

Geological Society of America
 Special Paper 423
 2007

Paleontological data from the Early Cambrian of Germany and paleobiogeographical implications for the configuration of central Perigondwana

Olaf Elicki*

Freiberg University, Geological Institute, 09599 Freiberg, Germany

ABSTRACT

Fossiliferous Early Cambrian strata from central Europe are known from two fragmentary preserved units situated in eastern Germany: the Görlitz syncline and the Torgau-Doberlug syncline. The fossil assemblages from both regions and their geological framework are presented. The taxonomic content, the internal structure, and the biostratigraphic positions of the containing assemblages are quite different. Trilobites and other shelly fossils (from Görlitz syncline) and archaeocyathans (from Torgau-Doberlug syncline) show strong relationships to equivalent faunas in Morocco, Spain, and France. Further, there are some indications for relationships to the Far East. The German faunas indicate very active faunal exchange within the peri-Gondwanan realm and probably over longer distances along the Gondwana margin, too. Together with the nearly shelf-wide consistent sedimentary facies patterns, consequently, they contradict the model of local and isolated basins for the areas of deposition. The current patchy geographical distribution of Cambrian sediments in central and southern Europe is interpreted as a phenomenon of (1) regionally different sedimentation rates on the Gondwanan shelf (probably by local origination of open intra-shelf basins caused by a general rifting process), and of (2) Late Cambrian to Early Ordovician different-scaled uplift and denudation of parts of the shelf. The content, the coinciding evolutionary patterns, and the paleogeographical relationships of the Cambrian faunas suggest that separation and evolution of terranes in central Perigondwana had not started before the end of the Cambrian or the beginning of the Early Ordovician. For Early and Middle Cambrian times at least, a slightly differentiated shelf-configuration of Perigondwana without isolated areas (terranes) fits best with the paleontological and sedimentological data.

Keywords: Cambrian, Perigondwana, paleogeography, Görlitz syncline, Torgau-Doberlug syncline

*elicki@geo.tu-freiberg.de

Elicki, O., 2007, Paleontological data from the Early Cambrian of Germany and paleobiogeographical implications for the configuration of central Perigondwana, in Linnemann, U., Nance, R.D., Kraft, P., and Zulauf, G., eds., The evolution of the Rheic Ocean: From Avalonian-Cadomian active margin to Alleghenian-Variscan collision: Geological Society of America Special Paper 423, p. 143–152, doi: 10.1130/2007.2423(05). For permission to copy, contact editing@geosociety.org. ©2007 Geological Society of America. All rights reserved.

INTRODUCTION

The geological roots of the European basement areas lie in the Neoproterozoic so-called “Avalonian-Cadomian orogenic belt,” which was situated at the periphery of Gondwana (Nance and Murphy, 1994; Torsvik et al., 1996). In Cambrian times the central European basement areas indicate first rifting tendency (ultramafic, mafic, and granitoid rocks), which—after widely accepted models—finally led to the break-up of peri-Gondwanan terranes (Linnemann et al., 2000; Kemnitz et al., 2002).

Generally, fossiliferous Cambrian strata are very rare in Germany. They are known from the Görlitz and the Leipzig areas, from the Franconian Forest, and from Thuringia (Fig. 1). The Thuringia deposits (two single research drillings from the 1960s) are not considered here because of (1) the very poor preservation of the few microfossil remains found and (2) the lack of biostratigraphic resolution of their general Cambrian age (Blumenstengel, 1980). All these deposits belong to the Saxo-Thuringian terrane (*sensu* Linnemann and Schauer, 1999). Among them, successions of biostratigraphically indicated Early Cambrian age are known from only two regions: from the Görlitz area (Görlitz syncline, a small area near the southeastern border to Poland) and from the Leipzig area (Torgau-Doberlug syncline). These successions

were deposited on or at the flank of the Cadomian consolidated basement (Lusatian block; Linnemann and Buschmann, 1995; Linnemann and Schauer, 1999; Jonas et al., 2000). The structural characteristic of the relations between the Cadomian basement and the marginal synclines is still a matter of discussion, mainly because of the poor outcrop conditions in the area (e.g., Franke, 1984; Buschmann et al., 1995, 2006; Linnemann and Buschmann, 1995; Linnemann and Schauer, 1999; Göthel, 2001).

Paleontological studies concerning the German Cambrian faunas have a long tradition. Initially, deeper investigations were focused on the Middle Cambrian successions of the Franconian Forest and the Leipzig area (Torgau-Doberlug syncline) and—later on—on Early Cambrian deposits of the Görlitz and Torgau-Doberlug synclines. Compilations of the state of knowledge at different times were given by Szdzy (1972, for the so-called “acadobaltic province”) and by Elicki (1997).

