

关于贵州青岩地区中三叠世青岩组上部的 菊石组合及其时代的再研究

——雷打坡化石组合的准确生物地层对比及年龄

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摘要 贵州青岩地区的青岩组上部包括雷打坡段和渔庆段, 其中, 雷打坡段的化石特别丰富, 为研究二叠纪末生物大灭绝后底栖动物的辐射和群落演化提供了十分重要的信息。根据青岩组雷打坡段和渔庆段的菊石重新研究, 划分出两个组合: 1) 安尼期中期的最晚阶段 (latest middle Anisian) 的 *Bulogites-Acrochordiceras* 组合; 2) 安尼期晚期的最早阶段 (earliest late Anisian) 的 *Rieppelites-Judicarites* 组合。其中, *Bulogites-Acrochordiceras* 组合包括了该时代的标志属 *Bulogites* 和 *Acrochordiceras*, 另有属 *Proarcestes*, *Sageceras* 和 *Beyrichitinae* 的未定属; 此组合可与意大利北部和匈牙利的 *Bulogites zoldianus* 带对比, 也可与美国内华达州西北部 *Balatonites shoshonensis* 带的 *Bulogites mojsvari* 亚带对比。*Rieppelites-Judicarites* 组合包括了该时代的标志属 *Rieppelites* 和 *Judicarites*, 另有特征属 *Ptychites* 和 *Gosauites*; 该组合可与意大利北部的 *Rieppelites cimeganus* 带对比, 也可与美国内华达州西北部 *Gymnotoceras weitschati* 带的 *Billingsites cordeyi* 亚带对比。上述组合表明, 青岩剖面的青岩组最高层位并不包含安尼期最晚期沉积, 因此, 该组历程不等于整个安尼期。根据所得化石以及对已发表材料的复核, 认为以往的“*Paraceratites trinodosus*”等安尼期晚期属种名单鉴定有误。青岩地区的安尼期中期/晚期界线在雷打坡段中部的靠下方。在富含化石的雷打坡剖面界线在其中部的靠上方。雷打坡化石组合的历程等于一个短时期, 正好包围安尼期中期/晚期界线。

关键词 化石组合 菊石 生物地层对比 年龄 安尼期中期/晚期界线 中三叠世 雷打坡 青岩

PRECISE BIOSTRATIGRAPHICAL CORRELATION AND AGE OF THE LEIDAPO FOSSIL ASSEMBLAGES, EARLY MIDDLE TRIASSIC OF QINGYAN, SOUTHWESTERN CHINA

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Abstract Unusually diverse fossil assemblages from Leidapo near Qingyan, Guizhou Province of southwestern China, provide important information on the main post-extinction radiation of benthic invertebrates and on the evolution of biocoenoses in the Early Mesozoic. Precise biostratigraphical correlation and age determination of the strata yielding these fossil assemblages are therefore of great importance. Revised biostratigraphical correlation based on am-

monoids shows that the Upper Qingyan Formation of the Qingyan region is of latest middle to earliest late Anisian age and that the middle/late Anisian boundary is situated in the upper middle part of the highly fossiliferous section at Leidapo. The Leidapo fossil assemblages thus span a short time interval, just bracketing the middle/late Anisian boundary.

Key words Fossil assemblages, ammonoids, biostratigraphical correlation, age, middle/late Anisian boundary, Middle Triassic, Leidapo, Qingyan

1 INTRODUCTION

The highly fossiliferous section at the small hillock called Leidapo in the northeastern vicinity of Qingyan is well-known for its taxonomically unusually diverse and well-preserved fossil assemblages of early Middle Triassic age. These fossil assemblages provide valuable information about the main Early Mesozoic post-extinction radiation of benthic invertebrates, with regard to taxonomy as well as regarding their palaeoautecology (e. g., Stiller, 2000, 2001; Chen, 2004). Palaeoecological analyses show that these fossil assemblages are the remains of ecologically complex shallow-marine communities (Stiller, 1995, 1997, 2001; Chen *et al.*, 2001). The Leidapo assemblages (often collectively referred to as the “Qingyan fauna”) thus also provide significant data on the evolution of biocoenoses after the period of dramatic ecological disturbance around the Permian-Triassic boundary. Even on a world wide scale, these fossil assemblages represent an important example of early Middle Triassic communities during the main Early Mesozoic radiation interval (e. g., Tong and Yin, 2009). Therefore, precise biostratigraphical correlation and age determination of the horizons yielding them are of great importance.

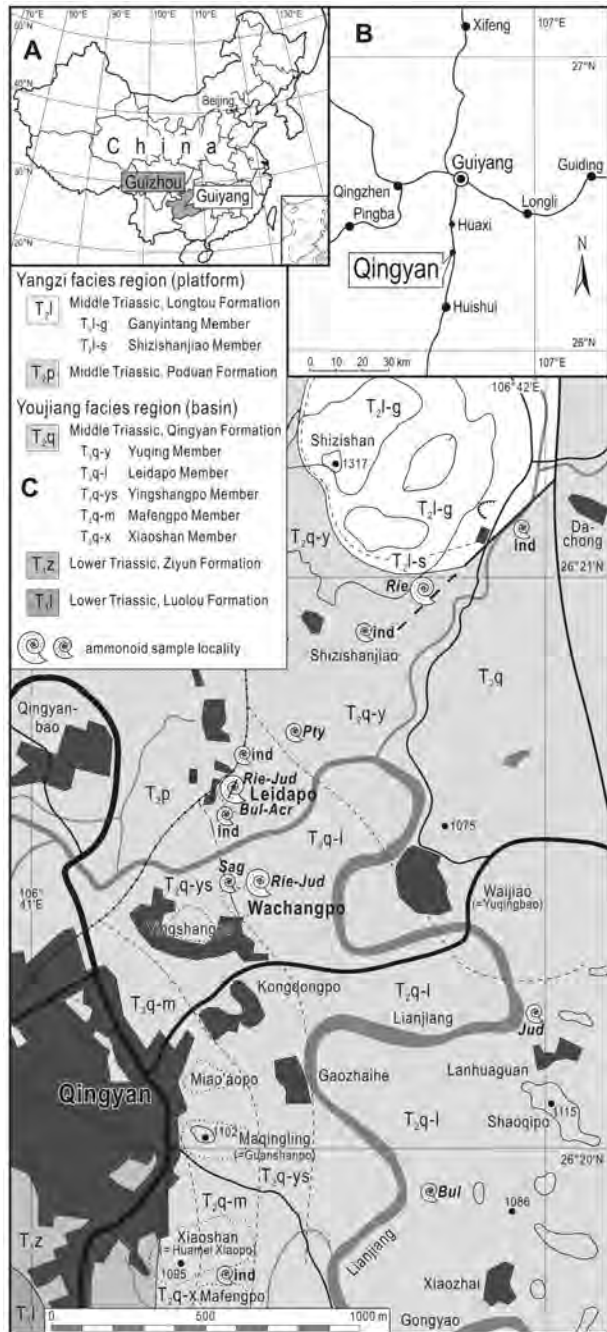
The specimens figured here are deposited in the collections of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, in Nanjing, P. R. China (NIGP). Additional ammonoid specimens from the northeastern vicinity of Qingyan not figured here are housed in the collections of the Geomuseum, University of Münster, in Münster, Germany (GMM, repository catalogue number: B6. c-41).

