deep River Basin (4, 5)*

The first major work on the Deep River Basin was done by Emmons (1856), who referred to the entire stratigraphic sequence as the ‘Chatham series’ but did not erect a more detailed stratigraphy for units within any of its constituent sub-basins. Campbell & Kimball (1923) later established names for units within the middle Sanford Sub-basin, and these were mapped in considerable detail by Reinemund (1955). The units recognized were (from oldest to youngest) the Pekin, Cumnock and Sanford formations. The Pekin and Sanford formations are lithologically similar redbed formations, but they are readily distinguished in the Sanford Sub-basin by the presence of the intervening Cumnock Formation, which contains abundant brown, tan, grey, green, and black shales and coals that formed in paludal to lacustrine depositional environments. This is the interval from which Bock (1953a, b) described *Howellisaura berryi* (Bock). Unfortunately, the Cumnock lithology only can be traced into the southernmost Durham Sub-basin. Therefore, the central and northern depositional sequences in that sub-basin are not so readily divided because they mostly are redbeds from bottom to top. Hoffman & Gallagher (1989) divided the stratigraphic sequence in the Durham Sub-basin into three successive lithofacies associations, of which their ‘lithofacies association I’ corresponds rather closely to all of the Pekin Formation and most of the Cumnock Formation. Their ‘lithofacies association II,’ well exposed in the Triangle Brick Quarry pit, in the past has been correlated with the lower part of the Sanford Formation (e.g. Huber *et al.* 1993a, fig. 8; Lucas *et al.* 1998). However, the conchostracan fauna preserved within this red, but lacustrine, stratigraphic interval is virtually identical with the conchostracan fauna that occurs near the top of the Cumnock Formation in the Sanford Sub-basin, indicating that ‘lithofacies association II’ instead is correlative with the

uppermost part of the Cumnock Formation. This leaves ‘lithofacies association III’ as being correlative with all of the Sanford Formation.

Kozur & Weems (2007) placed the age of ‘lithofacies association II’ at the base of the Norian, citing the occurrence of the reptile *Aetosaurus* in the Triangle Brick Quarry pit which Lucas *et al.* (1998) suggested appeared no earlier than the base of the Norian. An earlier origin for *Aetosaurus* has been suggested based on phylogenetic evidence presented by Sues *et al.* (2003), but this has been disputed (Lucas 2010). The recent report of dicynodont bones from this pit (Peyer *et al.* 2008) in the past would have added a Carnian flavor to the fauna found there, but this is no longer the case as a Norian (or perhaps even Rhaetian) dicynodont has been documented recently in Poland (Dzik *et al.* 2008). Thus, based only on evidence from vertebrates, ‘lithofacies association II’ is best interpreted as representing early Norian (Lacian) time. The conchostracans from the Triangle Brick Quarry provide an even more definitive age for this unit. They are species characteristic of the *Euestheria buravasi*–*Euestheria* n. sp. Zone, which occur in the Germanic Basin in the lower Norian lower Arnstadt Formation (lower Steinmergelkeuper). This fauna is quite different from the fauna found in the uppermost Carnian, which includes *Laxitextella freybergi* Kelber & Kozur and other late Tuvalian guide forms that also occur in the uppermost Carnian of the Newark Supergroup (e.g. the Fulton site in the Gettysburg Basin, Fig. 8). Below the *Euestheria buravasi*–*Euestheria* n. sp. Zone, there is in the Germanic Basin a very short interval in the basal Norian that is characterized by a monospecific fauna of *Palaeolimnadia schwanbergensis* Reible. This fauna occurs also in the basal Norian Warford Member (basal Passaic Formation) of the Newark Basin. In southeastern Asia, *Euestheria buravasi* Kobayashi also occurs in the lower Norian. Thus, the conchostracan fauna from the Triangle Brick Quarry section belongs to the lower Norian close to, but a little above, the Carnian–Norian boundary in agreement with Lucas *et al.* (1998).

#### *Dan River/Danville Basin (7)*

Early reconnaissance mapping suggested that there were two different basins in this area, but subsequent detailed mapping demonstrated that only a single elongate basin is present. The location of this basin, astride the North Carolina–Virginia border, resulted in the creation of two different stratigraphies for the constituent strata. Meyertons (1963), working in the northern Danville (Virginia) end of the basin, recognized a basal Dry Fork Formation that generally is overlain by, but partly



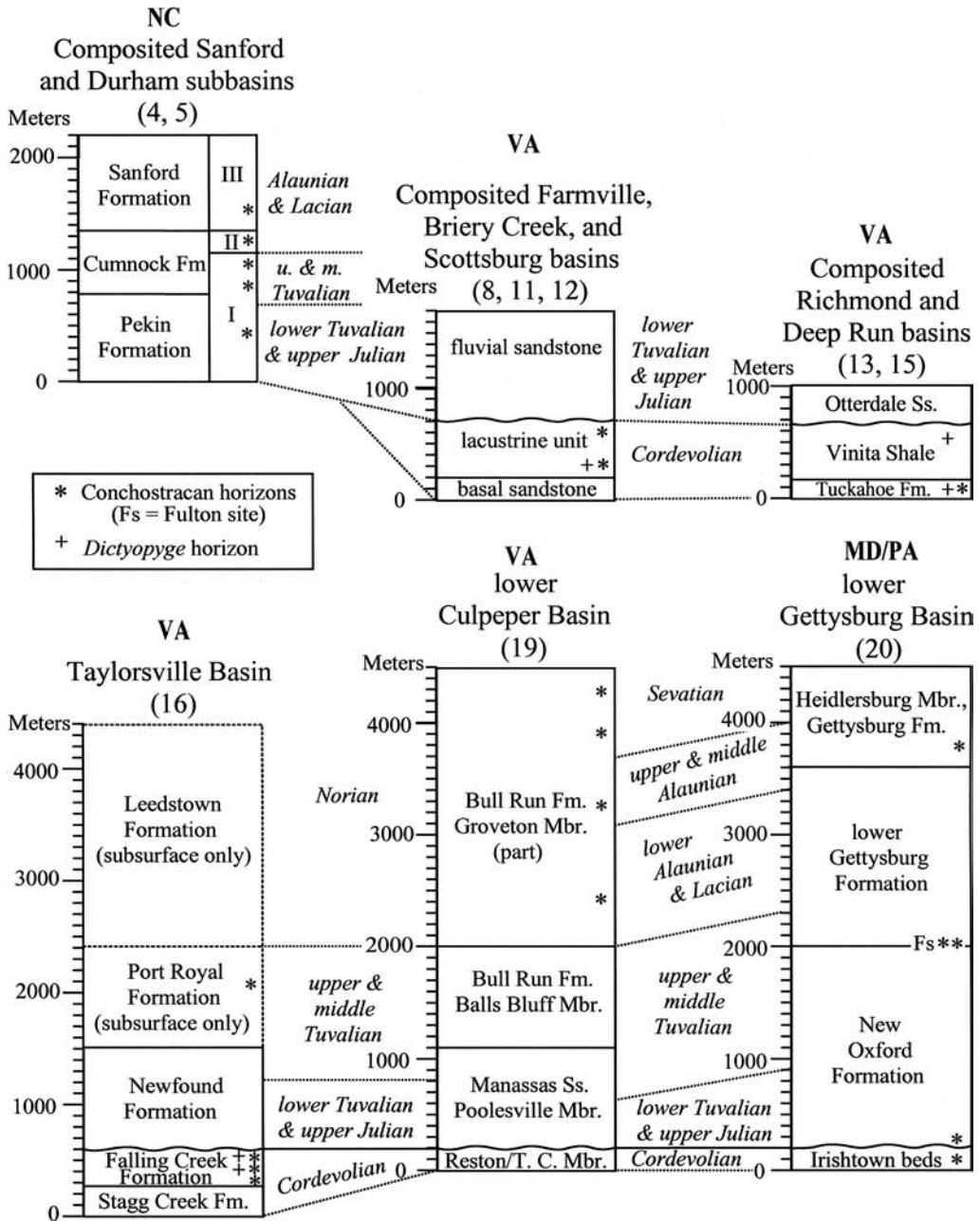
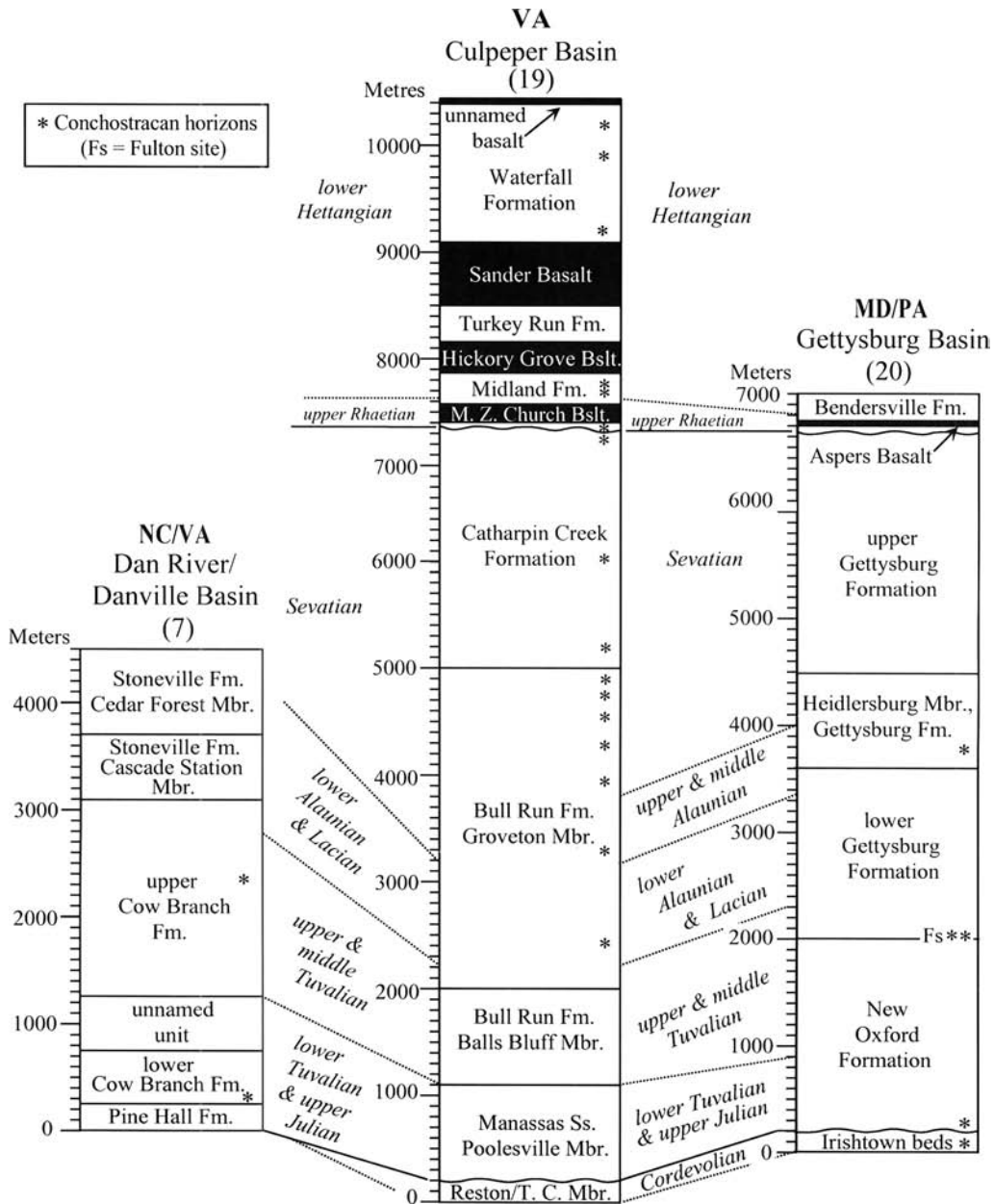


Fig. 8. Correlation chart of the lower strata in the southern and central part of the Newark Supergroup, showing their stratigraphy and the biostratigraphically important horizons in each basin.

intertongues with, a Leakesville Formation, which in turn is overlain disconformably by a Cedar Forest Formation. Within the Leakesville, Meyertons recognized two intertonguing members: the Cow Branch Member and the Cascade Station Member.

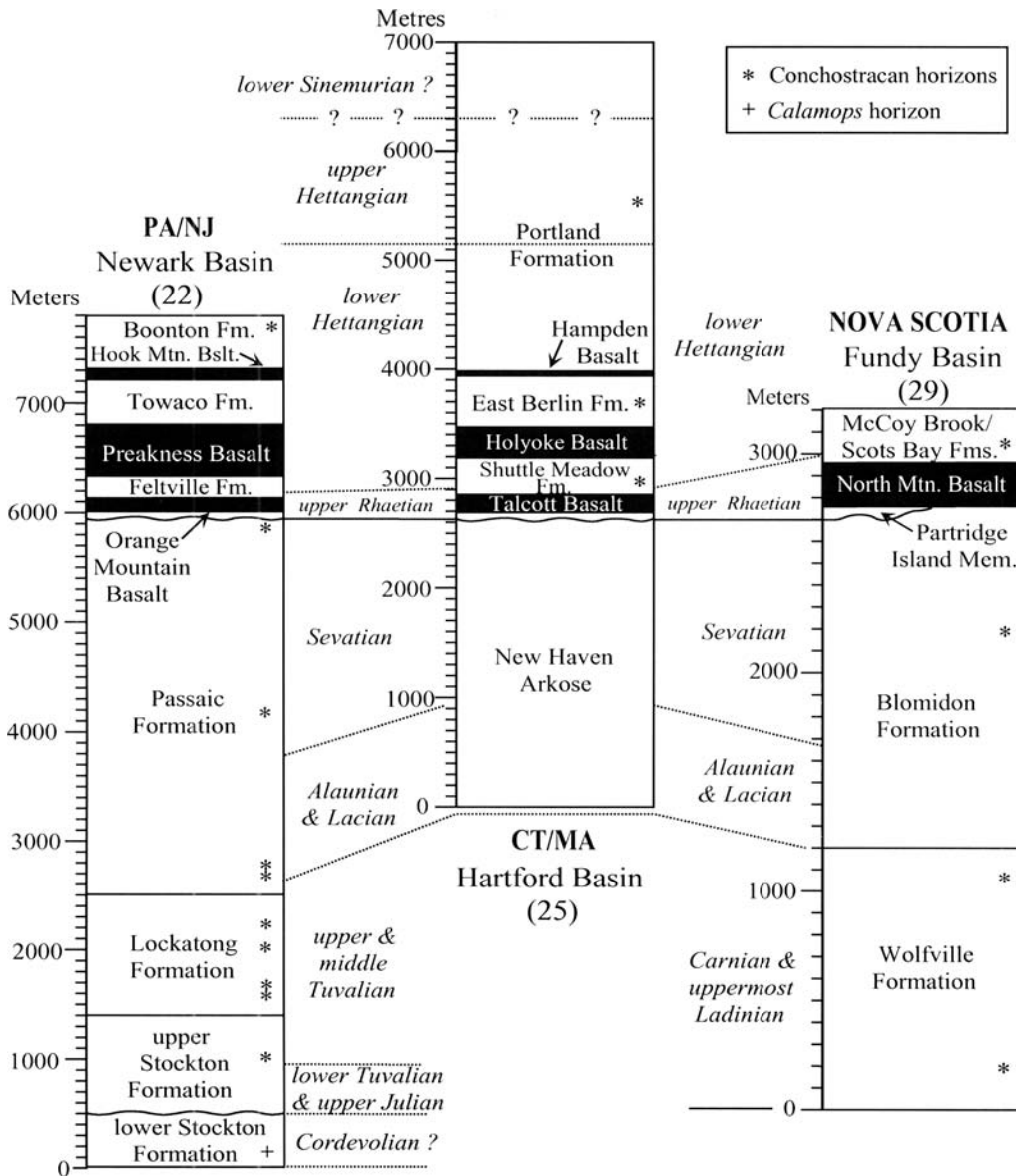
Thayer (1970), mapping in the southern Dan River (North Carolina) end of the basin, erected a distinctly different stratigraphy. Thayer named his basal coarse and mostly fluvial unit the Pine Hall Formation, which is overlain gradationally by his



**Fig. 9.** Correlation chart of the strata in the Dan River/Danville, Culpeper, and Gettysburg basins in the west-central part of the Newark Supergroup, showing their stratigraphy and the biostratigraphically important horizons in each basin.

finer and mostly lacustrine Cow Branch Formation. This in turn is overlain by, and partly intertongues with, the Stoneville Formation. More recently, Kent & Olsen (1997) have published a measured section from the base of the lower Cow Branch Formation into the lower part of the Cascade Station

Member that considerably increases the reported thickness of this interval. Aspects of all of these stratigraphies have been adopted here (Fig. 9). Conchostracans have been found so far only in the Cow Branch Formation at two different localities, one near Pine Hall in the 'lower Cow Branch' and



**Fig. 10.** Correlation chart of the strata in the Newark, Hartford, and Fundy basins in the northern part of the Newark Supergroup, showing their stratigraphy and the biostratigraphically important horizons in each basin.

the other at the Solite Quarry in the ‘upper Cow Branch’ (Kozur & Weems 2007).

*Scottsburg, Briery Creek, and Farmville basins (8, 11, 12)*

No formal lithostratigraphic names have been erected for the strata in any of the basins that lie along the trend of the Farmville Basin. Two basins (Randolph and Roanoke Creek) have yielded no

lacustrine strata so far, but the other three have paludal to lacustrine strata that contain the fish *Dictyopyge* (in the Scottsburg Basin) and conchostracans (in the Briery Creek and Farmville basins). The conchostracans and fish are all characteristic of the lower Cordevolian *Laxitextella multi-reticulata* Zone. These basins probably represent remnants of the ‘keel’ of a once continuous and much more extensive basin along this trend. The most completely-preserved stratigraphic section is

in the Farmville Basin, which has a basal sandstone unit, an intermediate paludal/lacustrine unit that contains conchostracans and fish, and a disconformably overlying fluvial to fanglomeratic unit. This sequence is very reminiscent of the stratigraphy found in the Richmond and Taylorsville basins. Wilkes (1982, 1987) and Goodwin *et al.* (1986) have provided general mapping of these basins. Detailed mapping has been published only for the northern part of the Farmville Basin (Marr 1980).

#### *Richmond and Deep Run basins (13, 15)*

The Deep Run Basin is a small, shallow eastern structural outlier of the Richmond Basin. It is separated from the main basin by only a few kilometers and has a stratigraphy identical to the basal part of the main basin (Shaler & Woodworth 1899). The stratigraphy of the Richmond Basin was established by Shaler & Woodworth (1899) and has been revised since by Cornet & Olsen (1990). The interpretation of Cornet & Olsen (1990) is complex and based in large part on interpretation of seismic lines. In the absence of any surface control, we choose to largely follow the original stratigraphy of Shaler & Woodworth (1899), in which the basal unit of the basin is the Tuckahoe Formation ('Tuckahoe Group' in Shaler & Woodworth 1899; reduced to Tuckahoe Formation by Cornet & Olsen 1990), the middle unit is the Vinita Shale, and the upper unit is the Otterdale Sandstone. In this stratigraphy, the productive coal beds constitute the upper member of the Tuckahoe Formation. The coal bed interval is the horizon from which Bock (1953a, b) described *Isaura midlothianensis* (*Euestheria* sp. indet. of *E. minuta* group) and *Howellisaura winterpockensis* (= *Euestheria winterpockensis*).

#### *Taylorsville Basin (16)*

The stratigraphy of the exposed Taylorsville Basin was described and mapped by Weems (1980, 1981, 1986). LeTourneau (2003) revised the stratigraphy of Weems and added several new formations for subsurface stratigraphic units that are higher than any exposed at the surface. Kozur & Weems (2007) rejected most of LeTourneau's revisions of the exposed stratigraphy. The only unit in the exposed portion of the Taylorsville Basin that has yielded conchostracans is the paludal to lacustrine Falling Creek Formation. The conformably underlying Stagg Creek Formation and the disconformably overlying Newfound Formation both formed in fluvial depositional environments that were not favorable for conchostracan colonization. Recently, Paul Olsen (Columbia University) has made available to the authors conchostracans from the

subsurface Port Royal Formation that were mentioned in LeTourneau (2003) but not described or illustrated. These specimens are identical with the fauna found in the upper (but not uppermost) Lockatong Formation of New Jersey, and they confirm the estimated stratigraphic position assumed for this unit in Kozur & Weems (2007) (see Fig. 8 for approximate sample horizon).

#### *Culpeper Basin (19)*

The stratigraphy of the Culpeper Basin has gone through a number of iterations. Roberts (1928) recognized a basal Manassas Sandstone overlain by a Bull Run Shale, but he did not describe the higher portions of the stratigraphic column. Lindholm (1979) provided the first inclusive stratigraphic compilation and applied stratigraphic names to the entire column. His work subsequently was revised and partially duplicated by Lee & Froelich (1989). Weems & Olsen (1997) synthesized the best aspects of both stratigraphies, and their stratigraphy is used here (Figs 8 & 9). The lowest formation in the basin is the Manassas Sandstone, which at its base includes the Tuscarora Creek Member in the northern part of the basin, the laterally equivalent Reston Conglomerate Member in the central part of the basin, and the Rapidan Member in the southern part of the basin. Unconformably above all of these is an upper Poolesville Sandstone Member. The Manassas is overlain by the Bull Run Formation, which consists of a lower Balls Bluff Siltstone Member and an upper Groveton Member. The Bull Run is overlain successively by the Catharpin Creek Formation, the Mount Zion Church Basalt, the Midland Formation, the Hickory Grove Basalt, the Turkey Run Formation, the Sander Basalt, and the Waterfall Formation. The Manassas Formation is composed of fluvial sandstones and siltstones that so far have yielded no conchostracans. Much of the overlying Balls Bluff siltstone of the Bull Run Formation also represents fluvial deposits, though they are quite fine-grained and reflect much lower energy conditions than the Manassas. One locality within the Balls Bluff (the *Rutiodon* and coelacanth locality described in Weems, 1979 and in Weems & Kimmel 1993) has yielded impressions that may be conchostracans but this is not definitive and the specimens, if real, are not well enough preserved to be useful for stratigraphic correlation. Above the Balls Bluff, the Groveton Member of the Bull Run Formation and all but the uppermost Catharpin Creek Formation have yielded many abundant conchostracan faunas of Norian age. These have been described in some detail in Kozur & Weems (2005, 2007) and can be assigned to the *Shipingia hebaozhaiensis* Zone, the *Redondestheria grovetonensis* Zone, and the

*Shipingia olseni* zones of Alaunian and Sevatian (middle and late Norian) age.

The highest beds of the Catharpin Creek Formation in the Culpeper Basin, about 15 m below the lowest Mt. Zion Church Basalt, have recently yielded a fauna consisting entirely of *Euestheria brodieana*, indicating its late (and probably latest) Rhaetian age. Only about 10 m below this, beyond a covered interval, a rich fauna dominated by *Shipingia olseni* demonstrates that this bed and beds below it are late Norian and older. Above the Mt. Zion Church Basalt, a fish-bearing unit in the middle part of the Midland Formation (the 'Midland fish bed') has yielded a more varied conchostracan fauna that includes *E. brodieana*, *Bulbilimnadia killianorum* (named in this paper) and very rare *Bulbilimnadia sheni*. The latter two species are completely unknown from the Rhaetian (even the uppermost Rhaetian) in the Germanic Basin region, but *B. killianorum* recently has been found by Grzegorz Niedźwiedzki and Grzegorz Pieńkowski, Warsaw, in the lowermost Hettangian continental strata of the Holy Cross Mountains (Poland). Therefore, the age of the Mt. Zion Church Basalt is just before (or possibly at) the Triassic–Jurassic boundary, the age of the lowest Midland Formation is unknown, and the middle and upper Midland are early Hettangian in age. In the middle Midland, *E. brodieana* and *B. killianorum* are by far the more abundant species, with *B. sheni* occurring only very rarely. By the upper part of the Midland, *B. sheni* is distinctly more common than *B. killianorum* and *E. brodieana* remains abundant. By the base of the Waterfall Formation, *B. killianorum* is gone and the fauna consists almost entirely of *E. brodieana* and *B. sheni*. About 800 m above the base of the Waterfall, *B. froelichi* makes its first appearance, and by the top of the Waterfall Formation *E. brodieana* and *B. sheni* both are gone. Thus, a rather rapid series of changes in the conchostracan fauna can be documented in the upper part of the Culpeper Basin column. As discussed in Kozur & Weems (2007), a rich conchostracan fauna in the Yale Peabody Museum collection, allegedly from the Turkey Run Formation, almost certainly is from the basal Waterfall Formation. So far, the Turkey Run Formation has yielded no conchostracans.

### *Gettysburg Basin (20)*

The stratigraphy of the southeastern Pennsylvania Gettysburg Basin was defined by Stose & Bascom (1929), and this stratigraphy later was extended into the Maryland part of the basin by Jonas & Stose (1938). These authors recognized two formations, a basal, predominantly fluvial New Oxford Formation and an overlying, predominantly

lacustrine Gettysburg Shale. This unit was later renamed the Gettysburg Formation (Glaeser 1963) to more accurately reflect the presence of the many facies within the unit that were much coarser than shale. Within the Gettysburg, Stose & Bascom (1929) also distinguished a ridge-forming interval that they named the Heidlersburg Member. They considered this interval to be sandstone-rich, but Smoot (1999) has pointed out that it is not much different from other parts of the Gettysburg Formation in its overall lithology. Cornet (1977) recognized two thin units at the very top of the Gettysburg Basin fill, a basalt that he informally called the Aspers basalt, and sedimentary strata above it. Weems & Olsen (1997) formalized this name as the Aspers Basalt and named the strata above the basalt the Bendersville Formation. Based on our conchostracan studies (Kozur & Weems 2007), it is now clear that the basal sequence of the New Oxford Formation is distinctly older than the strata that overlie them and is separated from the overlying strata by a disconformity, identifiable in the stratigraphic column shown in Stose & Bascom (1929) by a prominent quartzose conglomerate that lies 35 m above the basal unconformity. Stose & Bascom gave a detailed section of this sequence in an outcrop near Irishtown, and because of this these beds are here informally called the 'Irishtown beds.' In Kozur & Weems (2007) they were designated simply as an unnamed unit below the New Oxford Formation. A few horizons within the Gettysburg Basin have yielded abundant conchostracans, and it seems likely that many more are to be found.

One long-recognized conchostracan-bearing interval, considered in the past to lie within the New Oxford Formation, is a lacustrine sequence that occurs along Little Conewago Creek in Pennsylvania just south of the Susquehanna River. The geological map of York County, Pennsylvania (Stose & Jonas 1939) shows this locality as being near the middle of the New Oxford outcrop belt, and this was used by Cornet (1977) to estimate a relatively low horizon for this locality. However, Wanner (1926) estimated that this locality is nearly 2000 metres above the base of the New Oxford Formation, estimating strata thickness from an average regional 20° dip in this area. This is very nearly the full thickness of the New Oxford in its type area as measured by Stose & Bascom (1929). Stose & Jonas (1939) show a major fault immediately northwest of the Little Conewago Creek area within the New Oxford strike belt, seemingly with its west side up, so the New Oxford Formation probably is largely fault-repeated within this area. Thus, the stratigraphic level calculated by Wanner is probably close to correct, and the lake bed strata found along Little Conewago Creek probably are the basal lake beds of the Gettysburg

Formation and not an anomalous lake sequence within the normally fluvial New Oxford Formation. This interval has produced remains of phytosaurs (*Rutiodon carolinensis* and possibly *Rutiodon manhattanensis*, described in Doyle & Sues 1995), metoposaurs (*Buettneria perfecta*), fish, and conchostracans including abundant specimens of '*Estheria pennsylvanica* Wanner. This is the type area for '*E. pennsylvanica* Wanner, 1926, and the authors have collected numerous new specimens from this area and reassigned this species to a new genus (*Wannerestheria* n. gen.) described in the taxonomic portion of this paper. Comparison with conchostracan collections from a number of horizons within the Newark Basin in the Delaware River Valley, made by the authors and by Paul Olsen (Columbia University), indicates that *Wannerestheria pennsylvanica* occurs only in the upper part of the Lockatong Formation. Therefore, the lacustrine strata along Little Conewago Creek correlate with the upper part of the Lockatong, which is upper Tuvallian (uppermost Carnian) in age. Therefore, the Gettysburg Formation correlates with both the uppermost Lockatong and all of the Passaic Formation of the Newark Basin.

A second conchostracan-bearing interval, the Fulton site in Maryland (Kozur & Weems 2007), lies well to the southwest of the type area of the New Oxford and Gettysburg formations and also beyond several structural anomalies within the basin. These structural complications make it impossible to directly trace the Maryland lacustrine interval in a simple manner across the intervening region to the type area of the New Oxford and Gettysburg formations, and this has made its precise stratigraphic horizon rather problematic. Jonas & Stose (1938) mapped this horizon in Maryland as the basal interval of the Gettysburg Formation, and its lacustrine character is certainly typical of the Gettysburg. Conchostracans found at and near the Fulton site constitute a diverse upper Tuvallian fauna that can be readily correlated with the upper Tuvallian *Laxitextella freybergi* Zone of the Germanic Basin. Even the index species *L. freybergi* Kozur is present. At the same time, however, the more endemic form *Wannerestheria pennsylvanica* (Wanner) is present. Therefore the Fulton site seems to be at (or at least very close to) the same horizon as the type locality of *Wannerestheria pennsylvanica* along Little Conewago Creek. This supports the assignment of the Fulton site lake beds to the base of the Gettysburg Formation (see Figs 8 & 9).

#### *Newark Basin (22)*

The strata of the New Jersey portion of the Newark Basin were divided into three formations by

Kummel (1897), and these units were later carried over into the Pennsylvania portion of the Newark Basin by Bascom *et al.* (1909). In ascending order, these units were a predominantly fluvial Stockton Formation, a lacustrine Lockatong Formation, and a predominantly redbed Brunswick Formation. The Brunswick Formation included the bulk of the stratigraphic column of the Newark Basin, and this interval later was divided into seven formations by Olsen (1980), who, in doing so, abandoned the name 'Brunswick.' The interval represented by the former Brunswick Formation now is occupied by (in ascending order) the Passaic Formation, the Orange Mountain Basalt, the Feltville Formation, the Preakness Basalt, the Towaco Formation, the Hook Mountain Basalt and the Boonton Formation (Fig. 10). The Triassic part of the column (Stockton, Lockatong and Passaic formations) since then has been subdivided into a considerable number of members (Olsen *et al.* 1999).

Conchostracans occur at many levels in the Newark Basin, and much work remains to be done on the details of its conchostracan biostratigraphy. One fauna is now known from the upper part of the Stockton Formation. It is yet to be studied in detail, but it is obviously different from overlying faunas and belongs to a different conchostracan biozone than the biozone of the basal Lockatong (Kozur & Weems 2007). A number of horizons have been collected from the Lockatong Formation, and it now is known to include three successive faunas that can be readily distinguished from each other. The conchostracan fauna of the upper Passaic Formation belongs within the *Shipingia olseni* Zone (Kozur & Weems 2007), but more recently discovered faunas from much lower in the Passaic, yet to be described, clearly belong below the upper Alaunian *S. hebaozhaiensis* Zone. A conchostracan fauna from the Warford Member of the Passaic, toward the base of the formation, is clearly early Norian ('Lacian') in age. As conchostracan faunas from the upper (but not uppermost) part of the underlying Lockatong Formation (Smith Corner Member) are still of late Tuvallian (uppermost Carnian) age, the Carnian–Norian boundary lies somewhere between the Smith Corner Member of the Lockatong and the Warford Member of the Passaic. A distinct change in the regional climate has been documented in the Germanic Basin at the Carnian–Norian boundary (Kozur & Bachman 2010), and it may be that the Lockatong–Passaic boundary (which also reflects a major climatic shift) similarly corresponds to the Carnian–Norian boundary. Until conchostracan faunas are recovered from strata between the Smith Corner and Warford members, no more precise location for the Carnian–Norian boundary can be established in the Newark Basin. However,

the monospecific *Palaeolimnadia schwanbergensis* conchostracan fauna of the Warford Member is identical with the fauna from the basal Weser Formation (basal Norian) of the Germanic Basin. As the oldest Newark Basin occurrence of the Norian genus *Aetosaurus* also is in the Warford Member (= base of the Neshanician = base of Revuelian), this level may well represent the basal Norian as assumed by Kent & Olsen (2000).

Conchostracans apparently are rare in the Lower Jurassic part of the Newark Basin column. A few poorly preserved specimens, possibly but not certainly belonging to *Bulbilimnadia froelichi*, have been identified on a slab containing fossil fish from a horizon high in the Boonton Formation (see locality Table 1). This suggests that the Boonton Formation does not range higher than the lowest part of the Portland Formation in the Hartford Basin, which is consistent with the much thinner section of the Boonton as compared with the Portland.

#### *Hartford Basin (25)*

Krynine (1950) applied the first formal stratigraphy to the sediments of the Hartford Basin. In ascending order, he recognized a predominantly fluvial New Haven Arkose, a Meriden Formation that consisted of interbedded lava flows and fluvial to lacustrine strata, and a Portland Formation that is predominantly lacustrine in its lower part but fluvial toward its top. Rodgers *et al.* (1959) named the lava flows as members of the Meriden, and called them (in ascending order) the Talcott Lava Member, the Holyoke Lava Member, and the Hampden Lava Member. Lehman (1959) slightly modified these names and additionally named the sedimentary packages between them as formations. In ascending order these were the Talcott Basalt, the Shuttle Meadow Formation, the Holyoke Basalt, the East Berlin Formation and the Hampden Basalt (Fig. 10). The name Meriden was abandoned, but since has been revived as a group name by Weems & Olsen (1997).

Fossils are rare in the New Haven Arkose, but skeletal remains of *Rutiodon* and *Stegomus* (*Aetosaurus*) clearly indicate a late Carnian to Norian age for that unit (Lull 1953). Cornet (1977, p. 225) reported a lower Norian palynoflora from near the base of the New Haven, which suggests that deposition in the Hartford Basin did not begin until after the end of Carnian time, much later than in any other Newark Supergroup basin. Overlying units are much more fossiliferous (McDonald 1996). We have examined conchostracans from only two horizons, one from the middle of the East Berlin Formation and the other from the middle of the Portland Formation, but other

horizons have been reported (McDonald 1996). The specimens from the East Berlin Formation are not well-preserved but seem to be *Bulbilimnadia froelichi*, which was first described from the Waterfall Formation in the Culpeper Basin (Kozur & Weems 2005). The fauna from the middle of the Portland Formation seems to be composed of new species, more similar to forms found in the Kayenta Formation of the southwestern United States than to forms from lower horizons within the Newark Supergroup. Notably, *B. froelichi* seems to have disappeared before the middle Portland Formation, which suggests that the middle Portland is upper Hettangian in age.

#### *Fundy Basin (29)*

Powers (1916) named strata in the Fundy Basin (in ascending order) the Annapolis Formation (consisting of a lower Wolfville Sandstone member and an upper Blomidon Shale member), the North Mountain Basalt, and the Scots Bay Formation. Later, Klein (1962) abandoned the name Annapolis Formation and raised the Wolfville and Blomidon to formational rank (Fig. 10). Beds immediately beneath the Wolfville Formation, called the Lower Economy beds, have been ascribed a Middle Triassic age (Baird & Olsen 1983). Because they are considerably older than any other beds usually included in the Newark Supergroup, they generally have been excluded from the definition of the Newark Supergroup (e.g. Weems & Olsen 1997).