GEOLOGICAL SETTING

The poorly exposed succession of the Görlitz syncline (Charlottenhof Formation; Fig. 2) is characterized by a suite of shallow-marine massive dolostones (up to 100 m) and overlying bedded limestones (up to 80 m) called the Ludwigsdorf Member (Elicki and Schneider, 1992; Elicki, 1994). Siliciclastics (90–120 m) follow to the top (*Lusatiops* Member). Because of the complex tectonic situation, the stratigraphic continuations above and below are unknown.

Because of a strong diagenetic overprint the lower portion of the Ludwigsdorf Member (dolostones) does not yield any biotic remains. Former reports of problematic structures interpreted as probable “archaeocyathans” by Schwarzbach (1934) are rejected after critical re-evaluation (Elicki, 1997). The overlying bedded, and in its highest part nodular, limestones, in contrast, show many sedimentary patterns and are partly rich in fossils. These patterns allow a distinction of two facies realms: (1) shallow and open-marine facies and (2) restricted lagoonal facies (Elicki and Schneider, 1992). The former is characterized by more or less siliciclastic-influenced, bioclastic wackestone, packstone, and floatstone with phosphatic black pebbles, load casts, wave ripples, cross bedding, small channels, and a rich shelly fauna (Elicki and Schneider, 1992; see also below). The latter shows a regular alternation of “Zebra limestone” and dolomitic limestone with slumping and tepee-structures and a primary sulfate content (Elicki and Schneider, 1992). Besides some rare allochthonous remains, this second facies type is free of fossils.

The overlaying *Lusatiops* Member is represented by red and green claystone and siltstone with minor sandstone intercalations. The fossil content is dramatically reduced (some trilobites, brachiopods, and hyoliths). Taphonomic features suggest a rather quiet and deeper shelf environment than those of the underlying Ludwigsdorf Member (Geyer and Elicki, 1995).

The Early Cambrian succession of the Torgau-Doberlug syncline (subsurface outcrops; Fig. 3) has a thickness estimated to be ~700–1000 m (Brause, 1969), overlain by Middle Cambrian

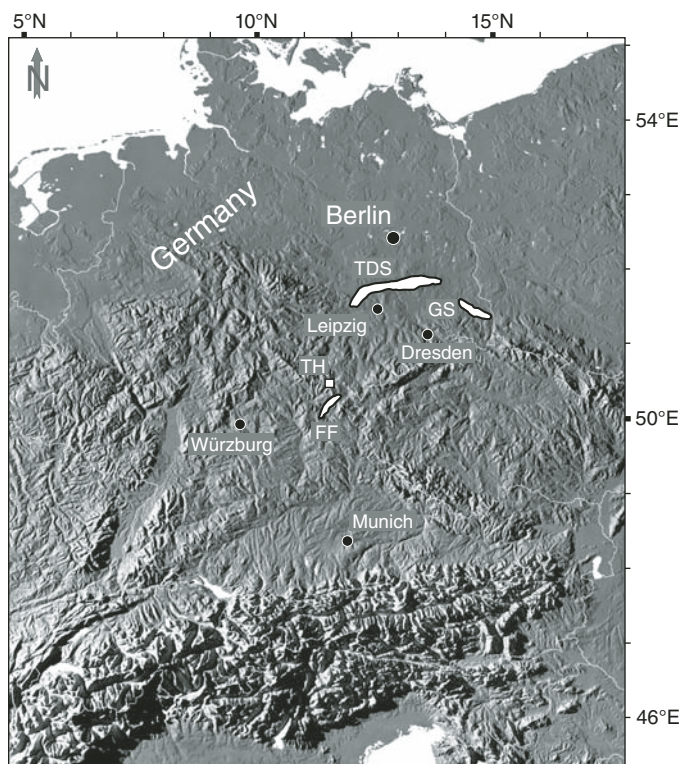


Figure 1. Physical geographic map of Germany, indicating regions containing Cambrian faunas mentioned in the text. FF—Franconian Forest; GS—Görlitz syncline; TDS—Torgau-Doberlug syncline; TH—location of two drillings in Thuringia providing Cambrian fossils.