2 LEIDAPO FOSSIL ASSEMBLAGES

The Leidapo section is located about 30 km south of Guiyang, the capital of Guizhou Province, in southwestern China (Text-fig. 1). Lithostratigraphically, the exposed strata are situated in the lower middle part of the Leidapo Member of the Upper Qingyan Formation. On the northeastern slope of Wachangpo, some hundred metres South of Leidapo, similar strata are present but exposures are very poor. The Upper Qingyan Formation is dominated by marly and sometimes silty mudstones and shales. Normally rather thin layers of marlstones to marly limestones occasionally occur but generally are rare. At Leidapo, such intercalations are more abundant than in the successions of the Upper Qingyan Formation above and below.

The abundant and diverse fossils of Leidapo have been described or mentioned in many publications since Koken (1900). The fossil assemblages of Leidapo (and Wachangpo) comprise about 300 species of macrofossils. Stiller (2001) listed some 269 macrofossil species from Leidapo and 281 from the entire Leidapo Member, including only reliably identified specimens from his own collections and after taxonomic revision of earlier descriptions. A number of further taxa not represented in these collections had been described earlier by other authors (see Stiller, 2001, for references), and some additional new taxa have been described in later publications (e. g., Deng and Kong, 2005; Stiller and Chen, 2006), further increasing these figures. These fossil assemblages also include a fairly rich microfossil fauna, as indicated below.

Bivalves, gastropods, and brachiopods are the most common groups, with taxonomic diversity



Text-figure 1 Geographical location of Qingyan, the Leidapo section, and other ammonoid localities near Qingyan.

A. General map of China with location of Guiyang marked. B. Map of central Guizhou Province with location of Qingyan South of Guiyang. C. Map of the northeastern vicinity of Qingyan showing ammonoid localities; geology after Guizhou Geological Team 108 (1976b, geological map and fig. 75), altered and emended, including the member boundaries of the Qingyan Formation after Stiller (2001 and personal field observations); *Bul-Acr*: *Bulogites-Acrochordiceras* assemblage, *Rie-Jud*: *Rieppelites-Judicarites* assemblage, *Sag*: *Sageceras*, *Bul*: *Bulogites*, *Rie*: *Rieppelites*, *Jud*: *Judicarites*, *Pty*: *Ptychites*, ind: ammonoids gen. et sp. indet.

highest in gastropods and bivalves. Less common constituents of the assemblages are formed by sponges, scleractinian corals, cephalopods (ammonoids, nautiloids), scaphopods, annelids, bryozoans, echinoderms (crinoids, echinoids), vertebrates (fish remains), and plants (calcareous algae and allochthonous remains of land plants). The microfauna comprises foraminifers, ostracods, echinoderms (roveacrinids, ophiuroids), and conodonts. Trace fossils represent further taxa of the former fauna.

These fossil assemblages represent the remains of flourishing, ecologically complex shallow-marine communities of a fairly modern aspect (Stiller, 1997, 2001). This suggests that at least in today's southwestern China, post-extinction recovery of shallow-marine ecosystems was well advanced or even was more or less finished by late middle to early late Anisian times. Taxonomic radiation and differentiation of biocoenoses were in full swing.