Baird & Olsen (1983) discussed a vertebrate fauna from the middle of the Wolfville Formation, which they assigned to the Carnian, and a vertebrate fauna from the upper Wolfville that they assigned to the Carnian–Norian. Conchostracans found in the lower part of the Wolfville Formation near Evangeline Beach constitute a monospecific *Euestheria minuta* (von Zieten) fauna of probable late Ladinian age, slightly older than other any conchostracan fauna so far known from anywhere else in the Newark Supergroup. Since this interval is close in age to the lower Cordevolian units in the United States, the question arises if there might be an upper Cordevolian–lower Julian unconformity separating these strata from higher strata in the Wolfville just as there is farther south. Unfortunately, the Evangeline Beach section lies across the Southern Bight of the Minas Basin from the type Wolfville area so, in the absence of any known outcrops of the intervening stratigraphic interval, it is not possible to determine if this is true or not. Conchostracans have been reported (but not illustrated) from the upper part of the type area of the Wolfville Formation at Medford Beach near Paddy Island (Cameron & Gould 2000); their described size is much too large to be *E. minuta*, so even without

Table 1. *Conchostracan localities in the Newark Supergroup*

Locality	Age	Unit	Latitude	Longitude	Other data	Conchostracan Zone
<b>Sanford Basin, North Carolina</b>						
Pomona Pipe Co. pit near Gulf	Early Tuvalian	Pekin Formation, near middle of unit	35.5694°N	79.2976°W	Goldston Quadrangle, Chatham Co., N.C.	Zone indeterminate
Bethany Church	Late early-middle Tuvalian	Cumnock Formation, about 80 m above the base	35.5584°N	79.2921°W	Goldston Quadrangle, Chatham Co., N.C.	<i>Howellisaura princetoniensis</i> Zone
Deep River coal basin (ANSP 31194)	Late early-middle Tuvalian	Cumnock Formation, about 100–200 m above base	Not reported	Not reported	Goldston Quadrangle?, Chatham Co., N.C.	<i>Howellisaura princetoniensis</i> Zone
Carbonton Dam site	Upper Tuvalian	Cumnock Formation, near middle of unit	35.5201°N	79.3480°W	Goldston Quadrangle, Chatham County, N.C.	<i>Anyuanestheria wingatella</i> Zone
River Road near Horseshoe Bend	Lacian	Cumnock Formation, near top of unit	35.4553°N	79.3845°W	Goldston Quadrangle, Moore County, N.C.	<i>Euestheria buravasi</i> – <i>Euestheria n. sp.</i> Zone
Stop 1.3 in Olsen <i>et al.</i> (1989)	Lacian	Sanford Formation, near bottom of unit	35.5081°N	79.3004°W	Pumam Quadrangle, Lee County, N.C.	<i>Norestheria barnaschi</i> – <i>Shipingia mcdonaldii</i> Zone
<b>Durham Basin, North Carolina</b>						
Triangle Brick Quarry, NMMNH and NC Museums	Lacian	'Lithofacies Association II' of Hoffman & Gallagher 1989	35.8694°N	78.8960°W	Green Level Quadrangle, Durham County, N.C.	<i>Euestheria buravasi</i> – <i>Euestheria n. sp.</i> Zone
<b>Dan River Basin, North Carolina</b>						
Solite Quarry	Late Tuvalian	Upper Cow Branch Formation, about 100 m below top?	36.5412°N	79.6698°W	Northeast Eden Quadrangle, Rockingham County, N.C.	Zone indeterminate
U.S. 220 road cut on N side of Dan River	Early Tuvalian	Lower Cow Branch Formation, about 10 m above the base	36.3875°N	79.9411°W	Mayodan Quadrangle, Rockingham County, N.C.	New zone just below <i>A. wingatella</i> Zone
<b>Briery Creek Basin, Virginia</b>						
Worthy property (YPM 34659 and YPM 220198)	Early Cordevolian	Lower lacustrine unit, about 100 m above base	37.2190°N	78.4445°W	Hampden Sydney Quadrangle, Prince Edward County, Va.	<i>Laxitextella multireticulata</i> Zone
Flournoy's coal pit *(YPM 34664)	Early Cordevolian	Lower lacustrine unit, about 100 m above base	37.1949°N	78.4754°W	Hampden Sydney Quadrangle, Prince Edward County Va.	<i>Laxitextella multireticulata</i> Zone
<b>Farmville Basin, Virginia</b>						
Little Willis River (YPM 34647)	Early Cordevolian	Within unnamed lacustrine unit about 450 m above its base	37.4113°N	78.3940°W	Willis Mountain Quadrangle, Cumberland Co., Va.	<i>Laxitextella multireticulata</i> Zone



<b>Richmond Basin, Virginia</b> Midlothian coal mine spoil (ANSP 31497)	Early Cordevolian	Lower Vinita Shale, probably within basal 50 m	37.5029°N	77.6402°W	Midlothian Quadrangle, Chesterfield Co., Va.	<i>Laxitextella</i> <i>multireticulata</i> Zone
Winterpock (ANSP 31197)	Early Cordevolian	Lower Vinita Shale, probably within basal 50 m	37.3459°N	77.7204°W	Winterpock Quadrangle, Chesterfield Co., Va.	<i>Laxitextella</i> <i>multireticulata</i> Zone
<b>Deep Run Basin, Virginia</b> Three Chopt Road fish locality	Early Cordevolian	Lower Vinita Shale, about 50 m above base	37.6351°N	77.5816°W	Glen Allen Quadrangle, Henrico Co., Va.	<i>Laxitextella</i> <i>multireticulata</i> Zone
<b>Taylorsville Basin, Virginia</b> Stagg Creek, older level	Early Cordevolian	Lower Falling Creek Fm., 40 m above base	37.7831°N	77.5450°W	Hanover Academy Quadrangle, Hanover Co., Va.	<i>Laxitextella</i> <i>multireticulata</i> Zone
Stagg Creek, younger level	Early Cordevolian	Lower Falling Creek Fm., 44 m above base	37.7833°N	77.5450°W	Hanover Academy Quadrangle, Hanover Co., Va.	<i>Laxitextella</i> <i>multireticulata</i> Zone
Little River site, W of C & O RR bridge	Early Cordevolian	Middle Falling Creek Fm., about 155 m above base	37.8225°N	77.4285°W	Ashland Quadrangle, Hanover Co., Va.	<i>Laxitextella</i> <i>multireticulata</i> Zone
Falling Creek, north of Ashland	Late Cordevolian	Upper Falling Creek Fm., near top (exact horizon uncertain)	37.7882°N	77.4855°W	Ashland Quadrangle, Hanover Co., Va.	<i>Laxitextella</i> <i>multireticulata</i> Zone
Wilkins Well (in LeTourneau 2003)	Tuvallian	Port Royal Fm., horizon not specified	38.2414°N	77.0125°W	Dahlgren Quadrangle, Westmoreland Co., Va.	<i>Howellisaura</i> ? <i>ovata</i> Zone
<b>Culpeper Basin, Virginia</b> Carriage Ford	Alaunian	Groveton Mbr., Bull Run Fm., 350 m above base	38.6420°N	77.5928°W	Nokesville Quadrangle, Fauquier Co., Va.	<i>Shipingia</i> <i>hebaozhaiensis</i> Zone
I-66 at VA Route 234, NW corner	Alaunian	Groveton Mbr., Bull Run Fm., 1250 m above base	38.8014°N	77.5264°W	Gainesville Quadrangle, Prince William Co., Va.	<i>Shipingia</i> <i>hebaozhaiensis</i> Zone
Sudley Road	Alaunian	Groveton Mbr., Bull Run Fm., 1850 m above base	38.8512°N	77.5215°W	Gainesville Quadrangle, Fairfax Co., Va.	<i>Shipingia</i> <i>hebaozhaiensis</i> Zone
Groveton Cemetery, Bull Run Battlefield	Sevastian	Groveton Mbr., Bull Run Fm., 2310 m above base	38.8136°N	77.5460°W	Gainesville Quadrangle, Prince William Co., Va.	<i>Redondestheria</i> <i>grovetonensis</i> Zone
Arcola	Sevastian	Groveton Mbr., Bull Run Fm., 2550 m above base	38.9499°N	77.5294°W	Arcola Quadrangle, Loudoun Co., Va.	<i>Redondestheria</i> <i>grovetonensis</i> Zone
Catharpin	Sevastian	Groveton Mbr., Bull Run Fm., 2750 m above base	38.8599°N	77.5673°W	Gainesville Quadrangle, Loudoun Co., Va.	<i>Shipingia olsenii</i> Zone

(Continued)

Table 1. Continued

Locality	Age	Unit	Latitude	Longitude	Other data	Conchostracan Zone
Broad Run west of power line	Sevastian	Groveton Mbr., Bull Run Fm., 2900 m above base	38.9635°N	77.5516°W	Arcola Quadrangle, Loudoun Co., Va.	<i>Shipingia olsenii</i> Zone
Lenah	Sevastian	Catharpin Creek Fm., 200 m above base	38.9612°N	77.5700°W	Arcola Quadrangle, Loudoun Co., Va.	<i>Shipingia olsenii</i> Zone
Cedar Run	Sevastian	Catharpin Creek Fm., 1050 m above base	38.6530°N	77.6768°W	Catlett Quadrangle, Fauquier Co., Va.	<i>Shipingia olsenii</i> Zone
Haymarket	Sevastian	Catharpin Creek Fm., 100 m below top and 2350 m above base	38.8481°N	77.6352°W	Thoroughfare Gap Quadrangle, Prince William Co., Va.	<i>Shipingia olsenii</i> Zone
Casanova	Sevastian	Catharpin Creek Fm., 50 m below top and 2400 m above base	38.6522°N	77.7044°W	Catlett Quadrangle, Fauquier Co., Va.	<i>Shipingia olsenii</i> Zone
Locality HAYM of Cornet (1977)	Late Rhaetian	Catharpin Creek Fm., 9.4 m below top and 2440 m above base	38.8124°N	77.6458°W	Thoroughfare Gap Quadrangle, Prince William Co., Va.	<i>Euesheria brodieana</i> Zone
Midland fish bed on Licking Run	Basal Hettangian	Midland Fm., 100 m above base	38.6172°N	77.7253°W	Midland Quadrangle, Fauquier Co., Va.	Upper <i>Bulbilimnadia killianorum</i> Zone
Killian Property	Early Hettangian	Midland Fm., 150 m above base	38.7734°N	77.6963°W	Thoroughfare Gap Quadrangle, Fauquier Co., Va.	<i>Bulbilimnadia sheni</i> Zone
Avalon Farm	Early Hettangian	Lower Waterfall Fm., 250 m above base	38.7551°N	77.6597°W	Thoroughfare Gap Quadrangle, Prince William Co., Va.	<i>Bulbilimnadia sheni</i> Zone
McDonald site on I 66 (YPM 202438 and YPM 202439)	Early Hettangian	Lower Waterfall Fm., About 300 m above base	38.8219°N	77.6855°W	Thoroughfare Gap Quadrangle, Prince William Co., Va.	<i>Bulbilimnadia sheni</i> Zone
Opal #1 core	Early Hettangian	Upper Waterfall Fm., 800 m above base	38.6333°N	77.8000°W	Warrenton Quadrangle, Fauquier Co., Va.	<i>Bulbilimnadia froelichi</i> Zone
Catletts Branch	Early Hettangian	Upper Waterfall Fm., 150 m below top and 1100 m above base	38.8234°N	77.6998°W	Thoroughfare Gap Quadrangle, Prince William Co., Va.	<i>Bulbilimnadia froelichi</i> Zone
<b>Gettysburg Basin, Maryland and Pennsylvania</b>						
Hanover Street, SE of town of New Oxford	Early Cordevolian	Irishtown beds, below New Oxford Fm., about 10 m above base	39.8450°N	77.0340°W	McSherrystown Quadrangle, Adams Co., Pa.	<i>Laxitextella multireticulata</i> Zone
Rheems locality of De Wet <i>et al.</i> (1998)	Early Tuvalian or late Julian	Basal Gettysburg Fm., about 30 m above base	40.1315°N	76.5831°W	Elizabethtown Quadrangle, Lancaster Co., Pa.	Conchostracans not identifiable

Locality 11 of Wanner (1926)	Late Tuvalian	Basal Gettysburg Fm., about 1650 m above base	40.0703°N	76.7353°W	Yorkhaven Quadrangle, York Co., Pa.	<i>Wannerstheria pennsylvanica</i> Zone
Locality 1 of Wanner (1926)	Late Tuvalian	Basal Gettysburg Fm., about 1700 m above base	40.0932°N	76.7264°W	York Haven Quadrangle, York Co., Pa.	<i>Wannerstheria pennsylvanica</i> Zone
Fulton site on Beaver Branch	Late Tuvalian	Gettysburg Fm., basal lake bed	39.6355°N	77.3347°W	Emmitsburg Quadrangle, Frederick Co., Md.	<i>Laxitextella freybergi</i> Zone
U.S. Rt. 15 SSE of Heidlersburg	Late Alauanian	Gettysburg Fm., lower Heidlersburg Mbr., about 200 m above base	39.9393°N	77.1432°W	Biglerville Quadrangle, Adams Co., Pa.	<i>Norestheria barnaschi-Shipingia mcdonaldi</i> Zone
<b>Newark Basin, Pennsylvania and New Jersey</b> Raven Rock Quarry	Early Tuvalian	Upper Stockton Fm., about 1050 m above base	40.4114°N	75.0305°W	Lumberville Quadrangle, Hunterdon Co., N.J.	Zone not yet established
Black Rock Tunnel (ANSP 16849)	Middle Tuvalian	Lockatong Fm., about 200 m above base	40.1438°N	75.5129°W	Phoenixville Quadrangle, Chester Co., Pa.	<i>Howellisaura ? ovata</i> Zone
Eureka quarry (ANSP 16848, ANSP 65528, ANSP 65530)	Late early-middle Tuvalian	Lockatong Fm., stratigraphic level unknown	40.2602°N	75.1815°W	Doylstown Quadrangle, Montgomery Co., Pa.	<i>Howellisaura princetonsensis</i> Zone
Princeton Library	Late early-middle Tuvalian	Lockatong Fm., about 200 m above base	40.3497°N	74.6578°W	Princeton Quadrangle, Mercer Co., N.J.	<i>Howellisaura princetonsensis</i> Zone
Granton Quarry (ANSP 31192)	Middle Tuvalian	Lockatong Fm., about 300 m above base	40.8447°N	73.9839°W	Central Park Quadrangle, Bergen Co., N.J.	<i>Howellisaura ? ovata</i> Zone
Skunk Hollow	Late Tuvalian	Lockatong Fm., about 600 m above base	Not reported	Not reported	Material provided by Paul Olsen, no specific locality given	<i>Wannerstheria pennsylvanica</i> Zone
Smith Corner	Late Tuvalian	Lockatong Fm., about 750 m above base	40.4544°N	75.0675°W	Lumberville Quadrangle, Hunterdon Co., N.J.	<i>Wannerstheria pennsylvanica</i> Zone
Warford Creek	Lacian	Passaic Fm., Warford Mbr., about 200 m above base	40.4694°N	75.0611°W	Lumberville Quadrangle, Hunterdon Co., N.J.	<i>Palaeolimnadia schwanbergensis</i> Zone
Milford	Lacian	Passaic Fm., about 300 m above base	40.5725°N	75.1123°W	Frenchtown Quadrangle, Hunterdon Co., N.J.	Zone indeterminate
150 m east of Cornet (1979) localities GHT 1, 3	Sevastian	Passaic Fm., 1750 m from top	40.3185°N	75.7850°W	Birdsboro Quadrangle, Berks Co., Pa.	<i>Shipingia olseni</i> Zone
Exeter, Constitution Avenue 14	Sevastian	Passaic Fm., 25 m from top	40.3134°N	75.8435°W	Birdsboro Quadrangle, Berks Co., Pa.	<i>Shipingia olseni</i> Zone

(Continued)

Table 1. Continued

Locality	Age	Unit	Latitude	Longitude	Other data	Conchostracan Zone
Fish bed at Boonton dam (specimens on fish slab YPM 12349)	Early Hettangian	Boonton Fm., about 400 m above base	40.8958°N	74.3978°W	Boonton Quadrangle, Morris Co., N.J.	<i>Bulbimimadia froelichi</i> Zone
<b>Hartford Basin, Connecticut</b>						
Durham fish bed of McDonald (1992)	?Earliest Hettangian	Shuttle Meadow Fm., About 50 m above base	Not reported	Not reported	Durham Quadrangle, Middlesex Co., Conn.	Material not examined
North Branford	Early Hettangian	Middle East Berlin Fm., about 80 m below top	41.3356°N	72.7686°W	Branford Quadrangle, New Haven Co., Conn.	<i>Bulbimimadia froelichi</i> Zone
Miner Brook (Westfield fish bed)	Early Hettangian	Middle East Berlin Fm., 82 m below top	41.5918°N	72.7006°W	Middletown Quadrangle, Middlesex Co., Conn.	<i>Bulbimimadia froelichi</i> Zone
Kelsey—Ferguson Quarry	Late Hettangian	Middle Portland Fm., about 1500 m above base	41.9806°N	72.6078°W	Broad Brook Quadrangle, Hartford Co., Conn.	Zone not yet defined
<b>Fundy Basin, Nova Scotia (Canada)</b>						
Evangeline Beach	Late Ladinian	Wolfville Fm., about 350 m above base	45.1389°N	64.3293°W	Wolfville Quadrangle (21 H/1), Kings Co., Nova Scotia	<i>Euestheria minuta</i> Zone
Medford Beach locality of Cameron & Gould (2000)	Carnian	Wolfville Fm., about 1,10 m above base	45.1838°N	64.3575°W	Wolfville Quadrangle (21 H/1), Kings Co., Nova Scotia	Zone indeterminate
Blomidon Cliff (YPM 34664)	Sevastian	Blomidon Fm., about 1000 m above base	45.2343°N	64.3546°W	Wolfville Quadrangle (21 H/1), Kings Co., Nova Scotia	<i>Shipingia olseni</i> Zone
Wasson Bluff, Station 11 of Olsen and Et-Touhami (2008)	?Earliest Hettangian	McCoy Brook Fm., near base of unit	Approximately 45.4000°N	Approximately 64.2500°W	Parrsboro Quadrangle (21 H/8), Cumberland Co., Nova Scotia	Material not examined

better identification they still must be at least Carnian in age. Conchostracans from the Blomidon Formation also have been reported but not illustrated by Cameron & Ford (1998). There are specimens, however, that we have seen and studied from high in the Blomidon Formation at Cape Blomidon. These demonstrate that the upper part of the Blomidon belongs within the *Shipingia olseni* Zone and thus is upper Norian (Sevastian) in age (Kozur & Weems 2007). This fauna also includes a new and so far endemic genus and species, *Acadiestheriella cameroni* n. gen. n. sp., described in the present paper.

No conchostracan data are available yet from the highest (Scots Bay) strata above the North Mountain Basalt, but the basal Scots Bay has recently produced Rhaetian palynomorphs (Cirilli *et al.* 2009). Based on the early Hettangian fauna now known from the middle of the stratigraphically equivalent Midland Formation in the Culpeper Basin, the age of this unit may range upward at higher levels into the early Hettangian. Olsen *et al.* (2003) created the name Partridge Island Member of the Blomidon Formation for a thin sequence of beds lying immediately beneath the North Mountain Basalt on Partridge Island near Parrsboro, Nova Scotia. They stated that these beds, which are at least partly lacustrine or paludal in origin, have a *Corollina*-dominated palynoflora. In the Newark Supergroup, this flora first appears in uppermost Rhaetian beds immediately above the major unconformity that includes uppermost Norian and most of Rhaetian time (Fig. 7). Although this palynoflora formerly was considered to mark the base of the Hettangian (e.g. Olsen *et al.* 2003), its Rhaetian age in the Fundy Basin recently has been established by Cirilli *et al.* (2009). This suggests that the Partridge Island Member is correlative with the beds just below the Mt. Zion Church Basalt in the Culpeper Basin (described above) that have produced a monospecific *Euestheria brodieana* conchostracan fauna. At the eastern end of its type section, the Partridge Island Member rests on weathered fluvial sandstones with apparent unconformity. The age and stratigraphic position of this unit, at its type locality, is well defined and firmly established. In other parts of the Fundy Basin, however, such as at the bluffs near Old Wife Rock and at Cape Blomidon, very light-coloured strata that have been referred to the Partridge Island Member almost certainly do not belong to that unit. Instead, these stratigraphic intervals appear to represent thick paleosols at the top of the Blomidon Formation immediately below the North Mountain Basalt. Unlike the Partridge Island Member, these paleosols are unfossiliferous, blocky in texture, and entirely lack the rhythmically interbedded gray and red pattern so obviously developed at Partridge Island. These paleosols are some

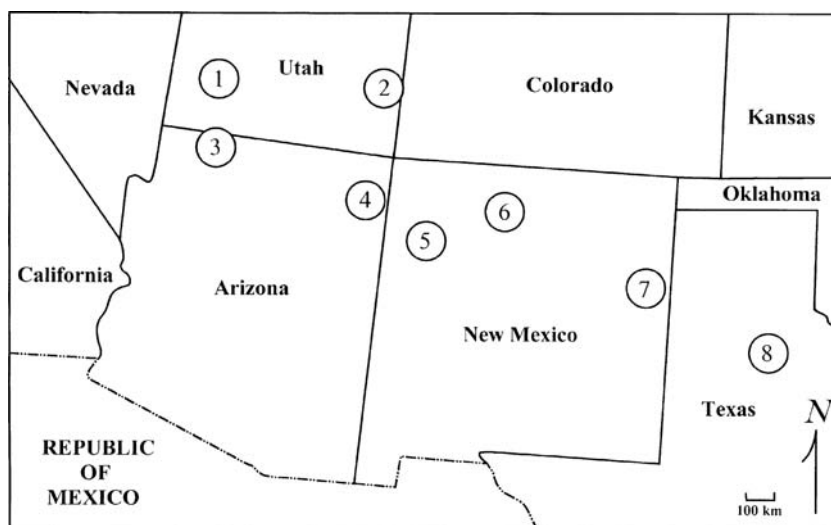
of the strongest physical evidence yet found for the presence of a long hiatus between deposition of the bulk of the Blomidon Formation and the time of extrusion of the North Mountain Basalt. The Partridge Island Member apparently occupies broad swales cut into the top of the underlying part of the Blomidon Formation, and therefore occurs only discontinuously beneath the North Mountain Basalt (Fig. 10).

The age range of Newark Supergroup strata in the Fundy Basin seems to be approximately as long as the age range of Newark Supergroup strata in the other Newark Supergroup basins, but the thicknesses of the Fundy strata are only about half the thicknesses of age-equivalent strata documented elsewhere. This suggests that the rate of deposition in the Fundy Basin during the Upper Triassic and basal Jurassic generally was much slower than it was in the other basins of the Newark Supergroup, though curiously the North Mountain Basalt is much thicker than its correlative basalts farther south.

#### *Southwestern United States*

The tectonic setting of the Triassic strata in the southwestern United States is very different from the setting of the Newark Supergroup, which was deposited in a series of rift-related valleys across the heart of central Pangaea. In the southwestern United States, deposition during the Triassic (and also during the Early Jurassic) was within a back-arc basin in a broad coastal floodplain setting along the western margin of Pangaea. The main occurrences of continental deposits are in two regions, the southern High Plains of the western United States in northern Texas and eastern New Mexico, and on the Colorado Plateau in northwestern New Mexico, northeastern Arizona, and southern Utah (Fig. 11). The stratigraphic units in different parts of these regions in some areas have been given identical names and sometimes different names, depending on local mapping history and variations in facies that are found in different areas (Fig. 12).

Unlike in the eastern United States, part of the Lower and Middle Triassic are represented by the Moenkopi Formation (Ward 1901), which consists of terrestrial shales, sandstones, and occasional impure limestones. In northern Arizona, the Moenkopi has been divided into three members: the Wupatki (McKee 1951, 1954), the Moqui (McKee 1951, 1954), and the Holbrook (Hager 1922; McKee 1951, 1954) from oldest to youngest. The oldest Triassic conchostracans in the southwestern United States have been found within the upper part of the Wupatki Member near Meteor Crater in Arizona (see Table 2 for details). This fauna



**Fig. 11.** Map showing areas in Texas, New Mexico, Arizona, and Utah where stratigraphically important collections of Upper Triassic and Lower Jurassic conchostracans have been made. 1, St. George region, Utah (Whitmore Point Member of Moenave Formation); 2, Moab region, Utah (Kayenta Formation); 3, Potter Canyon, Arizona (Moenave Formation, Whitmore Point Member); 4, Petrified Forest region, Arizona (Moenkopi Formation, Blue Mesa Member of Petrified Forest Formation, Bluewater Creek Formation); 5, Fort Wingate region, New Mexico ('Lake Ciniza' in Bluewater Creek Formation); 6, Taos region, New Mexico (Whitaker *Coelophys* quarry in Rock Point Formation); 7, Apache Canyon region, New Mexico (Redonda Formation); 8 – Lubbock region, Texas (Tecovas and Cooper Canyon formations). Localities 1 through 6 are on the Colorado Plateau; localities 7 and 8 are beneath the High Plains region of the west-central United States.

has yielded the following conchostracans: *Palaeolimnadia alsatica detfurthensis* Kozur & Seidel, very rare *P. nodosa* (Novozhilov) and *Euestheria exsecta* (Novozhilov) (Kozur, Lucas & Morales, in prep.). These forms indicate a Late Olenekian (Spathian) age for the Wupatki. This locality also is the type locality of the temnospondyl amphibian *Wellesaurus peabodyi* (Welles & Cosgriff 1965). The upper Moenkopi Holbrook Member at the Cottonwood Ruins locality near Winslow, Arizona has yielded large *Euestheria albertii albertii* (VOLTZ), which is the guide form for the lower Anisian Bithynian substage. Specimens as large as 6 mm in length, which are common among the Cottonwood Ruins material, are found only in the upper Bithynian. Therefore, the Holbrook can be placed confidently in the lower Anisian (Lucas & Schoch 2002).

Above the Moenkopi there is a long hiatus in deposition extending well into the Carnian (Fig. 12). This hiatus ended with deposition of the widespread Shinarump Conglomerate (Gilbert 1875) (later designated as a formation of the Chinle Group) and its probable stratigraphic equivalent the Camp Springs Conglomerate (Beede & Christner 1926) [later designated as a formation of the Chinle (or Dockum) Group]. This interval has a distinctive vertebrate fauna that is representative

of the Otischalkian faunachron, but so far no conchostracans are known from this interval. Immediately above the Shinarump, the next younger unit is the Bluewater Creek Formation (Lucas & Hayden 1989) (originally named as a member of the Chinle Formation, now part of the Chinle Group). The Bluewater Creek has yielded conchostracans in a lacustrine sequence known as 'Lake Ciniza'. Kozur has collected specimens from this interval that are dominantly *Anyuanestheria wingatella* (Tasch), but also include rare specimens of *Laxitextella seegisi* Kozur, which is the guide form found in the Lehrberg Beds in the Germanic Basin (upper part of lower Tualian), and also specimens of *Howellisaura princetonensis* (Bock), which also allows correlation of this interval with the lower part of the Lockatong Formation in the Newark Basin. Additionally, the vertebrate fauna from this unit includes the lowest occurrence of vertebrates characteristic of the Adamanian faunachron. Thus, this locality has produced a key fauna for correlation.

The Lake Ciniza conchostracan fauna can be closely correlated with conchostracan faunas in Europe, with a part of the Tecovas Formation of Texas, and with the lower Lockatong Formation of the Newark Basin, but its correlation relative to

Age (Ma)	Period	Stage	Substage	Fauna-chron	Southern Utah		Northern Arizona		Northwest New Mexico	Northeast New Mexico	Northern Texas		
201.5	LOWER JURASSIC (part)	Sinemurian		Dawan	Kayenta Fm.	(unnamed) *	Kayenta Fm.	(unnamed)					
		Hettangian				Springdale Mem.		Springdale Mem.					
				Wassonian									
	UPPER TRIASSIC	Rhaetian				Moenave Fm.	Whitmore Point Mem. *	Moenave Fm.	Whitmore Point Mem. *				
						Dinosaur Canyon Mem.		Dinosaur Canyon Mem.					
		Norian	Sevastian	Apachean			Rock Point Formation		Rock Point Formation	Rock Point Formation *	Redonda Formation *		
			Alaunian	Revueltian			Owl Rock Fm.		Owl Rock Formation	Owl Rock Formation			
		Carnian	Ladian		(uncertain)	Chinle Group	Petrified Forest Formation	Petrified Forest Fm	Painted Desert Member	Petrified Forest Fm	Painted Desert Member	Bull Canyon Formation	Cooper Canyon Formation
								Sonsela Member	Sonsela Member	Trujillo Formation	Trujillo Formation		
								Blue Mesa Mem *	Blue Mesa Mem				
			Tuvalian	Adamanian					Bluewater Creek Formation	Bluewater Creek Formation *	Garita Creek Formation	Tecovas Formation *	
			Julian	Otischalkian		Shinarump Fm.	Shinarump Formation	Shinarump Formation	Santa Rosa Formation	Colorado City Formation	Camp Springs Formation		
			Cordevolian										
		MIDDLE TRIASSIC	Ladinian		Berdyankian								
	Anisian			Perovkan		Moenkopi Formation	Moenkopi Formation	Holbrook Member *	Moenkopi Fm.	Anton Chico Mem.			
	LOWER TRIASSIC	Olenekian		Nonesian				Moqui Member					
		Induan		Lotsbergian				Wupatki Member *					

Fig. 12. Triassic and part of Lower Jurassic stratigraphy in part of the southwestern United States, showing the correlation of units across the area and their stratigraphic positions relative to the international marine timescale. Horizons that have produced conchostracan are shown by asterisks. Although Lucas (2010; Lucas & Tanner 2007) have reported *Protosuchus* from the Dinosaur Canyon Member of the Moenave Formation, the locality they reported is south of the Colorado River where the upper Dinosaur Canyon Member lithology lies at a horizon laterally equivalent to the Whitmore Point Member in northwestern Arizona and southeastern Utah. Therefore, the base of the Wassonian LVF does not extend down section as far as the Dinosaur Canyon Member in the area indicated on our chart. The boundary between the Adamanian and the Revueltian land vertebrate faunachrons could lie at the top, within, or at the base of the Sonsela Member of the Petrified Forest Formation.

another allegedly Bluewater Creek conchostracan fauna is problematic. According to Spencer Lucas (Albuquerque, personal communication) the Lake Ciniza strata belong within the middle part of the Bluewater Creek Formation. However, conchostracans from another (allegedly lower) Bluewater Creek locality (*Placerias* Quarry in Arizona) constitute a monospecific fauna of *Palaeolimnadia* n. sp., which is very similar and perhaps even identical with *Palaeolimnadia* n. sp. from the upper Schilfsandstein (uppermost Julian) of central Europe. This fauna is considerably older than the Lake Ciniza fauna. The overlying lower Blue Mesa Member of the Petrified Forest Formation is dominated by *Gregoriusella* n. sp., which is very similar to (and probably identical with) *Gregoriusella* n. sp., which occurs in the upper Tuvalian Coburg Sandstein. A single fragmentary

conchostracan from this locality has the microsculpture of *Laxitextella dorsorecta* and, based on the size and shape of this fragment, was from a specimen the same size as this species. Thus, a late Tuvalian age is probable for the lower Blue Mesa Member. This is in reasonable accord with the late early Tuvalian to middle Tuvalian age for the underlying Lake Ciniza fauna, but the 'lower Bluewater Creek' fauna seems much too old relative to these other two localities to be at all likely to belong within the Bluewater Creek Formation. This oldest fauna better matches the age that has been established for the Shinarump and Santa Rosa formations. In the latter formation, Bachmann, Kozur and Franz found a macroflora that is similar to that of the Lunz Beds in the Northern Alps and the Schilfsandstein in the Germanic Basin (late Julian). A similar flora from the Santa Rosa was

Table 2. *Conchostracan localities in the Southwestern United States*

Locality	Age	Unit	Latitude	Longitude	Other data	Conchostracan zone
<b>Arizona</b>						
Meteor Crater (MNA locality 1435)	Late Olenekian	Moenkopi Formation, Wupatki Member	On file at MNA	On file at MNA	Navajo Co., Az.	<i>Euestheria exsecta</i> Zone
Cottonwood Ruin (MNA locality 1436)	Late Bithynian (early Anisian)	Moenkopi Formation, Holbrook Member	On file at MNA	On file at MNA	Navajo Co., Az.	Upper <i>Euestheria albertii albertii</i> Zone
<i>Placeraspis</i> Quarry (NMMNH locality 858)	?Early Tuvalian	Bluewater Creek Formation, lower member	34.4359°N	109.4578°W	Salado Quadrangle, Apache Co., Az.	Zone indeterminate, but no younger than lower Tuvalian
P-50786 (NMMNH locality 3631)	Upper Tuvalian	Petrified Forest Formation, Blue Mesa Mbr.	34.9420°N	109.7667°W	Adamana Quadrangle, Apache Co., Az.	Zone indeterminate but upper Tuvalian
Potter Canyon (bed 22, locality 7734)	Latest Rhaetian	Moenave Formation, Whitmore Point Member	36.8802°N	112.8466°W	Mocassin Quadrangle, Mohave Co., Az.	<i>Euestheria brodieana</i> Zone
Potter Canyon (bed 43, locality 7735)	Earliest Hettangian	Moenave Formation, Whitmore Point Member	36.8802°N	112.8466°W	Mocassin Quadrangle, Mohave Co., Az.	<i>Bulbilimnadia killianorum</i> Zone
<b>New Mexico</b>						
Lake Ciniza beds (NMMNH locality 1864)	Late early (middle) Tuvalian	Bluewater Creek Formation, middle part	35.4614°N	108.5563°W	FortWingate Quadrangle, McKinley Co., N.M.	<i>Anyuanestheria wingatella</i> Zone
Whitaker quarry (NMMNH locality 3115)	Sevastian	Rock Point Formation	36.3355°N	106.4638°W	Ghost Ranch Quadrangle, Rio Arriba Co., N.M.	<i>Shippingia olseni</i> Zone
Apache Canyon (NMMNH locality 3590)	Late Sevastian to early Rhaetian	Redonda Formation	34.9976°N	103.4070°W	Apache Canyon Quadrangle, Quay Co., N.M.	<i>Redondestheria grovetonensis</i> Zone, <i>Shippingia olseni</i> Zone, <i>Gregoriusella polonica</i> Zone
<b>Texas</b>						
(Texas Tech locality 3628)	Late early (middle) Tuvalian	Tecovas Formation	On file at Texas Tech	On file at Texas Tech	Collette Springs Quadrangle, Crosby Co., Texas	<i>Anyuanestheria wingatella</i> Zone
(Texas Tech locality 0690)	Tuvalian	Tecovas Formation, lower part	On file at Texas Tech	On file at Texas Tech	Kalgary Quadrangle, Crosby Co., Texas	Zone indeterminate
<b>Utah</b>						
(NMMNH locality 6817)	Earliest Hettangian	Moenave Formation, Whitmore Point Mbr.	37.0996°N	113.5349°W	St. George Quadrangle, Washington Co., Utah	<i>Bulbilimnadia killianorum</i> Zone
Moab (NMMNH locality 3293)	Sinemurian	Kayenta Formation	38.6496°N	109.7349°W	Jug Rock Quadrangle, Grand Co., Utah	Zone not yet defined



described by Ash (1988). Therefore, the Santa Rosa and Shinarump formations may be time equivalents and facies equivalents to the Schilfsandstein as has been suggested by Prof. G. H. Bachmann (Halle, pers. comm.). The lower Bluewater Creek Formation with *Palaeolimnadia* n. sp. also may be a lateral facies equivalent of the upper Shinarump and upper Santa Rosa formations, or else it could represent an unusual facies of the Shinarump.

The Blue Mesa Member of the Petrified Forest Formation (Heckert & Lucas 2002; originally a member of the Chinle Formation of Gregory, 1950) has yielded conchostracans known elsewhere from the late Tuvolian. This stratigraphic assignment is in accord with the late Tuvolian age assigned to this unit by Litwin *et al.* (1991). There are several unconformities at the base and within the overlying Sonsela Member of the Petrified Forest Formation (Lucas *et al.* 2007a). Neither the Sonsela Member of the Petrified Forest Formation (Heckert & Lucas 2002) nor the laterally equivalent Trujillo Formation (Gould 1907) have yielded any well-preserved conchostracans. The vertebrates that are present in this interval are suggestive of the lower part of the Revuelian faunachron. The base of this LVF, however, is defined by the first occurrence of *Aetosaurus* and it has not been found in this unit yet, leaving open the possibility that the Sonsela is uppermost Adamanian. The Sonsela has yielded late Tuvolian palynomorphs (Litwin *et al.* 1991), which could be either in place or reworked from the beds immediately below. Therefore, whether the Sonsela is Carnian or Norian and whether it is Adamanian or Revuelian remains uncertain.

The base of the Norian cannot be defined as yet by conchostracans in the southwestern United States. It may lie at the Adamanian-Revuelian tetrapod boundary, which lies at the top, within, or at the base of the Sonsela Member of the Petrified Forest Formation. Unfortunately, the Sonsela has yielded no well-preserved conchostracans so far. In the underlying Blue Mesa Member, only a single well-preserved but low diversity conchostracan fauna is known which contains *Gregoriusella* n. sp. This form also occurs in the late Tuvolian *L. freybergi* Zone of the Germanic Basin. Its presence tends to support a late Tuvolian age for the Blue Mesa Member, but it is not a robust support because neither the late Tuvolian guide form *L. freybergi* nor any early Norian guide form (e.g. *Euestheria buravasi* or *Palaeolimnadia schwanbergensis*) is present. Therefore, the Norian base as defined by conchostracans is undeterminable for now in the southwestern United States.

At present there are two mutually exclusive ages that have been proposed for the Carnian–Norian boundary, each based on radiometric dates. These

conflicting dates have produced a ‘short Norian model’ and a ‘long Norian model’. New radiometric ages from the Chinle Group suggest that the ‘short Norian model’ (e.g. Ogg *et al.* 2008) may be correct. This model assumes a Norian duration of only about 13 Ma with its base at around 216.5 Ma. Irmis & Mundil (2008) dated the base of the Blue Mesa Member of the Petrified Forest Formation as being  $219.2 \pm 0.7$  Ma. J. Ramezani presented very similar values (219.4 Ma) for the base of the Blue Mesa Member in a lecture (New Chinle Ages) at the Colorado Plateau Coring Project meeting in Albuquerque (May 2009). Heckert and Lucas also have an unpublished analysis by Jim Mortensen that yielded an *c.* 219 Ma age for the base of the Blue Mesa (Spencer G. Lucas, Albuquerque, pers. comm., 2009).

In his talk on New Chinle Ages, Ramezani also presented radiometric ages of  $217.84 \pm 0.05$  Ma for the Sonsela Member and  $209.78 \pm 0.12$  Ma for the Black Forest Beds of the Painted Desert Member. The latter unit earlier was dated by Riggs *et al.* (2003) as being between 209 and 213 Ma, though they assumed that the actual age was closer to 209 Ma. Together with the radiometric ages of Ramezani for the Sonsela Member, the base of the Norian would seem to lie either around 218 Ma (base of Sonsela) or 217 Ma (top of Sonsela), either of which ages supports the ‘short Norian model’ of Ogg *et al.* (2008). Further studies are necessary to solve this problem, however. The only conchostracans known from the Petrified Forest Formation are from the basal Blue Mesa Member, and they represent a low diversity fauna of equivocal age. If the vertebrate biostratigraphic data for the Petrified Forest Formation can be confirmed by robust conchostracan data, then the ‘short Norian model’ would be probable. Even if the age of the Blue Mesa Member proves to be younger than previously assumed, however, the ‘long Norian model’ remains possible if the upper part of the Adamanian LVF ranges up through the lower Norian (Lacian). However, such a conclusion is not supported by conchostracan stratigraphy anywhere outside of the southwestern United States.

We used the ‘long Norian model’ in the present paper, specifically the submodel of Bachmann & Kozur (2004) and Kozur & Weems (2007) that proposes a duration for the Norian of *c.* 17–20 Ma based on an age for the Carnian–Norian boundary of  $225 \pm 3$  Ma. Most other authors who advocate the ‘long Norian model’ prefer a much longer duration for the Norian (e.g. Gallet *et al.* 2003 with a Norian duration of 25 Ma). The main support for the ‘long Norian model’ is an age of  $225 \pm 3$  Ma that was obtained from lower Norian rhyolites in southeastern Alaska (Gehrels *et al.* 1987). According to the conodont data of Savage & Gehrels

(1987), the rhyolites from which the radiometric age was obtained are bracketed below by beds with *Metapolygnathus primitius*, 1987, which was used in 1987 as a group of species of latest Carnian to earliest Norian age, and above by *Epigondolella abneptis*, 1987, which was used in 1987 as a group of lower Norian species that includes *E. quadrata* Orchard and *E. triangularis* (Budurov), though the holotype of *E. abneptis* comes from the middle Norian. Thus, Gehrels *et al.* (1987) clearly have established that the reported radiometric age was taken from within lowermost Norian strata. A modern re-investigation of this radiometric age is necessary, but it is noteworthy that a  $230.91 \pm 0.33$  Ma for the late early Tuvanian (Furin *et al.* 2006) and a corrected age of 231.4 Ma for the Adamanian LVF of Ishigualasto (Argentina) (Irmis & Mundil 2008) also support the 'long Norian model' because, if the base of the Norian lies at about 217 or 218 Ma, then the Tuvanian would be longer than the entire Norian, which seems very improbable.

Above the Sonsela Member, neither the Painted Desert Member of the Petrified Forest Formation (Heckert & Lucas 2002), the laterally equivalent Bull Canyon Formation of New Mexico (Lucas & Hunt 1989) nor the Cooper Canyon Formation of Texas (Lehman *et al.* 1992), have yielded conchostracans. However, Litwin *et al.* (1991) have reported Norian palynomorphs from this interval. This interval also has produced abundant vertebrates of the Revueltian faunachron. No Triassic strata are preserved above the Cooper Canyon Formation in Texas, and there is a major unconformity above the laterally equivalent Bull Canyon Formation in eastern New Mexico as well. In northwestern New Mexico and northeastern Arizona a somewhat younger unit occurs, the Owl Rock Formation (Lucas 1993; Lucas *et al.* 1997; originally described as the Owl Rock Member of the Chinle Formation by Stewart 1957) that also has not yielded conchostracans. This unit has yielded vertebrates, however, which are referable to the Revueltian faunachron (Lucas *et al.* 2007a; Spielmann *et al.* 2007) and indicate that it is not greatly younger than the underlying Petrified Forest Member.