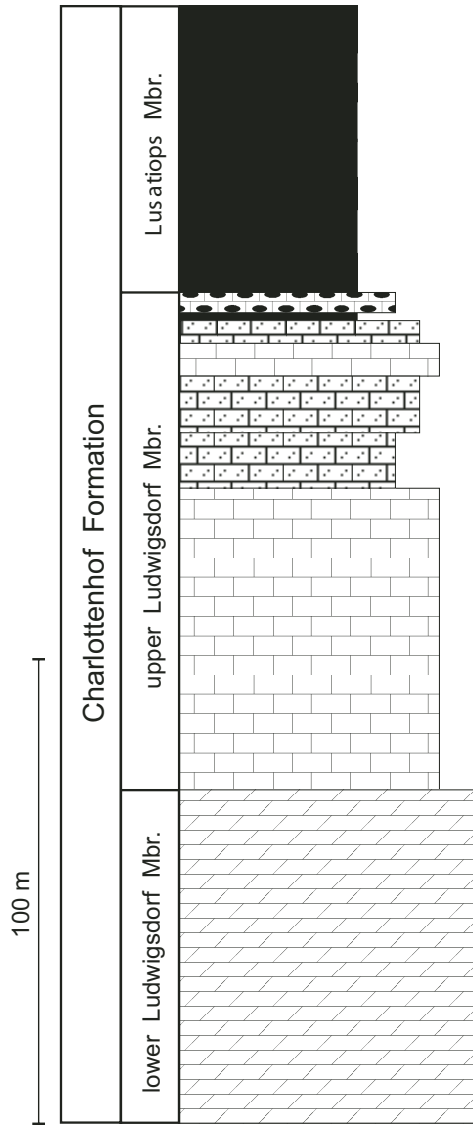


Figure 2. Lithological column of the Cambrian succession of the Görlitz syncline (after Elicki, 2005). Legend valid for Figures 2 and 3. Mbr.—member.

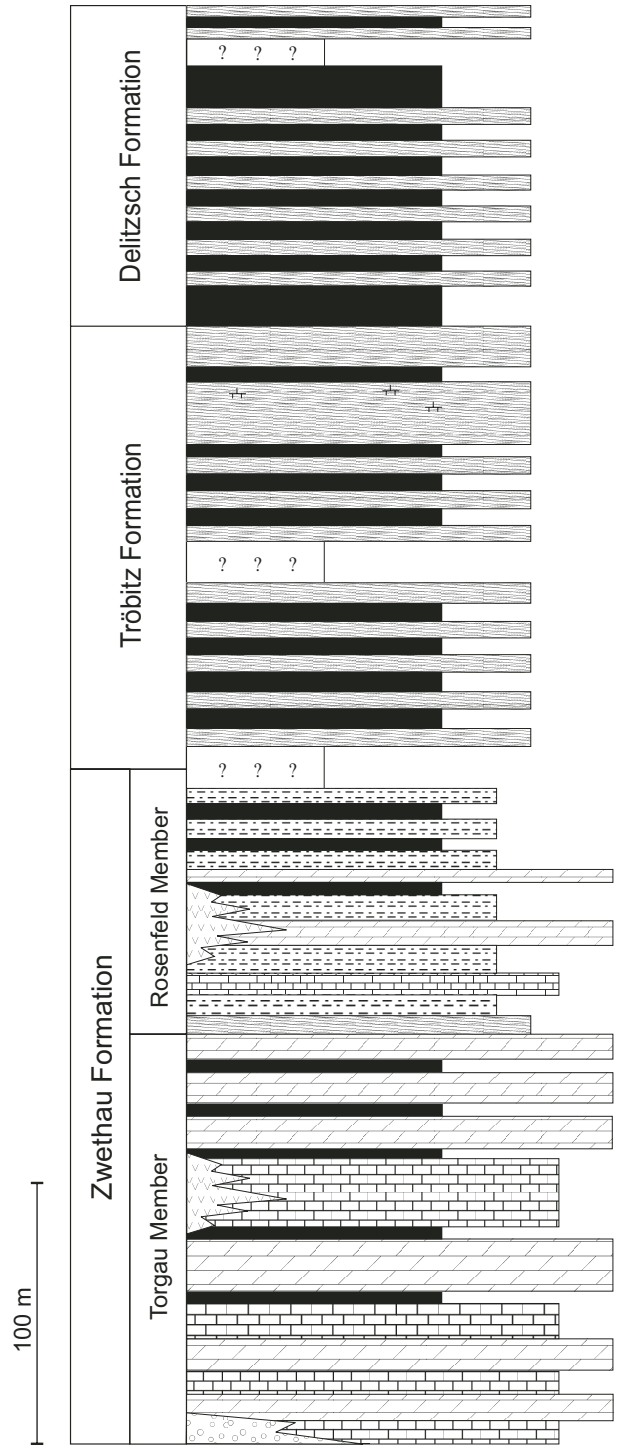
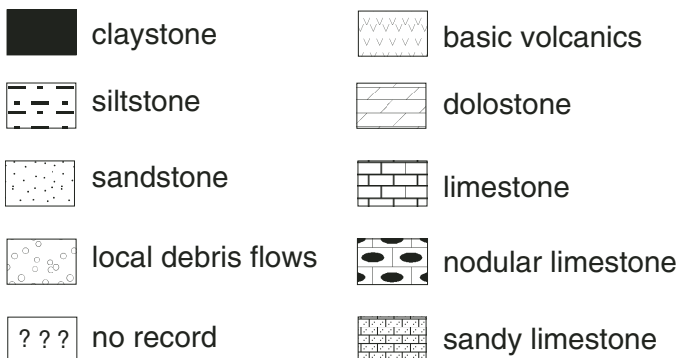


Figure 3. Lithological column of the Cambrian succession of the Torgau-Doberlug syncline (after Buschmann et al., 2006). See Figure 2 for legend.

strata of probably about the same thickness and covered by up to 200 m of Cenozoic rocks. Locally, Carboniferous sediments overlay the Cambrian strata.