3 BIOSTRATIGRAPHICAL CORRELATION OF THE UPPER QINGYAN FORMATION

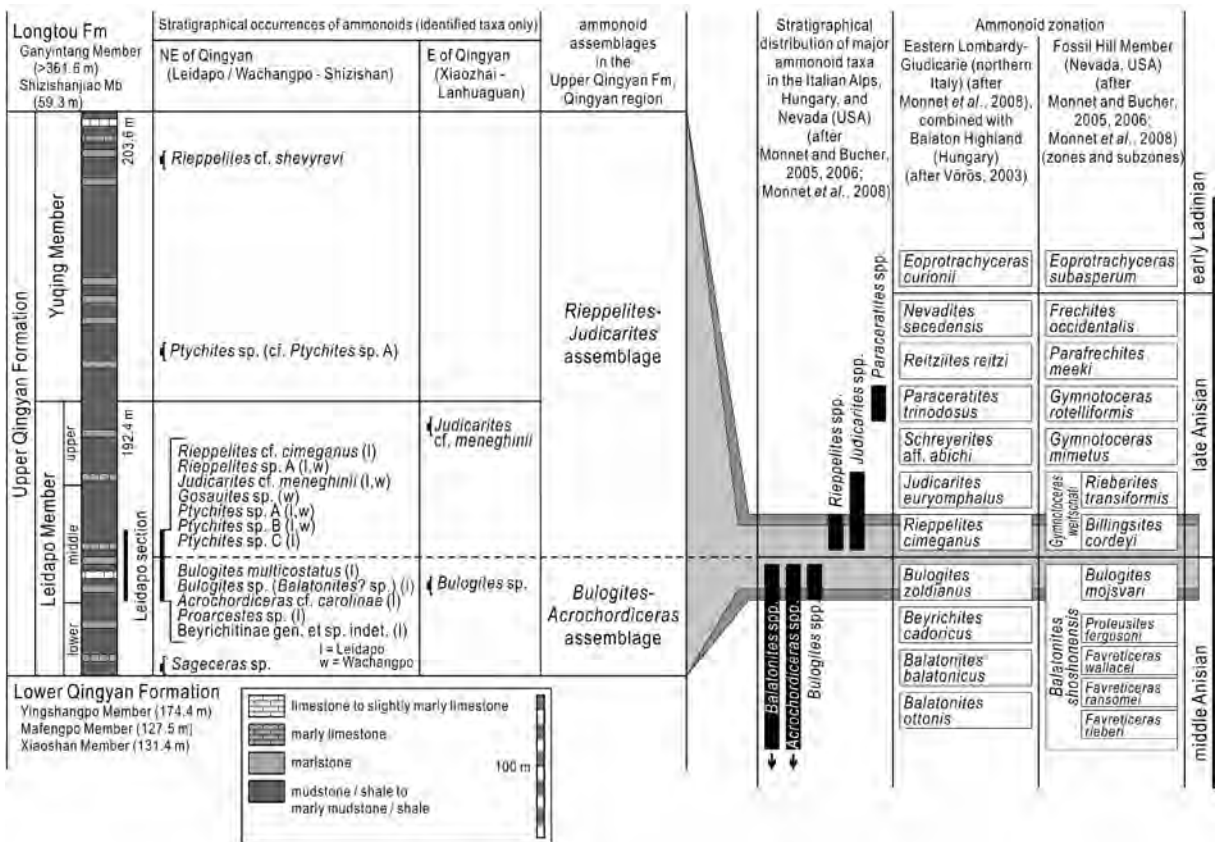
In the first publication on fossils from Qingyan, almost certainly from Leidapo, Koken (1900) estimated the age as Ladinian to Carnian. Hsu and Chen (1943) established the Anisian age of these faunas. Until recently, biostratigraphical correlation of the Qingyan Formation was based on ammonoid data of Wang Yigang (unpublished manuscript, 1964) (Yang *et al.*, 1982, p. 11). Wang's ammonoid zonation established in the northeastern vicinity of Qingyan has been used for a long time as the biostratigraphical standard for the marine Anisian in the whole of southwestern China and adjacent regions, and, in Chinese stratigraphy, the marine Anisian some years ago was even named Qingyanian, after the Qingyan Formation (e.g., Chen *et al.*, 2000; Yang *et al.*, 2000; National Stratigraphical Commission of China, 2001, 2002; Yin, 2003; Wu *et al.*, 2008). In that correlation, the Qingyan Formation was considered to be about equivalent to the Anisian, and the Upper Qingyan

Formation (Leidapo Member and Yuqing Member) to comprise the “*Paraceratites*” *binodosus* and *Paraceratites trinodosus* zones. Based on ammonoids from the Upper Qingyan Formation and conodonts from the lower part of the Longtou Formation, respectively, Stiller and Bucher (2008) and Wu *et al.* (2008), however, showed that the Qingyan Formation is not equivalent to the Anisian but that the Anisian (= Qingyanian) continues well into the overlying Longtou Formation.

The Upper Qingyan Formation in the northeastern vicinity of Qingyan in fact comprises latest middle to earliest late Anisian strata (Stiller and Bucher, 2008). At that locality, the uppermost strata of the Qingyan Formation are of earliest late Anisian age, and the Qingyan Formation does not encompass middle late or late late Anisian strata. Judging from re-study of available and figured ammonoid specimens, reports of stratigraphically

younger taxa such as *Paraceratites trinodosus* or “*Paraceratites*” [*Schreyerites*] *binodosus* from the Upper Qingyan Formation of this area are based on misidentifications. The whole succession is distinctly older than the *Paraceratites trinodosus* Zone. For detailed discussion and comparison with the former stratigraphical correlation see Stiller and Bucher (2008).

The Upper Qingyan Formation yields the following sequence of two ammonoid assemblages (Text-fig. 2). The lower part is characterised by the latest middle Anisian *Bulogites-Acrochordiceras* assemblage. This assemblage correlates well with the *Bulogites zoldianus* Zone in Lombardy-Giudicarie, northern Italy, as revised by Monnet *et al.* (2008) and of the Balaton Highland, Hungary (Vörös, 2003). It also correlates well with the *Bulogites mojsvari* Subzone of the *Balatonites shoshonensis* Zone in northwestern Nevada as de-



Text-figure 2 Ammonoids of the Upper Qingyan Formation in the northeastern vicinity of Qingyan and their biostratigraphical correlation using reliably identified taxa from the authors' own collections only. Correlation; proven stratigraphical range in light grey, possible maximum range in darker grey. Thickness of members after Guizhou Geological Team 108 (1976a, 1976b) and Guizhou Bureau of Geology and Mineral Resources (1987).

fined by Monnet and Bucher (2005). All known species of the genus *Bulogites* are restricted to this latest middle Anisian age.

The middle and upper parts of the Upper Qingyan Formation are characterised by the earliest late Anisian *Rieppelites-Judicariites* assemblage. This assemblage correlates well with the *Rieppelites cimeganus* Zone in Lombardy-Giudicarie, northern Italy, as revised by Monnet *et al.* (2008), and also with the *Billingsites cordeyi* Subzone of the *Gymnotoceras weitschati* Zone in northwestern Nevada as defined by Monnet and Bucher (2005). The genus *Rieppelites* is restricted to the basal late Anisian in Nevada (Monnet and Bucher, 2005) and northern Italy (Kustatscher *et al.*, 2006; Monnet *et al.*, 2008).