Above this level, there is a minor unconformity within the middle Norian (Alaunian). Deposition resumed regionally in the late Norian (Sevastian) and laid down a series of deposits previously mapped as the Church Rock Member (Stewart 1957) in southern Utah, the Church Rock Formation of the Chinle Group (Lucas 1993; Lucas *et al.* 1997) in north-northeastern Arizona, the Rock Point Formation (Lucas 1993; Lucas *et al.* 1997; originally described as the Rock Point Member of the Wingate Sandstone by Harshbarger *et al.* 1957, later moved to the Chinle Formation by Dubiel

1989) in east-northeastern Arizona and northwestern New Mexico, and the Redonda Formation in eastern New Mexico (Griggs & Read 1959; originally described as the Redonda Member of the Chinle Formation by Dobrovolsky & Summerson 1946). The Church Rock and the Rock Point are different names for what is essentially the same stratigraphic interval. These names were applied in different geographical areas and both were used for the first time in the geological literature in the year 1957. Lucas (1993) has suggested that the name Church Rock (with no designated type locality) be replaced by the name Rock Point (which does have a type locality), and this suggestion is followed here. This sequence has yielded conchostracans from two localities. One occurrence, at the Apachean-age Whitaker *Coelophysis* quarry in the Rock Point Formation of northwestern New Mexico, has yielded a new species of very large *Shipingia*, different from *S. olseni* and bearing a well-developed microsculpture that makes it more advanced than *S. hebaozhaiensis*. This form is too advanced to be Alaunian and therefore can be assigned a Sevastian age. The other occurrence is in the Redonda Formation of northeastern New Mexico, where several conchostracan species have been found including the type material of *Redondestheria novomexicoensis* and large specimens of *Shipingia olseni*. Above the *S. olseni* Zone, *Gregoriusella polonica* Kozur, Niedzwiedzki & Sulej occurs. This species characterizes the latest Sevastian(?) and basal Rhaetian in northern Germany and Lipie (Poland), so the highest strata in this sequence appear to range upward into the lowest part of the Rhaetian. Because the vertebrates within this sequence were the basis for creating the Apachean faunachron, the discovery of Sevastian-age conchostracans within it means that its stratigraphic range must be revised downward to include the Sevastian.

The immediately overlying Dinosaur Canyon Member of the Moenave Formation (Harshbarger *et al.* 1957) has yielded no conchostracan as yet. However, conchostracan have been reported from the Whitmore Point Member of the Moenave (Wilson 1967; Lucas & Milner 2006). Specimens found in the upper Whitmore Point Member that we received from Dr Andrew R. C. Milner (St. George, Utah) are mainly *Euestheria brodieana* (Jones) but also include a few *B. killianorum*. Additionally, Dr Spencer G. Lucas (Albuquerque) has provided material from his bed 43 (a 0.5 m-thick purple-brownish mudstone unit) of the upper Whitmore Point Member in Potter Canyon, northern Arizona (NMMNH locality 7735), about 1 km west of the type section of the Whitmore Point Member. This well-preserved material, from about 3.5 m below the Springdale Member of the

Kayenta Formation, is dominated by *E. brodieana* but also has common *B. killianorum*. These two occurrences demonstrate that the upper part of the Whitmore Point Member is earliest Hettangian in age and correlative with the basal Hettangian strata of Poland and the middle part of the Midland Formation above the basal Mt. Zion Basalt in the Culpeper Basin in the eastern United States. This conclusion is in accord with the palynological results of Cornet & Waanders (2006). Dr Spencer G. Lucas and Dr Wolfram Kürschner (Utrecht) have discovered a third and lower horizon in the lower Whitmore Point Member at Potter Canyon. This material comes from bed 22 of Lucas (a 2.6 m-thick black and greenish shale unit) that lies about 6 m above the Dinosaur Canyon Member of the Moenave Formation. More than 400 well-preserved conchostracan specimens were collected by Spencer G. Lucas and Wolfram Kürschner from these shales and all belong to *Euestheria brodieana*. A monospecific *E. brodieana* fauna is characteristic of the upper Rhaetian *E. brodieana* Zone, and this age designation is in agreement with data presented by Wolfram Kürschner at the Colorado Plateau Coring Project meeting in Albuquerque (May 2009), based on the presence of a carbon isotope minimum at this stratigraphic level that is the initial carbon isotope minimum within the uppermost Rhaetian. Thus, the Triassic–Jurassic boundary lies within the Whitmore Point Member, somewhat higher in the section than so far assumed. The palynoflora from the upper part of the underlying Dinosaur Canyon Member is close in age (Litwin *et al.* 1991; Cornet & Waanders 2006) and belongs to the top of the Rhaetian according to the new conchostracan and isotopic data from the lower Whitmore Point Member. Of particular importance is the fact that *B. killianorum* has never been found anywhere in Rhaetian strata, even in the uppermost Rhaetian strata of the Germanic Basin and England. Latest Rhaetian conodonts (including *Misikella posthernsteini* Kozur & Mock) are present in England at a level where *E. brodieana* occurs in the absence of *B. killianorum*, and this level clearly is below the level of the marine *Psiloceras spelae* Zone. Therefore, in continental beds, the *B. killianorum* Zone starts at a level no lower than that at which *Psiloceras spelae* Guex *et al.* occurs. On the other hand, the *B. killianorum* Zone also begins below the marine *P. planorbis* Zone. Therefore the *B. killianorum* Zone begins in (and may correspond to) the *P. spelae* Zone of the marine realm.

The Kayenta Formation (Baker 1936), of probable late Hettangian and/or Sinemurian age (Padian 1989), lies disconformably above the Moenave Formation. This is the youngest unit on the Colorado Plateau that has yielded

conchostracans. Their study is beyond the scope of the present paper, but it is worth noting that they seem to represent forms younger than the *Bulbilimnadia froelichi* Zone. They also may be younger than the conchostracans found in the middle of the Portland Formation, which in turn suggests that the youngest possible age for the Portland Formation of the Newark Supergroup is late Hettangian or early Sinemurian.

### Regional occurrence of conchostracans during the Early, Middle and Late Triassic

#### Early Triassic

Early Triassic to early Anisian conchostracans are very common in the Germanic Basin, where they have been long known and well studied, sometimes in continuous successions (see references in the last section). The synonyms of all of these species also are well known (Kozur 1982, 1983; Kozur & Seidel 1983a; Kozur & Hauschke 2008). Additionally, Lower Triassic conchostracans are well known (but mainly without modern revision) from the Russian Platform and adjacent areas such as the Precaspian Basin and Mangyshlak (see references in the previous section).

During the Early Triassic, conchostracans were common, not only in the Germanic Basin, on the Russian Platform, and in adjacent areas such as the Precaspian Basin and Mangyshlak, but also in the Tethys in the uppermost Permian to Upper Olenekian (Spathian) Werfen Group (Kozur 1987, 1999; Kozur & Mock 1993; Bachmann & Kozur 2004). Lower Triassic or uppermost Permian to Lower Triassic conchostracans also are well known from Siberia (Chernyshev 1934; Novozhilov 1946; Novozhilov [Novozhilov], 1958b; Molin 1965b; Sadovnikov & Orlova 1990, 1993; Orlova 1999), Kazakhstan (Zaspelova 1961), and China (Chang *et al.* 1976; Liu 1982, 1987b, 1988, 1989, 1990; Chen & Shen 1985; Liu *et al.* 1990). A few occurrences of Lower Triassic conchostracans are known from continental beds in North America (upper Wupatki Member of the Moenkopi Formation; Kozur, Lucas & Morales, in prep.) and brackish water beds in Greenland (Defretin-Lefranc 1969; Kozur & Seidel 1983a). Lower Triassic conchostracans are common as well in Gondwana, including India (Jones 1862; Ghosh & Shah 1978; Ghosh 1983; Ghosh *et al.* 1988; Tasch 1987), Australia, (Mitchell 1927; Cockbain 1974; Tasch & Jones 1979; Tasch 1987) and Africa (Janensch 1927; Leriche 1932; Marlière 1950; Teixeira 1950a, b, 1951; Kozur & Seidel 1983a, b). In South America, Lower Triassic conchostracans have not

been mentioned until now (see summary by Tasch 1987).

### *Middle Triassic*

Middle Triassic conchostracans are not so widely distributed as the Lower Triassic ones. Conchostracans were abundant in a few areas during the early Anisian (Aegean and lower Bithynian of the Röt and Grès à *Voltzia*) and late Ladinian (brackish equivalents of the upper Hauptmuschelkalk above the Cycloides Bank, and especially the Erfurt Formation = Lower Keuper) (Fig. 4). They have been recognized for quite a long time and are rather well studied (von Zieten 1830; Voltz 1835; Jones 1862, 1863, 1890, 1891; Defretin 1950; Reible 1962; Defretin-Lefranc 1963; Warth 1969; Gall 1971, 1976; Kozur 1974, 1982, 1999b; Kozur *et al.* 1993) and well correlated with the marine scale. In the middle Anisian through lower Ladinian (Pelsonian through Fassanian) interval, however, known strata are either marine or hypersaline and do not contain conchostracans.

Outside the Germanic Basin, Middle Triassic conchostracans have been studied from occurrences that are not well dated or else are isolated and lack context to establish the local conchostracan succession. Aegean and lower Bithynian conchostracans are known from the Mecsek Mountains in southern Hungary (Vadász 1952; Nagy 1959, 1960, 1968; Kozur *et al.* 1993), where they occur in brackish beds intercalated with brachyhaline marine deposits containing *Costatoria costata* (Zenker) and, in the Bithynian, *Myophoria vulgaris* (von Schlotheim). Well-dated conchostracan-bearing upper Bithynian (uppermost lower Anisian) strata with low faunal diversity are known from the Holbrook Member of the uppermost Moenkopi Formation of Arizona, USA (Kozur, Lucas & Morales, in prep.). A monospecific *Euestheria minuta* (von Zieten) fauna has been found in the lower Wolfville Formation in the Fundy Basin and will be described in a future paper. It indicates a Longobardian age for the lower Wolfville. Low-diversity, but characteristic upper Anisian (Illyrian) conchostracan faunas were described from northern Siberia close to the shore of the Laptev Sea; these have been well dated by bivalves and ammonoids (Novozhilov 1946, 1958b, c). Middle Triassic conchostracans of similar age (Anisian to lower Ladinian) are known from China, where they are taxonomically well studied (especially in Chang *et al.* 1976) but no more specifically dated than Middle Triassic.

Little is known about the Middle Triassic conchostracans of Gondwana. Mitchell (1927), Raymond (1946), Tasch & Jones (1979), and Tasch (1987) have described a few Middle Triassic conchostracans from Australia, mainly under the

name of the long-ranging form *Palaeolimnadia wianamattensis* (Mitchell). These occurrences actually may comprise more than one species. Gallego (1992) described an upper Ladinian fauna with *Euestheria minuta* (von Zieten) from Mendoza and San Juan in Argentina and a Middle Triassic fauna from the Santa Maria Formation off Rio Grande do Sul, Brazil. Katoo (1971) described different conchostracans from the lower part of this formation, among them forms he classified as *Lioestheria* sp. and some *Magniestheria* sp. of a size and outline that are known elsewhere only in the Olenekian to lower Anisian. On the basis of these identifications, he and Tasch (1987) assigned the Santa Maria Formation to the Late Triassic. Anderson & Anderson (1993) concluded that the tetrapods of the upper Santa Maria Formation indicate a Norian age for the upper part of that formation. However, Lucas (2002) has concluded that the tetrapods of the upper Santa Maria Formation are not Norian but Middle Triassic to late Carnian in age. As no tetrapods are known from the lower Santa Maria Formation, where conchostracans occur, either age is compatible with the age suggested by conchostracans for the lower Santa Maria Formation. Besides Middle Triassic forms, Katoo (1971) has illustrated from the upper Santa Maria Formation, under the name *Euestheria* cf. *E. minuta* (von Zieten), a *Laxitextella* of the *L. seegisi* Kozur group, which does not range higher than the Upper Carnian (middle Tuvalian). This latter occurrence supports the age range suggested by Lucas for the upper Santa Maria Formation.

### *Upper Triassic*

Upper Triassic conchostracans are as widely distributed as Lower Triassic ones. However, generic assignment of many of these species is not yet clear. Among described species, many are synonyms with some species being assigned by different authors to several different species and genera. In other cases, new species have been established by authors who were unaware that these same species already had been described from other regions. In addition to these considerable problems, many species were established on poorly preserved material that was neither well described nor well documented and needs to be revised by re-sampling from the type localities. Finally, a large percentage of Upper Triassic conchostracans have yet to be described.

The most complete lower and middle Carnian conchostracan successions are known from the Germanic Basin, and these successions are well correlated with the marine timescale. The taxonomy of Cordevolian conchostracans is well known (Reible 1962; Warth 1969; Kozur 1982; Kozur & Weems

2007). Julian conchostracans of the Schilfsandstein have been sampled and photographed but are not yet described. The lower Julian has not produced conchostracans because there is a rather long stratigraphic gap in this part of the section in the Germanic Basin. In other parts of the world, well dated lower Julian conchostracans *sensu stricto* (not including Cordevolian forms incorrectly assigned to the lower Julian) are unknown.

Four horizons with conchostracans are known from the Tuvallian Weser Formation and time equivalents. They occur in eastern France and southern Germany at the base of the Tuvallian (in equivalents of the Dolomie de Beaumont), in the higher part of the lower to middle Tuvallian Lehrberg Beds, in the upper Tuvallian Coburg Sandstein, and in the uppermost Tuvallian Heldburggipsmergel Member of the Weser Formation. The Tuvallian conchostracans of the Germanic Basin are taxonomically well studied and well dated (Reible 1962; Olempska 2004; Kozur & Weems 2007). Even so, if there is to be a comprehensive Tuvallian conchostracan zonation for the northern hemisphere, a synthesis still needs to be made with the Tuvallian conchostracan succession of the Newark Supergroup rift basins in eastern North America and with Tuvallian conchostracan faunas in the southwestern United States (Arizona, New Mexico, Texas). In the Germanic Basin, no conchostracans are present between the four stratigraphic levels mentioned above, all of which represent independent zones with only the two upper zones in direct succession. The intervening stratigraphic levels, barren of conchostracans, represent times of hypersaline deposition in which conchostracans could not live. In the Newark rift basins, the Tuvallian has in several rift basins continuous conchostracan successions in lake deposits without any prolonged hypersaline intervals. Additionally, the equatorial conchostracan fauna of the southern Newark rift basins is more diverse than the conchostracan fauna from the northern Newark rift basins and the still more northerly Germanic Basin. A conchostracan fauna nearly identical with that of the equatorial southern Newark rift basins occurs in the Tuvallian of the southwestern United States, but so far only *Anyuanestheria wingatella* (Tasch) has been established in the literature (Tasch 1978).

Carnian conchostracans also have been reported from other parts of Europe in fresh to brackish water intervals between marine sediments, for example, in the lower Carnian of the westernmost Southern Alps and western Carpathians (Tintori 1990; Tintori & Brambilla 1991; Kozur & Mock 1993). During the middle Carnian wet intermezzo of late Julian age (Kozur & Bachmann 2008), a large influx of fresh water took place in the northwestern Tethys region, resulting in brackish horizons within the

Lunz Formation that contain conchostracans (e.g. Hornung 2007); these have yet to be studied in detail.

Kobayashi (1952, 1954, 1975) has described or mentioned Upper Triassic conchostracans that occur in the Yamaguchi Prefecture, Japan within the Atsu Group just below the *Halobia* shale. '*Estherites*' *nakazawai* Kobayashi is a *Palaeolimnadia* from which only one specimen was illustrated. The holotype (and most of the illustrated specimens) of '*Estherites*' *atsuensis* Kobayashi also belong to *Palaeolimnadia*, and it may be that *P. nakazawai* is only a slightly deformed *P.atsuensis*. There is a second taxon, however, that he included with this species that is an *Anyuanestheria* with radial lirae. This fauna was assigned to the early Carnian by Kobayashi (1952, 1954, 1975) because the immediately overlying beds contained the bivalve *Halobia multistriata* Kobayashi & Aoti (= *Halobia aotii* Kobayashi & Ichikawa), which then was regarded as an early Carnian species (Kobayashi 1963). These conchostracans, however, are closely related to *Palaeolimnadia schwanbergensis* Reible, which was originally described in the Germanic Basin from the latest Carnian 'Berggips Beds' (Heldburggipsmergel Member of the Weser Formation). This species subsequently was found at another locality within the Heldburggipsmergel Member, where it also occurs together with upper Tuvallian conchostracans such as *Laxitextella freybergi* Kelber & Kozur. It occurs also as a monospecific fauna in the lowermost Arnstadt Formation (lowermost Norian) of the Germanic Basin, and in a similarly monospecific lowermost Norian fauna in the Warford Member of the Passaic Formation of the Newark Basin. Thus, the *P.atsuensis*/*P. nakazawai* fauna also is probably latest Carnian or possibly earliest Norian in age, which is in strong conflict with its present lower Carnian age assignment. According to Prof. Christopher A. McRoberts (Cortland, pers. comm., February, 2009), *Halobia multistriata* has been found in well dated beds from north-eastern Siberia that range in age from the lower Norian (e.g. upper *Dawsoni* Zone) up into the early middle Norian (*Rutherfordi* Zone), with an acme in the upper lower Norian (*Magnus* Zone). This means that a late Tuvallian to early Lacinian age for the *P.atsuensis* conchostracan fauna from Japan now does agree with the age range of its associated molluscan fauna.

Norian conchostracans are widely distributed and in part well dated, but many taxa still have to be revised and about 50% of the discovered taxa are yet to be described. Only a few of these new taxa will be described in the present paper. Norian conchostracans are accurately dated in several places in Asia (Kobayashi 1954). In eastern Asia,

well dated and rather diverse lower Norian conchostracans are known from Nam Phrom in Thailand (Kobayashi 1973, 1975, 1984) and also from the Norian of China (Chen 1974; Chang *et al.* 1976; Chen & Shen 1980). Well dated, but poorly preserved Norian conchostracan faunas are known from Hikiji in Japan, from Tonjin and other localities in Korea, and from Mon Cay in Vietnam (Ozawa & Watanabe 1923; Kobayashi 1975, 1984). In western Asia, Novozhilov & Kapelka (1960) described a diverse conchostracan fauna from Madygen in western Kirgistan that they assigned to the lower Norian. Kobayashi (1975) has cast doubt on such an exact age determination for continental beds that lack marine intercalations or marine underlying or overlying beds, but the fauna contains six species that occur in better-dated Norian beds from other places in Asia. Thus a Norian age can be accepted, though it is not clear if the age is precisely lower Norian or perhaps slightly younger.

Very rich conchostracan faunas occur in the Newark rift basins, where a continuous Norian conchostracan standard zonation can be developed. The richest lower Norian (Lacian) faunas are known from the Deep River, Culpeper and Newark basins, but these faunas are not yet fully revised and described. Only a few of these forms were illustrated in Kozur & Weems (2007). Middle Norian (Alaunian) faunas are known from the Culpeper, Gettysburg and Deep River basins. The richest upper Norian (Sevatian) faunas are known from the Culpeper, Newark and Fundy basins. Several uppermost Alaunian and Sevatian conchostracans of the Newark rift basins were described in Kozur & Weems (2007), and an additional form is described in the present paper.

A very important upper Norian conchostracan fauna from within the *Shipingia olseni* Zone occurs in the upper Redonda Formation of New Mexico. A somewhat older upper Norian conchostracan fauna occurs in the Ghost Ranch Quarry of New Mexico in the Rock Point Formation. This fauna cannot be precisely located yet relative to the Sevatian conchostracan faunas from the Newark rift basins or from Germany, but the co-occurrence of this fauna in the Ghost Ranch Quarry with the parasuchian *Redondasaurus* (Lucas & Tanner 2007) clearly places it within the Apachean land-vertebrate faunachron (LVF). These conchostracans are more advanced than those of the uppermost Alaunian, which therefore means that they are Sevatian, but they also are older than the uppermost Sevatian conchostracans of the Apache Canyon locality from the uppermost *Shipingia olseni* Zone.

Norian conchostracans occur in the Germanic Basin in the mid-basin Arnstadt Formation (Steinmergelkeuper) of northern and central Germany,

the contemporaneous Argiles bariolées dolomitiques Formation of eastern France and in the more marginal basin Stubensandstein Formation (Löwenstein Formation) of southern Germany. Except for a few local occurrences with rich faunas, conchostracans occur only rarely in the lower and middle Norian, and in the Sevatian they are only known from boreholes in northern Germany. Almost nothing has been published concerning the Norian conchostracans in the Germanic Basin. Warth (1969) illustrated a species from the lower part of the '3. Stubensandstein' which he identified as *Palaeoestheria dorsorecta* (Reible). The same material was reillustrated by Kozur & Weems (2007), determined to be an advanced *Shipingia hebaozhaiensis* Shen and assigned to the uppermost Alaunian. Hopf & Martens (1992) illustrated (but did not identify) a single conchostracan from the lower Steinmergelkeuper (lower Norian) of western Thuringia. Other occurrences have been mentioned but neither described nor illustrated (e.g. Bourquin & Durand 2006 from the Argiles bariolées dolomitiques Formation of eastern France).

Norian conchostracans from Gondwana are often either inadequately described, based on poorly preserved material, or not well dated and called Upper Triassic without any more detailed placement. Only in Morocco have well-preserved middle Norian *Shipingia hebaozhaiensis* Shen been found by Paul Olsen (Columbia), which will be described in a future joint paper with him. This, however, is not part of a true Gondwanan fauna, but a fauna of northern hemisphere aspect.

Well-dated Rhaetian conchostracan horizons in the northern hemisphere contain only low diversity faunas that include only small species of conchostracans. Lower Rhaetian conchostracans occur rarely in Western and Central Europe, but also are known from boreholes in northern Germany and from a quarry at Lipie in Upper Silesia (Poland). These lowest Rhaetian faunas consist nearly exclusively of *Gregoriusella polonica* n. gen. n. sp., both at Lipie and in northern Germany (in the basal few metres of the Exter Formation in a borehole at Tarnow). Only a few as yet undescribed additional generalized species of *Euestheria* also are present in the lower Rhaetian. Above this interval, the faunas start to include both *Gregoriusella polonica* n. gen. n. sp. and *Euestheria brodieana*. At first *Euestheria brodieana* is rare, but it progressively replaces *Gregoriusella polonica* up-section until, in the upper part of the lower Rhaetian, the faunas become monospecific *Euestheria brodieana* faunas that persist to the top of the Rhaetian.

In the region of the Germanic Basin (England, France, Germany and Poland) upper Rhaetian faunas are much more widely distributed. They

consist of monospecific faunas of *Euestheria brodieana* (Jones), described from England (Jones 1862, 1891; Reible 1962) and France (Battarel & Guérin-Franiatte 1971), with similar faunas also present in Germany (e.g. in the upper Rhaetian *Triletes* Beds in a temporary outcrop along the A4 near Moseberg close to Eisenach). The same monospecific *E. brodieana* fauna occurs in the upper Rhaetian beds immediately below the first lava flow in the Culpeper Basin. The so-called 'Rhaetian–Liassic' faunas with large conchostracans described by Bock (1953a), such as the *Congestheriella olsoni* (Bock) fauna of Venezuela, were incorrectly dated; they belong instead to the Late Jurassic and not to the Triassic (Gallego *et al.* 2009).

### Conchostracan zonation from the latest Permian through the Hettangian

Depending on the local geological setting (i.e. the presence or absence of continuous sequences with lake deposits), different areas at different stratigraphic intervals are most suitable for establishing a Triassic conchostracan zonation for the northern hemisphere. It is not unusual for conchostracan zonations to be combined from different regions. This is especially necessary to provide accurate correlation of the conchostracan zonation with the marine timescale.

The uppermost Permian conchostracan zonation, including the conchostracan zonation across the Permian–Triassic boundary and the correlation of the conchostracan zonation with the marine scale around the Permian–Triassic boundary, can be best established by combining the conchostracan zonations at Dalongkou (Xinjiang) with the Tunguska Basin (in northern Siberia) and with the Germanic Basin of central Germany and southeastern Poland (Holy Cross Mountains). Conchostracan faunas around the Permian–Triassic boundary in northeastern Siberia and in the basal Werfen Beds of Hungary must be also considered for accurate correlation with the marine scale.

The conchostracan zonation of the Lower Triassic and lower Anisian can be best established in continuous successions within the Germanic Basin in central and north-western Germany and in the lower Anisian in southern Germany and eastern France. The correlation of the Lower Triassic conchostracan zonation with the marine scale is best determined in the Werfen Group of Hungary, in the Southern Alps, and in the basal Triassic and Olenekian of northern Siberia. In the lower Anisian, intercalations of marine and conchostracan-bearing beds occur in the Germanic Basin and also in the Mecsek of southern Hungary and in northern Siberia. For the Middle Triassic above the lower

Anisian, the conchostracan successions of China are the best available for establishing a continuous conchostracan zonation, but for correlation with the marine timescale the conchostracans of northern Siberia and the upper Ladinian conchostracans of the Germanic Basin also must be considered.

The zonation of Lower Carnian conchostracans was established in the Germanic Basin, and this is the area where the future zonation of late Julian conchostracans also will be developed once the conchostracans and conchostracan successions of the Schilfsandstein are described. No well dated early Julian conchostracans are yet known. The Tuvalian conchostracan zonation was established partly in the Germanic Basin and partly in the Newark Supergroup. Supplementary zonations need to be established for the diverse equatorial conchostracan faunas of the southern Newark Supergroup Basins and for the southwestern United States. The best areas for developing a detailed Norian conchostracan zonation are in the Newark Supergroup and in the Germanic Basin, but additional zones also must be described from the southwestern United States and perhaps also from China and southeast Asia. The Rhaetian conchostracan zonation has been established in the Germanic Basin. The early Hettangian conchostracan zonation has been developed in the Newark Supergroup, but important additional data are now available from the southwestern United States and from marginal parts of the Germanic Basin in southeastern Poland.

### Upper Permian to basal Triassic conchostracan zonation

The conchostracan zonation of the Upper Permian to lowermost Triassic (Fig. 1) is remarkably uniform from the very high palaeolatitudes of northern Siberia to the low palaeolatitudes of Dalongkou (Xinjiang) and the Germanic Basin. Close to the Permian–Triassic boundary, correlations with the marine scale are possible using the conchostracan faunas from northeastern Siberia and the basal Werfen Beds in Hungary. We present here a conchostracan zonation that starts with the beginning of the tuffaceous part of the Siberian Trap in the Tunguska Basin. The beginning of this zonation can be best established from one section in the Guodikeng Formation on the southern limb of the Dalongkou anticline, Xinjiang. From the *Falsisca eotriassica* Zone upward, this zonation previously was established in the Germanic Basin by Kozur & Seidel (1983b) and Kozur (1993b). The *Falsisca eotriassica* and *F. postera* zones established in the Germanic Basin are also present at Dalongkou and in northern Siberia (Tunguska Basin and Taimyr) in the same succession and with the same

conchostracans. Below the *F. eotriassica* Zone, no conchostracans are present in the upper Zechstein (Late Permian) of Germany; only the lower Zechstein (Zechstein 1) has in its marginal facies yielded some conchostracans, among them a *Megasitum* n. sp., a species which is younger than the youngest Tatarian *Megasitum* but older than the upper Changhsingian *Megasitum* of the Guodikeng Formation (Dr Brigitte Hammerich, Freiburg, pers. comm.).

*Falsisca zavjalovi*–*Tripemphigus minutus* Zone

**Definition.** A distinctive fauna defined by the joint occurrence of the genera *Bipemphigus*, *Falsisca*, *Megasitum* and *Tripemphigus*.

**Lower boundary.** First appearance of *Falsisca zavjalovi* and *F. turaica*.

**Upper boundary.** Disappearance of the genera *Bipemphigus*, *Tripemphigus* and *Megasitum* (the latter genus in the upper part of the zone rare, may disappear somewhat earlier than the other two genera); in high latitudes additionally marked by the disappearance of *Hemicycloleia* and *Echinolimnadia*. The upper boundary of this zone marks the strongest extinction event within Permian conchostracan faunas, well below the Permian–Triassic boundary.

**Important conchostracan species.** *Bipemphigus gennisi* Novozhilov; *Bipemphigus* cf. *B. gennisi* Novozhilov (determined as *Cornia beijiangensis* Liu by Liu Shuwen in Cheng Zhengwu *et al.* 1989); *Bipemphigus* cf. *B. liaoningensis* Shen & Li; *Tripemphigus minutus* (Liu); *T. sibiricus* (Novozhilov) (occurrence at Dalongkou not quite certain, could be also a *T. minutus* with weaker microsculpture); *T. khovorkiliensis* Novozhilov (only in northern Siberia); *Megasitum vanum* (Novozhilov) (in Dalongkou determined as *Megasitum* cf. *M. vanum*); *Falsisca zavjalovi* (Novozhilov 1970) [determined by Liu Shuwen in Cheng *et al.* (1989) as *Falsisca beijiangensis* Liu 1987]; *F. turaica* (Novozhilov) [determined by Liu Shuwen in Cheng *et al.* (1989) as *Falsisca* cf. *F. kanandaensis* Novozhilov]. Additionally, there is *Beijianglimnadia qitaensis* Liu (= *B. elegans* Liu) (only at Dalongkou), *B. dalongkouensis* Liu (= *B. minuta* Liu, only at Dalongkou), *Polygrapta subovata* (Liu) (only at Dalongkou), *Echinolimnadia mattoxi* Novozhilov (only in northern Siberia), *Hemicycloleia mitchelli* (Etheridge) with a distribution both in high northern palaeolatitude Siberia (Tunguska Basin) and high southern palaeolatitude eastern Australia (Newcastle CM Group).

**Type locality.** Dalongkou (Xinjiang), southern limb of the Dalongkou anticline, and 65–107 m above the base of the Guodikeng Formation.

**Occurrence.** Dalongkou (Xinjiang), on the southern and northern limbs of the anticline; Guodikeng Formation of Xialongkou (Xinjiang), Changhsingian, on the southern limb of the anticline between 65 and 107 m above the base of the formation; northern Siberia (Tunguska Basin), in the Lebedeva and lower Khungtukun tuffs, Bugarikta Formation.

**Remarks.** Both *Tripemphigus sibiricus* and *T. minutus* are very small forms and in almost all features very similar. *T. minutus* has a stronger microsculpture, but it is of the same type as in *T. sibiricus*. Possibly these are only preservational and documentation differences, because the Dalongkou material is well-preserved and the microsculpture of *T. minutus* is shown in SEM photographs, while the microsculpture of *T. sibiricus* is shown only in a light optic photograph. Thus, it is entirely possible that *T. minutus* (Liu 1987) is a junior synonym of *T. sibiricus* (Novozhilov 1965), but this can be clearly determined only after investigation of the Dalongkou material, which is still inaccessible [see section titled 'Dalongkou (Xinjiang, NW China)']. If *T. minutus* is a junior synonym of *T. sibiricus*, the name of the zone will need to be changed to the *Falsisca zavjalovi*–*Tripemphigus sibiricus* Zone. No change of the content of the zone would be necessary, however. We could avoid this problem by defining a *Falsisca zavjalovi*–*Tripemphigus sibiricus* Zone in the Tunguska Basin, but this is a remote area and the succession of conchostracans there is not in a successive section, so definition of this zone in the Dalongkou section is much more suitable.

The lowermost known range of *Hemicycloleia mitchelli* in the Tunguska Basin is the base of the *Falsisca zavjalovi*–*Tripemphigus minutus* Zone, but elsewhere this species surely ranges lower. The uppermost range of this species, however, does accurately reflect the top of the *Falsisca zavjalovi*–*Tripemphigus minutus* Zone. This species cannot be used for correlation of the base of the *F. zavjalovi*–*T. minutus* Zone to eastern Australia, for example, because there it appears earlier than the *F. zavjalovi*–*T. minutus* Zone, and this also may be the case in northern Siberia. However, the top of the *F. zavjalovi*–*T. minutus* Zone can be recognized in Australia by the disappearance of *H. mitchelli* in the uppermost part of the Newcastle CM Group of the Sydney Basin (for range of *H. mitchelli* in the Sydney Basin, see Jones & Chen 2000).

The most characteristic genera in the *F. zavjalovi*–*T. minutus* Zone are typical Permian



genera (*Megasitum*) or Changhsingian genera (*Bipemphigus*, *Tripemphigus*). The lower boundary is defined by the appearance of *Falsisca zavjalovi*, but *Falsisca* straddles the Permian–Triassic boundary and the most diverse *Falsisca* faunas occur in the Changhsingian part of its range. Liu *in* Cheng *et al.* (1989) tends to define the Permian–Triassic boundary by the first appearance of *Falsisca*. However, *Falsisca jeskinaica* (Novozhilov) occurs as low as the Tatarian on the Russian platform, and *F. secreta* likewise occurs in the Tatarian of eastern Kazakhstan. Thus, the base of the *F. zavjalovi*–*T. minutus* Zone in some areas is not defined by the level where the first member of the genus *Falsisca* appears, though in Dalongkou and northern Siberia this is the case. *Beijianglimnadia* also begins close to the base of the *F. zavjalovi*–*T. minutus* Zone and ranges above this zone, though it does not range into the Triassic. *Polygrapta* is common in the *F. zavjalovi*–*T. minutus* Zone and also in the underlying Changhsingian beds (lower Guodikeng Formation, Wutonggou Formation). Large representatives of *Polygrapta* disappear at the top of the *F. zavjalovi*–*T. minutus* Zone, though rare small *Polygrapta* persist into the lowermost Triassic. The northern and southern high latitude *Hemicycloleia mitchelli* belongs to a typical Palaeozoic genus that died out at the top of the *F. zavjalovi*–*T. minutus* Zone. The northern latitude *Echinolimmadia mattoxi* is restricted to the *F. zavjalovi*–*T. minutus* Zone.

The disappearance of several typical Palaeozoic, Permian or Changhsingian genera at the top of the *F. zavjalovi*–*T. minutus* Zone marks its upper boundary. This is the strongest and most pronounced conchostracan turnover anywhere within the Permian, and it is well below the Permian–Triassic boundary and even below the FAD of the dicynodont *Lystrosaurus*. At that time, which was within the *C. changxingensis*–*C. deflecta* conodont zone (Fig. 1), no distinct changes in the low latitude marine faunas are seen except for temporary replacements of the warm water conodont faunas by cool water conodont faunas outside the equatorial belt.

As seen in the Tunguska Basin, the strong conchostracan faunal changes above the *Falsisca zavjalovi*–*Tripemphigus minutus* Zone occur within the very thick Khungtukunian tuffs of the Siberian Trap. This is a global bioevent in continental facies, probably caused by climatic changes related to this huge explosive volcanic event that occurred just before the effusion of the Siberian Trap flood basalts. At that time, which was within the *C. changxingensis*–*C. deflecta* conodont zone (Fig. 1), no distinct changes in the low latitude marine faunas are seen except for temporary replacements of the warm water conodont faunas by cool water conodont faunas outside the equatorial belt.

The difference between the low latitude fauna and northern high latitude faunas of the *F. zavjalovi*–*T. minutus* Zone are rather minor. *Hemicycloleia mitchelli* is restricted to high northern and southern latitudes. *Echinolimmadia mattoxi* is restricted to northern high latitudes. All other genera are widespread and occur both in low and northern high latitudes.

#### *Falsisca turaica*–*Falsisca zavjalovi* Zone

**Definition.** Co-occurrence of *Falsisca turaica* (Novozhilov) and *F. zavjalovi* (Novozhilov) without *Bipemphigus*, *Megasitum*, *Tripemphigus* and *F. eotriassica* Kozur.

**Lower boundary.** Disappearance of the important Palaeozoic, Permian and Changhsingian genera *Megasitum*, *Bipemphigus*, *Tripemphigus*, and (in high latitudes) *Hemicycloleia* and (in high northern latitudes) *Echinolimmadia*; this is the strongest conchostracan turnover within the Permian.

**Upper boundary.** Appearance of *Falsisca eotriassica*.

**Important conchostracan species.** *Falsisca turaica* (Novozhilov); *F. zavjalovi* (Novozhilov) (= *Falsisca beijiangensis* Liu and *F. semicircularis* Liu); *F. qitaiensis* Liu; *F. dalongkouensis* Liu; *Beijianglimnadia ? rotunda* Liu, 1989 (= *B. ? multilineris* Liu 1989).

**Type locality.** Dalongkou, on the southern limb of the anticline, 111–132 m above the base of the Guodikeng Formation.

**Occurrence.** Middle Guodikeng Formation of Dalongkou and Xiaolongkou (both Xinjiang), lower part of upper Changhsingian. Upper Khungtukun tuffs of the Tunguska Basin.

**Age.** The *F. turaica*–*F. zavjalovi* Zone is a short zone below the upper Changhsingian *E. eotriassica* Zone. As the latter zone begins distinctly above the base of the upper Changhsingian, the *F. turaica*–*F. zavjalovi* Zone belongs to the early part of the late Changhsingian.

**Remarks.** After the extinction of most Permian species at the end of the *F. turaica*–*F. zavjalovi* Zone, a late Changhsingian to Gangetian low-diversity conchostracan fauna begins.

#### *Falsisca eotriassica* Zone

**Definition.** Range Zone of *Falsisca eotriassica* Kozur & Seidel.

**Lower Boundary.** First appearance of *Falsisca eotriassica*.

*Upper boundary.* Disappearance of *F. eotriassica* and *F. zavjalovi*.

*Important conchostracan species.* *F. eotriassica* Kozur & Seidel; *Palaeolimnadia* aff. *cishyranica* (Novozhilov), only in the lower part of the zone but common; *Euestheria gutta* (Lyutkevich); *Falsisca bolodekitensis* (Novozhilov); *Falsisca postera* Kozur & Seidel, rare in the upper part of the zone; *Falsisca zavjalovi* (Novozhilov).

*Type locality.* Quarry at Caaschwitz, Läuseberg, in Thuringia, Germany. Upper Bröckelschiefer, uppermost Zechstein.