Early Cambrian deposition started after the Cadomian unconformity, with locally developed debris flows, followed by shallow-marine carbonates and subordinate siliciclastics (Zwethau Formation). In the lower part of the succession carbonates distinctly predominate (Torgau Member), whereas the upper part is characterized by alternations of siliciclastic-carbonate rocks and pure siliciclastics (Rosenfeld Member). Rarely, intrusive volcanics (diabases) occur (Freyer and Suhr, 1987; Buschmann et al., 1995; Elicki, 1999a,b).

The Torgau Member consists of up to 500 m or more of fossiliferous limestones and dolostones. Calcimicrobial, oolitic, and intraclastic limestones are common. Cyanobacteria and archaeocyathans are widespread, and some skeletal fossils were also recovered (Sdzuy, 1962; Freyer and Suhr, 1987, 1992; Elicki, 1992, 1994, 1999b; Elicki and Debrenne, 1993). Shallow depositional conditions are indicated by wave ripples, cross bedding, mudcracks, local evaporites, and biofacies (see below). The environment is interpreted as a shallow subtidal to intertidal ramp with shoals and lagoons (Elicki, 1992, 1999a,b).

The poorly investigated overlying Rosenfeld Member (up to 280 m) is represented by an alternation of limestones, dolostones, and siliciclastics (with some diabases in the upper part). Freyer and Suhr (1987) reported a probable higher amount of siliciclastics and of redeposited materials (archaeocyathans, cy-

nobacteria, shelly remains) as well as graded carbonates, which led these authors to interpret a transitional facies into a “basinal” environment.

Because of the complex structure of the Torgau-Doberlug syncline, the transition into the overlying sandstones and claystones of the Middle Cambrian Tröbitz Formation and Delitzsch Formation remains unclear (Brause, 1969; Elicki, 1997). Regardless an outstanding detailed sedimentological investigation of this siliciclastic succession, a deeper shelf environment below storm-wave base is assumed, based on the cyclicity of deposition and of the containing fauna (some trilobites and traces, occasional brachiopods, hyoliths, and others; see Table 2 below), .

EARLY CAMBRIAN BIOTA

The fossils of the Charlottenhof Formation (Görlitz syncline) come from the upper Ludwigsdorf Member and the *Lusatiops* Member. The taxonomic content of both members is shown in Table 1. The fauna of the upper Ludwigsdorf Member is dominated by hyoliths and disarticulated poriferans, echinoderms, and cancelloriids (Elicki and Schneider, 1992; Elicki, 1994). Further common faunal elements are trilobites, brachiopods, bivalves, archaeogastropods, and monoplacophorans (Table 1). Rather rare are phosphatic microproblematica and cyanobacteria. The fossil assemblage shows distinct changes in its vertical occurrence. Whereas the oldest strata of the upper Ludwigsdorf Member contain only poorly preserved brachiopod and poriferan

TABLE 1. CAMBRIAN FOSSILS OF THE GÖRLITZ SYNCLINE

	Predominant taxa	Miscellaneous taxa
Early Cambrian	Trilobites: <i>Serrodiscus silesius</i> , <i>Lusatiops lusaticus</i> , <i>Lusatiops</i> sp., <i>Ferralsia saxonica</i> , <i>Calodiscus</i> cf. <i>lobatus</i> , aff. <i>Calodiscus lobatus</i> , “ <i>Holmia</i> ” <i>zimmermanni</i> , “ <i>Acanthomicmacca</i> ” <i>schwarzbachii</i>	Anabariids: <i>Tiksitheca korobovi</i> , <i>Cambrotubulus decurvatus</i> , <i>C. corniformis</i>
	Molluscs: <i>Pojetaia runnegari</i> , <i>Fordilla germanica</i> , <i>F. troyensis</i> , <i>Beshtashella tortilis</i> , <i>Pelagiella subangulata</i> , <i>P. lorentzi</i> , <i>P. aff. adunca</i> , <i>Pelagiella</i> sp., <i>Yuwenia juliana</i> , <i>Y.(?) cf. bentleyi</i> , <i>Obtusocoelus</i> sp., <i>Planutenia flectata</i> , <i>P. inclinata</i> , <i>Anabarella australis</i> , <i>Bemella</i> aff. <i>jacutica</i> , <i>Bemella</i> sp., <i>Khairkhanina evoluta</i>	Hyolithelminths: <i>Torella mutila</i> , <i>T. lentiformis</i> , <i>Hyolithellus</i> cf. <i>micans</i>
	Hyolithes: <i>Lenalituus pusillus</i> , <i>Conothea circumflexa</i> , <i>Microcornus elongatus</i> , <i>M. parvulus</i> , <i>Obliquatheca aldanica</i> , <i>Orthothea</i> sp., <i>Tchuranitheca curvata</i> , <i>Trapezovitus mirus</i> , <i>Hyolithes divaricatus</i> , <i>Hyolithes</i> sp., <i>Burithes</i> sp., <i>Egdetheca</i> cf. <i>aldanica</i> , sulcavethids indet.	Cyanobacteria: <i>Obruchevella delicata</i> , <i>Endoconchia angusta</i> , <i>Epiphyton</i> sp.
	Poriferans: <i>Dodecaactinella cynodontota</i> , <i>Eiffelia araniformis</i> , unidentified heteractinid remains	Problematic fossils: <i>Rhombocomiculum cancellatum</i> , <i>Aetholicopalla adnata</i> , <i>Coleoloides typicalis</i> , <i>Microcoryne cephalata</i> , <i>Cambroclavus ludwigsdorfensis</i> , <i>Halkieria</i> sp.
	Chancelloriids: <i>Allonnia tetrathallis</i> , <i>A. tripodophora</i> , <i>Allonnia</i> sp., <i>Archiassterella hirundo</i> , <i>A. pentactina</i> , <i>Chancelloria primaria</i> , <i>Chancelloria</i> sp.	
	Indeterminate brachiopods and echinoderms	