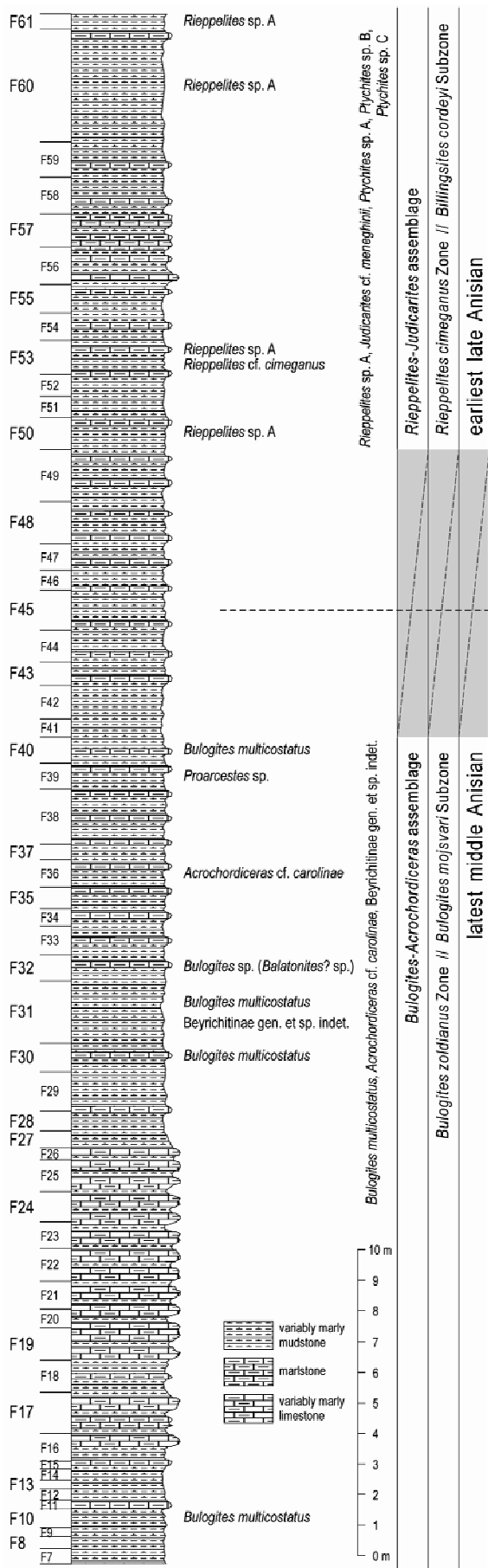
The middle/late Anisian boundary is situated in the upper middle part of the Leidapo section, approximately at sampling unit F45 (above F40 and below F50) of Stiller (2001) (Text-fig. 3). The exact position of the biostratigraphical boundary is uncertain because of the relative scarcity of ammonoids in the fossil assemblages and thus the relative scarcity of bedrock-controlled ammonoid specimens. The middle/late Anisian boundary therefore is situated in the lower middle part of the Leidapo Member.

The fossil site on the northeastern slope of Wachangpo can be correlated with the upper part of the Leidapo section, of earliest late Anisian age. Its ammonoids belong to the *Rieppelites-Judicariites* assemblage. The other fossil groups are also very similar to those in the upper part of the Leidapo section.

The exact biostratigraphical ages of the lower and upper boundaries of the Upper Qingyan Formation are somewhat uncertain. However, the documented occurrences of ammonoids suggest that the *Bulogites-Acrochordiceras* assemblage ranges downwards to the lower boundary of the Leidapo Member, maybe even into the underlying Yingshangpo Member (upper Lower Qingyan Formation); and that the *Rieppelites-Judicariites* assemblage ranges upwards to the upper boundary of

the Yuqing Member, probably even into the overlying Shizishanjiao Member (lower Longtou Formation). The lower boundary of the Upper Qingyan Formation is thus most probably situated within the equivalent of the *Bulogites zoldianus* Zone (northern Italy, Hungary) and of the *Bulogites mojsvari* Subzone (*Balatonites shoshonensis* Zone; Nevada); and the upper boundary most probably lies within the equivalent of the *Rieppelites cimeganus* Zone (northern Italy) and of the *Billingsites cordeyi* Subzone (*Gymnotoceras weitschati* Zone; Nevada). The Upper Qingyan Formation thus encompasses two ammonoid zones/subzones or probably even less (Text-fig. 2).

Conodont data for the upper Lower and the Upper Qingyan Formation are almost lacking. Conodonts seem to be rare in the marly mudstones with occasional thin intercalations of marlstones to marly limestones of the Upper Qingyan Formation, probably for facies reasons. Stiller (2001, p. 322) listed several conodont taxa from limestone horizons in the uppermost Yingshangpo Member (top of the Lower Qingyan Formation; sample localities near Leidapo and on the northwestern slope of Wachangpo) and the lower part of the Leidapo section (approximately sampling unit F20). Although confirming an Anisian age, these conodonts do not allow precise biostratigraphical correlation. However, some recent publications provide conodont data for the lower and middle Lower Qingyan Formation and the lower Longtou Formation that, by bracketing the Upper Qingyan Formation, corroborate a latest middle to earliest late Anisian age for this unit. Yao *et al.* (2004) found the earliest Anisian conodonts 1.5 m below the lower boundary of the Qingyan Formation and showed that the Xiaoshan Member (lower Lower Qingyan Formation) is of early Anisian age. This was confirmed by the findings of Ji *et al.* (2009) and Chen *et al.* (2010). Ji *et al.* (2009) furthermore reported middle Anisian conodonts from the upper Mafengpo Member (middle Lower Qingyan Formation). Wu *et al.* (2008) studied conodonts from the lower Longtou Formation and showed that the Shizishan-



jiào Member and the lower part of the Ganyintang Member are of late Anisian age.