*Occurrence.* Upper Bröckelschiefer (uppermost Zechstein) of the Germanic Basin, including the uppermost part of the short reversed palaeomagnetic interval below the long normal interval that straddles the Permian–Triassic boundary and the lower part of the long normal interval. Dalongkou (Xinjiang), on the southern limb of the anticline from 132 m to c. 180 m above the base of the Guodikeng Formation, slightly above the FAD of *F. postera* at 171.2 m above the base of the Guodikeng Formation. Lower part of the co-occurrence interval of *Dicynodon* and *Lystrosaurus*. Upper part of the upper Khungtukunian tuffs and possibly also in sedimentary intercalations within the lower Putorana flood basalt of the Siberian Trap of the Tunguska Basin and Taimyr (only *Falsisca bolodekitensis* is reported from the latter beds). Also possibly in the uppermost Permian of NE Siberia (only *P. cishyranica* is reported).

*Age.* Late Changhsingian below the base of the Buntsandstein and the age-equivalent base of the Boundary Clay at Meishan, central and northwestern Iran, and in Transcaucasia.

*Remarks.* Kozur & Seidel (1983b) introduced this zone as the lower subzone of the *F. eotriassica* Zone *s.l.* that comprised the entire *Falsisca* fauna of the Germanic Basin from the base of the *F. eotriassica* Zone *s.s.* to the disappearance of the genus *Falsisca*. Kozur (1993) later regarded the *F. eotriassica* Zone as an independent zone.

The index species is very similar to *Falsisca bolodekitensis* (Novozhilov) found in sedimentary intercalations within the lower Putorana basalt. However, *F. bolodekitensis* displays much narrower and much more numerous growth bands than *F. eotriassica*. *F. bolodekitensis* is rarely present in the *eotriassica* Zone of the Germanic basin and was assigned by Kozur & Seidel (1983a, pl. 1, fig. 6) to *F. eotriassica*. The occurrence of *F. bolodekitensis* in the (upper) *eotriassica* Zone of the Germanic Basin may indicate that this zone ranges perhaps up to the level of the lower Putorana flood

basalts of the Siberian Trap together with *Lystrosaurus*.

However, *Falsisca zavjalovi* is also present in the *F. eotriassica* Zone of the Germanic Basin. In the Tunguska Basin, *F. zavjalovi* is common in the Khungtukun tuffs, but it does not occur as high as the sediments intercalated within the Putorana flood basalts. Thus, the *F. eotriassica* Zone (with *F. zavjalovi*) of the uppermost Zechstein of the Germanic Basin is no younger than the tuffs below the Putorana flood basalts. This is confirmed by the presence of *F. podrabineki* in the sediments intercalated within the Putorana flood basalts (Sadovnikov & Orlova 1993), because *F. podrabineki* is restricted to the *F. postera* Zone of the lowermost Buntsandstein in the Germanic Basin. Thus, the distinct climatic change at the Zechstein–Buntsandstein boundary, which coincides with the base of the Boundary Clay at the base of the *C. meishanensis*–*H. praeparvus* Zone (Kozur 1998a, b; Bachmann & Kozur 2004), also coincides with the beginning of the eruption of wide-spread flood basalts in the Siberian Trap (Fig. 1).

#### *Falsisca postera* Zone

*Definition.* Range of *F. postera* without *F. eotriassica*.

*Lower boundary.* Disappearance of *Falsisca eotriassica* Kozur & Seidel, *F. zavjalovi* (Novozhilov) and probably *F. bolodekitensis* (Novozhilov); the last species may range a little higher.

*Upper boundary.* Disappearance of *F. postera*, which remains common even into the uppermost *F. postera* Zone. The FAD of *Falsisca verchojanica* (Molin) usually follows a distinct *Falsisca*-free interval, so this FAD generally cannot be used for defining the top of the *F. postera* zone. In the southern limb of the anticline at Dalongkou, the youngest *F. postera* was found 199 m above the base of the Guodikeng Formation, the FAD of *F. verchojanica* is at 210 m above the base of the Guodikeng Formation, and the LOD of *Dicynodon* is at 219 m above the base of the Guodikeng Formation. These distances represent only very short time intervals because the sedimentation rate at Dalongkou is extremely high.

An exception to this pattern of succession is found in the Zachełmie quarry east of the village Zagnańsk, north of Kielce, Holy Cross Mountains. There is only a 1.4 m-thick interval without *Falsisca* that separates the highest occurrence of *F. postera* from the lowest occurrence of *F. verchojanica*. As continental beds generally do not yield conchostracans or other fossils in every layer, this can be regarded as an essentially continuous succession from the *F. postera* zone to the *F. verchojanica* Zone. The first conchostracans

from this section were reported by Ptaszyński & Niedźwiedzki (2004, 2006) and *F. postera* was correctly assigned to the uppermost Permian in Ptaszyński & Niedźwiedzki (2006). In addition to *F. postera*, juvenile *F. postera* were incorrectly reported as *F. eotriassica*. *F. verchojanica* was not found in these first studies, but it was later reported in Kuleta *et al.* (2007).

*Important conchostracan species.* *Falsisca postera* Kozur & Seidel, in some beds abundant; *F. podrabineki* (Novozhilov), rare; *Euestheria gutta* (Lytkevich), dominant; *E. oertlii* Kozur, very rare; *E. jakutica* (Novozhilov), very rare.

*Type locality.* Section Nelben (formerly called the 'old quarry close to the Saale bridge near Könnern'), NW of Halle, Sachsen-Anhalt, Germany. Cycle 1 and basal part of Cycle 2 below the horizon of the alpha 2 oolitic limestones.

*Occurrence.* Cycle 1 and lower part of cycle 2 (below the horizon of the alpha 2 oolitic limestones) of the Calvörde Formation (lower Graubank Horizon *s.s.*) of the lowermost Buntsandstein in central and northern Germany. The Clayey Sandstone member (except its uppermost part) of the Calvörde Formation of Thuringia. Lower three-fourths of the Jaworzna Formation of the basal Buntsandstein in the abandoned Zachelmie quarry on the western part of Chełm Hill east of the village of Zagnańsk, about 8 km north of the town of Kielce, Holy Cross Mountains. This occurrence lies at the southeastern margin of the northern Germanic Basin and is especially important because the *F. postera* Zone is separated from the overlying *F. verchojanica* Zone of the basal Triassic by only a 1.4 m-thick *Falsisca*-free interval. Basal Werfen Group of the Balaton Highland, Hungary. Upper, but not uppermost part of the co-occurrence interval of *Lystrosaurus* and *Dicynodon* at Dalongkou (Xinjiang). *F. postera* is known with certainty from 171.2 m to 199 m above the base of the Guodikeng Formation on the southern limb of the anticline. The co-occurrence interval of *Lystrosaurus* and *Dicynodon* is from 161 m to 219 m above the base of the Guodikeng Formation. Putorana flood basalts of the Siberian Trap. In the Tunguska Basin *Falsisca podrabineki* is restricted to sedimentary intercalations between the Putorana flood basalts (Sadovnikov & Orlova 1993). In the Germanic Basin this species is restricted to the *F. postera* Zone. Therefore the Putorana flood basalts can be correlated with the *F. postera* Zone.

*Age.* Late Changhsingian. The correlation of the *postera* Zone with the latest Permian shallow water *H. praeparvus* Zone in the lowermost Werfen Group of Hungary and the correlation of

the overlying *F. verchojanica* Zone with the basal Triassic in northern and northeastern Siberia places the continental Permian–Triassic boundary between the *F. postera* and *F. verchojanica* zones. This was later confirmed by Korte & Kozur (2005), who found the first minimum of the negative excursion in  $\delta^{13}\text{C}_{\text{carb}}$  around the Permian–Triassic boundary in the lower oolite bank alpha 2 horizon immediately above the top of the *F. postera* Zone in the Nelben section. In marine sections this minimum is situated at the base of the *Hindeodus parvus* Zone, which defines the base of the Triassic.

*Remarks.* The *postera* Zone was introduced by Kozur & Seidel (1983*b*) as a subzone of the *F. eotriassica* Zone *s.l.* At that time *F. postera* was regarded as a subspecies of *F. eotriassica*. In the Nelben section, both *Falsisca postera* and the *F. postera* zone (formerly subzone) were established by Kozur & Seidel (1983*a, b*). In this section the uppermost Zechstein and the cycle 1 and lower cycle 2 of the Calvörde Formation are exposed. Two horizons with oolitic limestone occur, one in the lower part of cycle 1 and one in the lower part of cycle 2 (Szurlies 1998). The upper horizon of oolitic limestone was assigned to the 'oolitic limestone beta' by Kozur & Seidel (1983). However, Paul & Klarr (1988) later subdivided the alpha oolitic limestone horizon into two horizons, alpha 1 and alpha 2. The oolitic limestone horizon in the basal part of cycle 2 of the Nelben section does not correspond to the beta horizon, but rather to the alpha 2 horizon. This is the level at which *F. postera* disappears in the Nelben section. The lower part of cycle 2 is the highest and most prominent level of grey-coloured rock in the Graubank Horizon *sensu* Schulze (1969). Kozur (1998*a, b*) used the Graubank Horizon in the sense of Schulze (1969) and therefore put the top of the *F. postera* Zone (and with it the top of the Permian) within the upper Graubank Horizon. Since then, Brüning (1986) restricted the Graubank Horizon to the lower part of cycle 2, and this restricted definition of the Graubank horizon is preferred (Szurlies 1999). Bachmann & Kozur (2004) placed the Permian–Triassic boundary at the base of the minimum of the  $\delta^{13}\text{C}_{\text{carb}}$ , which occurs at the alpha 2 oolitic limestone horizon within the Graubank Horizon in the lower part of cycle 2 of the Nelben section (Korte & Kozur 2005). This coincides perfectly with the top of the *F. postera* Zone in this section and so it was chosen as the Permian–Triassic boundary by Kozur (1998*a, b*).

*Falsisca verchojanica* Zone + *Falsisca* cf. *F. verchojanica* Zone

*Definition.* Range of *Falsisca verchojanica* (Molin) and of *F. cf. F. verchojanica* of the

advanced *F. verchojanica* group. *Falsisca* cf. *F. verchojanica* (Molin) is a separate species, but for now we cannot describe this species because we have no suitable holotype. The well-preserved material from Xiaolongkou was confiscated and is unavailable for study [see section titled 'Dalongkou (Xinjiang, northwest China)']. *F. cf. F. verchojanica* from the Germanic Basin (see Kozur & Seidel 1983a) is clearly a different species from *F. verchojanica*, but all known specimens are either not fully preserved or deformed. Additionally, in the Chinese material there appear to be two different species that occur above the interval that contains *F. verchojanica*.

*Lower boundary.* LOD of *F. postera* Kozur & Seidel, FAD of *F. verchojanica* (Molin).

*Upper boundary.* The upper boundary of the *F. verchojanica* Zone *s.s.* is at the FAD of *F. cf. F. verchojanica* (= *Falsisca* n. sp.), illustrated by Kozur & Seidel (1983a, pl. 3, figs 6 & 7) under the name *Falsisca eotriassica* n. subsp. The upper boundary of the *Falsisca* cf. *F. verchojanica* Zone is characterised by the disappearance of the genus *Falsisca* Novozhilov, which is at the same horizon where the tetrapod *Lystrosaurus* disappears.

*Important conchostracan species.* *Falsisca verchojanica* (Molin); *Euestheria gutta* (Lytkevich), rare; *E. oertlii* Kozur. In the *F. cf. F. verchojanica* Zone the latter two species and *Falsisca* n. sp. (= *F. cf. F. verchojanica*) are present.

*Type locality.* Dalongkou (Xinjiang), on the southern limb of the anticline. Uppermost Guodikeng Formation (from G 210 m to G 232.7 m) and lower Jiucaiyan Formation. Gangetian (lower Brahmanian, basal Triassic). A latest Changhsingian age cannot be excluded for the lowermost *F. verchojanica* Zone below the level where *Dicynodon* disappears (in Dalongkou between 210 m and 219 m above the base of the Guodikeng Formation).

*Occurrence.* Uppermost Guodikeng Formation and lower Jiucaiyan Formation of Dalongkou, Xinjiang. Together with the *F. cf. F. verchojanica* Zone in the lower 200 m of the Jiucaiyan Formation of Xiaolongkou, Xinjiang. Lowermost Triassic of northeastern Siberia. Lowermost Triassic of the Russian Platform. The *Falsisca* cf. *F. verchojanica* Zone occurs in the variegated lower part of the sandy Claystone member of the Calvörde Formation in Thuringia (Gangetian Substage of the Brahmanian Stage) and in the middle and upper Jiucaiyan Formation of Xiaolongkou, Xinjiang. Uppermost Jaworzna Formation of the basal Buntsandstein above the *F. postera* Zone (see under this zone) in the abandoned Zachemie quarry on the western

part of Chełm Hill east of the village of Zagnańsk, about 8 km north of the town of Kielce, Holy Cross Mountains. *F. verchojanica* also occurs in sedimentary intercalations between the Marininskii flood basalts of Taimyr (Sadovnikov & Orlova 1993).

*Age.* Gangetian Substage of the Brahmanian (Induan) Stage. The base of the *F. verchojanica* Zone was first correlated with the base of the Triassic at the FAD of *H. parvus* by Kozur (1998a, b), but the lowermost part of the *F. verchojanica* Zone that overlaps with the last occurrences of *Dicynodon* at Dalongkou could possibly belong to the latest Changhsingian. *Falsisca verchojanica* in Siberia always has been reported as coming from the basal Triassic, but the basis for this conclusion is rather indirect. In the Verchojanian Range in NE Siberia, *F. verchojanica* occurs only along its western slope (pers. comm. Dr N. G. Sadovnikov, Moscow), whereas *Otoceras* and lowermost Triassic ammonoids are found only along its eastern slope. In the Germanic Basin, the minimum  $\delta^{13}\text{C}_{\text{carb}}$  value lies in the Nelben section immediately above the top of the *F. postera* Zone (Korte & Kozur 2005), but in Nelben *F. verchojanica* has not yet been found immediately above the last *F. postera*. In the Holy Cross Mountains, *F. postera* is common up to the top of the *F. postera* zone, and 1.4 m above this zone *F. verchojanica* is present. The correlation of the *postera/verchojanica* boundary in the Nelben section with the marine Permian–Triassic boundary ultimately was confirmed by establishing the relationships between magnetostratigraphy, magnetosusceptibility and cyclostratigraphy (MSEC) in the Nelben section by Bachmann, Hansen, Szurlies, and Toft. These unpublished results, by comparison with the Meishan (south China) GSSP for the base of the Triassic, Jimsar (Xinjiang) and other sections, indicate that the location of the PTB is within the Graubankzone *s.s.*, in the lower part of Cycle 2 in the alpha 2 oolitic limestone horizon of the Nelben section (pers. comm. from Prof. G. Bachmann, Halle and Dr H. J. Hansen, Copenhagen whom we thank very much for this information and permission to cite it here as unpublished data).

*Remarks.* The equivalents of both the *F. postera* Zone and the *F. verchojanica* Zone in the lowermost Buntsandstein can be found in the Tunguska Basin and in Taimyr in sedimentary intercalations within the Putorana and Marininskii flood basalts, respectively. Therefore, the Permian–Triassic boundary lies within the flood basalts of the Siberian Trap.

In undoubtedly Lower Triassic beds (e.g. in the uppermost Guodikeng Formation above the last occurrence of *Dicynodon* in Dalongkou, in the

Jiucaiyan Formation of Dalongkou and Xiaolongkou (both Xinjiang), as well as in the lower Sandy Claystone Member of the Calvörde Formation of the lower Buntsandstein in Thuringia) advanced very large (>7 mm), slender *Falsisca* occur which belong to the *F. verchojanica* group. In general they have a very fine reticulation, which unfortunately is usually not recognizable or only visible in the posteroventral part of the carapace. On the basis of the latter feature, Liu (1987a) established the genus *Difalsisca*, which is here regarded as a junior synonym of *Falsisca*. In all investigated sections, the underlying *F. postera* zone is separated from this zone by a short interval in which no *Falsisca* are present. In the rapidly deposited Dalongkou section, the interval between the last *F. postera* and the first *Falsisca verchojanica* group is very short (above G 199 m and below G 210 m). In this section, the lowermost part of the *F. verchojanica* Zone + *F. cf. verchojanica* Zone (lower 9 m of more than 200 m) may belong to the uppermost Permian because in this interval are the highest occurrences of the Permian tetrapod genus *Dicynodon*. Most of the *F. verchojanica* Zone + *F. cf. F. verchojanica* Zone coincides with the range of *Lystrorhynchus* without *Dicynodon*. Most of the concurrent range zone of *Lystrorhynchus* and *Dicynodon* can be assigned to the Changhsingian [see section titled 'Dalongkou (Xinjiang, NW China)'], and the *Lystrorhynchus* fauna without *Dicynodon* certainly belongs to the Lower Triassic. The upper range of the *F. verchojanica* Zone + *F. cf. F. verchojanica* Zone is well established in the Xiaolongkou section (Xinjiang), where it ends about 200 m above the base of the Jiucaiyan Formation (there about 300 m thick). This level coincides with the highest occurrence of *Lystrorhynchus*. Nowhere is *Falsisca* known to range into the Gandarian (Dienerian), *Lystrorhynchus* also probably does not range higher than the Gangetian, which would make its total range upper Changhsingian through Gangetian.

The time of disappearance of the conchostracan *Falsisca* and the tetrapod *Lystrorhynchus* coincides with the time at which (warm and) cold-water adapted conodonts such as *Hindeodus* disappeared worldwide in the marine realm. This extinction event coincides with a strong warming that occurred in the uppermost Gangetian and at the base of the Gandarian (base of Dienerian).

**Lower Triassic conchostracan zonation.** A Lower Triassic conchostracan zonation (Figs 13–15) was established in the Germanic Basin by Kozur & Seidel (1983a, b) and later refined (Kozur 1993a, b; Bachmann & Kozur 2004; Kozur & Weems 2007; Kozur & Hauschke 2008; see Figs 13 & 14). This zonation can be traced throughout the entire northern hemisphere (wherever conchostracans are present)

and across large parts of Gondwana. It is also closely correlated with the marine scale (e.g. Kozur & Seidel 1983a, b; Kozur 1993a, b, 1999; Kozur & Mock 1993; Bachmann & Kozur 2004; Kozur & Weems 2007). Among Triassic conchostracans, the taxonomy of the Lower Triassic forms is best known (e.g. Kozur & Seidel 1983a; Shen *et al.* 2002; Bachmann & Kozur 2004; Goretzki 2003; Kozur & Hauschke 2008).

The *F. verchojanica* + *F. cf. F. verchojanica* zones were discussed in the previous section. The Lower Triassic conchostracan zones, and their correlation with the Germanic Triassic and the marine scale, are shown in Figures 13 and 14. In Figure 15 the uppermost Permian to lower Smithian conchostracan zones are correlated with Milankovich cyclicity (short eccentricity cycles), the palaeomagnetic data of Szurlies (2004, 2007) and the  $\delta^{13}\text{C}_{\text{org}}$  curve of Korte & Kozur (2005). Many of these conchostracan zones can be seen to have very short time spans.

#### *Molinesstheria seideli* Zone

**Definition.** Range of *Molinesstheria seideli* Kozur and *Vertexia tauricornis* Lyutkevich without *Estheriella*.

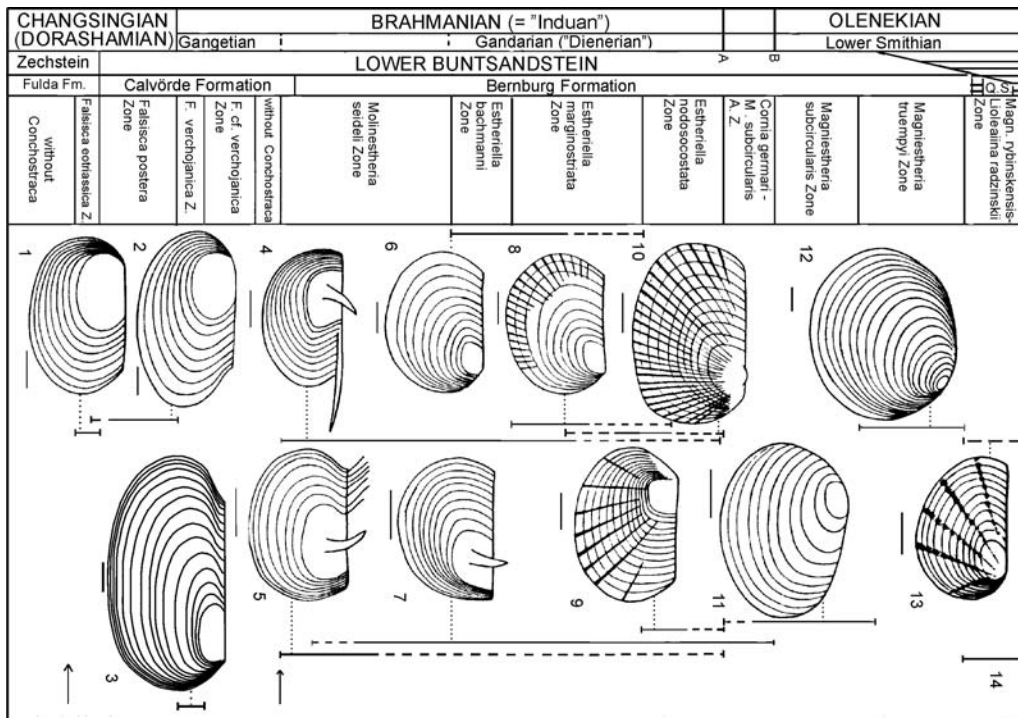
**Lower boundary.** First occurrence of *Molinesstheria seideli* Kozur and *Vertexia tauricornis* Kozur.

**Upper boundary.** FAD of *Estheriella bachmanni* Kozur & Hauschke.

**Important conchostracan species.** *Molinesstheria seideli seideli* Kozur, very common (especially in the lower part of the zone); *Vertexia tauricornis tauricornis* Lyutkevich, common in the lower part of the zone; *V. tauricornis transita* Kozur & Seidel, common only in the middle and upper part of the zone; *Cornia germari* (Beyrich), absent in the basal part of the zone, then rare, and from the middle part of the zone increasingly common toward the top; *Euestheria gutta* (Lyutkevich), in the lower part of the zone locally common, above that very rare; *E. oertlii* Kozur, generally rare; *Magniestheria ? malangensis* (Marlière), rare; *M. lerichi* (Marlière), very rare.

**Type locality.** Lindenschlucht at Süßer See, west of Halle/Saale (Sachsen-Anhalt, Germany). Upper Calvörde Formation (upper part of eccentricity cycle 10 of the uppermost Calvörde Formation) and lower Bernburg Formation. Lower Gandarian (lower Dienerian).

**Occurrence.** Uppermost Calvörde Formation (upper eccentricity cycle 10) and lower Bernburg Formation (eccentricity cycles 1 to lower



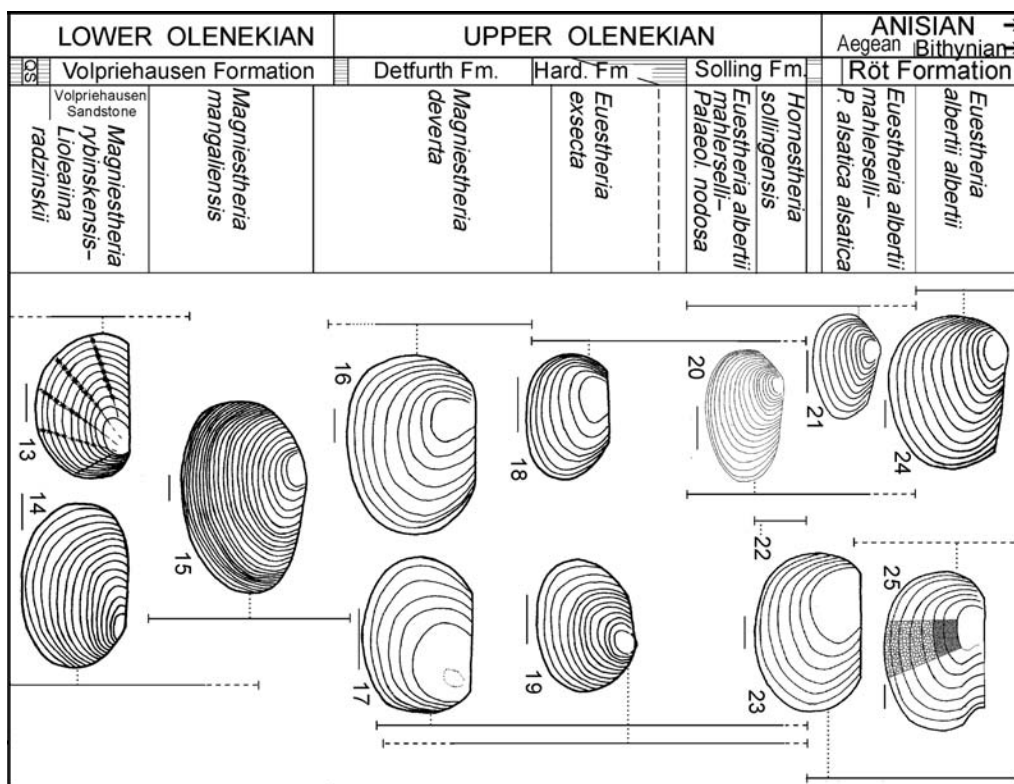
**Fig. 13.** Conchostracan zonation of the Lower Buntsandstein of the Germanic Basin. This is the standard conchostracan zonation for the upper Changhsingian to lower Smithian interval in the Boreal realm, the low and middle latitudes of the northern hemisphere and in northern to central Gondwana. Vertical distances not to scale. Updated after Kozur & Weems (2007). The ranges of the index species and some selected other species are shown. For *Magniestheria rybinskensis*, only the range below the Volpriehausen Formation is shown. Scale = 1 mm. Arrows indicate times of conchostracan immigration into the Germanic Basin following facies-controlled conchostracan-free intervals (Sabkha deposits) that are present throughout the entire Germanic Basin. Q.S., Quickborn Sandstein; 1, *Falsisca eotriassica* Kozur & Seidel; 2, *Falsisca postera* Kozur & Seidel; 3, *Falsisca verchojanica* (Novozhilov); 4, *Molinestheria seideli* Kozur; 5, *Vertexia tauricornis* Lyutkevich; 6, *Estheriella bachmanni* Kozur & Hauschke n. sp.; 7, *Cornia germari* (Beyrich); 8, *Estheriella marginostriata* Kozur; 9, *Estheriella nodosocostata* (Giebel); 10, *Estheriella costata* Weiss; 11, *Magniestheria subcircularis* (Chernyshev); 12, *Magniestheria truempyi* Kozur & Seidel; 13, *Liolaeina radzinskii* Kozur & Seidel; 14, *Magniestheria rybinskensis* (Novozhilov), for illustration and upper range see Figure 14. See also explanation to Figure 15.

eccentricity cycle 4) of the northern and central Germanic Basin. Russian Platform (lower Krasnobakov podsvita of the upper Vochmin Formation, middle Kopan Formation), Pripjat Depression (middle Korenev Formation). Greenland (?), Xinjiang, Angola (?), Congo (?), India (?). In the last 4 areas, neither *M. seideli* nor *V. tauricornis* have been found. Only a few species such as *C. germari* are found there, and these occur also in the succeeding two zones.

**Age.** Early Gandarian (early Dienerian) Substage of late Brahmanian (Induan) Stage.

**Remarks.** The base of this zone in the Germanic Basin marks a time of immigration when conchostracans from outside the Germanic Basin appear after

the conchostracan-free upper but not uppermost Calvörde Formation. Therefore, the zone could begin somewhat earlier outside the Germanic Basin, but not much earlier, because below the conchostracan-free upper (not uppermost) Calvörde Formation *Falsisca* cf. *F. verchojanica* is still present. In Xinjiang (NW China) *Molinestheria*, *Vertexia* and real *Cornia* are not yet present in the Gandetian with *Falsisca* cf. *F. verchojanica* (Molin), as is the case in the Germanic Basin, though above the top of the *Falsisca* cf. *F. verchojanica* Zone and the contemporaneous top of the *Lystrorhynchus* fauna at least *Cornia* is common. Thus, there is not a very long gap between the *Euestheria*–*Falsisca* fauna of the *F. verchojanica*–*F. cf. F. verchojanica* zones and the *Vertexiidae*-dominated fauna of the *Molinestheria seideli* Zone.



**Fig. 14.** Conchostracan zonation of the Middle (Volpriehausen and Solling formations) and Upper Buntsandstein (Röt Formation) in the Germanic Basin. This standard conchostracan zonation applies to the Olenekian to lower Anisian of Eurasia and also the upper Spathian and lower Anisian of North and (partly) South America. The ranges and illustrations (except *Hornestheria sollingensis* Kozur & Lepper n. gen. n. sp.) of the index species and of some selected species are shown. Scale = 1 mm. Updated after Kozur & Weems (2007). Vertical distances not to scale. QS, Quickborn-Sandstone; 13, *Lioleaiina radzinskii* Kozur & Seidel; 14, *Magniestheria rybinskensis* (Novozhilov); 15, *Magniestheria mangaliensis* (Jones); 16, *Magniestheria deverta* (Novozhilov); 17, *Palaeolimnadia alsatica defurthensis* Kozur & Seidel; 18, *Palaeolimnadia nodosa* (Novozhilov); 19, *Euestheria exsecta* (Novozhilov); 20, *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp., slender morphotyp; 21, *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp., stout morphotyp; 22, *Hornestheria sollingensis* Kozur & Lepper n. sp., because of space limitations, only the range is shown; 23, *Palaeolimnadia alsatica alsatica* Reible; 24, *Euestheria albertii albertii* (Voldt); 25, *Dictyonatella dictyonata* (Reible).

*Estheriella bachmanni* Zone

**Definition.** Occurrence of *Estheriella bachmanni* Kozur & Hauschke without radially ribbed *Estheriella*.

**Lower boundary.** FAD of *Estheriella bachmanni* Kozur & Hauschke.

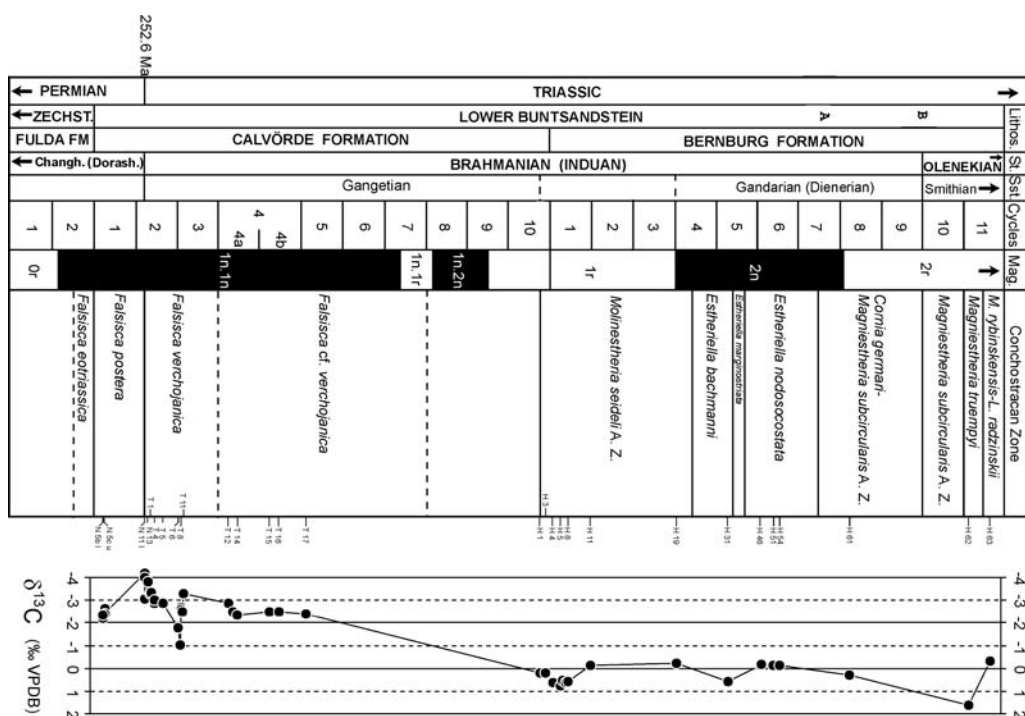
**Upper boundary.** FAD of the ribbed *Estheriella marginostriata* Kozur.

**Important conchostracan species.** *Estheriella bachmanni* Kozur & Hauschke; *Molinestheria seideli postera* Kozur & Seidel; *Vertexia tauricornis tauricornis* Lyutkevich; *V. tauricornis transita* Kozur

& Seidel; *Cornia germari* (Beyrich), common; *Euestheria gutta* (Lyutkevich), very rare; *E. oertlii* Kozur, generally rare; *Magniestheria ? malangensis* (Marlière), rare; *M. lerichi* (Marlière), very rare.

**Type locality.** Large clay pit Beesenlaublingen near Alsleben, NW of Halle, Sachsen-Anhalt, Germany. At this locality all conchostracan zones from the *Molinestheria seideli* Zone up to the *Estheriella nodosocostata* Zone are exposed in superposition.

**Occurrence.** Middle eccentricity cycle 4 to lower eccentricity cycle 5 of the central basin portion of the Bernburg Formation in central and northern



**Fig. 15.** Correlation of the uppermost Permian to lower Smithian conchostracan zonation with the palaeomagnetic zones of Szurlies (2001), re-numbered by Bachmann & Kozur (2004), the short eccentricity Milankovitch cycles after Bachmann & Kozur (2004) and the carbon isotope record from lake limestones after Korte & Kozur (2005). After Kozur & Weems (2007). The biostratigraphic lower boundary of the Olenekian (B) at the base of the *M. subcircularis* A. Z. at the base of cycle 10 of the Bernburg Formation marks one of the two biggest conchostracan turnovers in the Triassic. According to the palaeomagnetic correlation with Chaohu in South China, the base of the Olenekian (A) lies deeper, within the Gandarian (Dienerian) conchostracan fauna.

Germany, for example, at Beesenlaublingen; borehole Halle-Süd, basal Kraftsdorf Sandstone of Kraftsdorf west of Gera, Thuringia, Germany; and at the Finne, northern Thuringia, Germany.

**Age.** Early Gandarian (early Dienerian) of the Germanic Basin.

**Remarks.** *Estheriella bachmanni* Kozur & Hauschke was originally assigned by Kozur & Seidel (1983a) to *Polygrapta rybinskensis* (Novozhilov). However, Goretzki (2003) pointed out that the type species of *Polygrapta* [*Estheria* (*Polygrapta*) *chatangensis* Novozhilov, 1946] has a free umbonal area (with a distinct sculpture) that is larger than the free umbonal area in *Estheriella*. Therefore, *Estheriella bachmanni* cannot belong to *Polygrapta*. *Estheriella bachmanni* lacks radial ribs, but in all other features it corresponds to *Estheriella* (see discussion in Kozur & Hauschke 2008). Since the radially-ribbed *Estheriellacea* Kobayashi clearly evolved from the unribbed species *Estheriella bachmanni* (as shown by

Kozur & Seidel 1983a) and not from radially-ribbed Late Paleozoic Leaiacea Raymond, the radially-ribbed Late Paleozoic and Triassic conchostracans are not directly related to each other. Jones & Chen (2000) have argued that *Estheriella* is a bivalve, based on their study of the type material of *Estheriella costata* Weiss and *E. nodosocostata* (Giebel). The type material of these species is from the marginal part of the central basin facies, and it was found mainly in siltstones and sandstones that preserve only impressions of the shells and none of the original shell material. In *Estheriella* from claystones, the chitinous shell material is sometimes preserved, and it is just like the shell material of other conchostracans. Also, in these cases, there is no hinge present, as would be expected in bivalves.

#### *Estheriella marginostriata* Zone

**Definition.** Range of *Estheriella marginostriata* Kozur without *Estheriella nodosocostata* (Giebel).

**Lower boundary.** FAD of *Estheriella marginostriata* Kozur & Seidel.



*Upper boundary.* FAD of *Estheriella nodosocostata* (Giebel).

*Important conchostracan species.* *Estheriella bachmanni* Kozur & Hauschke, common in the lower part of the zone, rare in the upper part of the zone and there mostly occurring as transitional forms to *E. marginostriata* Kozur; *Estheriella marginostriata* Kozur; *Cornia germani* (Beyrich), very common; *Euestheria oertlii* Kozur, very common; *Molinesstheria seideli seideli*, rare; *M. seideli postera* Kozur, rare to common; *Magniesteria ? malangensis* Marlière, rare; *Vertexia tauricornis tauricornis* Lyutkevich, very rare; *V. tauricornis transita* Kozur & Seidel, common.

*Type locality.* Outcrop at the railway station for Kraftsdorf. Kraftsdorf Sandstone of the middle Bernburg Formation (middle eccentricity cycle 5 of this formation). Gandarian (Dienerian).

*Occurrence.* Lower Bernburg Formation (middle eccentricity cycle 5 of this formation, Gandarian = Dienerian) of the Germanic Basin. Gandarian (Dienerian) of Russian Platform and of Greenland.

*Age.* Early part of the late Gandarian (late Dienerian) Substage of Brahmanian (Induan) Stage.

*Remarks.* *Estheriella marginostriata* is the oldest *Estheriella* species with radial ribs, and it occurs at the beginning of a very rapid period of evolution within *Estheriella*. Soon after its appearance, it evolved into *E. costata* Weiss, which in turn rapidly evolved into *E. nodosocostata* (Giebel). Therefore, the *E. marginostriata* Zone comprises only a very short time interval (duration less than half a short eccentricity cycle) within the middle part of eccentricity cycle 5 of the Bernburg Formation.

#### *Estheriella nodosocostata* Zone

*Definition.* Range of *Estheriella nodosocostata* (Giebel).

*Lower boundary.* FAD of *Estheriella nodosocostata* (Giebel).

*Upper boundary.* LOD of *Estheriella nodosocostata* (Giebel). As *E. nodosocostata* generally is rare in the upper part of the *E. nodosocostata* Zone, the boundary with the overlying *Cornia germari*–*Mangiesteria subcircularis* Zone is often difficult to recognize. *Molinesstheria* and *Vertexia* do not occur as high as this zone, and *Mangiesteria subcircularis* does not appear until after the beginning of the overlying *Cornia germari*–*Mangiesteria subcircularis* Zone.

*Important conchostracan species.* *Estheriella nodosocostata* (Giebel), in some beds as mass occurrences, especially in siltstones and fine sandstones, in claystones that have mass occurrences of *Cornia germari* rare or absent; *E. costata* Weiss (= *E. sastryi* Gosh), in some levels common; *E. marginostriata* Kozur, only in the lower part of the zone and rare; *Cornia germari* Beyrich, very common, except in beds that have mass occurrences of *E. nodosocostata* and there rare or absent; *Euestheria gutta* (Lyutkevich), very rare; *Magniesteria lerichi* (Marlière), very rare; *M. ? malangensis* (Marlière), very rare; *Molinesstheria seideli postera* Kozur & Seidel, common to rare; *Vertexia tauricornis transita* Kozur & Seidel, common to rare, but in the upper part of the zone mostly absent.