Note: For the brachiopods no taxonomic names are presented here because of the rejection of earlier decisions of the extremely poorly preserved and indeterminate material (Freyer 1981a; Ivar Puura, Tartu University, personal commun.). Sources: Based on Freyer (1977), Elicki (1994, 1996, 1998), and Geyer and Elicki (1995).

remains, the following levels are of higher diversity. So, the mentioned oldest faunas are followed by an association of brachiopods, poriferans, and hyoliths (with minor content of trilobites and chancelloriids), which, in turn, are overlain by strata yielding only some problematic remains (echinoderms?). Subsequently, a poriferan-dominated fauna developed, with minor trilobite and chancelloriid remains, which changed into the most fossiliferous level bearing a hyolith-poriferan-echinoderm-trilobite-dominated association with chancelloriids, molluscs, and phosphatic small shelly fossils. The youngest carbonate layer just provided a limited poriferan-brachiopod fauna with some hyoliths and chancelloriids. In contrast to the partly very fossiliferous upper Ludwigsdorf Member, the immediately overlying pure shaly *Lusatiops* Member contains a depleted fauna consisting of some trilobites, scarce brachiopods, and very rare hyoliths.

Paleoecologically, the Görlitz fossil assemblages indicate a normal-marine mesotrophic environment dominated by large numbers of semi-infaunal and infaunal suspension feeders and deposit feeders (hyoliths, bivalves, other molluscs, echinoderms, chancelloriids, trilobites, and brachiopods) followed by filter feeders (poriferans) (Elicki, 2003, 2005). The location of this molluscan-dominated habitat is interpreted as relatively proximal. Changes in the physical outer conditions (sea-level changes, siliciclastic influx, salinity, and ?climate) are assumed to be responsible for changes in the diversity and composition of the assemblages (Elicki and Schneider, 1992).

Following the paleontological and the sedimentological data, the Görlitz depositional area can be summarized as an open-marine, moderately wave-influenced, well-oxygenated shelf environment during a transgressive stage under mesotrophic conditions. Restricted-marine, higher salinity areas with distinctly depleted fauna were situated locally in proximal position (Elicki and Schneider, 1992; Elicki, 2005).

The fauna from the subsurface Early Cambrian carbonates of the Torgau-Doberlug syncline (Zwethau Formation) is quite different from that of the Görlitz syncline. The most conspicuous faunal elements here are archaeocyathans and calcimicrobes (Freyer and Suhr, 1987, 1992; Elicki and Debrenne, 1993; Elicki, 1999b), forming archaeocyathan-calcimicrobial reef mounds and calcimicrobial carpets (Elicki, 1999b; Wotte, 2004). Shelly fossils are represented by some bradoriids and additional phosphatic small shelly fossils, by a few trilobite remains, some chancelloriid and sponge spicules, as well as by undeterminable disarticulated echinoderms (Sdzuy, 1962; Elicki, 1994). Some of them (e.g., poriferans, tintinnoids, bradoriids) are enriched in distinct layers.