4 CORRELATION AND AGE OF THE LEIDAPO FOSSIL ASSEMBLAGES

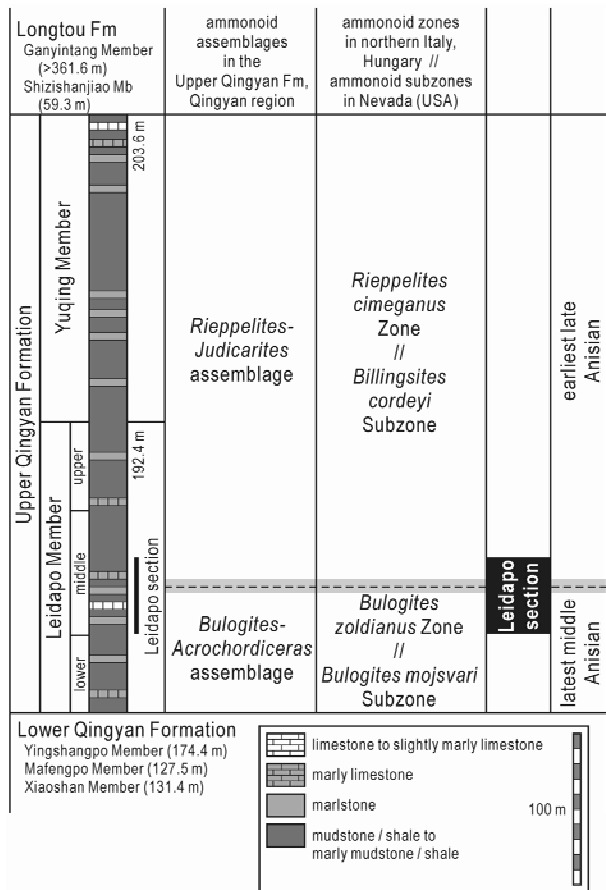
Based on these findings and especially on the ammonoid data, the biostratigraphical correlation and age of the Leidapo fossil assemblages can be precisely determined. These taxonomically highly diverse assemblages, representing the fossil remains of ecologically complex shallow-marine communities, come just from the middle/late Anisian boundary (Text-fig. 4). The older Leidapo assemblages are found in the uppermost horizons of the lithological succession yielding the *Bulogites-Acrochordiceras* assemblage, and the younger Leidapo assemblages occur in the lowermost horizons of the succession yielding the *Rieppelites-Judicarietes* assemblage. Taking into account the great thickness of the Upper Qingyan Formation (about 400 m [Guizhou Geological Team 108, 1976a, 1976b; Guizhou Bureau of Geology and Mineral Resources, 1987]) and the finding that this unit encompasses only two or probably even less than two ammonoid zones/subzones, the Leidapo section (about 50 m thick) represents only a fairly short period of time. In summary, the Leidapo fossil assemblages thus originated during a short time interval straddling the middle/late Anisian boundary.

5 TAXONOMIC REMARKS

The latest middle Anisian *Bulogites-Acro-*

Text-figure 3 Ammonoids of the Leidapo section, biostratigraphical correlation, and middle/late Anisian boundary. Generalised columnar section of the strata exposed at Leidapo with sampling units F7 to F61 after Stiller (2001), slightly altered. Bedrock-controlled ammonoid samples are given in horizontal writing; ammonoid taxa written vertically were collected in the lower or upper portion of the section, respectively, but are not bedrock-controlled. Approximate position of the middle/late Anisian boundary (dashed line) and maximum range of possible boundary position (grey colour) marked.

chordiceras assemblage comprises the age-diagnostic taxa *Bulogites multicostatus* Wang, in Zhao *et al.* (1965) and *Acrochordiceras* cf. *carolinae* Mojsisovics, 1882. Additional taxa include *Proarcestes* sp., *Sageceras* sp., and Beyrichitinae gen. et sp. indet. (Text-fig. 5, Table I).



Text-figure 4 The Leidapo section yielding the Leidapo fossil assemblages represents a short time interval just bracketing the middle/late Anisian boundary. Exact position of the middle/late Anisian boundary slightly uncertain; maximum range of possible boundary position marked by light grey colouring around dashed horizontal line (compare text and Text-fig. 3). Thickness of members after Guizhou Geological Team 108 (1976a, 1976b) and Guizhou Bureau of Geology and Mineral Resources (1987).

Age-diagnostic taxa of the earliest late Anisian *Rieppelites-Judicarites* assemblage are *Rieppelites* cf. *cimex* (Mojsisovics, 1882), *Rieppelites* sp. A, *Rieppelites* cf. *shevyrevi* Monnet and Bucher, 2005, and *Judicarites* cf. *meneghinii* (Mojsisovics, 1882). Additional characteristic taxa include *Gosauites* sp., *Ptychites* sp. A, *Ptychites* sp. B, and *Ptychites* sp. C (Text-figs. 6–8, Table I).

Table I Measurements of figured specimens

NIGP	ammonoid taxon	mm
143730	<i>Acrochordiceras</i> cf. <i>carolinae</i>	52.5
143731	<i>Bulogites multicostatus</i>	58.0
143732	<i>Bulogites multicostatus</i>	79.0
143733	<i>Bulogites multicostatus</i>	55.5
151863	<i>Proarcestes</i> sp.	ca. 35, deformed
151864	Beyrichitinae gen. et sp. indet.	43.5
151865	<i>Sageceras</i> sp.	38.5
143734	<i>Rieppelites</i> cf. <i>cimex</i>	33.5
143735	<i>Rieppelites</i> sp. A	54.5
143736	<i>Judicarites</i> cf. <i>meneghinii</i>	50.0
143737	<i>Judicarites</i> cf. <i>meneghinii</i>	37.0
143738	<i>Gosauites</i> sp.	73.0
143739	<i>Ptychites</i> sp. A	81.0
143740	<i>Ptychites</i> sp. B	122.0
151866	<i>Ptychites</i> sp. C	75.0
143741	<i>Rieppelites</i> cf. <i>shevyrevi</i>	58.5
143742	<i>Rieppelites</i> cf. <i>shevyrevi</i>	46.5
143743	<i>Rieppelites</i> cf. <i>shevyrevi</i>	35.5

NIGP: repository catalogue number; mm: maximum diameter or maximum measurement of fragment, in mm, rounded to 0.5 mm