*Type locality.* Large clay pit Beesenlaublingen near Alsleben, Sachsen-Anhalt, Germany. Uppermost eccentricity cycle 5 to lower eccentricity cycle 7 of the Bernburg Formation. Upper Gandarian (upper Dienerian). In case the beds with abundant conchostracans of the *E. nodosocostata* Zone eventually are removed during mining from the clay pit, the Lindenschlucht outcrop at Süßer See, west of Halle/Saale (Sachsen-Anhalt, Germany) is proposed as a parastratotype. *E. nodosocostata* is relatively rare in this outcrop, but there are several outcrops with rich occurrences of *E. nodosocostata* east of the Harz Mountains, such as the road cut from Unterrißdorf to Oberrißdorf, west of Halle, Sachsen-Anhalt, which has excellently preserved *E. nodosocostata* and all other species that occur in this zone. In all of these cases, the outcrops may disappear in the future.

*Occurrence.* The central basin part of the central and northern Germanic Basin, uppermost eccentricity cycle 5 to lower eccentricity cycle 7 of the Bernburg Formation. The southernmost known occurrence in the Germanic Basin is in sandstones near Bad Salzungen, southern Thuringia. Russian Platform, northern Urals, Pricaspian depression, Hungary (thin brackish intercalation in the *Claraia aurita* Zone of the Seis Member (Aracs Marl Formation, Werfen Group), Timan (in northern Russia), Jakutia (northeastern Siberia), eastern Greenland, upper Feixianguan Formation, Langdai (Guizhou, China), Xinjiang, India (part of the Panchet Group), Gabon (Africa), eastern Africa and Australia. Outside of the Germanic Basin, Russian Platform and northern India, where occurrences of *E. nodosocostata* and (or) *E. costata* are widespread, the *E. nodosocostata* Zone is mainly recognizable by the occurrence of *Cornia germari* and less often by the occurrence of *Magniesteria lerichi* and *M. ? malangensis*. All of these taxa may occur in the immediately underlying and

overlying zones, so often only the relatively short interval from the upper *Molinesstheria seideli* Zone up to the *Cornia germari*–*Magniestheria subcircularis* Zone can be recognised collectively. In the Germanic basin, this interval comprises 7 short eccentricity cycles (c. 700,000 years), shorter than the average duration of one Triassic ammonoid or conodont zone.

*Age.* Late Gandarian (late Dienerian) Substage of Brahmanian (Induan) Stage.

*Remarks.* The *E. nodosocostata* Zone can be readily recognised by the presence of the index species, but it also can be recognised by mass occurrences of *Cornia germari* (without *Molinesstheria seideli seideli* and *Vertexia tauricornis tauricornis*). As *Cornia germari* has a world-wide distribution, the *E. nodosocostata* Zone can be recognised both in the northern hemisphere and in Gondwana. *C. germari* also occurs in brackish beds in marine deposits, where it often can be found in huge numbers on single bedding planes (e.g. in the *Claraia aurita* Zone of the Seis Member in Hungary, in the *Vavilovites sverdrupi* Zone in northeastern Siberia, and in brackish upper Gandarian beds in Greenland). These occurrences permit the *E. nodosocostata* Zone to be very closely correlated with the marine scale. As *C. germari* is very common in the interval from the upper *M. seideli* Zone up to the *Cornia germari*–*Magniestheria subcircularis* Zone, in marine beds and most of Gondwana, correlation can be made only collectively for these zones of short to very short duration.

In China, *Palaeolimnadia pusilla* Shen is seemingly the same as *C. germari*. This species is accompanied there by *Magniestheria ? lerichi* (Marlière) (junior synonym: *Euestheria langdaiensis* Shen), and *M. ? malangensis* (Marlière) (junior synonym: *Euestheria orbicula* Shen). *Euestheria leidayensis* Shen from the same beds is based on deformed specimens, probably of *M. lerichi*.

*Cornia germari*–*Magniestheria subcircularis* Zone  
*Definition.* Co-occurrence of *Cornia germari* (Beyrich) and *Magniestheria subcircularis* (Chernyshev).

*Lower boundary.* Disappearance of *Estheriella nodosocostata* (Giebel). The appearance of *Magniestheria subcircularis* (Chernyshev) may be a little later. As *E. nodosocostata* is very rare in the uppermost part of the *E. nodosocostata* Zone and *M. subcircularis* is very rare in the lower *C. germari*–*M. subcircularis* Zone, the exact position of the boundary between these two zones is difficult to recognise and requires careful sampling,

though both zones are quite distinct away from this boundary zone.

*Important conchostracan species.* *Cornia germari* (Beyrich), very common; *Magniestheria subcircularis* (Chernyshev), in the lower part of the zone rare, in the upper part moderately common; *Euestheria gutta* (Lytkevich), very rare; *Magniestheria ? lerichi* (Marlière), very rare.

*Type locality.* Road cut at Marienburg, Niedersachsen, Germany, upper short eccentricity cycle 7 to top of cycle 9 of the upper Bernburg Formation.

*Occurrence.* Widely distributed in the central basin facies of the central and northern Germanic Basin in central and northern Germany and Poland, upper Bernburg Formation, uppermost Gandarian (uppermost Dienerian). *Claraia aurita*-bearing Werfen Beds of Hungary (Kozur & Mock 1993), upper Gandarian (upper Dienerian).

*Age.* Latest Gandarian (latest Dienerian).

*Remarks.* The *Cornia germari*–*Magniestheria subcircularis* Zone is dominated by *Cornia germari*, which occurs often as monospecific faunas. In contrast to older *Cornia germari*-dominated faunas, other Vertexiidae (*Vertexia*, *Molinesstheria*) and *Estheriella* are absent. Occasionally, especially in the upper part of the zone, some bedding planes with *Magniestheria subcircularis* are present. In the lower part of eccentricity cycle 7 of the upper Bernburg Formation, the youngest representatives of *E. nodosocostata* are found, but the species is very rare in this interval. In the upper part of eccentricity cycle 7, no *Estheriella nodosocostata* have been found and some transitional forms between *Magniestheria ? malangensis* and *M. subcircularis* occur. This level currently is regarded as the lowest part of the *C. germari*–*Magniestheria subcircularis* Zone, but this assignment is not yet certain.

*Magniestheria subcircularis* Zone

*Definition.* Range of *Magniestheria subcircularis* (Chernyshev) without *Cornia germari* (Beyrich).

*Lower boundary.* Disappearance of *Cornia germari* (Beyrich).

*Upper boundary.* Appearance of *Magniestheria truempyi* (Kozur & Seidel).

*Important conchostracan species.* *Magniestheria subcircularis* (Chernyshev), common; *M. endybalica* (Molin), very rare; *Euestheria gutta* (Lytkevich), very rare; *Lioleaiina triasiana* (Chernyshev), rare; *L. jakutica* (Molin), very rare.

*Type locality.* Road cut at Marienburg, Niedersachsen, Germany, short eccentricity cycle 10 of the upper Bernburg Formation.

*Occurrence.* Upper but not uppermost Bernburg Formation of the Germanic Basin in the central basin facies (not on swells, such as the Eichsfeld Swell and its surroundings), southward to the Thuringian Basin. Kuzneck Basin of southern Siberia (part of the Malcev Formation), northeastern Siberia (Jakutia), eastern and central Africa. In northeastern Siberia, this zone can be firmly dated as basal Olenekian because *Cornia germari* is present there in the immediately underlying upper Gandarian (upper Dienerian) *Vavilovites sverdrupi* ammonoid zone.

*Age.* Earliest Smithian Substage (earliest Olenekian Stage).

*Remarks.* The sudden end of the Gandarian (Dienerian) conchostracan fauna, with its spined Vertexiidae, is one of the strongest extinction events that struck Triassic conchostracan faunas. The spined Vertexiidae (*Cornia*) disappeared suddenly in the upper Bernburg Formation within conchostracan-rich sediments and without any gap between it and overlying faunas.

In the Germanic Basin the *M. subcircularis* Zone is generally represented by monospecific faunas of the index species.

#### *Magnietheria truempyi* Zone

*Definition.* Range zone of *Magnietheria truempyi* (Kozur & Seidel).

*Lower boundary.* FAD of *Magnietheria truempyi* (Kozur & Seidel).

*Upper boundary.* LOD of *Magnietheria truempyi* (Kozur & Seidel).

*Important conchostracan species.* *Magnietheria truempyi* (Kozur & Seidel).

*Type locality.* Southern slope of railroad cut west of the Ertinghausen tunnel, about 2.75 km SE of Volpriehausen, Solling Mountains. TK 25 Nr. 4324; R: 35 52 960, H: 57 52 370. Rail km 43.974. Lower part of short eccentricity cycle 11 of the upper Bernburg Formation.

*Occurrence.* In the Germanic Basin this zone occurs only in those parts of the central basin facies where the gap between the Bernburg Formation and the Volpriehausen Formation has a minimal duration, for example, around Halle (Sachsen-Anhalt, Germany), borehole Halle-Süd, west of Halle at Oberrißdorf (type locality of the index species), SW of Halle at Wangen where the

*M. truempyi* Zone occurs in the sandy marginal facies of the uppermost Bernburg Formation. Solling Mountains (southern Niedersachsen, Germany) where the most complete exposure of the Bernburg Formation is found. Madagascar, in beds immediately below the *Flemingites* beds (which represent the second ammonoid zone of the Olenekian) and above the *Claraia* beds (which represent the upper Gandarian).

*Age.* Early Smithian Substage (Early Olenekian Stage).

*Remarks.* *Magnietheria truempyi* is the type species of *Magnietheria* Kozur & Seidel. This genus, which is very characteristic of the Olenekian, and was originally established as a subgenus of *Liograptia* Novozhilov by Kozur & Seidel (1983b), but even then these authors pointed out that it had evolved from *Euestheria* Deperét & Mazeran. Shen *et al.* (2002) have shown that *Magnietheria* is not closely related to *Liograptia*. They were able to demonstrate a close relationship with *Euestheria*, and regarded *Magnietheria* as a subgenus of *Euestheria*. Kozur & Bachmann (2004) later elevated *Magnietheria* to a genus.

#### *Magnietheria rybinskensis*–*Lioleaiina radzinskii* Zone

*Definition.* Occurrence of *Magnietheria rybinskensis* (Novozhilov) and *Lioleaiina radzinskii* Kozur & Seidel without *Magnietheria mangaliensis* (Jones).

*Lower boundary.* FAD of *Magnietheria rybinskensis* (Novozhilov), which evolved from *M. truempyi* Kozur & Seidel.

*Upper boundary.* FAD of *Magnietheria mangaliensis* (Jones), which evolved from *M. rybinskensis* (Novozhilov).

*Important conchostracan species.* *Magnietheria rybinskensis* (Novozhilov), very abundant; *Lioleaiina radzinskii* Kozur & Seidel, mostly rare, in the Volpriehausen Sandstone sometimes common; *Euestheria gutta gutta* (Lyutkevich), very rare.

*Type locality.* Southern slope of railroad cut west of the Ertinghausen tunnel, about 2.75 km SE of Volpriehausen, Solling Mountains, TK 25 Nr. 4324; R: 35 52 960, H: 57 52 370. Upper 5 m of short eccentricity cycle 11 of the upper Bernburg Formation and the overlying Volpriehausen Sandstone of the lower Volpriehausen Formation. Lower Smithian.

*Occurrence.* Uppermost Bernburg Formation (upper half of short eccentricity cycle 11 of the Bernburg Formation in the centre of the Germanic Basin in central and northern Germany, Poland)

and Volpriehausen Sandstone of the lower Volpriehausen Formation of the northern and central Germanic Basin, Russian Platform, Mangyshlak, Kuzneck Basin (southern Siberia). All lower (but not lowermost) Smithian (Lower Olenekian).

*Age.* Early (but not earliest) Smithian Substage (Early Olenekian).

*Remarks.* '*Pseudestheria*' *rybinskensis* Novozhilov, 1960 originally was not well described, and the illustrations (drawings) could not be assigned to any Triassic genus with certainty. Goretzki (2003) re-studied the type material and has shown that '*Pseudestheria*' *rybinskensis* Novozhilov, 1959 and '*Lioestheria*' *quellaensis* Novozhilov, 1960 are synonyms. These forms belong to *Magniestheria*. For '*Lioestheria*' *quellaensis* this was clear even from the original description and illustration, but not for '*Pseudestheria*' *rybinskensis*, which has name priority.

The base of the *Magniestheria rybinskensis*–*L. radzinskii* Zone can be readily recognised by the transition from *M. truempyi* to *M. rybinskensis*, which occurred in the Germanic Basin in the uppermost Bernburg Formation (but only in the central basin facies where the entire Bernburg Formation is preserved), in the Solling Mountains in the 5 m below the Volpriehausen Formation. In the Halle region the base of the *M. rybinskensis*–*L. radzinskii* Zone is located 1–3 m below the base of the Volpriehausen Sandstone, and in the Wangen section SW of Halle it is located only 0.5 m below the Volpriehausen Sandstone. In most regions of the Germanic Basin, the lower part of the *M. rybinskensis*–*L. radzinskii* Zone that is present in the uppermost Bernburg Formation has been removed by pre-Volpriehausen erosion. The Volpriehausen Sandstone also belongs to this zone and is widely distributed across the entire central and northern Germanic Basin. In the lower *Magniestheria rybinskensis*–*L. radzinskii* Zone of the Germanic Basin, a monospecific *M. rybinskensis* fauna generally is found, but in the Volpriehausen Sandstone *Liroleiina radzinskii* may be common, for example, in the former clay pit Walpernhain, eastern Thuringia, Germany.

#### *Magniestheria mangaliensis* Zone

*Definition.* Stratigraphic range of *Magniestheria mangaliensis* (Jones).

*Lower boundary.* FAD of *Magniestheria mangaliensis* (Jones).

*Upper boundary.* FAD of *Magniestheria deverta* (Novozhilov).

*Important conchostracan species.* *Magniestheria mangaliensis* (Jones), mass occurrences; *M.*

*rybinskensis* (Novozhilov), only in the lower part of the zone; *Liroleiina radzinskii* Kozur & Seidel, only in the lower part of the zone and very rare.

*Type locality.* Large clay pit Baalberge near Bernburg, NE of the Harz Mountains, Germanic Basin. Upper part of the Lower Olenekian (upper Smithian).

*Occurrence.* Volpriehausen Formation above the Volpriehausen Sandstone of the Germanic Basin, Russian Platform, Mangyshlak, China, Mangli Beds of the Panchet Group in India, Angola. Upper Aracs Marl Formation of the Werfen Group in Hungary. Accompanying conodonts in the Werfen Group of Hungary (*Pachycladina* association) indicate Early Olenekian (late Smithian) age (the conchostracans were derived from brackish intercalations in the marine beds). Within the marine Werfen Beds of Hungary, in the Germanic Basin, on the Russian Platform and in Mangyshlak the *M. mangaliensis* Zone is overlain by Upper Olenekian (Spathian) deposits, confirming the late Smithian age of the *M. mangaliensis* Zone.

*Age.* Late Smithian (late Early Olenekian).

*Remarks.* *M. mangaliensis* is a very dominant form in this zone. If it is present, usually no other conchostracans occur. This is the case in such widely separated areas as India, the Germanic Basin and Hungary. This zonal index species occurs also in brackish beds (Germanic Basin, Werfen Group of Hungary), where it is the only species present and sometimes is found as mass assemblages. *M. mangaliensis* that have been reported from the Middle and Upper Triassic of South America (e.g. Geinitz, 1876; Gallego 1992) do not belong to this species; they are probably *Euestheria buravasi* (Kobayashi) which is also known from the lower Norian of Thailand. More than 20 years ago, Tasch (1987, p. 100) expressed doubts that these forms belong to *M. mangaliensis*.

#### *Magniestheria deverta* Zone

*Definition.* Stratigraphic range of *Magniestheria deverta* (Novozhilov), in the middle and upper part of the zone together with *Euestheria exsecta* (Novozhilov) and *Palaeolimnadia alsatica defurthensis* Kozur & Seidel.

*Lower boundary.* FAD of *Magniestheria deverta* (Novozhilov).

*Upper boundary.* LOD of *Magniestheria deverta* (Novozhilov).

*Important conchostracan species.* *Magniestheria deverta deverta* (Novozhilov), very common; *Magniestheria deverta bogdoensis* (Lopato), in the

lower part common; *Euestheria exsecta* (Novozhilov), very common in the middle and upper part of the zone; *Palaeolimnadia alsatica detfurthensis* Kozur & Seidel, mostly common in the middle and upper part of the zone; *P. ? cf. P. mecsekensis* Nagy, very rare.

*Type locality.* Beesenstedter Grund, southeastern foreland of Harz Mountains. Detfurth Clay. Lower Spathian (lower part of Upper Olenekian).

*Occurrence.* Lower Spathian of the Germanic Basin (uppermost Volpriehausen Formation, Detfurth Formation, lowermost Hardeggen Formation), Pricaspian Depression (Bolshoe Bogdo), northern Siberia (eastern Taimyr Mountains), and in the lower Val Badia Member of the Csopak Marl Formation (Werfen Group) of Hungary.

*Age.* Early Spathian (early Late Olenekian).

*Remarks.* All occurrences of the *deverta* Zone can be clearly assigned to the lower Spathian. At the Bolshoe Bogdo, in the Balaton Highland and in the eastern Taimyr Mountains, marine intercalations with lower Spathian ammonoids are present. In the Germanic Basin, the type locality contains abundant *Pleuromeia* megaspores (*Talchirella daciae* Antonescu & Taugourdeau-Lantz) and miospores, including mass occurrences of *Densoisporites neijburgii* (Schulz) Balme without *Cycloverrutriletes presselensis* Schulz; this association is characteristic of the lower Spathian. The type locality Beesenstedter Grund is generally assigned to the Detfurth Formation.

#### *Euestheria exsecta* Zone

*Definition.* Co-occurrence of *Euestheria exsecta* (Novozhilov) and *Palaeolimnadia ? nodosa* (Novozhilov) without *Magniestheria deverta* (Novozhilov) and *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp.

*Lower boundary.* LOD of *Magniestheria deverta* (Novozhilov).

*Upper boundary.* FAD of *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp.

*Important conchostracan species.* *Euestheria exsecta* (Novozhilov), very abundant; *Palaeolimnadia alsatica detfurthensis* Kozur & Seidel; *P. ? nodosa* (Novozhilov), common; *P. ? cf. P. ? mecsekensis* Nagy, rare.

*Type locality.* Outcrop at the cemetery of Leißling, Sachsen-Anhalt (Germanic Basin), lower, but not lowermost Hardeggen Formation (Hardeggen 2?). Lower Spathian (lower part of Upper Olenekian).

*Occurrence.* Lower Spathian of the Germanic Basin (Hardeggen 2–4), Pricaspian Depression (Bolshoe Bogdo), northern Siberia (eastern Taimyr Mountains), middle and upper Val Badia Member of the Csopak Marl Formation (Werfen Group) of Hungary. Wupatki Member of Moenkopi Formation, near Meteor Crater, Arizona.

*Age.* Early, but not earliest Spathian (early Late Olenekian).

*Remarks.* *Euestheria exsecta* clearly dominates in the *E. exsecta* Zone, but it is a rather long-ranging form that is very abundant also in the middle and upper part of the underlying *M. deverta* Zone and ranges up to the uppermost Spathian *Hornestheria sollingensis* Zone. Therefore the *E. exsecta* Zone is an interval Zone. At the Bolshoe Bogdo and in Hungary, marine intercalations in the *E. exsecta* Zone contain *Tirolites cassianus*, which indicates an early Spathian age.

#### *Euestheria albertii mahlerselli*– *Palaeolimnadia ? nodosa* Zone

*Definition.* Co-occurrence of *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp., *E. exsecta* (Novozhilov), *Palaeolimnadia alsatica detfurthensis* Kozur & Seidel and *P. ? nodosa* (Novozhilov).

*Lower boundary.* FAD of *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp.

*Upper boundary.* FAD of *Hornestheria sollingensis* Kozur & Lepper n. sp.

*Important conchostracan species.* *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp.; *E. exsecta* (Novozhilov); *Palaeolimnadia alsatica detfurthensis* Kozur & Seidel; *P. ? nodosa* (Novozhilov).

*Type locality.* Quarry Würgassen, TK 25 Nr. 4322; R: 3529350, H: 5723715, Solling Mountains, Trendelburg-Schichten of Solling-Formation.

*Occurrence.* Lower part of Solling Formation up to Trendelburg Beds of the Solling Formation of the Solling Mountains (Germany).

*Age.* Late Spathian (upper Upper Olenekian).

*Remarks.* *E. exsecta*, *P. alsatica detfurthensis* and *P. ? nodosa* dominate in the lower part of the *E. mahlerselli*–*P. ? nodosa* Zone. *E. albertii mahlerselli* dominates in the upper part of the zone (upper Trendelburg Beds), but the other species of the zone are still present and sometimes even common.

#### *Hornestheria sollingensis* Zone

*Definition.* Range of *Hornestheria sollingensis* Kozur & Lepper n. sp.

*Lower boundary.* FAD of *Hornestheria sollingensis* Kozur & Lepper n. sp.

*Upper boundary.* LOD of *Hornestheria sollingensis* Kozur & Lepper n. sp., *Euestheria exsecta* (Novozhilov) and *Palaeolimnadia ? nodosa* (Novozhilov).

*Important conchostracan species.* *Hornestheria sollingensis* Kozur & Lepper n. sp.; *Euestheria exsecta* (Novozhilov), rare; *Palaeolimnadia alsatica detfurthensis* Kozur & Seidel; *P. ? nodosa* (Novozhilov).

*Age.* Latest Spathian. Karlshafen Beds of the Solling Formation.

*Remarks.* *Hornestheria* is common in China and there restricted to the Anisian. *Hornestheria* species of China have been wrongly assigned to the unrelated Lower Permian genus *Protomonocarina* Tasch. *Hornestheria ziguiensis* (Shen) is very similar to *H. sollingensis*, but not identical to it. Because of the occurrence of *Hornestheria*, an Anisian age cannot be excluded for the *H. sollingensis* Zone, but the typical Late Olenekian species *Euestheria exsecta*, *Palaeolimnadia alsatica detfurthensis* and *P. ? nodosa* are still present in this zone, and all of these are missing in the overlying earliest Anisian Stammen Beds. Therefore, the conchostracans in the Karlshafen Beds of the Solling Formation indicate a somewhat ambiguous age, because guide forms of the Spathian occur together with *Hornestheria*, which is more typical of the Anisian. The palynological index species of the Anisian, *Hexasaccites thiergartii* (Mädler) Kozur, does not occur in this zone and first appears considerably higher in the uppermost Solling Formation (Brugman 1986). However, this palynological index form has not been directly correlated with the pelagic Olenekian–Anisian boundary. Its lowest occurrence is in the lower Aszófő–Formation of the Balaton Highland, at the Spathian–Anisian boundary level, but these shallow marine beds have not been precisely correlated with the pelagic Olenekian–Anisian boundary. Even so, it is clear that *Hexasaccites thiergartii* begins close to the base of the pelagic Anisian, so the absence of this species in the Karlshafen Beds and its FAD in the overlying Stammen Beds of the uppermost Solling Formation strongly suggest a latest Spathian age for the Karlshafen Beds and the *Hornestheria sollingensis*-Zone within it.

#### *Preliminary Middle Triassic conchostracan zonation*

The Middle Triassic conchostracan taxonomy has been well defined in China (e.g. Chang *et al.*

1976). Modern taxonomic research has been conducted on the conchostracans in the lower Anisian of the Germanic Basin and in the Holbrook Member of the Moenkopi Formation of Arizona (e.g. Reible 1962; Gall 1971; Kozur 1982; Kozur & Seidel 1983b; Kozur, Lucas & Morales, in prep.), in the Anisian of northern Siberia (e.g. Novozhilov 1965) and in the upper Ladinian of the Germanic Basin (e.g. Warth 1969; Kozur & Seidel 1983a). The Middle Triassic conchostracans of China generally were not dated any more precisely than Middle Triassic, but Prof. Shen Yanbin (Nanjing) has sent us important data about marine intercalations that provide more detailed correlations for some of the Middle Triassic conchostracan faunas. The lower Anisian and upper Ladinian conchostracans of the Germanic Basin have been correlated in detail with marine faunas of the Röt and Upper Muschelkalk through ammonoids, bivalves, etc. The upper Longobardian Erfurt Formation and Grabfeld Formation below the *Estheria* Beds of the upper Grabfeld Formation have only yielded a few marine and brackish intercalations, but all of these have yielded enough information to show that they are all Longobardian in age and that the base of the Carnian is at the base of the *Estheria* Beds. In northern Siberia the Anisian age of the conchostracan faunas has been determined by correlation with intercalated marine beds that contain ammonoids. For most of the Middle Triassic (the Pelsonian and Illyrian substages of the Anisian and the Fassanian substage of the Ladinian) no detailed correlations between Middle Triassic conchostracan faunas and the marine zonation can be made as yet. For the northern Siberian and Chinese faunas it is not possible to designate a type locality, and it is also difficult to establish which species except the index species also occur in these zones. For these reasons no type localities are designated, and accompanying species are only mentioned when they are important for the definition of the zone, for comparisons with other faunas or when the total fauna is known. In some cases, age and faunal composition of a zone are rather well known but the zone is only proven to exist within a limited area (e.g. within the Germanic Basin or China) and has yet to be found outside that area. For all of these reasons, we must regard the Middle Triassic conchostracan zonation as preliminary (Fig. 16).

#### *Euestheria albertii mahlerselli*–*P. alsatica alsatica* Zone

*Definition.* Co-occurrence of *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp. and *Palaeolimnadia alsatica alsatica* (Reible).

*Lower boundary.* Disappearance of *Euestheria exsecta* (Novozhilov), *Hornestheria sollingensis*

Stage	Substage	Conchostracan Zone	Germanic Basin	China	northern Siberia	North America
Ladinian	Longobardian	<i>Euestheria minuta</i>	<i>Euestheria minuta</i>	<i>Euestheria minuta</i>		
	Fassanian	<i>Euestheria franconica</i>	<i>Euestheria franconica</i>			
Anisian	Illyrian	<i>Xiangxiella bicostata</i>		<i>Xiangxiella bicostata</i>		
		<i>Diaplexa tiganensis</i>		<i>Diaplexa tiganensis</i>	<i>Diaplexa tiganensis</i>	
	Pelsonian					
	Bithynian	<i>Euestheria albertii albertii</i>	<i>Euestheria albertii albertii</i>	<i>Euestheria albertii albertii</i>	<i>Euestheria albertii albertii</i>	upper <i>E. albertii</i> Zone
Aegean	<i>Euestheria albertii mahlerselli-P. alsatica alsatica</i>	<i>Euestheria albertii mahlerselli-P. alsatica alsatica</i>	<i>Euestheria a. mahlerselli-P. alsatica alsatica</i>	<i>Euestheria a. mahlerselli-P. alsatica alsatica</i>		

Fig. 16. Middle Triassic conchostracan zonation.

Kozur & Lepper n. sp., *Palaeolimnadia alsatica defurthensis* Kozur & Seidel and *P. ? nodosa* (Novozhilov). Appearance of *Palaeolimnadia alsatica alsatica* (Reible).

*Upper boundary.* Appearance of *Euestheria albertii albertii* (Voltz).

*Important conchostracan species.* *Euestheria albertii mahlerselli* Kozur & Lepper n. subsp. and *Palaeolimnadia alsatica alsatica* (Reible).

*Occurrence.* Upper Solling Formation (Stammen Beds in the Solling Mountains and correlative Thuringian *Chirotherium* Sandstone of Thuringia and the northern part of southern Germany) to middle Röt Formation below the Dolomitische Grenzbank with *Costatoria costata* (Zenker) and *Myophoria vulgaris* (von Schlotheim). Solling Mountains, Thuringia, Franconia (Germany), all in the Germanic Basin. Lower Patacs Siltstone Formation of the Mecsek Mountains (Hungary), Aegean. Guizhou (China), lower Anisian.

*Age.* Aegean (early part of early Anisian).

*Remarks.* The *E. albertii mahlerselli-P. alsatica alsatica* Zone usually has a monospecific fauna of *E. albertii mahlerselli*. This species is rather long-ranging and occurs throughout the late Spathian and Aegean. Nevertheless, this zone is readily distinguished from the underlying uppermost Spathian *H. sollingensis* Zone by the absence of all Spathian

or late Spathian guide forms, such as *E. exsecta*, *H. sollingensis*, *P. alsatica defurthensis* and *P. ? nodosa*. Only *P. alsatica alsatica* first appears at the base of this zone; it is generally rare and ranges up to the Bithynian.

The Anisian age of this zone is demonstrated by its co-occurrence with *Hexasaccites thiergartii* (Mädler) Kozur. The first Bithynian faunal elements appear at the base of the overlying conchostracan zone.

*Euestheria albertii albertii* Zone

*Definition.* Occurrence of *Euestheria albertii albertii* (Voltz) without *Diaplexa tiganensis* Novozhilov.

*Lower boundary.* FAD of *Euestheria albertii albertii* (Voltz).

*Upper boundary.* FAD of *Diaplexa tiganensis* Novozhilov.

*Important conchostracan species.* *Euestheria albertii albertii* (Voltz), very common; *E. ? dactylis* Shen, rare; *Euestheria* n. sp. C *sensu* Kozur et al. (1993), rare; *Dictyonatella dictyonata* (Reible), *Liroleaia* n. sp. A (= *Praeleaia* sp. Warth 1969; Gall 1971), very rare; *Magniestheria ?* n. sp. A *sensu* Isaura sp. A Gall (1971), rare; *Magniestheria* n. sp. B *sensu* Kozur et al. (1993), rare; *Palaeolimnadia alsatica alsatica* Reible, common; *P. mecsekensis* Nagy, common; *Palaeolimnadia* n. sp. A *sensu* Kozur et al. (1993) ex gr. *P. paucilinearis* Shen, rare.

**Occurrence.** Upper part of Upper Röt Claystones (= upper part of Upper Variegated Member) and Myophoria Beds Member of Röt Formation of Germany (*E. albertii albertii* has its FAD in the level with joint occurrence of *C. costata* and *M. vulgaris* at the base of the Bithynian), and Grès à *Voltzia* of Lorraine (France), Germanic Basin, lower Bithynian. Upper Patacs Siltstone Formation and Magyarürög Anhydrite Member of the Mecsek Mountains (Hungary), lower and middle Bithynian. Holbrook Member of the uppermost Moenkopi Formation of Arizona, upper Bithynian. Lower Badong Formation, Hubei (China), Anisian. Lower Anisian of northern Siberia, there *Euestheria albertii albertii* was described as *Estheria (Diaplexa) tiganensis* Novozhilov by Novozhilov (1946). Lower Anisian South America.

**Age.** Bithynian (early Anisian).

**Remarks.** The *E. albertii albertii* Zone was introduced by Kozur *et al.* (1993). The authors recognised the continuous increase in size of *E. albertii albertii*. This species first appears in the Germanic Basin in the middle part of the Upper Röt Claystone of Franconia at a horizon where it co-occurs with *Costatoria costata* and *Myophoria vulgaris*. There, and in the upper part of the Upper Röt Claystone, *E. albertii albertii* is very primitive, and its maximum length is only 4 mm. In the *Myophoria* Beds (Lower and Upper Dentritic Beds) of Franconia and in the time-equivalent Grès à *Voltzia* of Lorraine, the maximum length of *E. albertii albertii* is 5 mm, and in the Holbrook Member (upper Bithynian) of Arizona the maximum length is 6–6.3 mm. In the upper Patacs Siltstone Member of the Mecsek Mountains in Hungary *E. albertii albertii* begins also with small forms that have a maximum length of 4 mm. In the uppermost Patacs Siltstone Member and in the Magyarürög Anhydrite Member, the maximum length increases to 5–5.5 mm. The FAD of *M. vulgaris* and *E. albertii albertii* within the Röt Formation of the Germanic Basin coincides with the base of the Bithynian. Thus, during the Bithynian, the increase in the maximum length of *E. albertii albertii* was approximately 2 mm, or about 50% greater than the length of the most primitive forms.

#### *Diaplexa tiganensis* Zone

**Definition.** Occurrence of *Diaplexa tiganensis* Novozhilov without *Xiangxiella bicostata* Shen.

**Lower boundary.** FAD of *Diaplexa tiganensis* Novozhilov.

**Upper boundary.** FAD of *Xiangxiella bicostata* Shen.

**Important conchostracan species.** *Diaplexa tiganensis* Novozhilov, 1946 (junior synonym: *Diaplexa* ?

*xuanhanensis* Chen 1974), common; *Palaeolimnadia triangularis* Shen, common; *Vileginia tuberculata* (Novozhilov 1946) (junior synonym: *Sedovia fecunda* Novozhilov 1958); *V. dorofeevi* (Novozhilov) (junior synonym: *Tigjanium borchgrevinkii* Novozhilov).

**Occurrence.** Margin of the Laptev Sea in Siberia, upper Anisian (?middle Anisian). Badong Formation of Xuanhan (Sichuan, China), early Illyrian (late Anisian) or Pelsonian (middle Anisian).

**Age.** ?Pelsonian, early Illyrian (late Anisian).

**Remarks.** The much better documented *Diaplexa* ? *xuanhanensis* Chen, 1974 from the Anisian to lower Ladinian Badong Formation of Xuanhan, Sichuan (China) cannot be separated from *D. tiganensis* Novozhilov, 1946 and, therefore, is regarded as a junior synonym of *D. tiganensis*.

Middle(?) and upper Anisian conchostracan faunas are characterized by coarsely reticulated Palaeolimnadiidae, which in the past have been assigned to different genera and even to different families. These are: *Diaplexa* Novozhilov 1946; *Vileginia* Novozhilov 1958; *Tigjanium* Novozhilov 1958; *Sedovia* Novozhilov 1958. *Vileginia* replaced *Diaphora* Novozhilov 1946, a homonym of *Diaphora* Stephens 1827 (in Southern & Nicklas 1827), Macquart, 1834, and Löw, 1879; see Kobayashi 1954.

*Diaplexa* has a small, flat, free umbonal area. *Vileginia*, *Tigjanium* and *Sedovia* have a large, flat, free umbonal area and cannot be separated from each other. Therefore, *Sedovia* and *Tigjanium* are regarded as junior synonyms of *Vileginia*. Whether reticulation appears as a reticulum or as convex tubercles depends on the preservation. *Diaplexa* and *Vileginia* may be separated on the base of the size of the flat umbonal area, but this is not a pronounced difference.

The occurrences close to the Laptev Sea in northern Siberia are surely of Anisian age, as indicated by associated bivalves and a few ammonoids; the occurrence of *Hungarites*, *Gervillia arctica* Kiparisova, and two *Trigonodus* species probably indicates a late Anisian (Illyrian) age, but these marine faunal elements were not illustrated. Thus, a middle Anisian (Pelsonian) age cannot be excluded.

The Chinese material is from the lower part of the Anisian to lower Ladinian (Fassanian) Badong Formation of Xuanhan, Sichuan. The probably late Illyrian or Fassanian genus *Xiangxiella* Shen was not reported from this level, and the lower Anisian guide form *Euestheria albertii albertii* also is missing. Thus, an early Illyrian or (and) Pelsonian age is probable for the occurrences of *Diaplexa tiganensis* (= *Diaplexa* ? *xuanhanensis* Chen) from China.



*Xiangxiella bicostata* Zone

*Definition.* Range of *Xiangxiella bicostata* Shen.

*Lower Boundary.* FAD of *Xiangxiella bicostata* Shen.

*Upper boundary.* LOD of the genus *Xiangxiella* Shen.

*Important conchostracan species.* *Xiangxiella bicostata* Shen (synonyms: *Xiangxiella xilingxiensis* Shen and probably also *X. elongata* Shen, based on a badly deformed specimen); *X. acuta* Shen; *Euestheria hubeiensis* Shen; *E. shizibaoensis* Shen; *E. ? dactylis* Shen; *E. lepida* Shen; *Palaeolimnadia machaolingensis* Shen.

*Occurrence.* Upper Badong Formation, Hubei (China), upper Illyrian to Fassanian.

*Age.* Upper Illyrian to Fassanian.

*Remarks.* This zone can be readily recognized by the presence of *Xiangxiella*, which has on the free umbonal area two ridges that form an acute angle. Similar forms with only one prominent umbonal ridge were assigned to *Protomonocarina* Tasch by Shen in Chang *et al.* (1976), but they are not congeneric with the badly preserved Lower Permian genus *Protomonocarina*, in which the umbonal ridge is segmented and may represent an imprint of an appendage. The Middle Triassic forms of '*Protomonocarina*' belong to *Hornestheria* Kozur & Lepper n. gen.

The *X. bicostata* Zone is restricted to the upper Badong Formation, Hubei (China). However, this probably does not mean that the *X. bicostata* Zone is an endemic fauna, because conchostracan faunas of late Illyrian–Fassanian age so far are unknown from any other part of the northern hemisphere or from Gondwana. In the Germanic Basin, this time interval is represented by marine or hypersaline beds without conchostracans. In North America this time interval is not represented by any known sediments.

The age of the upper Badong Formation is rather well known. The conchostracans of the *X. bicostata* Zone occur only in the upper part of the Anisian to Fassanian Badong Formation, according to Prof. Shen (Nanjing, pers. comm.), above a marine horizon with Illyrian marine bivalves (*Adygella illyrica*). Thus, the *X. bicostata* Zone must be late Illyrian or Fassanian.

*Euestheria franconica* Zone

*Definition.* Range of *Euestheria franconica* (Reible).

*Lower boundary.* FOD of *Euestheria franconica* (Reible), *Euestheria minuta* (von Zieten) and *Euestheria* n. sp.

*Upper boundary.* LOD of *Euestheria franconica* (Reible).

*Important conchostracan species.* *Euestheria franconica* (Reible); *E. minuta* (von Zieten); *Euestheria* n. sp.

*Occurrence.* This zone is restricted to brackish intercalations in the marine Upper Muschelkalk of the Germanic Basin above the Cycloides Bank.

*Age.* Fassanian.

*Remarks.* As this zone occurs only in brackish beds, it is possible that it overlaps with the *Xiangxiella bicostata* Zone and that *Xiangxiella bicostata* does not occur for facies reasons. However, it is also possible that the *X. bicostata* Zone is restricted to the upper Anisian.

*Euestheria minuta* Zone

*Definition.* Range of *Euestheria minuta* (von Zieten) without *Xiangxiella* and *Laxitextella multireticulata* (Reible).

*Lower Boundary.* LOD of *E. franconica* (Reible).

*Upper boundary.* FAD of *Laxitextella multireticulata* (Reible).

*Important conchostracan species.* *Euestheria minuta* (von Zieten), dominant; *Liroleaiina* n. sp. A (= *Praeleaia* sp. Warth, 1969), very rare.