The widespread occurrence of archaeocyathans—commonly viewed as adapted to low-nutrient conditions (e.g., Brasier, 1990, 1992; Debrenne and Zhuravlev, 1997)—supports the assumption of a rather oligotrophic environment. The predominating mode of food production was by photosynthesis (cyanobacteria) and filter-feeding (archaeocyathans). The scarce shelly fauna was represented by suspension- and deposit-feeders (trilobites, chancelloriids), as well as by spicule-bearing filter-feeders (poriferans). Wherever indications of very shallow-water or higher salin-

ity conditions occur (lagoons or back shoal areas; see Elicki, 1999a), the abundance of all organisms decreases dramatically. The highest shelly fossil content is in open-marine areas adjacent to archaeocyathan-calcimicrobial reef mounds and to oolitic shoals (Elicki, 1992; Elicki and Debrenne, 1993; Wotte, 2004). The overwhelming majority of organisms lived epibenthically. A synthesis of the paleontological and sedimentological data points to shallow-ramp depositional environment divided into oolitic shoals, open-marine reef-mounds, and inter-reef areas, and shallow areas of higher salinity; most proximal, intertidal flats were well developed (Elicki, 1999a,b). The fossil content of the Cambrian sediments in the Torgau-Doberlug syncline is shown in Table 2 (for a complete overview, Middle and ?Upper Cambrian fossils are also listed).

BIOSTRATIGRAPHY AND PALEOBIOGEOGRAPHY

The fossiliferous Early Cambrian sediments of Germany represent different biostratigraphic levels (Fig. 4). For the identification of the biostratigraphic age, scales based on different taxonomic groups were used, so the problem of a high-resolution correlation between these scales must be considered. Thus, from the Early Cambrian assemblage of the Görlitz syncline several trilobites and additional shelly fossils (Table 1) can be used for biostratigraphy. In contrast, from the Early Cambrian of the Torgau-Doberlug syncline only one rather endemic trilobite is reported, but the rich assemblage of archaeocyathans (Table 2) provides a good biostratigraphic datum.

For the Ludwigsdorf Member and the overlying *Lusatiops* Member of the Görlitz syncline, trilobites indicate that the stratigraphic difference between these two members is negligible (Geyer and Elicki, 1995). The trilobite assemblage, consisting mainly of *Ferralsia saxonica*, *Serrodiscus silesius*, *Calodiscus* cf. *lobatus*, and *Lusatiops lusaticus*, marks a biostratigraphic position in the higher Banian of the Atlasian series following the new biostratigraphic scheme for western Gondwana proposed by Geyer and Landing (2004). This stratigraphic level corresponds to the middle to upper Marianian stage in Spain (Liñán et al., 1996; Álvaro et al., 1998) and roughly to the upper Atdabanian to early Botoman *Bergeroniellus micmacciformis*–*Erbiella* level of the widely used Siberian scale (Brasier, 1989a).

The co-occurrence of some small shelly fossils supports this conclusion. Following the shelly-fossil biostratigraphy, the pseudoconodont *Rhombocorniculum cancellatum* and the gastropod *Pelagiella lorenzi*, occurring together with the mentioned trilobites, allow correlation with an interval from the *Rhombocorniculum cancellatum* zone to the *Lapworthella cornu* zone (sensu Brasier, 1989a) and the *Microcornus parvulus* zone (sensu Rozanov and Zhuravlev, 1992), respectively. This interval correlates to horizons of Comley (Ac3–Ac4) and Nuneaton (Purley Shale, both England), Newfoundland (lower Brigus Formation), Sweden (Gislöv Formation), China (lower Qiongzhusian), and Siberia (upper Atdabanian to early Botoman) (Brasier, 1989a; Jiang, 1992). Generally the whole assemblage of small shelly fossils