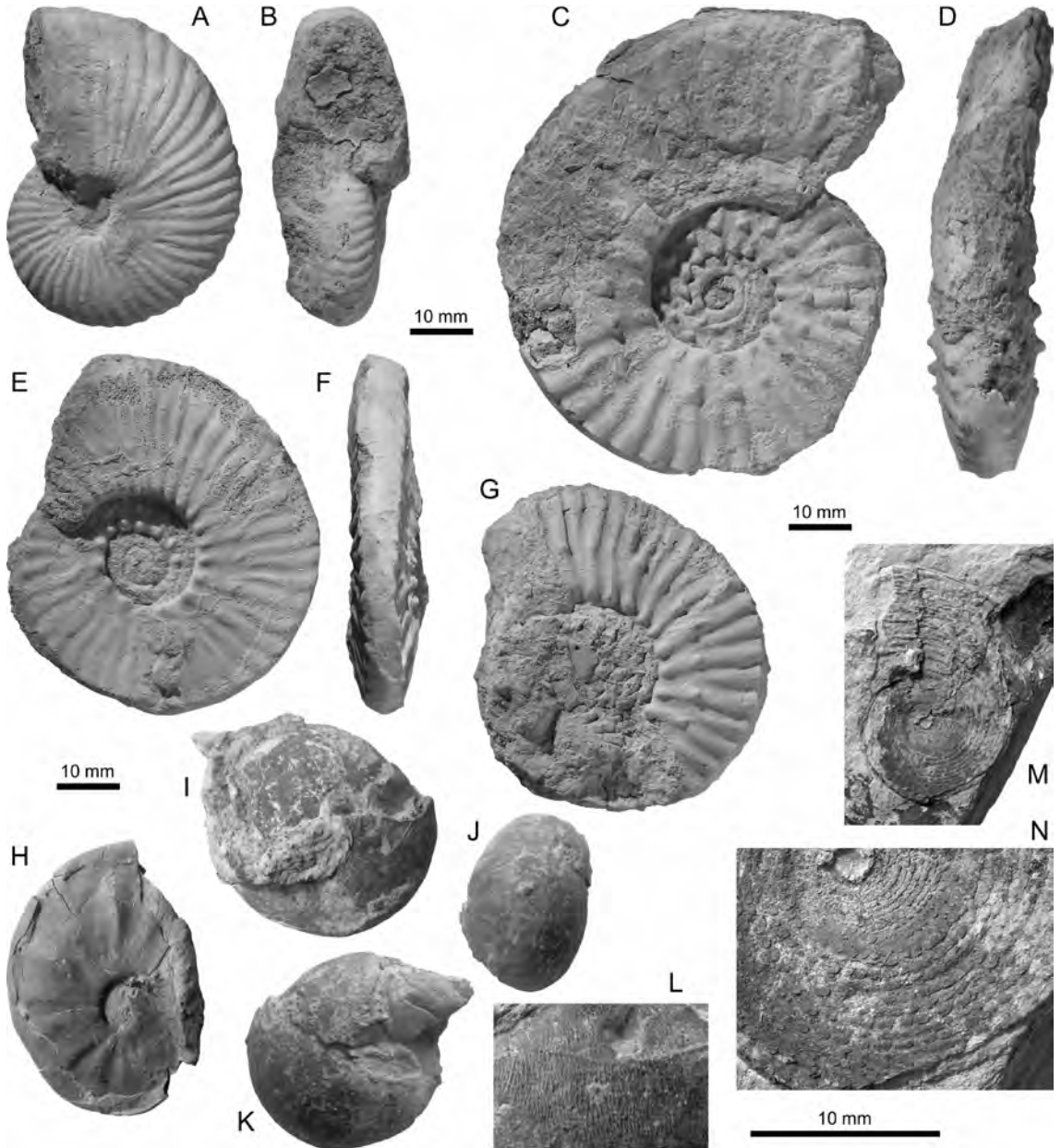
Apart from these reliably identified taxa, the collection of ammonoid specimens from the Upper Qingyan Formation studied comprises some further taxa (Stiller, 2001; Stiller and Bucher, 2008). However, for preservational reasons and because of the relative scarcity of ammonoids in the Upper Qingyan Formation, resulting in a comparatively small number of specimens, the available samples of these additional taxa do not allow reliable taxonomic identification. Although this indicates that the Upper Qingyan Formation yields a few further ammonoid taxa, the biostratigraphical correlation of this unit is clear.

Specimens from the Upper Qingyan Formation assigned to various species of the genus *Paracerasites* in earlier publications belong either to *Bulogites multicostatus* or to the genus *Rieppelites* (for synonymy see Stiller and Bucher, 2008). *Rieppelites* morphologically resembles *Paracerasites*, but it differs from the latter genus especially in the absence of a ventral keel (Text-figs. 6, 8).

The earliest late Anisian genus *Rieppelites* distinctly predates the genus *Paraceratites* (Text-fig. 2).