*Occurrence.* Upper Ladinian of Eurasia from the Germanic Basin to China. Upper Ladinian of North Africa and Argentina. Upper Ladinian (lowermost Wolfville Formation) of the Fundy Basin, northeastern Canada.

*Age.* Longobardian (late Ladinian).

*Remarks.* The *Euestheria minuta* Zone is the youngest Triassic conchostracan Zone that occurs not only in the entire northern hemisphere, but also in parts of Gondawana (North Africa and Argentina). Despite this fact, it is not characterized by a very distinctive fauna, but rather by the absence of any distinctive taxa, such as *Diaplexa*, *Vileginia*, and *Xiangxiella*, which occur below *E. minuta*, and *Laxitextella*, which occurs above the *E. minuta* Zone. In most of these faunas, only *E. minuta* is present. The very rare *Liroleaiina* n. sp. also is known only from the middle Longobardian of the Germanic Basin (Erfurt Formation). As *E. minuta* is similar to other *Euestheria* species, often older or younger

*Euestheria* species have been determined as *E. minuta*, such as the Spathian *E. exsecta* (by Chang *et al.* 1976), the lower Anisian *E. albertii* (e.g. by Reible, 1962) and some small Upper Triassic *Euestheria*. Real *E. minuta* have not been found below the *E. franconica* Zone and no true *E. minuta* occurs in the Anisian. *E. hubeiensis* Shen from the upper Illyrian to Fassanian *X. bicostata* Zone may be the forerunner of *E. minuta*. *Euestheria winterpockensis* (Bock 1953) (junior synonym: *Cyzicus (Euestheria) minutus multicosatus* Geyer 1987), the successor of *E. minuta*, as well as *Laxitextella multireticulata* (Reible), which also evolved from *E. minuta*, are common in the lower Carnian (Cordevolian). *E. minuta* occurs as well, at least a part of *Cyzicus (Euestheria) minutus albertii* (Voltz 1835) *sensu* Geyer (1987) persists into the Cordevolian of the Germanic Basin, and *E. minuta* occurs in the *L. multireticulata* Zone of the Newark Supergroup (Kozur & Weems 2007), where it is locally common.

#### *Preliminary Upper Triassic and lower Hettangian conchostracan zonation*

Upper Triassic conchostracans are less well studied than Lower and Middle Triassic conchostracans. Only in a few intervals (e.g. the Cordevolian) is the taxonomy of Upper Triassic conchostracans well known, most forms described and their stratigraphic and regional ranges known. In the lower Julian, no conchostracans are known from anywhere in the world. During this time interval, a very significant sea-level drop produced a gap in all shallow water marine sedimentation areas (e.g. above the Wetterstein Formation and the Cassian Dolomite in the Northern and Southern Alps), and even continental areas with outflow to the sea show a break in deposition. Therefore no well dated lower Julian continental sediments with conchostracans are known. In contrast, very rich and diverse conchostracans faunas are known from the upper Julian Schilfsandstein, but all species have yet to be described. At least two different faunas are present. In the Tuvalian, four conchostracan zones can be recognized in the Germanic Basin and can be closely correlated with the marine scale. The upper two zones occur in direct superposition, but the other zones are separated by conchostracan-free hypersaline beds. In North America, the Newark Supergroup has yielded abundant conchostracan faunas in the Tuvalian interval, even some from between the conchostracan zones of the Germanic Basin, but most of these faunas either are not yet described or in need of revision, and several intervals remain to be sampled. In the Norian, several zones were established by Kozur & Weems (2005, 2007), but some of these zones

now can be subdivided. The diagnostic species to do this, however, remain to be described.

In addition to the problems cited above, the generic assignment of several species in the Tuvalian and Norian is not yet resolved because their phylomorphogenetic lineages have yet to be investigated. Thus, the Upper Triassic conchostracan zonation (Fig. 17) for now must remain preliminary, in some cases without type localities and often with incomplete knowledge of the species other than the index species that occur in these zones.

#### *Cordevolian and Julian conchostracan zones and faunas*

##### *Laxitextella multireticulata* Zone

*Definition.* Occurrence of *Laxitextella multireticulata* (Reible) without *L. laxitexta* (Sandberger).

*Lower Boundary.* FAD of *L. multireticulata* and *Euestheria winterpockensis* (Bock).

*Upper Boundary.* FAD of *L. laxitexta*.

*Important conchostracan species.* *Laxitextella multireticulata*; *Euestheria minuta* (von Zieten); *E. winterpockensis* (Bock).

*Occurrence.* This zone occurs with the same species both in the lower variegated Estherienschichten of the upper Grabfeld Formation in the Germanic Basin and in the lowermost strata of the Newark Supergroup in the eastern United States. There, it occurs in the Irishtown Beds below the New Oxford Formation in the Gettysburg Basin (Maryland and Pennsylvania), in the Falling Creek Formation of the Taylorsville Basin (Virginia), in the Tuckahoe Formation of the Deep Run and Richmond basins (Virginia), and in the lacustrine unit in the Farmville, Briery Creek, and Scottsburg basins (Virginia).

*Age.* Early Cordevolian. In the Germanic Basin, the FAD of *L. multireticulata* coincides with the FAD of the palynotaxon *Patinasporites densus* Leschik. Slightly higher is the FAD of *Vallasporites ignacii* Leschik. In the Carnian GSSP at Stuares Wiesen, these two species begin immediately above the base of the Carnian, as defined by the base of the *Daxatina canadiensis* Zone (Broglia Loriga *et al.* 1999). The beginning of this sporomorph association in the Germanic Basin, close to the base of the 'Estheria' Beds of the upper Grabfeld Formation, there defines the base of the Carnian (Schulz & Heunisch 2005). The correlation of this association with the base of the Carnian in the Germanic Basin was first recognized by Hauschke & Heunisch (1989). In the western part of the Southern

Stage	Substage	Conchostracan Zone	Germanic Basin	Newark Supergroup		SW United States
				Newark Basin	other basins	
Hettangian		<i>Bulbilimnadia froelichi</i>		<i>Bulbilimnadia froelichi</i>	<i>Bulbilimnadia froelichi</i>	
		<i>Bulbilimnadia sheni</i>			<i>Bulbilimnadia sheni</i>	
		<i>Bulbilimnadia killianorum</i>	<i>Bulbilimnadia killianorum</i>		<i>Bulbilimnadia killianorum</i>	<i>B. killianorum</i>
Rhaetian		<i>Euestheria brodieana</i>	<i>Euestheria brodieana</i>		uppermost <i>E. brodieana</i> Zone	uppermost <i>E. brodieana</i> Zone
		<i>Gregoriusella polonica</i>	<i>Gregoriusella polonica</i>			<i>Gregoriusella polonica</i>
Norian	Sevatian	<i>Shipingia olseni</i>	<i>Shipingia olseni</i>	<i>Shipingia olseni</i>	<i>Shipingia olseni</i>	<i>Shipingia olseni</i>
		<i>Redondestheria grovetonensis</i>			<i>Redondestheria grovetonensis</i>	<i>R. grovetonensis</i>
	Alaunian	<i>Shipingia hebaozhaiensis</i>	<i>Shipingia hebaozhaiensis</i>		<i>Shipingia hebaozhaiensis</i>	
		<i>N.barnaschi-S.mcdon</i>	<i>N.barnaschi-S.mcdon</i>		<i>Shipingia mcdonaldi</i>	
	Lacian	small <i>Shipingia</i> and large <i>Euestheria</i>	small <i>Shipingia</i> and large <i>Euestheria</i>		small <i>Shipingia</i> and large <i>Euestheria</i>	
		<i>Euestheria buravasi</i> – <i>Euestheria</i> n. sp.	<i>Euestheria buravasi</i> – <i>Euestheria</i> n. sp.		<i>Euestheria buravasi</i> – <i>Euestheria</i> n. sp.	
	<i>Palaeolimnadia schwanbergensis</i>	<i>Palaeolimnadia schwanbergensis</i>	<i>Palaeolimnadia schwanbergensis</i>			
Carnian	Tuvalian	<i>Laxitextella freybergi</i> - <i>P. schwanbergensis</i>	<i>Laxitextella freybergi</i> - <i>P. schwanbergensis</i>			
		<i>Laxitextella freybergi</i>	<i>Laxitextella freybergi</i>	<i>Wannerestheria pennsylvanica</i>	Fulton site fauna/ <i>W. pennsylvanica</i>	
				<i>H. ? ovata</i>		
		<i>Laxitextella seegisi</i>	<i>Laxitextella seegisi</i>	<i>H. princetonensis</i>	<i>H. princetonensis</i>	<i>A. wingatella</i>
	Julian	<i>E. gallegoi</i>	<i>E. gallegoi</i>			
			Schilfsandstein faunas			
	Cordevolian	<i>Laxitextella laxitexta</i>	<i>Laxitextella laxitexta</i>			
		<i>L. multireticulata</i>	<i>L. multireticulata</i>		<i>L. multireticulata</i>	

Fig. 17. Conchostracan zones of the Upper Triassic and Hettangian.

Alps, transitional forms between *Laxitextella multireticulata* and *L. laxitexta* from the upper *L. multireticulata* Zone occur somewhat above the Ladinian–Carnian boundary, where another undescribed species of *Laxitextella* first appears (Tintori 1990; Tintori & Brambilla 1991; Kozur & Mock 1993). The *L. multireticulata* Zone represents the oldest conchostracan fauna in most of the Newark Supergroup of eastern North America. Only in the Fundy Basin (southeastern Canada) has a latest Middle Triassic conchostracan fauna been found in the lower Newark Supergroup.

*Remarks.* In the lower *L. multireticulata* Zone, only typical specimens of the index species occur, with a reticulation composed exclusively of very small polygons that sometimes are arranged in irregular vertical or oblique stripes. Some of these polygons also may be elongated parallel to the growth

lines. In the upper part of this zone, in addition to typical forms, there also occur specimens that have some parts of the carapace covered with reticulations that are larger than normal and other parts covered with reticulations that are as small as in the type material. These advanced *L. multireticulata* are probably transitional forms to *L. laxitexta*. The upper part of the *L. multireticulata* Zone cannot be recognized in the Germanic Basin, because there the appropriate interval for the transition from the *L. multireticulata* Zone to the *L. laxitexta* Zone has soil horizons that have produced no conchostracans.

At nearly all localities in the Newark Supergroup where the *L. multireticulata* Zone is found, these beds also produce the fish *Dictyopyge* (Kozur & Weems 2007). So far, only the Irishtown beds below the new Oxford Formation in the Gettysburg Basin (see Fig. 9) have failed to produce *Dictyopyge* or any other fish.

*Gregoriusella fimbriata*–*Laxitextella laxitexta* Zone  
*Definition.* Occurrence of *Gregoriusella fimbriata* (Warth) and *Laxitextella laxitexta* (Sandberger).

*Lower boundary.* FAD of *Laxitextella laxitexta* (Sandberger).

*Upper boundary.* LOD of *Gregoriusella fimbriata* (Warth) *s.s.*

*Important conchostracan species.* *Gregoriusella fimbriata* (Warth); *Gregoriusella* n. sp.; *Laxitextella laxitexta* (Sandberger).

*Occurrence.* The *Gregoriusella fimbriata*–*Laxitextella laxitexta* Zone is known so far only from the Germanic Basin and England.

*Age.* Late Cordevolian.

*Remarks.* In the lower part of this zone, only *Laxitextella laxitexta* occurs along with some rare indeterminate small specimens of *Euestheria*. A small *Gregoriusella* n. sp. that is much less abundant than *L. laxitexta* first appears slightly higher, then in the middle and upper part of the zone the similarly small *Gregoriusella fimbriata* comes to dominate the assemblage.

The upper boundary of this zone is difficult to define, because in the Germanic Basin it is followed by an interval barren of conchostracans that is particularly rich in pedogenic soil beds. A stratigraphic gap then follows. Above the gap, *Gregoriusella* cf. *G. fimbriata* and *Laxitextella* cf. *L. laxitexta* are present in the basal Schilfsandstein, but this fauna is poorly preserved. The lower Schilfsandstein above the basal beds is again dominated by *Laxitextella* of the *L. laxitexta* group, but *Gregoriusella* cf. *G. fimbriata* is no longer present or else very rare. A further change occurs in the upper Schilfsandstein, where in the Gaildorf Horizon a fauna occurs that contains many *Laxitextella* of the *L. laxitexta* group, among them a new species. *Palaeolimnadia* n. sp. is also common. This new species may be identical with *Palaeolimnadia* n. sp. from the lower Blue-water Creek Formation of northeastern Arizona. Forms similar to *L. laxitexta* persist upward to the middle Tuvallian. Two conchostracan zones can be established for the upper Julian after description of the conchostracan faunas of the Schilfsandstein in the Germanic Basin.

#### *Tuvallian conchostracan zones of the Germanic Basin*

##### *Eosolimnadiopsis gallegoi* Zone

*Definition.* Range Zone of *Eosolimnadiopsis gallegoi* Kozur.

*Lower boundary.* FAD of *Eosolimnadiopsis gallegoi* Kozur.

*Upper boundary.* LOD of *Eosolimnadiopsis gallegoi* Kozur.

*Important conchostracan species.* *Eosolimnadiopsis gallegoi* Kozur; *Anyuanestheria* n. sp. C Kozur; *Laxitextella* n. sp. C Kozur.

*Occurrence.* Only known from the Germanic Basin, where it occurs in the basal Rote Wand of the Weser Formation (base of the Upper Gypsum Keuper) in southern Germany, and the equivalent Dolomie de Beaumont Horizon in eastern France.

*Age.* Earliest Tuvallian, immediately above the middle Carnian wet intermezzo (MCWI) *sensu* Kozur & Bachmann (2008a).

*Remarks.* The Dolomie de Beaumont Horizon of Eastern France contains the bivalve *Costatoria vestita* (von Alberti). Intercalated brackish marls and brackish to freshwater facies equivalent to the Dolomie de Beaumont yield conchostracans typical of the *Eosolimnadiopsis gallegoi* Zone. According to Prof. Renato Posenato, Ferrara, (pers. comm.) *C. vestita* occurs in latest Julian and earliest Tuvallian strata, and his specimens (sampled *in situ*) came from near the supposed Julian/Tuvallian boundary. Taking into consideration that the conchostracans of the *E. gallegoi* Zone have been derived from beds immediately above the middle Carnian wet intermezzo, this level can be assigned to the earliest Tuvallian.

##### *Laxitextella seegisi* Zone

*Definition.* Occurrence of *Laxitextella seegisi* Kozur.

*Lower boundary.* FAD of *Laxitextella seegisi* Kozur.

*Upper boundary.* LOD of *Laxitextella seegisi* Kozur and *L. cf. L. laxitexta* (Sandberger).

*Important conchostracan species.* *Gregoriusella bocki* (Olempska); *Krasiestheria parvula* Olempska; *Laxitextella* cf. *L. laxitexta* (Sandberger); *Laxitextella seegisi* Kozur; n. gen. A n. sp. A.

*Occurrence.* Lehrberg Beds of southwestern Germany (Seegis 1997); Krasiejów locality in Opole Silesia, southwestern Poland (Olempska 2004).

*Age.* Later part of early Tuvallian to middle Tuvallian. The Lehrberg Beds have in marginal parts of the Germanic Basin a brackish to fresh water fauna, but in the deeper parts of the basin there also is a fauna from a slightly hypersaline–marine

environment with dolomites and gypsum that includes *Reubenella* sp. Among euryhaline marine ostracods that also can live in brackish environments, Seegis (1997) mentioned and illustrated what he called *Simeonella alpina* (Bunza & Kozur 1971). However, all of his specimens represent *Simeonella nostorica* Monostori that clearly can be distinguished from the upper Julian *Simeonella alpina*. *S. nostorica* is common in the marine lower Tuvallian of Hungary and Austria, indicating a late early Tuvallian age for the *Laxitextella seegisi* Zone of the Lehrberg Beds.

*Remarks.* *Gregoriusella bocki* (Olempska) and *Krasiestheria parvula* Olempska so far have been found only in the Krasiejów locality in Opole Silesia, southwestern Poland. The co-occurrence of *Laxitextella* cf. *L. laxitexta* and *Laxitextella seegisi* (= *Laxitextella* sp. A of Olempska 2004), which also are common in the Lehrberg Beds of southwestern Germany, indicates that both horizons have the same age. Kozur & Weems (2007) assigned the vertebrates from Krasiejów (Poland) to the lower Adamanian land vertebrate faunal chron (LVF) because the fauna includes *Stagonolepis*, the index taxon for the Adamanian, and also a few holdover Otischalkian taxa (e.g. *Parasuchus* and *Metoposaurus*). Lucas *et al.* (2007b) have since sought to define the base of the Adamanian by the LOD of *Parasuchus* and *Metoposaurus*, but this definition makes the Otischalkian–Adamanian boundary diachronous because these last Otischalkian elements occur only locally in the lower Adamanian where *Stagonolepis* is present. The time-transgressive nature of this boundary is readily demonstrated by conchostracan correlations, because the late Otischalkian (*sensu* Lucas *et al.* 2007b) conchostracan faunas of the *L. seegisi* Zone of Krasiejów correlate in North America with horizons that contain Adamanian land vertebrate faunas. Lucas (2010) concurs with this conclusion and has returned to defining the base of the Adamanian as the FAD of *Stagonolepis* and thus returning the famous Krasiejów fauna to the Adamanian as advocated by Kozur & Weems (2007) and removing the contradiction between conchostracan correlations and the land-vertebrate definition of the Otischalkian–Adamanian boundary in North America and Europe.

According to Dr Sulej, (Warsaw, pers. comm.) the following vertebrates have been found at the Krasiejów site: *Metoposaurus diagnosticus krasiejowensis* Sulej; *Cyclotosaurus intermedius* Sulej & Majer; *Teratosaurus silesiacus* Sulej; *Stagonolepis* sp., *Paleorhinus* sp. (= *Parasuchus* sp.), and *Silesaurus opolensis* Dzik. The occurrence of *Teratosaurus* at a Tuvallian locality initially seemed surprising, because this genus was described

originally from the Norian of southern Germany. However, according to Dr Sulej (pers. comm.), the Krasiejów *Teratosaurus silesiacus* is more primitive than the southern German species *T. suevicus*.

In North America, the *Anyuanestheria wingatella* Zone from the 'Lake Ciniza' facies in New Mexico corresponds to the *L. seegisi* Zone. Very similar faunas occur also in the middle Cumnock Formation of the Deep River Basin (palaeoequatorial southern Newark Supergroup).

#### *Laxitextella freybergi* Zone

*Definition.* Range of *Laxitextella freybergi* Kelber & Kozur without *Palaeolimnadia schwanbergensis* Reible.

*Lower boundary.* FAD of *Laxitextella freybergi* Kelber & Kozur.

*Upper boundary.* FAD of *Palaeolimnadia schwanbergensis* Reible.

*Important conchostracan species.* *Laxitextella freybergi* Kelber & Kozur; *Laxitextella dorsorecta* (Reible) emend.; *Euestheria hausmanni* (Schmidt); new species of *Euestheria* and *Gregoriusella*.

*Occurrence.* Upper Tuvallian Coburg Sandstein of the Germanic Basin. Upper Tuvallian Fulton site of the Gettysburg Basin.

*Age.* Late Tuvallian. The advanced *Laxitextella* species, transitional to *Shipingia*, indicate a late Tuvallian age for the Coburg Sandstein. According to Schulz & Heunisch (2005) and Heunisch (2005), the overlying Mainhardt Formation also contains Tuvallian sporomorphs. Thus, the Coburg Sandstein lies in the upper, but not the uppermost part of the Tuvallian *Enzonalesporites vigens–Spiritisporites spirabilis* Phase (van den Bergh 1987). This means that the Coburg Sandstein is late, but not latest Tuvallian in age (see also Bachmann & Kozur 2004).

*Remarks.* The *Laxitextella freybergi* Zone has a diverse fauna. Most of the species are new and will be described by Kelber & Kozur (in prep.).

#### *Laxitextella freybergi*–*Palaeolimnadia schwanbergensis* Zone

*Definition.* Co-occurrence of *Laxitextella freybergi* Kelber & Kozur and *Palaeolimnadia schwanbergensis* Reible.

*Lower boundary.* FAD of *Palaeolimnadia schwanbergensis* Reible.

*Upper boundary.* LOD *Laxitextella freybergi* Kelber & Kozur and *L. dorsorecta* (Reible).

*Important conchostracan species.* *Laxitextella freybergi* Kelber & Kozur; *L. dorsorecta* (Reible); *Palaeolimnadia schwanbergensis* Reible.

*Occurrence.* So far only known from the Germanic Basin in gypsum-free intervals of the Heldburg Gypsum Member of the Weser Formation.

*Age.* Latest Carnian (latest Tuvallian). According to Schulz & Heunisch (2005) and Heunisch (2005), the Mainhardt Formation contains the youngest Tuvallian sporomorphs. This formation is the marginal Germanic Basin equivalent of the Heldburg Gypsum Member.

*Remarks.* The *Laxitextella freybergi*–*Palaeolimnadia schwanbergensis* Zone contains a typical upper Tuvallian fauna, the diversity of which is somewhat reduced compared with the Coburg Sandstone. *Palaeolimnadia schwanbergensis* also appears in this zone, and its monospecific faunas are characteristic of the immediately overlying lowermost Norian zone both in the Germanic Basin and in the Newark Basin (in the Warford Member of the Passaic Formation where the lowest *Aetosaurus* occurs in the Newark, Huber *et al.* 1993). At the upper boundary of the *L. freybergi*–*P. schwanbergensis* Zone, all late Tuvallian elements disappear. Correlatively, *P. schwanbergensis* becomes much more common.

#### *Tuvallian conchostracan zones of North America*

Only zones are described from which rich material is present and the species present are at least partly described. Further zones will be described in a future paper, such as a lower Tuvallian *Gregoriusella* n. sp. Zone from the upper Stockton Formation.

##### *Anyuanestheria wingatella* Zone

*Definition.* Range of *Anyuanestheria wingatella* (Tasch).

*Lower boundary.* FAD of *Anyuanestheria wingatella* (Tasch) and *Howellisaura princetonensis* (Bock).

*Upper boundary.* LOD of *Anyuanestheria wingatella* (Tasch) and *Howellisaura princetonensis* (Bock).

*Important conchostracan species.* *Anyuanestheria wingatella* (Tasch); *Howellisaura princetonensis* (Bock); *Laxitextella seegisi* Kozur; *Congestheriella elliptoidea* (Bock).

*Type locality.* Carnian 'Lake Ciniza' lake beds, Blue Water Creek Formation, McKinley County, New Mexico.

*Occurrence.* Carnian 'Lake Ciniza' lake beds, New Mexico, Adamanian LVF, middle Tuvallian. Middle Cumnock Formation, Deep River Basin (Sanford Subbasin), parts of the Dockum Group, Texas.

*Age.* Adamanian LVF, middle Tuvallian.

*Remarks.* This zone is very important for the correlation of different Tuvallian zones within North America and between North America and the Germanic Basin. *Howellisaura princetonensis* and *Congestheriella elliptoidea* allow a correlation with the *H. princetonensis* Zone of the lower Lockatong Formation in the Newark Basin. *H. princetonensis* is also common in the lower Cumnock Formation of the Durham Subbasin (Deep River Basin), though *Anyuanestheria wingatella* is not known yet from that horizon. It does, however, co-occur with *H. princetonensis* in the middle Cumnock Formation. The presence of *Laxitextella seegisi* allows correlation with the late early to middle Tuvallian *L. seegisi* Zone of the Germanic Basin.

The following three zones occur in well-established superposition in the Tuvallian Lockatong Formation of the Newark Basin. The middle zone, the *Howellisaura ? ovata* Zone, is an endemic monospecific fauna, most probably related to a facies not normally well suited to conchostracans. According to van Houten (1962, 1964), parts of the Lockatong Formation were deposited in a natron lake, though this interpretation has been called into question by Smoot (2006). The low diversity conchostracan fauna of the lower quarter of the Lockatong Formation (up to the Princeton Member) obviously lived in a nearly normal fresh water lake. The species found there also occur outside of the Newark Basin. The succeeding monospecific *Howellisaura ? ovata* fauna, however, is only known from the Newark Basin. It appears abruptly in the Nursery Member of the Lockatong Formation and ranges up to the Skunk Hollow Member, where *H. ? ovata* (Lea) begins to co-occur with *Wannerestheria pennsylvanica* (Wanner). By the Smith Corner Member, *W. pennsylvanica* totally replaces *H. ? ovata*. *W. pennsylvanica* also is known outside the Newark Basin, but only from the adjacent and connected Gettysburg Basin. Thus, the fauna of this zone also appears to be strongly endemic.

##### *Howellisaura princetonensis* Zone

*Definition.* Occurrence of *Howellisaura princetonensis* Bock without *Anyuanestheria wingatella* (Tasch).

*Lower boundary.* FAD of *Howellisaura princetonensis* Bock.

*Upper boundary.* FAD of *Howellisaura ? ovata* (Lea) in the Newark Basin.

*Important conchostracan species.* *Howellisaura princetonensis* Bock; *Congestheriella elliptoidea* (Bock).

*Occurrence.* Lower fourth of Lockatong Formation up to the top of the Princeton Member of the Lockatong Formation in the Newark Basin. Lower Cumnock Formation of the Sanford Subbasin.

*Age.* Adamanian LVF of middle Tuvalian age.

*Remarks.* Kozur & Weems (2007) established originally a *Euestheria princetonensis*–*E. ovata* Zone because the exact range of these guide forms within the Lockatong Formation was not yet known.

#### *Howellisaura ? ovata* Zone

*Definition.* Occurrence of *Howellisaura ? ovata* (Lea) without *Wannerestheria pennsylvanica* (Wanner).

*Lower boundary.* FAD of *Howellisaura ? ovata* (Lea) in the Newark Basin.

*Upper boundary.* FAD of *Wannerestheria pennsylvanica* (Wanner).

*Important conchostracan species.* *Howellisaura ? ovata* (Lea), often as monospecific faunas; *Howellisaura princetonensis* Bock, only in the lower part and rare.

*Type locality.* Railroad cut at south end of Black Rock tunnel near Phoenixville, Pennsylvania (40.1438 N, 75.5129 W).

*Occurrence.* Endemic fauna from the lower Lockatong Formation (Nursery Member to Byram Member) in the Newark Basin.

*Age.* Middle Adamanian LVF. Middle Tuvalian.

*Remarks.* A direct correlation with conchostracan faunas outside the Newark Basin is not possible for this endemic fauna. As the index species of the overlying *Wannerestheria pennsylvanica* Zone occurs together with *L. freybergi* in the late Tuvalian conchostracan fauna of the Fulton site in the Gettysburg Basin, and this site can be readily correlated with the *L. freybergi* Zone of the Germanic Basin, the *H. ? ovata* Zone must be older than these late Tuvalian conchostracan faunas and, of course, younger than the *H. princetonensis* Zone, which does occur outside of the Newark Basin.

#### *Wannerestheria pennsylvanica* Zone

*Definition.* Range of *Wannerestheria pennsylvanica* (Wanner).

*Lower boundary.* FAD of *Wannerestheria pennsylvanica* (Wanner).

*Upper boundary.* FAD of *Palaeolimnadia schwanbergensis* Reible.

*Important conchostracan species.* *Wannerestheria pennsylvanica* (Wanner), strongly dominating or occurring as a monospecific fauna; *Howellisaura ? ovata* (Lea), only in the lower part of the zone (Skunk Hollow Member).

*Type locality.* Lower Little Conewago Creek, York County, Pennsylvania, at and between locality 1 (40.0932 N, 76.7264 W) and locality 11 (40.0703 N, 76.7353 W) of Wanner (1926).

*Occurrence.* Basal Gettysburg Formation of the Gettysburg Basin. Upper Lockatong Formation (Skunk Hollow Member to the top of the formation) in the Newark Basin.

*Age.* Late Tuvalian.

*Remarks.* *Wannerestheria pennsylvanica* (Wanner) first appears in the Skunk Hollow Member of the Lockatong Formation in the Newark Basin, where it co-occurs with *Howellisaura ? ovata* (Lea). Higher up in the upper Lockatong Formation, the conchostracan fauna changes to a monospecific *W. pennsylvanica* fauna, especially abundant in the Smith Corner Member. In the basal Gettysburg Formation of the Gettysburg Basin, rich monospecific *W. pennsylvanica* faunas are also common. Farther to the southwest, a much more diverse fauna occurs in the basal Gettysburg Formation at the Fulton site. This conchostracan fauna is important for correlation with other conchostracan faunas because it is diverse and contains the following species: *Euestheria hausmanni* (Schmidt), *Laxitextella freybergi* Kelber & Kozur, *Wannerestheria pennsylvanica* (Wanner), and n. gen. A n. sp. B. This fauna probably can be assigned specifically to the lower part of the *L. freybergi* Zone, because n. gen. A occurs in the Germanic Basin only below the Coburg Sandstone (in which occurs the type *L. freybergi* Zone). The Fulton site fauna may well represent the upper part of the conchostracan-free interval between the *L. seegisi* Zone and the *L. freybergi* Zone in the Germanic Basin. Therefore, the Fulton site fauna, because it contains the index species for both the *L. freybergi* Zone and the *W. pennsylvanica* Zone, is important because it establishes a correlation (or at least an overlap) between these two zones.

#### *Norian, Rhaetian and lower Hettangian conchostracan zonation*

##### *Palaeolimnadia schwanbergensis* Zone

*Definition.* Occurrence of *Palaeolimnadia schwanbergensis* Reible without *Laxitextella*

*freybergi* Kelber & Kozur and other upper Tuvallian guide forms.

*Lower boundary.* LOD of *Laxitextella freybergi* Kelber & Kozur.

*Upper boundary.* FAD of *Euestheria buravasi* Kobayashi and *Euestheria* n. sp. aff. *E. hausmanni* (Schmidt).

*Important conchostracan species.* *Palaeolimnadia schwanbergensis* Reible.

*Type locality.* Along Warford Creek, just east of New Jersey State Road 29 (40.4694 N, 75.0611 W), about 200 m above the base of the Warford member of the Passaic Formation.

*Occurrence.* Warford Member of basal Passaic Formation, lowermost Norian, which is also the lowest reported occurrence of *Aetosaurus* in the Newark Basin. Lowermost 10 m of the Arnstadt Formation (Steinmergelkeuper), in its central basin facies in the Germanic Basin where there is no gap between it and the underlying Weser Formation (Upper Gypsum Keuper). Basal Norian. In more marginal facies, where there is a time gap between the Weser Formation and the Arnstadt Formation, the base of the Arnstadt Formation begins with the next younger *Euestheria buravasi*-*Euestheria* n. sp. Zone.

*Age.* In the Germanic Basin and in the Newark Basin, earliest Norian.

*Remarks.* In the Germanic Basin, *Palaeolimnadia schwanbergensis* first appears in the latest Tuvallian, but it occurs there together with a typical latest Tuvallian fauna (*L. freybergi* and other late Tuvallian guide forms).

*Euestheria buravasi*-*Euestheria* n. sp. Zone

*Definition.* Occurrence of *Euestheria buravasi* Kobayashi and *Euestheria* n. sp. aff. *E. hausmanni* (Schmidt).

*Lower boundary.* FAD of *Euestheria buravasi* Kobayashi and *Euestheria* n. sp. aff. *E. hausmanni* (Schmidt).

*Upper boundary.* FOD of *Shipingia* of the *Shipingia ? mansuyi* (Kobayashi) group.

*Important conchostracan species.* *Euestheria buravasi* Kobayashi; *Euestheria* n. sp. aff. *E. hausmanni* (Schmidt); *Euestheria bunopasi* (Kobayashi); *Anyuanestheria* n. sp. A.

*Type locality.* Triangle Brick Quarry in the Durham Subbasin of the Deep River Basin, Durham County, North Carolina (35.8694 N, 78.8960 W).

*Occurrence.* Triangle Brick Quarry in the Durham Subbasin of the Deep River Basin (NC), ('lithofacies Association II,' equivalent to the uppermost Cumnock Formation in the adjacent Sanford Subbasin). Lower Arnstadt Formation (lower Steinmergelkeuper) above its lowermost part in Thuringia and northern Germany. Lower Norian of Thailand.

*Age.* *Euestheria buravasi* was originally described from the early Norian of Thailand (Kobayashi 1975). An earliest Norian age also is indicated by vertebrates from the Triangle Brick Quarry. *Aetosaurus arcuatus* (Marsh) in particular indicates an age no older than Norian (Lucas *et al.* 1998). The co-occurrence of a dicynodont at this quarry (Sues *et al.* 2001) in the past has been considered as evidence of a Carnian age for this deposit, but this is no longer true because a Norian (or possibly Rhaetian) dicynodont recently has been reported from Poland (Dzik *et al.* 2008). Thus, this particular tetrapod assemblage is completely compatible with an early Norian age.

*Interval with small Shipingia and large Euestheria*

*Remarks.* Between the lower Norian *Euestheria buravasi*-*Euestheria* n. sp. Zone and the middle Norian *Shipingia hebaozhaiensis* fauna, there is both in the Germanic Basin and in the Newark Supergroup a diverse conchostracan fauna that has not been investigated adequately. It consists of small *Shipingia* similar to *Shipingia ? mansuyi* (Kobayashi 1954), large *Euestheria*, in part previously described from the Norian of SE Asia but in need of taxonomic revision, and partly of new taxa. This fauna belongs to a new zone that can be only established after adequate taxonomic work is completed on this fauna. The age of this fauna is late Lacinian to early Alauinian.

*Norestheria barnaschi*-*Shipingia mcdonaldi* Zone

*Diagnosis.* Range of *Norestheria barnaschi* Kozur & Weems n. sp. and *Shipingia mcdonaldi* Kozur & Weems n. sp.

*Lower boundary.* FAD of *Norestheria barnaschi* Kozur & Weems n. sp. and *Shipingia mcdonaldi* Kozur & Weems n. sp.

*Upper boundary.* FAD of large *Shipingia hebaozhaiensis* Shen.

*Important conchostracan species.* *Norestheria barnaschi* Kozur & Weems n. sp.; *Shipingia mcdonaldi* Kozur & Weems n. sp.; *Euestheria* sp.

*Type locality.* Borehole Malschenberg 1 (Etzold & Franz 2005). Basal Stubensandstein 3, uppermost Alauinian.



*Occurrence.* Upper part of middle Arnstadt Formation in the central basin facies, lowermost Stubensandstein 3 in the more marginal facies of the Germanic Basin. In the Wachsenburg section (Thuringia), this zone occurs immediately below the Wachsenburg Sandstone of the middle (grey) Steinmergelkeuper (middle Arnstadt Formation). Heidlrsburg Member of the Gettysburg Formation of the Gettysburg Basin (Pennsylvania). Sanford Formation of the Sanford Subbasin (Deep River Basin) (North Carolina).

*Age.* Middle Norian (Alaunian).

*Remarks.* The *N. barnaschi*–*S. mcdonaldi* Zone comprises the lower part of the *S. hebaozhaiensis* Zone *sensu* Kozur & Weems (2007). The small to medium-sized *S. hebaozhaiensis* of the lower *S. hebaozhaiensis* Zone *sensu* Kozur & Weems (2007) are here considered to be an independent species, *S. mcdonaldi* n. sp. Often a monospecific fauna of *S. mcdonaldi* occurs, for example, in the Heidlrsburg Member and in the middle Steinmergelkeuper immediately below the Wachsenburg Sandstone of western Thuringian Basin. Sometimes only *N. barnaschi* is present. In the Malschenberg borehole, *Norestheria* n. sp. occurs immediately above *S. mcdonaldi*. In North America *N. barnaschi* has not been found.

#### *Shipingia hebaozhaiensis* Zone

*Definition.* Range Zone of *Shipingia hebaozhaiensis* Shen *s.s.* (big forms).

*Lower Boundary.* FAD of *S. hebaozhaiensis* Shen *s.s.*

*Upper Boundary.* LOD of *S. hebaozhaiensis* Shen *s.s.*

*Important conchostracan species.* Most localities yield monospecific faunas of big *S. hebaozhaiensis*, though occasionally undescribed species of *Euestheria* also occur.

*Occurrence.* Lower middle part of the Groveton Member of the Bull Run Formation in the Culpeper Basin (Virginia), upper Alaunian; upper part of middle Arnstadt Formation (upper part of middle Steinmergelkeuper) of northern Germany, upper Alaunian; lowermost Stubensandstein 3 of Württemberg (southwestern Germany), upper Alaunian; Morocco (material provided by Dr Paul E. Olsen, Columbia University), upper Alaunian; China, middle Norian (upper Alaunian).

*Age.* Late Alaunian.

*Remarks.* When Kozur & Weems (2005) established the *S. hebaozhaiensis* Zone in the Newark

Supergroup, only the typical large *S. hebaozhaiensis* with well-developed microsculpture were known from the Newark Supergroup and China. We use the original concept of the *S. hebaozhaiensis* Zone. Kozur & Weems (2007) later assigned small to moderately large and more slender forms without distinct microsculpture to *S. hebaozhaiensis*, but in the present paper these forms are separated as a new species, *S. mcdonaldi*. They always occur below, and thus are older than, the large *S. hebaozhaiensis s.s.*, which are restricted to the upper Alaunian, but they still are of Alaunian age.

#### *Redondestheria grovetonensis* Zone

*Definition.* Range zone of *Redondestheria grovetonensis* Kozur & Weems.

*Lower boundary.* FAD of *Redondestheria grovetonensis* Kozur & Weems.

*Upper boundary.* LOD of *Redondestheria grovetonensis* Kozur & Weems.

*Important conchostracan species.* *Redondestheria grovetonensis* Kozur & Weems; *Shipingia olseni* Kozur & Weems.

*Occurrence.* Upper middle part of the Groveton Member of the Bull Run Formation at the Groveton locality and across an interval of at least nine lake beds east of Arcola, Culpeper Basin, Virginia, lower Sevatian.

*Age.* Early Sevatian.

*Remarks.* The *R. grovetonensis* Zone and the genus *Redondestheria* Kozur *et al.* have not been found outside of North America, probably because of provincialism. In North America, *Redondestheria* is found in the Newark Supergroup and in the Chinle Group of New Mexico.

#### *Shipingia olseni* Zone

*Definition.* Occurrence of *Shipingia olseni* Kozur & Weems in the absence of *S. hebaozhaiensis* Shen and *Redondestheria* Kozur, Weems & Lucas.

*Lower boundary.* LOD of *Redondestheria grovetonensis* Kozur & Weems.

*Upper boundary.* LOD of *Shipingia olseni* Kozur & Weems.

*Important conchostracan species.* In the Newark Supergroup, mostly a monospecific *S. olseni* fauna occurs. Rarely, small Norian *Euestheria* are present (also known from China and Southeast Asia) that are not well studied in the Newark Supergroup. In the Germanic Basin, unlike in the Newark Supergroup, *S. olseni* is uncommon and several other species occur which have yet to be described.