TABLE 2. CAMBRIAN FOSSILS OF THE TORGAU-DOBERLUG SYNCLINE

	Predominant taxa	Miscellaneous taxa
C _u	Trace fossils: <i>Cruziana semiplicata</i> , <i>C. forcata</i>	
		?Arthropods: <i>Oxyprymna schloppensis</i>
Middle Cambrian	Trilobites: <i>Badulesia tenera</i> , <i>Bailiella</i> cf. <i>emarginata</i> , <i>Conocoryphe gemina</i> , <i>C. palpebralis</i> , <i>C. (Parabailiella)</i> sp., <i>Condylopyge rex</i> , <i>C. regia</i> ; <i>Clavagnostus?</i> sp., <i>Dorypyge</i> sp., <i>Ellipsocephalus incultus</i> , <i>Hypagnostus</i> cf. <i>truncatus</i> , <i>Jincella?</i> cf. <i>sulcata</i> , <i>Micmacca anomocaroides</i> , <i>Olenoides</i> sp., <i>Paradoxides brausei</i> , <i>P. saxonicus</i> , “ <i>P.</i> ” cf. <i>insularis</i> , <i>P.</i> cf. <i>pinus</i> , <i>P.</i> aff. <i>asturianus</i> , <i>P.?</i> aff. <i>enormis</i> , <i>P. (Acadoparadoxides)</i> sp., <i>Peronopsis</i> sp., <i>Peronopsella inaequalis</i> , <i>Protolenus annulatus</i> , <i>P.</i> cf. <i>annulatus</i> , <i>Parasolenopleura lusatica</i> , <i>Solenopleura picardi</i> , <i>Ornamentaspis? frankenwaldensis</i>	Hyoliths: <i>Hyolithes</i> cf. <i>oelandicus</i> , <i>Orthotheca</i> aff. <i>affinis</i> , <i>Orthotheca</i> sp.
	Brachiopods: <i>Acrothele</i> cf. <i>quadrilineata</i> , <i>Acrothele</i> sp., <i>Eoorthis</i> aff. <i>primordialis</i> , <i>Lingulella ferruginea</i> , <i>Lingulella</i> sp.	Undetermined trace fossils, echinoderm remains, and helcionellids
Early Cambrian	Archaecyathia: <i>Cordobicyathus germanicus</i> , <i>Nochorocyathus</i> sp., <i>Urcyathus perejoni</i> , <i>Degeletticyathus?</i> sp., <i>Inessocyathus freyeri</i> , <i>Afiacyathus paracompositus</i> , <i>Erismacoscinus tainius</i> , <i>Erismacoscinus</i> aff. <i>primus</i> , <i>Retecoscinus</i> aff. <i>guadalquivirensis</i> , <i>Coscincyathus?</i> sp., <i>Neoloculicyathus magnus</i> , <i>Dictyocyathus stipatus</i> , <i>Protopharetra gemmata</i> , <i>Protopharetra dissuta</i>	Trilobites: <i>Dolerolichia pretiosa</i>
	Cyanobacteria: <i>Epiphyton</i> sp., <i>Girvanella</i> sp., <i>Renalcis</i> sp., <i>Kordephyton</i> sp., <i>Proaulopora</i> cf. <i>glabra</i> , <i>Botomaella</i> sp., <i>Subtifloria</i> (= <i>Botominella</i>) sp.	Bradoriids: <i>Hipponicharion elickii</i> , lipabdominids indet.
		Chancelloriids: <i>Archiasterella pentactina</i> , <i>A. hirundo</i> , <i>Allonia tripodophora</i> , <i>A. tetrathallis</i> , <i>Chancelloria</i> sp.
		Hyolithelminths: <i>Torellella lentiformis</i> , <i>T. curva</i>
		Anabarids: <i>Tiksitheca licis</i> , <i>Cambrotubulus</i> cf. <i>decurvatus</i>
		Problematic fossils: <i>Tintinnoidella praecursa</i> , <i>Cambroclavus</i> sp., <i>Halkieria</i> sp.
		Undetermined trace fossils, and poriferan and echinoderm remains

Note: C_u—Upper Cambrian. Sources: Based on Sdzuy (1957a, 1957b, 1962, 1970), Freyer (1981b), Elicki (1994, 1999b), Elicki and Debrenne (1993), and Gozalo and Hinz-Schallreuter (2002).

from the Görlitz syncline is very typical for Gondwanan higher Early Cambrian strata.

In contrast to the Görlitz syncline, trilobites are rather rare in Early Cambrian strata of the Torgau-Doberlug syncline. The only known taxon from the area is represented by the neoredlichiid *Dolerolichia pretiosa* (Sdzuy, 1962), so that the biostratigraphic value reasoned from comparison with taxonomic relatives is limited. Nevertheless, *D. pretiosa* points to a lower Early Cambrian age (“probably older than the Görlitz trilobite fauna”; Sdzuy, 1962, p. 1096), which can be correlated to the upper part of the lower Ovetian (E. Liñán, 2005, pers. commun.) corresponding to the middle Issendalenian of Geyer and Landing (2004).

Much more biostratigraphic data are provided by archaeocyathans. The assemblage of ten regular species (nine genera)

and four irregular species (three genera) from seven drilling cores (Table 2) is best compared with assemblages from Spain and Morocco (Elicki and Debrenne, 1993). Consequently, the Torgau-Doberlug syncline assemblage allows a biostratigraphic classification to the middle Issendalenian of the Atlasian series of western Gondwana (Geyer and Landing, 2004), which is correlative with the lower Ovetian of Iberia and roughly coeval to the lower Atdabanian stage of Siberia. However, a precise age remains a matter of discussion, as the biostratigraphic significance of the West Gondwanan archaeocyathans is not fully understood and systematic assignments depend more or less on individual systematic concepts. The non-trilobitic shelly fauna and the calcimicrobes from the Torgau-Doberlug syncline do not yield further biostratigraphic information.