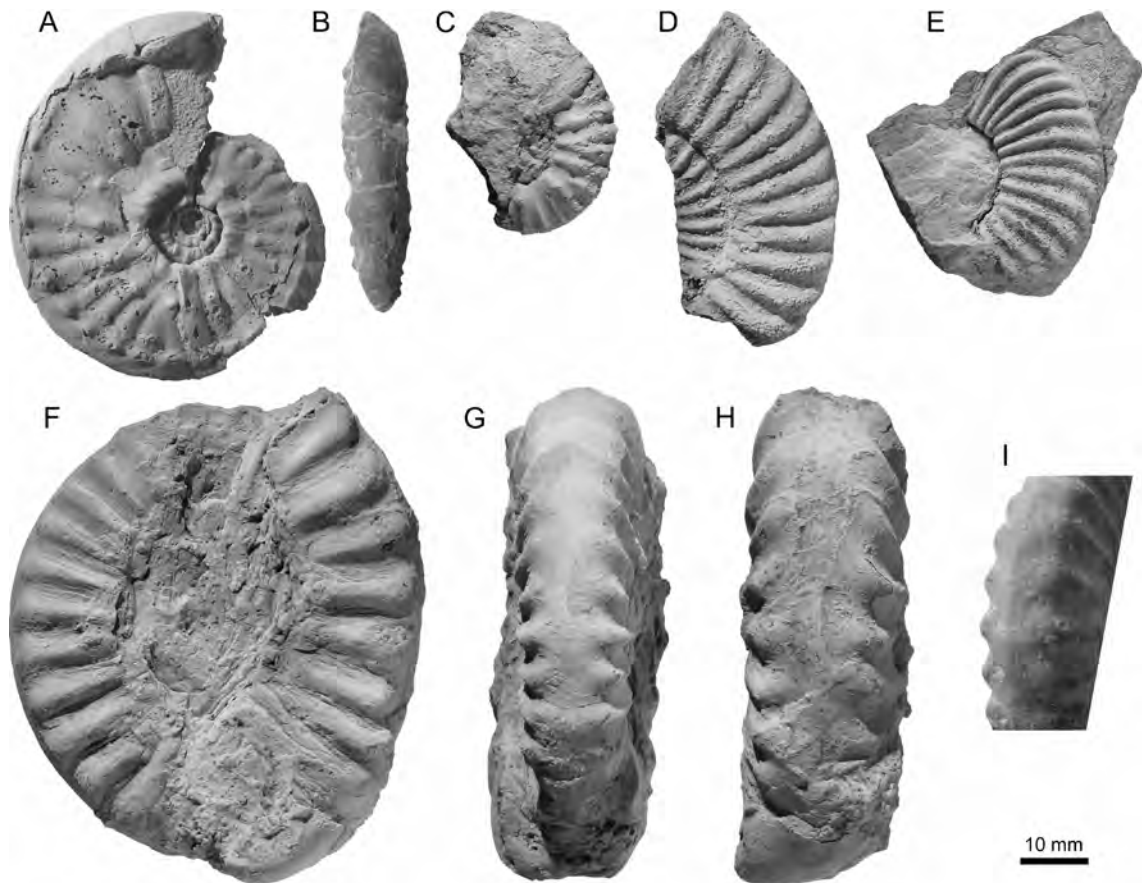
The genus *Ptychites* is represented by three distinct forms (Text-fig. 7). *Ptychites* sp. A has a broadly rounded venter crossed by regularly spaced

folks and shows affinities with *Ptychites stachei* Mojsisovics, 1882. *Ptychites* sp. B differs from *Ptychites* sp. A in its smooth shell and triangular whorl section, suggesting some affinities with *Discoptychites domatus* (Hauer, 1851) and *Ptychites gradinarui* (Bucher, 1992). Although only known



Text-figure 5 Ammonoids of the *Bulogites-Acrochordiceras* assemblage from the lower middle Leidapo Member (latest middle Anisian, early Middle Triassic) of the lower portion of the Leidapo section (A—L) and from the lowermost Leidapo Member (latest middle Anisian, early Middle Triassic) of the northwestern slope of Wachangpo (M, N), northeastern vicinity of Qingyan, Guizhou Province, southwestern China.

A, B. *Acrochordiceras* cf. *carolinae* Mojsisovics, 1882; NIGP 143730. C, D. *Bulogites multicostatus* Wang, in Zhao *et al.* (1965); NIGP 143732. E, F. *Bulogites multicostatus* Wang, in Zhao *et al.* (1965); NIGP 143731. G. *Bulogites multicostatus* Wang, in Zhao *et al.* (1965); NIGP 143733. H. Beyrichitinae gen. et sp. indet.; NIGP 151864. I—L. *Proarcestes* sp.; NIGP 151863; L. detail of I showing the typical Runzelschicht. M, N. *Sageceras* sp.; NIGP 151865; N. detail of M.



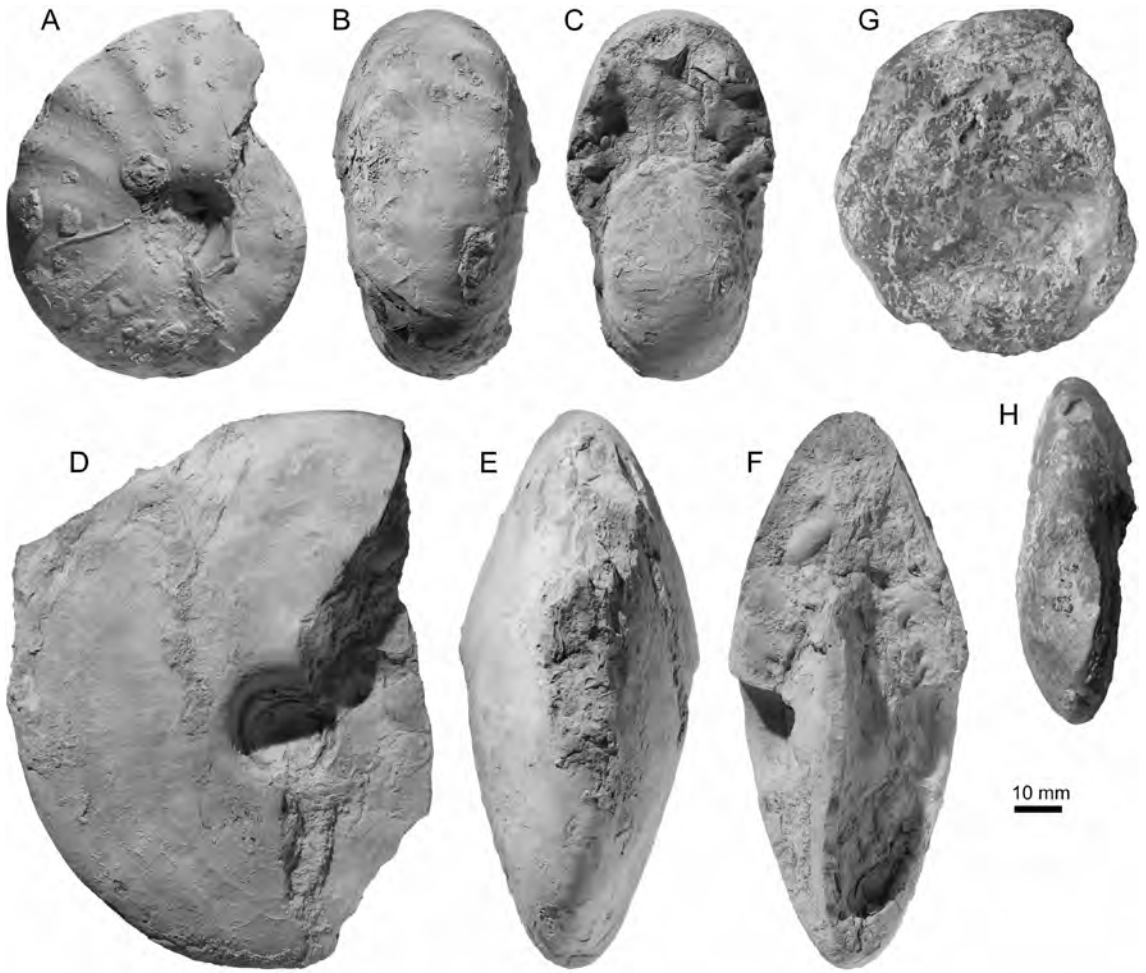
Text-figure 6 Ammonoids of the *Rieppelites-Judicarites* assemblage from the lower middle and upper Leidapo Member (earliest late Anisian, early Middle Triassic) of the northeastern vicinity of Qingyan, Guizhou Province, southwestern China.