In the upper *S. olseni* zone this is also the case in the Newark Supergroup. In the southwestern United States several undescribed new species also are present in this zone, including a large *Euestheria*, a *Shipingia* and a new genus. Additionally, *Redondestheria novomexicoensis* Kozur, Weems & Lucas occurs, which is more advanced than *R. grovetonensis*.

*Type locality.* Cedar Run section, Catharpin Creek Formation, Culpeper Basin.

*Occurrence.* Uppermost Catharpin Creek Formation (Haymarket locality), middle Catharpin Creek Formation (Cedar Run locality), upper Groveton Member of the Bull Run Formation (northwest of Arcola), all in the Culpeper Basin (Virginia); Constitution Avenue section (Exeter, Pennsylvania), in the uppermost 21–28 m of the Passaic Formation (according to measurements by Fowell & Olsen 1993), Boyertown Road section, middle Passaic Formation, both in the Newark Basin (Pennsylvania and New Jersey); upper Blomidon Formation in the Fundy Basin, (Nova Scotia, Canada); Duke Ranch Member of the upper Redonda Formation of New Mexico; upper Arnstadt Formation in northern Germany.

*Age.* All occurrences of the *S. olseni* Zone have a Sevatian age, and this species occurs up to the top of the Sevatian. No *Shipingia olseni* have been found anywhere in the Rhaetian.

*Remarks.* After the description of several new species that occur within the presently defined *S. olseni* Zone, this zone certainly can be divided into subzones.

#### *Gregoriusella polonica* Zone

*Definition.* Range of *Gregoriusella polonica* Kozur, Niedźwiedzki & Sulej n. sp.

*Lower boundary.* LOD of very large *Shipingia olseni* Kozur & Weems and the likewise very large *Redondestheria novomexicoensis* Kozur, Weems & Lucas.

*Upper boundary.* LOD of *Gregoriusella polonica* Kozur, Niedźwiedzki & Sulej n. sp.

*Important conchostracan species.* *Gregoriusella polonica* Kozur, Niedźwiedzki & Sulej n. sp. In the lower part of this zone, mostly monospecific faunas occur. In the upper part of the zone, *Euestheria brodieana* (Jones) becomes steadily more abundant and ultimately dominates the fauna.

*Type locality.* Active clay pit of Lipie, Upper Silesia, Poland, Germanic Basin. Grey, plant-bearing mudstones and siltstones with some

sandstone intercalations, lowermost Rhaetian. In the middle of the 4 m thick succession begins the Rhaetian sporomorph guide form *Rhaetopollis germanicus* Schulz.

*Occurrence.* Lower Exter Formation of northern Germany, lower Rhaetian; southwestern Poland (Upper Silesia), lower Rhaetian. Upper Redonda Formation of New Mexico. Both in the Germanic Basin and in the upper Redonda Formation above the *S. olseni* Zone.

*Age.* Early part of early Rhaetian. This zone possibly may begin in the uppermost Sevatian, but if so is not demonstrable at this time.

*Remarks.* The similarly small *E. brodieana* can be distinguished from *Gregoriusella polonica* only by the microsculpture. Therefore, in faunas that are not well-preserved, the distinction between the *G. polonica* Zone and the *E. brodieana* zone may be difficult to discern.

The base of the Olenekian and the base of the Rhaetian mark the two most sweeping turnovers in conchostracan faunas within the Triassic. The changes in the conchostracan faunas at the base of the Rhaetian are more striking in one way because the upper Norian faunas were dominated by very large conchostracans, while the Rhaetian (and Hettangian) conchostracan faunas are everywhere composed of very small forms.

#### *Euestheria brodieana* Zone

*Definition.* Range of *E. brodieana* (Jones), in the absence of both the lower Rhaetian *Gregoriusella polonica* Kozur, Niedźwiedzki & Sulej n. sp. and the basal Hettangian genus *Bulbilimnadia* Shen.

*Lower boundary.* LOD of *Gregoriusella polonica* Kozur, Niedźwiedzki & Sulej n. sp.

*Upper Boundary.* FAD of *Bulbilimnadia killianorum* n. sp.

*Important conchostracan species.* Both in the Germanic Basin and in the Newark Supergroup, the *E. brodieana* Zone consists of monospecific *E. brodieana* conchostracan faunas.

*Occurrence.* Upper Rhaetian of England, Germany, and France (Argiles de Levallois); upper part of lower Rhaetian in Germany; uppermost Rhaetian in uppermost Catharpin Creek Formation immediately below the first lava flow, Culpeper Basin.

*Age.* In Europe, all published occurrences of the *E. brodieana* fauna have been in upper or uppermost Rhaetian strata. Recently, *E. brodieana* has shown up in the upper part of the lower Rhaetian. This

earliest known occurrence is with *Gregoriusella polonica*, so this fauna is assigned to the upper *Gregoriusella polonica* Zone. Somewhat below the marine middle Rhaetian, *E. brodieana* totally replaces *Gregoriusella polonica*. Thus, the full range of the *E. brodieana* Zone is late early Rhaetian through late Rhaetian.

#### *Bulbilimnadia killianorum* Zone

**Definition.** Co-occurrence of *Bulbilimnadia killianorum* Kozur, Weems & Lucas n. sp. and *Euestheria brodieana* (Jones) without *Bulbilimnadia sheni* Kozur & Weems or with rare *B. sheni* in the upper part of the zone.

**Lower boundary.** FAD of *Bulbilimnadia killianorum* Kozur, Weems & Lucas n. sp.

**Upper boundary.** Strong decrease in the abundance of *Bulbilimnadia killianorum* Kozur, Weems & Lucas n. sp. and a strong correlative increase in the abundance of *Bulbilimnadia sheni* Kozur & Weems, such that the number of *B. sheni* greatly exceed the number of *B. killianorum* Kozur, Weems & Lucas n. sp.

**Important conchostracan species.** *Euestheria brodieana* Jones, dominant; *Bulbilimnadia killianorum* Kozur, Weems & Lucas n. sp., rare in the lowermost part of the zone, above it common; *B. sheni* Kozur & Weems, very rare and only in the upper part of the zone.

**Type locality.** Potter Canyon, northern Arizona, about 1 km west of the type section of the Whitmore Point Member.

**Occurrence.** Lower third of Midland Formation in the Culpeper Basin. Middle and upper Whitmore Point Member of the Moenave Formation in southern Utah and NE Arizona. Early Hettangian of Sołtyków, Holy Cross Mountains, southeastern Poland (Pieńkowski 2004).

**Age.** Earliest Hettangian.

**Remarks.** The changeover from Rhaetian to Hettangian conchostracan faunas is very gradual. The monospecific *E. brodieana* fauna of the uppermost Rhaetian is followed by a basal Hettangian fauna that is still strongly dominated by *E. brodieana*, but additionally includes some *B. killianorum*. Somewhat later, *E. brodieana* still dominates, but by this point *B. killianorum* becomes common and in the upper *B. killianorum* Zone very rare *B. sheni* also occur. The successive, still lower Hettangian fauna also is dominated by *E. brodieana*, but *B. sheni* has become more common than *B. killianorum* among *Bulbilimnadia*. This level is assigned to the *B. sheni* Zone. *B. killianorum* disappears in the upper

part of the *B. sheni* Zone, but *E. brodieana* is still dominant. Only in the late early Hettangian *B. froelichi* Zone does *Bulbilimnadia* become dominant and *E. brodieana* disappear.

#### *Bulbilimnadia sheni* Zone

**Definition.** Co-occurrence of *Bulbilimnadia sheni* Kozur & Weems and other Liassic conchostracans along with dominant *Euestheria brodieana* (Jones). *B. sheni* is more common than *B. killianorum* within the genus *Bulbilimnadia*, and by the upper *B. sheni* Zone is the only *Bulbilimnadia* species present.

**Lower boundary.** The base of the *B. sheni* Zone is placed at the level where *B. sheni* becomes more common than *B. killianorum*.

**Upper boundary.** LOD of *Euestheria brodieana* (Jones), FAD of *B. froelichi* Kozur & Weems.

**Important conchostracan species.** *Euestheria brodieana* (Jones), dominant; *Bulbilimnadia sheni*, common; *Palaeolimnadia* cf. *P. longmenshanensis* Shen, very rare; *P.* cf. *P. semicircularis* Shen, very rare and only in the lower part of the zone. *Bulbilimnadia killianorum* n. sp. is still present but always distinctly rarer than *B. sheni*.

**Occurrence.** Middle Midland Formation to lower Waterfall Formation in the Culpeper Basin (Virginia), lower Hettangian; middle East Berlin Formation in the Hartford Basin (Connecticut and Massachusetts), lower Hettangian.

**Age.** Early, but not earliest Hettangian.

#### *Bulbilimnadia froelichi* Zone

**Definition.** Range Zone of *B. froelichi* Kozur & Weems.

**Lower boundary.** LOD of *Euestheria brodieana* (Jones), FAD of *B. froelichi* Kozur & Weems.

**Upper boundary.** LOD of *B. froelichi*.

**Important conchostracan species.** *Bulbilimnadia froelichi* Kozur & Weems; *Palaeolimnadia baitianbaensis* Chen.

**Occurrence.** Upper Waterfall Formation of the Culpeper Basin.

**Age.** Late early Hettangian.

**Remarks.** The fauna of this zone consists almost exclusively of *B. froelichi*, but this may be due to this faunal horizon only being sampled at a single locality. Except for *B. froelichi*, only a very few *Palaeolimnadia* cf. *P. baitianbaensis* Chen are known from this locality. Rhaetian holdovers

(e.g. *E. brodieana*) are absent. At least one zone above this one is represented by material collected by Nicholas McDonald from the lower and middle Portland Formation in Connecticut. This material will have to be named and described before the next successive zone can be properly defined.

### Summary

Because of their lifestyle, their reproductive strategy, and their rapid rate of evolution, conchostracans are exceptionally well suited for establishing a widespread and detailed biozonation for continental rocks of the Triassic System. Many Triassic conchostracan species are distributed throughout the entire northern hemisphere, and in the Late Permian to Middle Triassic interval some of these forms also are found in Gondwana as well. Upper Triassic Gondwanan conchostracan faunas are different from conchostracan faunas of the northern hemisphere. In the late Carnian and Norian, some provincialism has been documented even within the northern hemisphere. For example, the late Carnian *Howellisaura* and the Sevastian *Redondestheria* seem to be restricted to North America, while *Acadiestheriella* n. gen. so far has been found only in the Sevastian deposits from the Fundy Basin of southeastern Canada.

The tolerance by conchostracans of a variety of aqueous environments, ranging from temporary fresh water pools, permanent lakes, and alkaline lakes to brackish marine environments, makes them some of the most commonly found invertebrates in continental environments and also makes it possible to find them in marginal marine or intertonguing marine and marginal marine environments where they can be closely intercorrelated with the standard marine biozones of the Triassic. The stratigraphic resolution that can be achieved with conchostracan zones is often as high as for ammonoid and conodont zones found in pelagic marine deposits.

In this paper, we establish a conchostracan zonation for the Changhsingian (Late Permian) to Hettangian (Early Jurassic) of the northern hemisphere. Within the Triassic alone, we recognize 34 conchostracan biozones that permit detailed correlation of strata within this period. For the most part, this zonation is very well correlated with the marine scale and is especially robust for the Changhsingian to early Anisian interval, for the late Ladinian to Cordevolian interval, and for the Rhaetian to Hettangian interval. Conchostracan faunas within the Changhsingian to early Anisian interval unequivocally establish that the Permian–Triassic boundary lies within the flood basalts of the Siberian Trap. Thus, the acme of this flood basalt event precisely matches the Permian–

Triassic boundary. For much of the Middle and Upper Triassic, our zonation is preliminary, in great measure because many of the taxa within this interval are undescribed. Also, because of some late Carnian endemism in North America, several zones are established for local usage in the Newark Supergroup of the eastern United States and in the Chinle Group of the American southwest.

In the Late Triassic, there are two major extinctions among conchostracans. The first is in the early Norian (Lacian), when fairly diverse forms descended directly from Carnian forebearers mostly go extinct. This is followed by a brief interval within the Lacian of low conchostracan diversity, followed by a radiation of new forms including the characteristic Norian genera *Redondestheria* and *Shipingia*. Through the remainder of the Norian these forms tend to become larger overall. The second major extinction was at the end of the Norian, when both *Redondestheria* and *Shipingia* went extinct. Throughout the Rhaetian and the early Hettangian (earliest Jurassic), conchostracan faunas consist universally of small forms and generally are represented by low diversity faunas. It was not until after the major CAMP volcanic episode, in the region that was to become the Atlantic Ocean, that conchostracan faunas became larger and more diverse again. This prolonged Rhaeto–Hettangian interval of small and low diversity faunas probably reflect global environmental stress caused by the CAMP volcanic event.

Some conchostracan taxa, of exceptional stratigraphic importance for the Triassic but not previously recognized, are described here in an accompanying appendix. These represent five new genera, six new species and a new subspecies.

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## Appendix 1 – Description of some new, stratigraphically important taxa

### Family Euestheriidae

#### Defretin-Lefranc, 1965

##### Genus *Euestheria* Depéret & Mazeran, 1912

*Type species. Posidonia minuta* von Zieten, 1833

*Euestheria albertii mahlerselli* Kozur & Lepper *n. subsp.*

1993 *Euestheria* n. sp B – Kozur, Mahler & Sell, p. 258, figs 3–4

1993 *Euestheria albertii* n. subsp. A – Kozur, Mahler & Sell, p. 258, figs 3–6

*Derivatio nominis.* In honour of Horst Mahler, Veitshöchheim, Franconia (Germany) and Jürgen Sell, Euerdorf, Franconia (Germany), for their excellent work on the fauna of the Solling and Röt formations in Franconia, Germany.

*Holotype.* The specimen illustrated by Kozur *et al.* (1993) in figs 3–6, rep.-no. SMTE 5826/13-18, from the collection of Horst Mahler/Jürgen Sell.

*Type locality.* Aura, southwest of Bad Kissingen (Franconia, Germany), TK 25: 5826 Bad Kissingen Süd, R: 35 72 750, H: 55 60 475.

*Stratum typicum.* Greenish-grey claystones in the uppermost Thuringian *Chirotherium* Sandstone.

*Diagnosis.* Very small, strongly convex *Euestheria* with commonly stout but also more rarely slender morphotypes. The strongly convex umbo is situated at the end of the anterior third of the shell and somewhat overreaches the dorsal margin. In front of the umbo, the dorsal margin is short, directed obliquely downward and only

slightly separated from the anterior margin. Behind the umbo, the dorsal margin is straight, directed slightly downward and separated from the posterior margin by a posterodorsal corner. Anterior margin higher and somewhat less convex than the posterior margin. Strongest curvature of the anterior and posterior margins somewhat above the mid-line, at the posterior margin sometimes partly along the mid-line. Ventral margin convex, with strongest curvature somewhat anterior to the mid-length. The 9–20 growth bands are narrow and rather uniform; only in the umbonal field are they somewhat narrower and not so pronounced. Free umbonal field very small. Very well-preserved specimens show an indistinct, very small reticulation.

*Measurements.* Stout morphotype:  $l = 2.4\text{--}3.3$  mm,  $h = 1.6\text{--}1.9$  mm,  $l/h = 1.11\text{--}1.44$

*Slender morphotype.*  $l = 2.35\text{--}3.2$  mm,  $h = 1.5\text{--}1.8$  mm,  $l/h = 1.57\text{--}1.74$

*Age.* Late Spathian and Aegean. *Euestheria albertii mahlerselli*–*Palaeolimnadia alsatica alsatica* Zone.

*Occurrence.* *Euestheria albertii mahlerselli* occurs rarely in the lower Solling Formation, where the Spathian guide forms *Euestheria exsecta* (Novozhilov), *Palaeolimnadia nodosa* (Novozhilov) and *P. alsatica defurthensis* Kozur & Seidel are still dominant. In younger parts of the Solling Formation, the frequency of *E. albertii mahlerselli* increases upward as the frequency of the other three mentioned species decreases. In the basal Anisian upper Solling Formation Stammen Beds of the Solling Mountains and in the contemporaneous Thuringian *Chirotherium* Sandstone of Thuringia and Franconia, *E. albertii mahlerselli* is either the only known species (Franconia, Solling Mountains) or it co-occurs with *P. alsatica alsatica* Reible (Thuringia). The Spathian guide forms *E. exsecta*, *P. nodosa* and *P. alsatica defurthensis* are no longer present in that level.

In the lower and middle Röt Formation, below the basal Bithynian ‘Dolomitische Grenzbank’ of the middle Röt Formation with *Costatoria costata* (Zenker) and *Myophoria vulgaris* (von Schlotheim), the same conchostracan fauna is present as in the upper Solling Formation. This level can be correlated with the Aegean by marine faunas (Kozur 1999). The upper Solling Formation Stammen Beds/Thuringian *Chirotherium* Sandstone interval also belongs to the Aegean as indicated by the first occurrence of the sporomorph *Hexasaccites thiergartii* (Mädler) Kozur (Brugman 1986; Bachmann & Kozur 2004). Thus, the total range of *E. albertii mahlerselli* is late Spathian to Aegean.

*Remarks.* The only significant difference between *E. albertii mahlerselli* and *E. albertii albertii* (Voltz) is the consistently smaller size of *E. albertii mahlerselli*. Additionally, typical specimens of *E. albertii albertii* are proportionately higher (i.e. their  $l/h$  index is smaller).

Typical *E. albertii albertii* from the Grès à *Voltzia* in Lorraine are 5 mm long. The most primitive representatives of *E. albertii albertii* come from the basal Bithynian middle Röt Formation (‘Dolomitische Grenzbank’). They reach a maximum length of 4 mm and are found together with *Costatoria costata* and *Myophoria vulgaris* (Kozur *et al.* 1993). Advanced *E. albertii albertii*, from the upper Bithynian Holbrook Member of the Moenkopi Formation of Arizona, are up to 6–6.3 mm long.

### Genus *Gregoriusella* n. gen.

*Derivatio nominis.* In honour of Grzegorz Niedźwiedzki PhD, Warsaw, for his excellent palaeontological work on the continental Triassic of Poland. Grzegorz (Latinized) = *Gregorius*.

*Type species.* *Gregoriusella polonica* Kozur, Niedźwiedzki & Sulej n. sp.

*Diagnosis.* Strongly convex, generally oval, very small to small carapace. The strongly convex umbo is situated in the anterior third of the carapace and overreaches the short dorsal margin. The 12–25 narrow growth bands have a uniform width. The microsculpture on the outer growth bands consists of often indistinct, short radial lirae; on the inner growth bands there are short radial lirae, fine reticulations or a pitted surface. If the outer layer of the shell is present, then between the radial lirae or within the reticulations a pitted surface can be recognized.

*Assigned species.* *Gregoriusella polonica* Kozur, Niedźwiedzki & Sulej n. sp.; *Palaeoestheria fimbriata* Warth, 1969; *Menucoestheria bocki* Olempska, 2004; *Gregoriusella* spp. (several yet to be described new species, mainly from the Tuvalian).

*Age.* Upper Cordevolian to lower Rhaetian.

*Remarks.* Two species, here assigned to *Gregoriusella*, in the past were classified as *Palaeoestheria* (*P. fimbriata* Warth 1969) and *Menucoestheria* (*M. bocki* Olempska 2004). *Palaeoestheria* Barnard (1929) was not adequately defined and was used by him in a broad sense for all fossil conchostracans without diagnosis. He listed three species under this genus, and from these Raymond (1946) selected *Estheria anomala* Jones as the type species. This Lower Cretaceous species is not well known, but it does have a distinct free umbonal area and therefore is probably a limnadiid conchostracan. Microsculpture is not reported from this species. This genus therefore is quite different from *Gregoriusella* and can be distinguished by its larger size, larger free umbonal area and absence of microsculpture, though the last characteristic may be an artefact because the type species is not well known and no modern description has been made.

The type species of *Menucoestheria* Gallego & Covačević, 1998 (*M. ternaraensis* Gallego 1998) is a large

conchostracan with reticulation on the inner growth bands and radial lirae on the outer growth bands. It may be a junior synonym of *Anyuanestheria* Zhang & Chen 1976 but this is uncertain because *Menucoestheria* is a Gondwanan genus and it cannot be proven as yet that it evolved from *Laxitextella*. *Gregoriusella* has a rather similar microsculpture, but the space between the radial lirae is pitted. During the upper Cordevolian in the Germanic Basin, *Gregoriusella* evolved from small *Euestheria*, while *Anyuanestheria* was evolving from large *Laxitextella* of the *L. laxitexta* group. In this case, the difference in size between *Anyuanestheria* and *Gregoriusella* can be used to differentiate the two genera. The same difference exists between *Gregoriusella* and *Menucoestheria*.

*Euestheria* Depéret & Mazeran, 1912 is very similar, but it has either no microsculpture or a microsculpture that consists of mostly indistinct fine reticulations. *Gregoriusella* gradually evolved during the late Cordevolian from *Euestheria* by development of radial lirae, at first only on the outer growth bands though in later forms the entire shell may have radial lirae. The oldest species is *Gegoriusella fimbriata* (Warth). This species evolved during the Cordevolian from *Euestheria* by development of rather indistinct radial lirae. The microsculpture of this species is rather misleadingly documented in Warth (1969, pl. 3). On this plate the holotype is shown together with two SEM photographs of microsculpture. These SEM pictures are neither from the holotype nor from *Gegoriusella fimbriata*. They are of shell fragments of transitional forms between *Laxitextella* Kozur and *Anyuanestheria* Zhang & Chen which are much larger and have much more distinct microsculpture.

*Gregoriusella polonica* Kozur,  
Niedźwiedzki & Sulej n. sp.

(Fig. A1, Photographs 1–10)

*Derivatio nominis.* In reference to its occurrence in Poland.

*Holotype.* The specimen in Figure A1: 1, 2; ZPAL V33/543 in the collection of the Institute of Paleobiology, Polish Academy of Science, Warsaw.

*Locus typicus.* Clay quarry at Lipie, Upper Silesia, Poland.

*Stratum typicum.* Within a 4 m succession of plant-bearing grey mudstones and siltstones with some sandstones. Upper conchostracan horizon with first *Rhaetipollis germanicus* Schulz. Lowermost Rhaetian.

*Material.* More than 100 specimens.

*Diagnosis.* Small, oval, strongly convex carapace. Umbo situated in the anterior third of the carapace, strongly convex, overreaches the dorsal margin. Dorsal margin short, straight to very slightly convex, with gradual transition into the anterior and posterior margins.

Anterior and posterior margins symmetrically rounded, anterior margin higher than posterior margin and curvature less than in posterior margin. Posterodorsal margin somewhat bevelled. Ventral margin symmetrically rounded. The 12–25 growth bands are narrow and rather uniform. The microsculpture on the outer growth bands consists of short radial lirae, but the middle and inner growth bands are finely reticulated or pitted. If the outer layer of the shell is preserved, the space between the lirae or within the reticulae are densely pitted (Fig. A1: 10).

*Measurements.*  $l = 2.2\text{--}3.3$  mm,  $h = 1.3\text{--}2.3$  mm,  $l/h = 1.25\text{--}1.44$

*Age.* Uppermost Sevatian and lower Rhaetian.

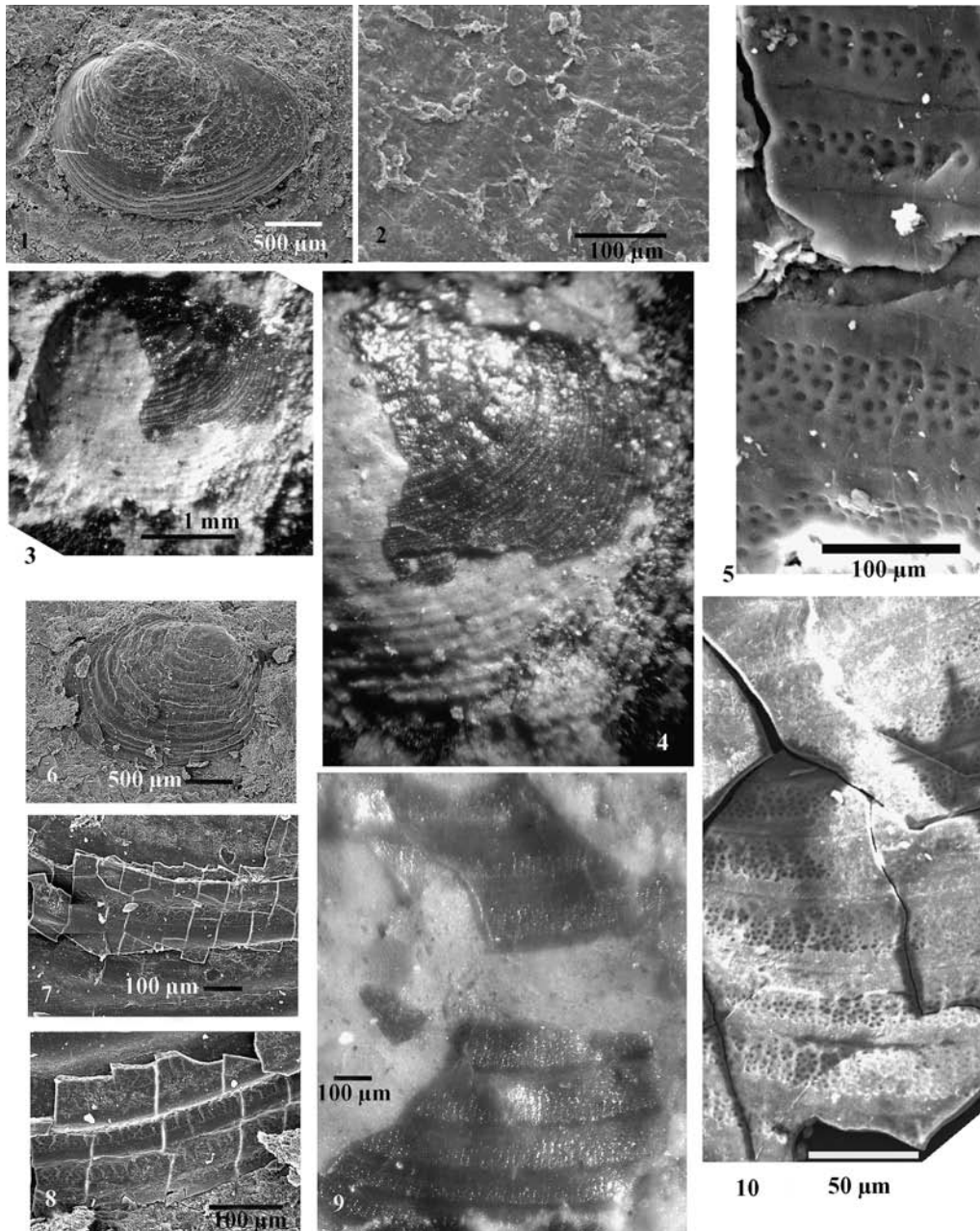
*Occurrence.* In grey claystones, siltstones, and rarely sandstones, all rich in plant detritus, Lipie, Upper Silesia, uppermost Norian to lowermost Rhaetian. In the basal Exter Formation (also rich in plant detritus) in the Tarnow borehole from northern Germany, uppermost Norian to lowermost Rhaetian. Upper Redonda Formation (Duke Ranch Member) in Apache Canyon, New Mexico, lowermost Rhaetian.

*Remarks.* At Lipie, *Rhaetipollis germanicus* first appears in the middle of the exposed four metres of sediments, where *G. polonica* is present. In general, the FAD of *R. germanicus* is regarded as a marker for the base of the Rhaetian, but it is very rare or perhaps even absent in the basal-most part of the Rhaetian. As the very large (often 10–12.5 mm long) *Shipingia olsenii* and *Redondestheria novomexicoensis* that characterize the upper Sevatian are no longer present in the *G. polonica* Zone, the entire *G. polonica* Zone is assigned to the lowermost Rhaetian, but it remains possible that this zone could begin slightly before the Norian–Rhaetian boundary.

*Gregoriusella bocki* (Olempska) is larger than *G. polonica* (up to 4.8 mm long) and also is the largest known species of *Gregoriusella*. The ventral margin is only slightly convex. *Gregoriusella fimbriata* (Warth) is perfectly oval. The anterior and posterior margins have almost the same height and the posterodorsal margin is not distinctly bevelled.

### Family Xiangxiellidae Shen 1976

The Xiangxiellidae were established by Shen Yan-Bin (in Chang *et al.* 1976) as a subfamily of the Vertexiidae Kobayashi 1954. The Xiangxiellidae, with one or two rather broad radial elements on the free umbonal area, are only distantly related to the Vertexiidae, which have a hollow spine on the free umbonal area and often also possess long spines on the dorsal margin and sometimes a long posterodorsal spine. The umbonal spine is often deformed and may be squeezed onto the umbonal area to give the appearance of a conical umbonal sculpture or a radial element. Where undeformed, however, it stands



**Fig. A1.** 1–10: *Gregoriusella polonica* Kozur, Niedźwiedzki & Sulej n. sp., lower Rhaetian *G. polonica* Zone; 1, 2: Holotype, outer layer of the shell corroded and radial lirae therefore not preserved in their full length, SEM picture, Lipie (Upper Silesia), upper conchostracan horizon, material from G. Niedźwiedzki, Warsaw. 1: total view; 2: detail of shell surface with partly preserved radial lirae. 3, 4: Specimen with deformed anterior margin, shell partly preserved. From borehole Tarnow 1–65, sample KO 7-02-10 at 956.7–956.8 m, 1.0–1.1 m above the base of the Exter Formation; 3: total view; 4: detail. 5: Microsculpture of the outer layer of the shell with very indistinct radial lirae and reticulation, both distinctly pitted, SEM picture, from borehole Tarnow 1–65, sample KO 7-02-12, lower Exter Formation at 954.15 m, 3.55 m above the base of the Exter Formation, 6–8: Lipie (Upper Silesia), specimen with preserved different layers of the shell, SEM pictures, material from G. Niedźwiedzki, Warsaw; 6: Total view; 7: Preserved outer layer of shell in the middle part of the carapace, with



perpendicular or oblique to the shell surface. Most probably, the Xiangxiellidae evolved from such representatives of the Palaeolimnadiidae Tasch, in which a node is present on the free umbonal area. If this node became elongated, it easily could have changed into an umbonal radial element. *Palaeolimnadia* with an umbonal node, such as *P. alsatica detfurthensis* Kozur & Seidel, are present in the Spathian. In some specimens, the umbonal node already has become oval and these or similar forms could be the forerunners of the Xiangxiellidae.

### *Genus Hornestheria Kozur & Lepper n. gen.*

*Derivatio nominis.* In honour of the late Dr Manfred Horn (1934–1999, Wiesbaden).

*Type species.* *Hornestheria sollingensis* Kozur & Lepper n. gen. n. sp.

*Diagnosis.* Shell small to moderately large, with rather low convexity. Dorsal margin moderately long, straight, with a distinct posterodorsal corner but often only an indistinct anterodorsal corner. The anterior margin is slightly rounded, with its greatest curvature generally distinctly above the mid-line. In most species, the lower part of the anterior margin is strongly oblique. The posterior margin is strongly rounded and often in the upper part oblique. Its greatest curvature is somewhat below the mid-line. The ventral margin is moderately to strongly convex. The free umbonal area is distinct, but not very large. It bears a swollen radial element that is often quite distinct, but for preservational reasons it is sometimes not recognizable. There are 7–17 growth bands; the inner bands have a dense, fine reticulation, but in adult forms the outer growth bands bear only fine, short radial lirae.

*Age.* Uppermost Spathian and Anisian.

*Occurrence.* Karlshafen Beds of the Solling Formation (uppermost Spathian) of the Solling Mountains, Anisian of China.

*Assigned species.* *Hornestheria sollingensis* Kozur & Lepper n. gen. n. sp.; *Protomonocarina sinensis* Shen 1976; *Protomonocarina carinata* Shen 1976; *Protomonocarina oblonga* Shen 1976; *Protomonocarina ziguiensis* Shen 1976; *Protomonocarina hubeiensis* Shen 1976; *Protomonocarina buzhuangheensis* Shen 1976; *Protomonocarina xiangxiensis* Shen 1976.

*Remarks.* Chang *et al.* (1976) assigned the Anisian species that we now assign to *Hornestheria* to the Lower Permian genus *Protomonocarina* Tasch 1962. Only one specimen of one species shows what might be interpreted as a characteristic feature of this latter genus, namely a radial element on the free umbonal area that is distinctly segmented. This radial element, however, clearly is not a sculptural element, but rather a soft part element (appendage) that is visible through the chitinous shell. Even if the radial ridge on the free umbonal area is a sculptural radial element, *Protomonocarina* Tasch, 1962 still would be a junior synonym of *Lioestheria* Depéret & Mazeran 1912. The type species of this genus, *Estheria (Lioestheria) lallyensis*, also has a radial element on the free umbonal area and no reticulation on the growth bands, just as in *Protomonocarina*.

Some species of *Curvacornutus*, which Novozhilov (1970) described from the Tatarian of Russia, are similar, but they have a distinctly curved radial element, and the shell is not reticulated. The type species of *Curvacornutus*, the Lower Permian *C. primus* Tasch from North America, is based on a single specimen that probably is not closely related to the species that Novozhilov (1970) described under this genus. The Permian *Megasitum* Novozhilov 1970 is distinctly different in that it has a larger free umbonal area and a much wider and larger radial element.

### *Hornestheria sollingensis Kozur & Lepper n. gen. n. sp.*

(Fig. A2, Photographs 1–7)

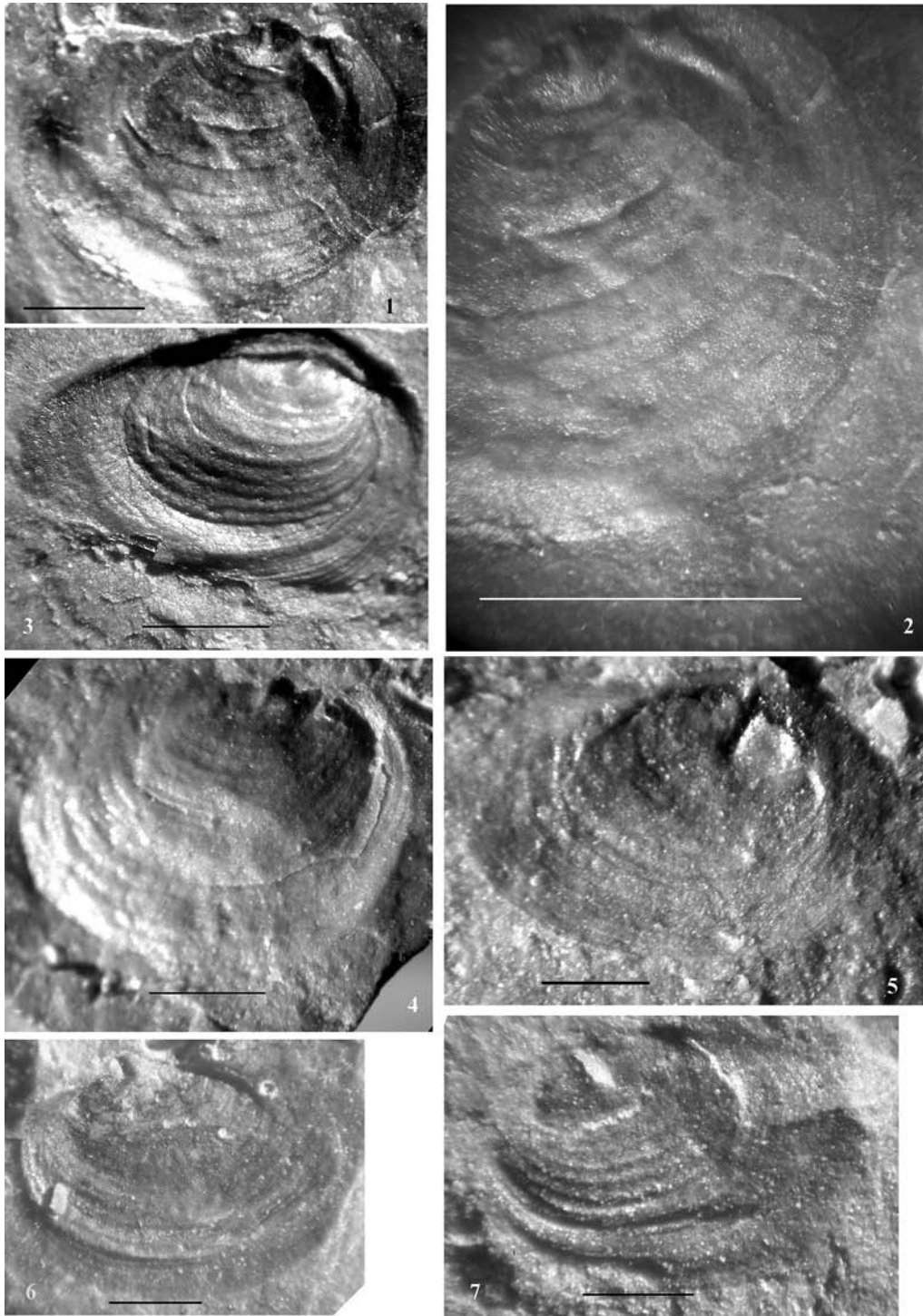
*Derivatio nominis.* In reference to its occurrence in the Solling Formation of the Solling Mountains.

*Holotype.* Figure A2: 1, 2, rep. no. Kozur-Lepper 2003.53 MLU (in the collection of the Institut für Geologische Wissenschaften of the Martin-Luther-Universität Halle).

*Type locality.* Quarry Frohriepel Berg (Fa. Bunk), TK 25 Nr. 4322; R: 35 31 300, H: 57 24 570.

*Stratum typicum.* Karlshafen Beds of the Solling Formation, in a greenish-grey claystone with a rich conchostracan fauna, about 4 m above its basal boundary with the Trendelburg/Karlshafen Beds. Uppermost Spathian.

**Fig. A1.** (Continued) fine reticulation; **8:** preserved outer layer of the shell on the outer growth bands with radial lirae, space between the radial lirae pitted. **9:** Carapace surface with partly preserved shell, including outer layer of the shell, distinct radial lirae, from borehole Tarnow 1–65, sample KO 7-07-9 at 956.95 m, 0.85 m above the base of the Exter Formation; **10:** Shell fragment from the surface of a complete carapace, outer layer well-preserved, SEM picture, radial lirae with pitted surface between the radial lirae on the outer growth bands, in the upper part of the picture (growth bands from the middle part of the shell) pitted surface without radial lirae. From borehole Tarnow 1–65, sample KO 7-02-7 at 957.8 m, base of Exter Formation. The material illustrated in 3–5, 9, and 10 is deposited in the collection of the Institut für Geologische Wissenschaften, Martin-Luther-Universität Halle.



**Fig. A2.** 1–7: *Hornestheria sollingensis* Kozur & Lepper n. gen. n. sp., from quarry Frohrieper Berg (Fa. Bunk), TK 25 Nr. 4322; R: 35 31 300, H: 57 24 570. Karlshafen Beds (Solling Formation), greenish-grey claystone with rich conchostracan fauna, about 4 m above the basal boundary on the Trendelburg/Karlshafen Beds. Uppermost Spathian.