A, B. *Rieppelites* sp. A; NIGP 143735; lower middle Leidapo Member, upper portion of the Leidapo section; B. ventral view showing the unkeeled venter. C. *Rieppelites* cf. *cimeganus* (Mojsisovics, 1882); NIGP 143734; lower middle Leidapo Member, upper portion of the Leidapo section. D. *Judicarites* cf. *meneghinii* (Mojsisovics, 1882); NIGP 143736; lower middle Leidapo Member, northeastern slope of Wachangpo. E. *Judicarites* cf. *meneghinii* (Mojsisovics, 1882); NIGP 143737; upper Leidapo Member, northwest of Lanhuaguan. F—I. *Gosauites* sp.; NIGP 143738; lower middle Leidapo Member, northeastern slope of Wachangpo; I. oblique ventral view showing the weak ventral keel.

from a single, not well preserved specimen, *Ptychites* sp. C represents a separate taxon. It is distinguished from the two previous forms by its much more compressed and involute shell shape, with a narrowly rounded venter and distant, weak lateral folds. Morphologically, it somewhat resembles the genus *Flexoptychites*.

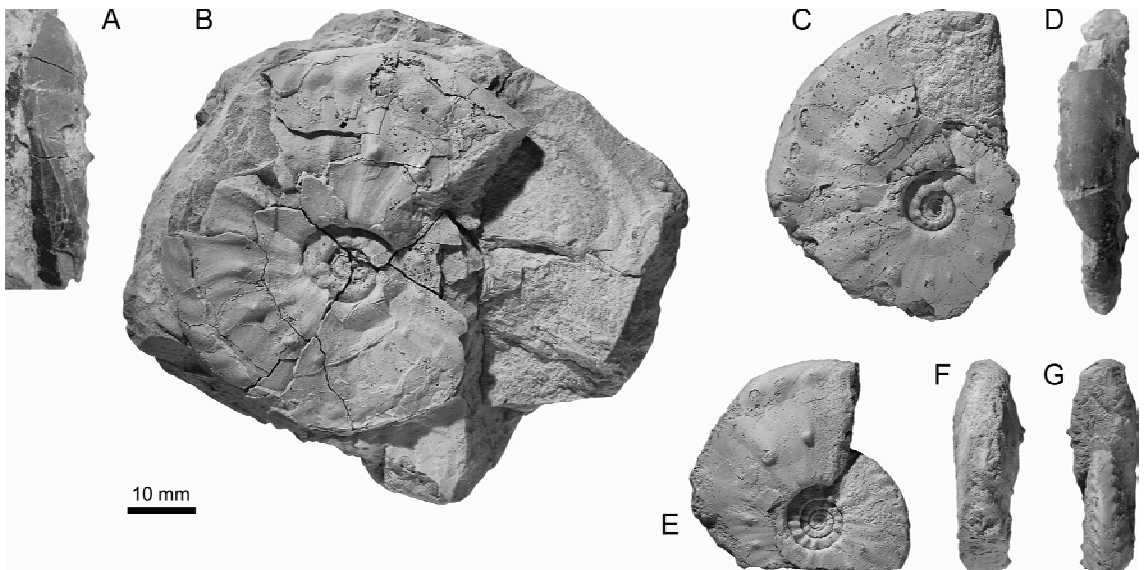
Some of the main results reported in this contribution have already been published in Stiller and Bucher (2008). Here, additional detailed data and interpretations have been presented, focusing especially on the precise biostratigraphical correlation and age of the Leidapo fossil assemblages.

Acknowledgements We are grateful for constructive review comments by an anonymous reviewer. The fieldwork of F. Stiller in Guizhou was financially supported by the Studienstiftung des deutschen Volkes (1992, 1994), Alfried Krupp von Bohlen und Halbach-Stiftung and Stiftung Bildung und Wissenschaft (1992), National Natural Science Foundation of China and Deutsche Forschungsgemeinschaft (2002), Heinrich Hertz-Stiftung and Gesellschaft zur Förderung der Westfälischen Wilhelms-Universität zu Münster (2003). This study was also partially supported by the Swiss National Science Foundation (project 200020-113554 to H. Bucher).



Text-figure 7 Ammonoids of the *Rieppelites-Judicarites* assemblage from the lower middle Leidapo Member (earliest late Anisian, early Middle Triassic) of the upper portion of the Leidapo section, northeastern vicinity of Qingyan, Guizhou Province, southwestern China.

A—C. *Ptychites* sp. A; NIGP 143739. D—F. *Ptychites* sp. B; NIGP 143740. G, H. *Ptychites* sp. C; NIGP 151866.



Text-figure 8 Ammonoids of the *Rieppelites-Judicarites* assemblage from the upper Yuqing Member (uppermost part of the Upper Qingyan Formation; earliest late Anisian, early Middle Triassic) of Shizishanjiao, northeastern vicinity of Qingyan, Guizhou Province, southwestern China.

A—G. *Rieppelites* cf. *shevyrevi* Monnet and Bucher, 2005. A, B. NIGP 143741. C, D. NIGP 143742. E—G. NIGP 143743. A, D, F, G. ventral views showing the unkeeled venters.

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