*Material.* More than 100 specimens in different preservation.

*Diagnosis.* With the characteristics of the genus. The small, only slightly convex shell has a straight dorsal margin with an indistinct anterodorsal corner and a distinct posterodorsal corner. The anterior margin is slightly to moderately rounded, with the greatest curvature somewhat above the mid-line. The lower part of the anterior margin is only slightly or occasionally moderately bevelled. The posterior margin is more strongly rounded than the anterior margin, with its greatest curvature situated in the middle. It is slightly (or, rarely, moderately) bevelled in its upper part. The ventral margin is moderately convex. The length of the free umbonal area is 25–30% of the total length of the shell. It has a distinctly swollen but rather narrow radial element that is about half as long as the height of the free umbonal area. The 13–17 growth bands and the free umbonal area all have a fine and dense reticulation. On the outer growth bands, the reticulation is replaced by delicate, short, radial lirae.

*Measurements.*  $l = 3.0\text{--}3.8$  mm,  $h = 1.95\text{--}2.85$  mm,  $l/h = 1.3\text{--}1.66$

*Age.* Uppermost Spathian.

*Occurrence.* Karlshafen Beds of the Solling Formation in the Solling Mountains, Germany.

*Remarks.* The Anisian *Hornestheria* species of China are smaller (2.0–2.8 mm long), and only in *H. ziguiensis* (Shen, 1976) are short indistinct radial lirae present on the outermost growth bands of adult forms. This latter species is most similar to *H. sollingensis* in its outline, but it is consistently smaller (2.3–2.8 mm long), and the reticulation and radial lirae are weaker than in *H. sollingensis*. The other Anisian *Hornestheria* species have a different outline in addition to their smaller size and weaker sculpture. In some specimens the lower part of the anterior margin and the upper part of the posterior margin are strongly bevelled, as in *H. sinensis* (Shen), or else they have a subrectangular outline, as in *H. carinata* (Shen).

### Family Estheriellidae Kobayashi 1954 *emend.* Kozur & Seidel 1983

#### *Genus* *Acadiestheriella* n. gen.

*Derivatio nominis.* The genus is named in honour of Acadia University in Wolfville, Nova Scotia.

*Type species.* *Acadiestheriella cameroni* n. gen. n. sp.

*Diagnosis.* Carapace small to moderately large, moderately convex. Dorsal margin long, straight, without distinct corners at the anterior and posterior margins. Free umbonal area distinct but small, situated terminally (anterodorsally). The 8–12 growth bands have a dense, fine reticulation and bear small to large, roundish nodes arranged in four to seven (rarely eight) radial lines.

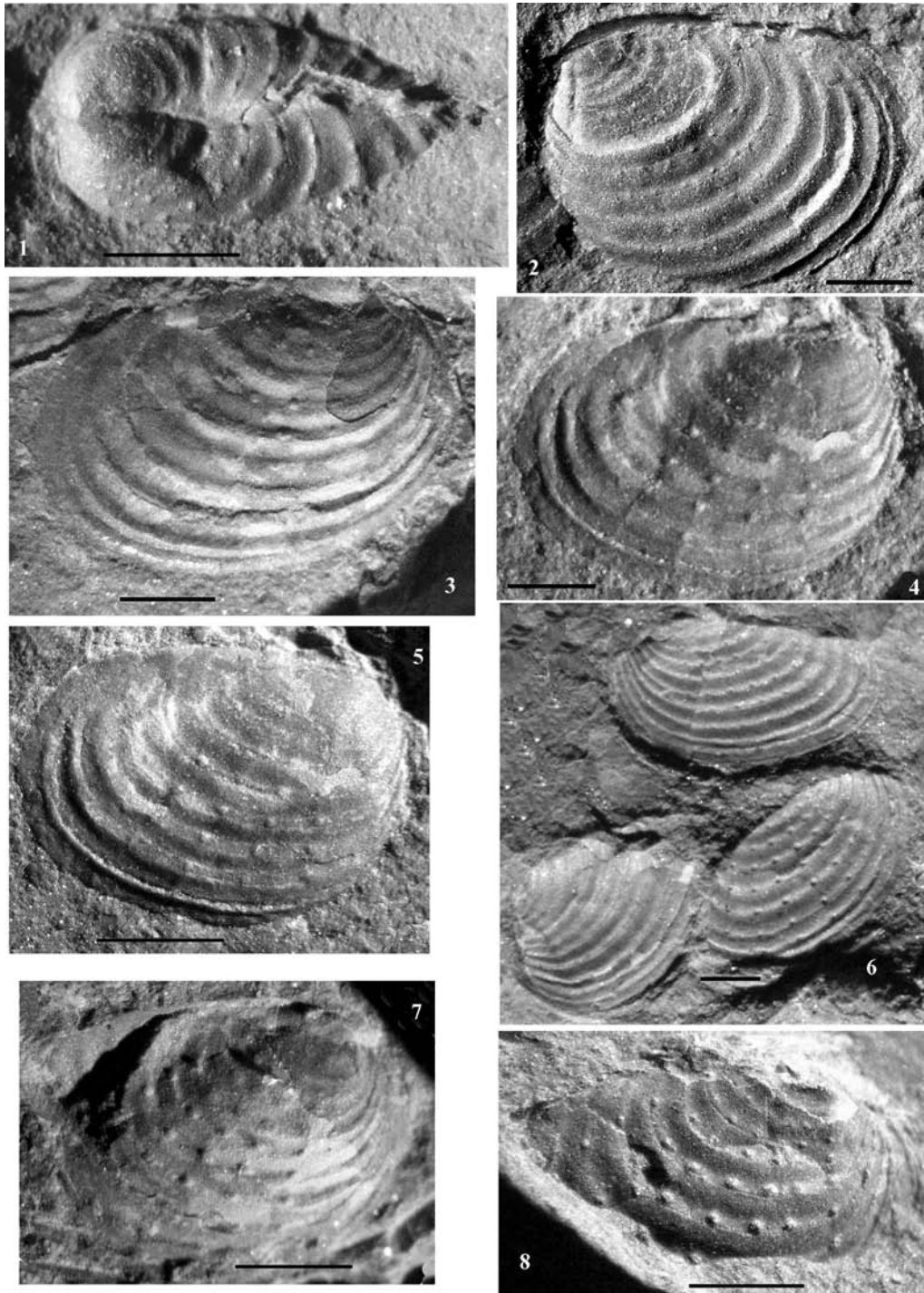
*Assigned species.* *Acadiestheriella cameroni* n. gen. n. sp.

*Age.* Sevatian.

*Occurrence.* So far only known from the Fundy Basin (southeastern Canada).

*Remarks.* Most similar is *Lioleiina* Novozhilov 1952 *emend.* Kozur & Seidel 1983. This genus has two to five radial ridges on the lateral shell surface that bear nodes at crossing points with the growth lines. Exceptionally, the radial ridges are broken up into radial lines of nodes. However, these nodes are situated on elevated radial line segments, so even in these forms low radial ridges are present. Characteristic of *Lioleiina* is a dorsal ridge with nodes parallel and very close to the dorsal margin. This dorsal ridge or line of nodes at the dorsal margin and parallel to it is not present in *Acadiestheriella*. The youngest *Lioleiina* are found in the Anisian and Ladinian of the Germanic Basin and consistently have three nodose radial ribs on the lateral shell and one along the dorsal margin. Earlier, lower Olenekian *Lioleiina* have up to five nodose lateral ribs and one dorsal rib. Thus, the trend in this genus is toward reduction of the nodose radial ribs. As *Acadiestheriella* has up to eight radial lines of nodes, it seems unlikely that it was derived directly from *Liolaia*. More probably, *Acadiestheriella* evolved directly from *Estheriella* Weiss 1875. This would explain why four to seven, and sometimes even eight, radial lines of nodes are present in *Acadiestheriella*. It is not likely that the trend toward reduction of the number of radial nodose ribs within the *Lioleiina* from the Smithian to the Longobardian would be reversed above the Ladinian. *Estheriella* Weiss 1875 is most readily distinguished from *Acadiestheriella* by the presence of nodose ridges in *Estheriella* instead of the radial lines of isolated nodes that are characteristic of *Acadiestheriella*. As in *Estheriella*, the nodose sculpture is very variable in *Acadiestheriella*. In *Lioleiina*, the nodose sculpture is more uniform.

**Fig. A2.** (Continued) **1, 2:** Holotype; 1: total view; 2: Detail of the anterior part, showing microsculpture of very fine reticulation and indistinct radial lirae; **3:** Radial element readily visible; **4–7:** Specimens with preserved distinct, narrow radial elements. Scale: 1 mm. All material is deposited in the collection of the Institut für Geologische Wissenschaften, Martin-Luther-Universität Halle.



**Fig. A3.** 1–8: *Acadiestheriella cameroni* n. gen. n. sp., Blomidon Provincial Park, Fundy Basin, Nova Scotia, southeastern Canada, upper Blomidon Formation, Sevatian. **1:** Dorsal view of a double-valved specimen, anterior margin to the left. Nodes arranged in seven distinct radial lines; **2:** Specimen with a few small nodes arranged in six indistinct radial lines; **3:** Specimen with a few nodes, arranged in four indistinct short radial lines; **4, 5:** Holotype, nodes

*Acadiestheriella cameroni* n gen. n. sp.

(Fig. A3, Photographs 1–8)

*Derivatio nominis.* The species name is in honour of Professor Barry Cameron, recently retired from Acadia University, who first reported (but did not describe) this form from the Fundy Basin.

*Holotype.* NSM007GF023.017, part and counterpart, Figure A3: 4, 5.

*Type locality.* 45.2343 N, 64.3546 W, about 3 km SE along the shoreline from the bottom of steps down to beach at White Water picnic area in Blomidon Provincial Park, Cape Blomidon, Nova Scotia, Canada.

*Stratum typicum.* Near the middle of the Blomidon Formation in the Fundy Basin.

*Material.* More than 20 specimens on 17 small slabs of rock (4 with counterparts), deposited in the collections of the Nova Scotia Museum, Halifax, Nova Scotia (NSM007GF023.001 through NSM007GF023.17).

*Diagnosis.* As for the genus.

*Description.* Carapace small to moderately large, moderately convex. Dorsal margin long, straight, without distinct corners at the anterior and posterior margin. Anterior margin slightly rounded, anteroventral margin slightly oblique. Posterior margin stronger and symmetrically rounded, greatest curvature either somewhat higher than in anterior margin or else in anterior and posterior margins at the same height. Ventral margin convex. Free umbonal area distinct but small, located anterodorsally. The 8–12 growth bands are densely and finely reticulated and bear small to large roundish nodes that are arranged in four to seven (rarely eight) radial lines. The nodes are roundish, very variable, distinct to indistinct, and small to large. They are widely separated and situated at the boundary between adjacent growth bands. The six to eight radial lines of nodes sometimes reach from the outermost growth band to the innermost growth band adjacent to the free umbonal area, but often they are considerably shorter and restricted to only the middle growth bands. In this case, only two or three nodes may be present in a single radial line. Occasionally, the nodes may be totally absent.

*Measurements.*  $l = 3\text{--}5$  mm;  $h = 2.1\text{--}3.3$  mm;  $l/h = 1.32\text{--}1.7$

*Age and occurrence.* As for the genus.

*Remarks.* *A. cameroni* may be an endemic form because it is only known from the Sevatian middle Blomidon Formation of the Fundy Basin, where it is locally common.

**Family inc.***Genus Wanneresteria* n. gen.

*Derivatio nominis.* In honour of H. E. Wanner, who discovered and named this species (Wanner 1926).

*Type species.* *Estheria mangaliensis pennsylvanicus* Wanner 1926.

*Diagnosis.* Medium-sized, sub-ovate to sub-oblong carapace, moderately convex. Dorsal margin long and straight but without anterodorsal and posterodorsal corners. Anterior and posterior margin convex, nearly of the same height. Ventral margin convex. Free umbonal area small, situated in the anterodorsal corner. Growth bands widest posteroventrally, otherwise rather uniform and strongly elevated at the contact between two adjacent growth bands. When the shell is preserved, contact between two adjacent growth bands possess small, densely-spaced roundish nodes; these are not visible or only indistinctly visible when the shell is not preserved.

*Assigned species.* *Estheria mangaliensis pennsylvanicus* Wanner 1926.

*Occurrence.* Basal Gettysburg Formation of the Gettysburg Basin and upper Lockatong Formation (Skunk Hollow Member to the top of the formation) of the Newark Basin. Upper Tuvalian.

*Remarks.* The densely-spaced small nodes on the growth lines clearly distinguish *Wanneresteria* n. gen. both from *Euestheria* Depéret & Mazeran 1912 and *Howellisaura* Bock 1953. *Euestheria* is further distinguished by a stronger convexity of the shell, especially in the umbonal area, and by a shorter straight part of the dorsal margin.

*Wanneresteria pennsylvanica* (Wanner 1926)

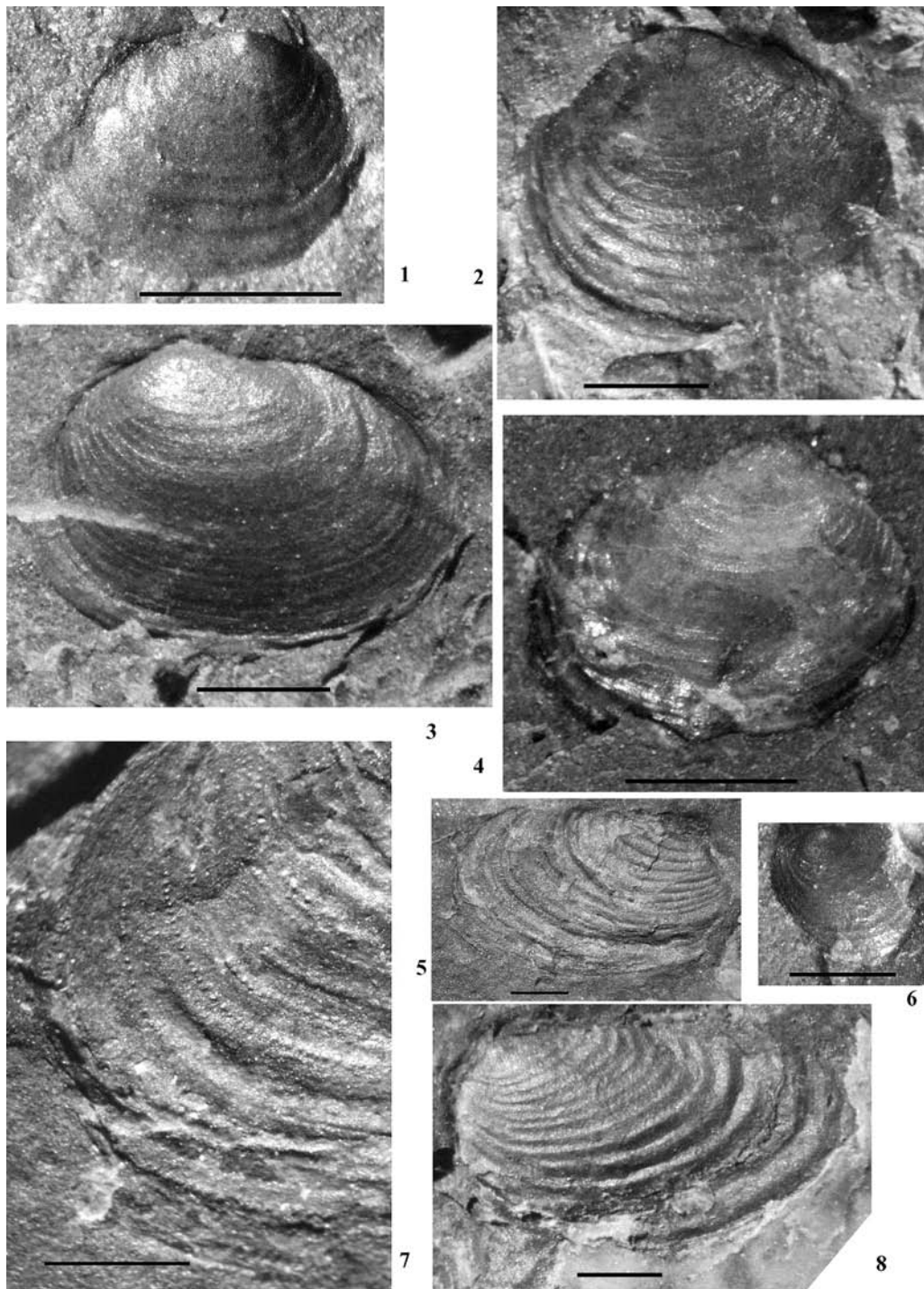
(Fig. A4, Photographs 5, 7, 8)

1926 *Estheria mangaliensis pennsylvanicus* new subspecies – Wanner, p. 25, text-figure 2.

*Neotype.* USNM 539462, Figure A5: 5,7. Paratype: USNM 539461, Figure A5: 8.

*Type locality.* 40.0932 N, 76.7264 W, along abandoned road bed on north side of Little Conewago Creek, York Haven quadrangle, York County, Pennsylvania.

**Fig. A3.** (Continued) arranged in four distinct radial lines; photographs taken under different directions of light; **6:** Cluster of three specimens, one specimen with very distinct nodes, arranged in six distinct radial lines, another specimen with indistinct nodes, arranged in five radial lines and a third specimen without nodes; **7:** Specimen with large nodes arranged in five distinct radial lines; **8:** Specimen with both large and small distinct nodes arranged in seven distinct radial lines. Scale: 1 mm. All material is deposited in the collection of the Nova Scotia Museum, Halifax, Nova Scotia.



**Fig. A4.** 1, 6: *Bulbilimnadia killianorum* Kozur, Weems & Lucas n. sp., Potter Spring Canyon, NMMNH locality number 7735, upper Whitmore Point Member of Moenave Formation, purple mudstone, bed 43 of Lucas, basal Hettangian *B. killianorum* Zone; **1**: Holotype; **6**: specimen with damaged posterior part. **2, 3**: *Euestheria brodieana*

*Stratum typicum*. The basal lake bed sequence of the Gettysburg Formation.

*Material*. More than 100 specimens, including perhaps a dozen specimens on two slabs of shale that have the neoholotype and neoparatype specimens of this species.

*Diagnosis*. Same as for genus.

*Remarks*. Wanner (1926) described this conchostracan as a new subspecies, *Estheria mangaliensis pennsylvanicus*, but he failed to designate a holotype and, so far as we can determine, he did not place any of his described material in a museum. Therefore, *Estheria mangaliensis pennsylvanicus*, as originally described, must be considered a *nomen dubium* in the absence of any designated type material. Since Bock (1953a) declared Wanner's subspecies to be a junior synonym of *Howellisaura ? ovata* (Lea), it has been largely forgotten. We have relocated Wanner's type locality, however, and gathered numerous new specimens that are indistinguishable from his published material. Close examination of this new material shows that it is actually a distinct species that does not even belong to the same genus as *H. ? ovata*. It is smaller (3.7–5.5 mm against 6–8 mm for *H. ? ovata*), more slender, and the growth lines are more pronounced (distinctly elevated at the contact between two adjacent growth bands). The growth lines between adjacent growth bands also bear densely-spaced small nodes. These nodes are readily recognisable in specimens with well-preserved shells, but they are only indistinctly recognisable in forms without preserved shells. As we have now placed some of our new material in the Smithsonian collections and designated a neotype and a paraneotype, Wanner's taxon is now re-established with valid type material.

## Family Shipingidae Kozur & Weems 2005

### Genus *Shipingia* Shen 1976

*Type species*. *Shipingia hebaozhaiensis* Shen 1976

#### *Shipingia mcdonaldi* n. sp.

2007 *Shipingia hebaozhaiensis* Shen, pars – Kozur & Weems, p. 146, P. 6, figures 3–5, ? 6

*Derivatio nominis*. Species named in honour of Professor Nicholas McDonald of Westminster School, for his many years of research on the Newark Supergroup basins and his many years of collecting important specimens from them.

*Holotype*. The specimen illustrated by Kozur & Weems, 2007, in pl. 6, figure 5, USNM 538458.

*Type locality*. 39.9393 N, 77.1432 W, on the west side of U.S. Highway 15, south-southeast of Heidlersburg, Pennsylvania.

*Stratum typicum*. Heidlersburg Member of Gettysburg Formation, Gettysburg Basin.

*Material*. More than 100 specimens, including the specimen illustrated by Kozur & Weems 2007, in pl. 6, figure 3 (USNM 538459), the specimen illustrated by Kozur & Weems, 2007, in pl. 6, figure 4 (USNM 538460), the top specimen illustrated by Kozur & Weems, 2007, in pl. 6, figure 6 (USNM 538726), and the bottom specimen illustrated by Kozur & Weems, 2007, pl. 6, figure 6 (USNM 538727).

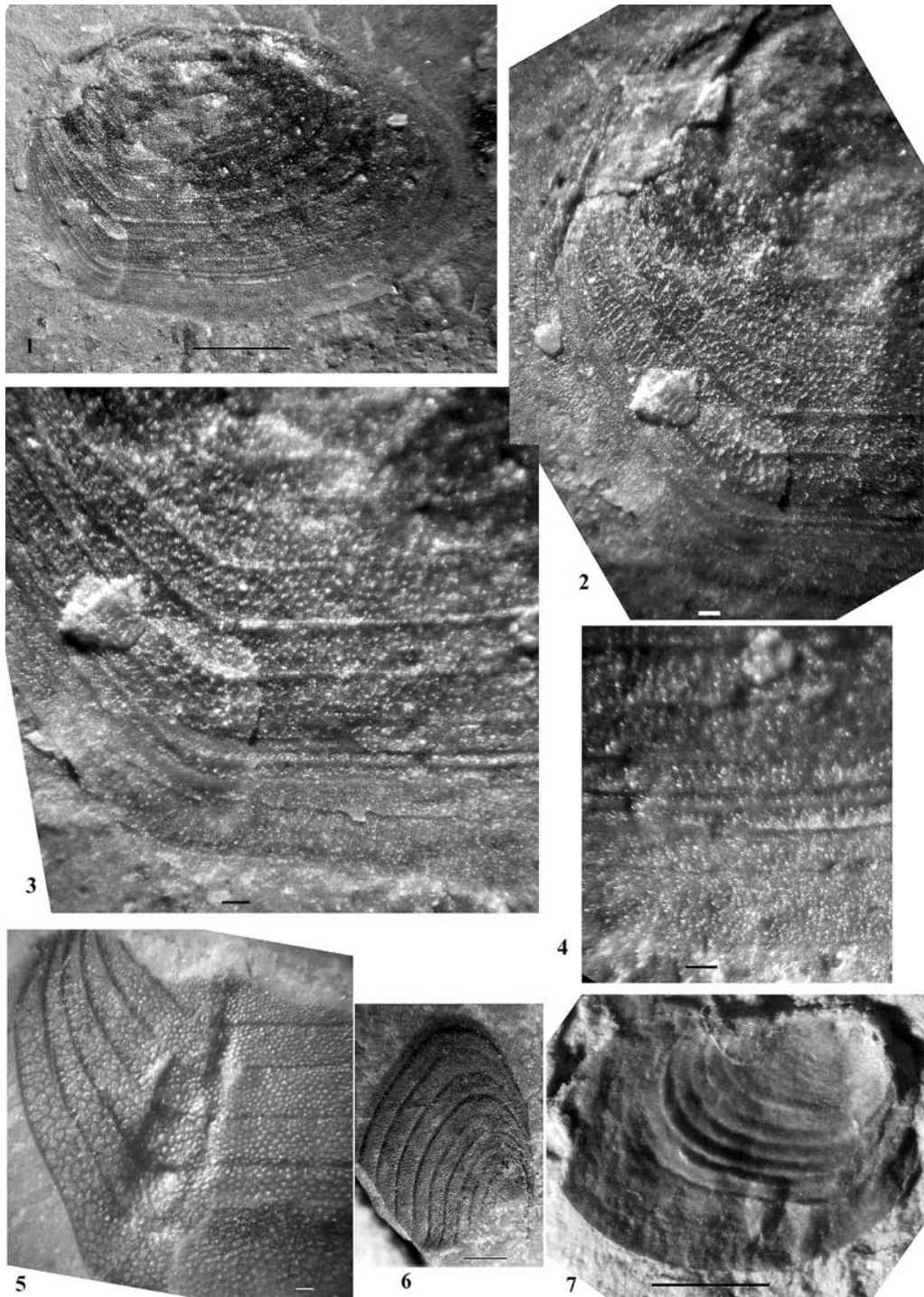
*Diagnosis*. Medium-sized slender carapace with low convexity. Dorsal margin long, straight, distinctly separated from the anterior and posterior margin. Anterior margin rounded in its upper part, strongly oblique and only slightly rounded in its lower part. The oblique part ranges higher up than the mid-line, so that the strongest curvature is in the upper third. Posterior margin higher than the anterior margin, strongly and symmetrically rounded, with its strongest curvature somewhat above the mid-line and its lower part slightly oblique. Ventral margin convex. The umbo is situated in the anterior third, but still distinctly behind the anterodorsal corner. The 10–12 growth lines are wide in the posterior region and especially in the posteroventral part. The free umbonal area is distinct but small. Growth bands smooth or with an indistinct fine reticulation.

*Measurements*.  $l = 3.3\text{--}5.5$  mm;  $h = 1.8\text{--}3.0$  mm;  $l/h = 1.7\text{--}2.0$

*Age*. Alauian.

*Occurrence*. Heidlersburg Member of the Gettysburg Formation of the Gettysburg Basin. Upper part of middle

**Fig. A4.** (Continued) (Jones), different morphotypes, Potter Spring Canyon, NMMNH locality number 7735, northern Arizona, upper Whitmore Point Member of Moenave Formation, purple mudstone, bed 43 of Lucas, basal Hettangian *B. killianorum* Zone. **4:** *Euestheria brodieana* (Jones), Potter Spring Canyon, NMMNH locality number 7734, northern Arizona, lower Whitmore Point Member of Moenave Formation, greenish-grey to black shales, bed 22 of Lucas, upper *E. brodieana* Zone, upper Rhaetian. **5, 7, 8:** *Wannerestheria pennsylvanica* (Wanner), lower Little Conewago Creek, York County, Pennsylvania, from locality 1 (40.0932°N, 76.7264°W) of Wanner (1926), type locality of *W. pennsylvanica*. Basal Gettysburg Formation of the Gettysburg Basin; **5:** total view of neotype, **7:** Detail of the posterior third, small nodes on the growth lines readily visible; **8:** Paratype specimen without preserved shell, small nodes only indistinctly visible. Scale = 1 mm. The specimens illustrated in 1–4 and 6 are deposited in the collection of the New Mexico Museum of Natural History & Science in Albuquerque. The specimens illustrated in 5, 7 and 8 are deposited in the collections of the Museum of Natural History of the United States National Museum.



**Fig. A5.** 1–4: *Norestheria barnaschi* n. gen. n. sp., holotype, from borehole Morsleben 52 A, northern Germany, Arnstadt Formation, sample 132 at 162.9–163.0 m (119.6 m above the base of the Arnstadt Formation), uppermost Alaunian. 1: Total view; 2: Detail of the anterior part of the shell; 3: Detail of the anteroventral part, showing the abrupt



Arnstadt Formation of Thuringia and northern Germany. Basal part of 'Stubensandstein 3' of southern Germany.

*Remarks.* Kozur & Weems (2007) initially regarded *S. mcdonaldi* n. sp. as juvenile specimens of *Shipingia hebaozhaiensis* Shen, but *S. mcdonaldi* occurs both in the Germanic Basin and in the Newark Supergroup earlier than true *S. hebaozhaiensis*, which is consistently larger (6–8 mm), not so slender ( $l/h = 1.5–1.6$ ) and has an anterior margin that is not so strongly oblique in its lower part. This new species also differs from *Shipingia baxinensis* Shen in that it lacks a distinct microsculpture of radial lirae.

### Genus *Norestheria* n. gen.

*Derivatio nominis.* In reference to the occurrence of this genus in the Norian.

*Type species.* *Norestheria barnaschi* n. gen. n. sp.

*Diagnosis.* Carapace moderately large to large, only slightly convex. Free umbonal area distinct but rather small, situated between the anterodorsal and mid-dorsal field. Dorsal margin straight to slightly convex, rather short, with a gradual transition to the anterior margin and a normally indistinct posterodorsal corner. Anterior margin higher than posterior margin, in its lower part with a long oblique region that is not rounded and in its upper part slightly rounded. Posterior margin strongly rounded in its middle region, but in its upper part obliquely directed and straight or only slightly rounded. The lower part of the posterior margin is long, oblique and either straight or only slightly rounded or else rounded and only slightly bevelled. The ventral margin is straight in its anterior and middle region and slightly convex in its posterior region. There is an abrupt angular change going from the ventral to the anterior margin, but the transition from the ventral to the posterior margin is gradual. There are 8–13 growth bands with a peculiar shape. Ventrally or anteroventrally they are straight, but then they tilt abruptly to similarly straight but obliquely oriented growth bands in the lower part of the anterior quarter. The microsculpture consists of a dense reticulation, partly accompanied by radial lirae. In the abruptly tilted anterior quarter, the elements of the microsculpture are distinctly larger.

*Assigned species.* *Norestheria barnaschi* n. gen. n. sp.; *Norestheria* n. sp.

*Age.* Upper Alauian.

*Occurrence.* Upper part of middle Arnstadt Formation in northern Germany. Basal Stubensandstein 3 of southern Germany.

*Remarks.* *Laxitextella* Kozur, 1982 does not have the abrupt change in the direction of the growth bands at the end of the anterior quarter of the shell. Although we have this abrupt tilt of the growth bands at the same place in two different species, we cannot quite exclude that this tilting is at least enhanced by deformation. The tilting is accompanied either by an abrupt change in the size of reticulation or of the radial lirae, so it also may be accompanied by an abrupt change in shell thickness at this point. In that case, it would be prone to deformation localized at this place. In *Laxitextella* the reticulation and other microsculpture elements do not become abruptly larger in the anterior quarter of the shell. Additionally, the shell is more convex, especially in the umbonal area.

### *Norestheria barnaschi* n. gen. n. sp.

(Fig. A5, Photographs 1–4)

*Derivatio nominis.* In honour of Dr Jens Barnasch, Kassel, for his excellent stratigraphic work in the Keuper of northern and middle Germany.

*Holotype.* The specimen illustrated in Figure A4: 1–4.

*Type locality.* Borehole Morsleben 52 A, northern Germany

*Stratum typicum.* Arnstadt Formation, sample 132 at 162.9–163.0 m (119.6 m above the base of the Arnstadt Formation), uppermost Alauian.

*Material.* Four specimens.

*Diagnosis.* Moderately large flat carapace. Free umbonal area distinct, but rather small, situated between the anterodorsal and mid-dorsal fields. Dorsal margin relatively short, straight to very slightly convex. Anterior margin in the upper part slightly rounded, in the lower part

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**Fig. A5.** (Continued) change from the straight ventral part to the oblique lower part of the anterior margin, accompanied by a distinct change of the type and size of the microsculpture (see also 2); **4:** Microsculpture of the ventral part; **5:** *Norestheria* n. sp., detail of the anteroventral part, showing the abrupt change from the straight ventral part to the oblique lower part of the anterior margin, which is accompanied by a distinct increase of the size of the reticulation. From borehole Malschenberg 1 (southern Germany) at 60.1–60.2 m, basal Stubensandstein 3, upper Alauian; **6:** *Norestheria* n. sp., fragmentary specimen with its posterior margin in the upper part and its dorsal margin to the right. Posterodorsal corner readily recognisable. From borehole Malschenberg 1 (southern Germany) at 60.0 m, basal Stubensandstein 3, upper Alauian; **7:** *Bulbilmnadia killianorum* n. sp., Killian site, Fauquier County, Virginia, Culpeper Basin, middle Midland Formation, lower *B. sheni* Zone in which *B. sheni* is more abundant than *B. killianorum* (lower Hettangian). Scale of Figs 1, 6, 7 = 1 mm; Figs 2–5 = 100  $\mu$ m. The material illustrated in 1–6 is deposited in the collection of the Institut für Geologische Wissenschaften, Martin-Luther-Universität Halle. The specimen illustrated in 7 is deposited in the collections of the Museum of Natural History of the United States National Museum.

straight and strongly oblique. Transition to the ventral margin abrupt and angular. Posterior margin distinctly lower than anterior margin, in the middle part strongly convex, in the upper part oblique and straight or only slightly convex, in the lower part convex. Anterior and middle part of the ventral margin straight or only very slightly convex. Posterior part of the ventral margin convex. 10–12 growth bands are present. At the border of the anterior quarter they tilt upward abruptly at a sharp angle from horizontal and parallel in the anterior part of the ventral margin to obliquely upward in the anterior quarter. The microsculpture consists of fine dense reticulation with radial lirae. Where the growth lines turn abruptly upwards, the microsculpture in the anterior quarter changes to distinctly larger elements.

*Measurements.*  $l = 4.5\text{--}5.6$  mm;  $h = 3.0\text{--}3.3$  mm;  $l/h = 1.47\text{--}1.55$

*Age.* Upper Alauian.

*Occurrence.* Upper part of middle Arnstadt Formation in the Germanic Basin.

*Remarks.* There is another undescribed species of *Nor-estheria* from the basal Stubensandstein 3 (Fig. A4, photographs 5 and 6). It has a microsculpture that consists only of a dense fine reticulation that abruptly changes into a coarse reticulation in the anterior quarter, at the point where the direction of the growth lines abruptly changes.

## Family Bulbilimnadiidae Kozur & Weems 2005

### Genus *Bulbilimnadia* Shen 1976

*Type species.* *Bulbilimnadia bullata* Shen 1976

### *Bulbilimnadia killianorum* Kozur, Weems & Lucas *n. sp.*

(Fig. A4, Photographs 1, 6; Fig. A5, Photograph 7)

*Derivatio nominis.* In honour of Jim and Bobbie Killian, who graciously let us dig on their property to recover numerous well-preserved lower Hettangian conchostracans, among them supplementary specimens of *B. killianorum*.

*Holotype.* New Mexico Museum of Natural History specimen NMMNH P-58455 (Fig. A4: 1).

*Paratype.* United States National Museum specimen USNM 538728 (Fig. A5: 7).

*Type locality.* NMMNH locality 7735 (36.8801N, 112.8473W), Potter Canyon, Mohave County, northern Arizona.

*Stratum typicum.* 0.5 m-thick bed 43 of Spencer Lucas, purple mudstone in the Whitmore Point Member

of the Moenave Formation, about 3.5 m below the base of the Springdale Member of the Kayenta Formation.

*Material.* More than 100 specimens. Eight specimens from the Midland Formation of Virginia are included under the lot number USNM 538729. Specimens from the Whitmore Point Member of Utah and Arizona are on New Mexico Museum of Natural History slabs numbered P-51076, P-51080, P-51082, P-51085, P-51086, and P-58440.

*Diagnosis.* Small to very small, strongly convex carapace. Free umbonal area large (but for the genus rather small), with small, roundish node on the end of the anterior third of the free umbonal area, close to the dorsal margin. Umbo located at the end of the anterior third to the mid-length of the carapace, strongly convex, somewhat overreaching the straight to slightly convex dorsal margin. Convex anterior and posterior margins develop gradually from the dorsal margin. Anterior margin in the lower part somewhat bevelled, with its strongest curvature somewhat above the mid-line. Posterior margin symmetrically rounded with its strongest curvature in the mid-line. Ventral margin strongly convex. 9–17 rather narrow and uniform growth lines are present that bear an indistinct fine reticulation.

*Measurements.*  $l = 1.5\text{--}3.1$  mm;  $h = 1.28\text{--}2.1$  mm;  $l/h = 1.24\text{--}1.75$

*Age.* Basal Hettangian *B. killianorum* Zone to lower middle part of lower Hettangian *B. sheni* Zone.

*Occurrence.* Lower and middle Midland Formation of the Culpeper Basin. Upper Whitmore Point Member of the Moenave Formation of northern Arizona and southern Utah. Early Hettangian of Sołtyków, Holy Cross Mountains, southeastern Poland.

*Remarks.* The successor species *Bulbilimnadia sheni* Kozur & Weems, 2005 has an elongated node on the free umbonal area. The small round node on the free umbonal area of this new species is fairly robust but still small for a member of the genus *Bulbilimnadia*. Although *B. killianorum* is not a typical *Bulbilimnadia*, it is connected by intermediate transitional forms to *Bulbilimnadia sheni* Kozur & Weems and thus is the direct forerunner of the first typical species of a lineage restricted to the Hettangian. For this reason, it would be pointless to establish a new genus for this single species, which is probably transitional between *Euestheria brodieana* (Jones) and *Bulbilimnadia sheni* Kozur & Weems.

## Note added in proof

After completion of this paper, some new radiometric data have been published and presented for the late Carnian and Norian part of the continental Chinle Group. Ramezani *et al.* (2009 abstract and 2009 GSA talk in Portland, Oregon) presented new radiometric data and new stratigraphic data pertaining to previously reported radiometric dates from the Chinle section in Petrified Forest National

Park (Albuquerque, May, 2009). According to these new data, the 219.4 Ma age date was not derived from the basal Blue Mesa Member as initially reported, but from the middle of the overlying Sonsela Member. Thus, the estimated age of c. 219 Ma for the basal Blue Mesa no longer can be regarded as accurate. For the upper Blue Mesa Member, 223.1 Ma is now given. This upper Tuvalian value is not in contradiction with the  $230.91 \pm 0.33$  Ma age reported for the upper part of the lower Tuvalian section of the Lagonegro Basin (Italy) (Furin 2006) and also is not in contradiction with the  $225 \pm 3$  Ma age reported for the basal Norian of Alaska (Gehrels *et al.* 1987). As a whole, the radiometric data from the continental Late Triassic of the southwestern USA cannot be used reliably as yet for refining the numeric ages of the late Carnian and Norian. First, as shown by Dickinson & Gehrels (2008), the detrital zircons of the Chinle yield a wide range of age estimates for most of the members. Second, the lithostratigraphic assignment of some data is not well established (e.g. the 219.4 Ma age date reported for the basal Blue Mesa has been reassigned to the middle Sonsela, see above). Finally, the bio- and chronostratigraphic assignment of some members has not yet been determined. Thus, at present the Sonsela Member has a vertebrate fauna which could be found in either the uppermost Adamanian or in the Revueltian land vertebrate stages. According to Spencer Lucas (pers. comm. 2010), the Norian base could be within the Sonsela Member, but such an assumption can be neither confirmed nor rejected as yet. Until such time as well preserved conchostracans are found in the Sonsela Member or until either the Norian vertebrate guide form *Aetosaurus* or undoubtedly Tuvalian guide forms are found within it, the correct age assignment of the Sonsela will remain uncertain.

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