		West-Gondwana		Iberia	Germany		
					GS	TDS	FF
Middle Cambrian	Celtiberian	Languedocian	Languedocian				Berglesh.
		Caesaraugustan	Caesaraugustan				Lippertsg.
		Agdzian	Leonian		Delitzsch		Triebenreuth
					Tröbitz		Wildenstein
Early Cambrian	Atlasian	Banian	Marianian	Charlottenh.			Galgenberg
		Issendalenian	Ovetian		Zwethau		Tiefenbach
	Corduban	Corduban					

Figure 4. Stratigraphic scheme of the German Cambrian correlative to the Iberian (Sdzuy et al., 1999) and the western Gondwana scale (proposed by Geyer and Landing, 2004). The Cambrian of Thuringia, found in two drilling cores, is not included because of a lack of biostratigraphic data (available from only a few very poorly preserved microfossils) for a more precise determination within the Cambrian. Berglesh.—Bergleshof Formation; Charlottenh.—Charlottenhof Formation; FF—Frankenwald Forest; GS—Görlitz syncline; Lippertsg.—Lippertsgrün Formation; TDS—Torgau-Doberlug syncline.

Paleobiogeographically, the German Early Cambrian biota show distinct relations to the Mediterranean area. Thus, the genus *Lusatiops* is known outside the Görlitz syncline only from the Iberian Chains and, amazingly, from Korea (Geyer and Elicki, 1995). The Görlitz genus *Ferralsia* is reported from the southern Montagne Noire (France) and the Görlitz species *F. saxonica* from the Sierra Morena (Spain) (Geyer and Elicki, 1995; Álvaro et al., 1998). In the latter region, as in the Görlitz syncline, *Serrodiscus silesius* co-occurs with *Lusatiops* and with *Ferralsia*. The only known Early Cambrian trilobite genus from the Torgau-Doberlug syncline region, *Dolerolichia*, is not yet reported elsewhere. It belongs to the neoredlichids, which are widely distributed in the Mediterranean area. The closest morphological relatives of *Dolerolichia* come from the Spanish-Moroccan region and from southern China (Sdzuy, 1962).

The archaeocyathans from the Torgau-Doberlug syncline were formerly used to conclude a paleobiogeographical Siberia connection (Freyer and Suhr, 1987). However, a critical re-investigation of the material has led to the rejection of such an affinity: the archaeocyathans of the Torgau-Doberlug syncline instead

show distinct relations to the Sierra Morena area (Spain) and Morocco (Elicki and Debrenne, 1993).

The non-trilobitic shelly fauna from the Görlitz syncline is very similar to more or less coeval assemblages along the so-called "Paleotethyan belt" (Brasier, 1989b; Bengtson et al., 1990; Brock et al., 2000). *Anabarella australis* (helcionellid) and *Yuwenia* (gastropod) are known only from Australia and Germany (Görlitz syncline) (Runnegar in Bengtson et al., 1990; Elicki, 1994, 1996; Brock et al., 2000; Gubanov et al., 2004a,b). Other common molluscs are *Pelagiella*, *Bemella*, *Obtusoconus*, *Fordilla*, and *Pojetaia* (Elicki, 1994, 1996). *Beshtashella* (gastropod) is described from the Görlitz syncline, Spain, Australia, southern China, and Kazakhstan (Elicki, 1994; Gubanov et al., 2004b). Other shelly microfossils also point to a closer connection of areas that were hitherto assumed as positioned at great distances: the pseudoconodont *Rhombocorniculum cancellatum* from the Görlitz syncline is known from Avalonia, Baltica, Kazakhstan, Mongolia, southern China, and Siberia in roughly coeval strata (e.g., Walliser, 1958; Landing et al., 1980; Brasier, 1989a; Elicki and Schneider, 1992). Additionally, cambroclaves (Görlitz and Torgau-Doberlug synclines), representing very uncommon phosphatic microproblematika, are reported from Sardinia, Australia, Kazakhstan, and China (Mambetov and Repina, 1979; Bengtson et al., 1990; Jiang, 1992; Elicki and Wotte, 2003). In any case, in addition to some of the trilobites (see above), the paleogeographic distribution of the German small shelly fossils seems to support probable Cambrian relationships of the Mediterranean province to eastern Gondwana (Early Cambrian: Pillola, 1991, 1993; Middle Cambrian: Sdzuy, 1972; Late Cambrian: Shergold et al., 2000).

Because of the widespread distribution of the Early–Middle Cambrian taxa, Gubanov (2002) and Gubanov et al. (2004b) concluded that the Cambrian paleocontinents must have been situated closer together than was previously assumed. For the Early Cambrian, in any case, the high degree of accordance of the shelly faunas along the Gondwanan margins suggests an intensive and more or less uninterrupted exchange of taxa (1) within the western Perigondwana realm, (2) along the Gondwana margins, and (3) probably to other paleocontinents.

DISCUSSION AND CONCLUSIONS

Typical for the Cambrian of the Saxo-Thuringian zone of Perigondwana is a sedimentary gap between the late Neoproterozoic (Ediacaran) and the higher Early Cambrian, as well as the widespread absence of Upper Cambrian (Furongian) strata because of nondeposition and/or intensive uplift-related denudation (Linnemann et al., 2000). Generally, not only for the German successions but also for most of central and southern European Mediterranean, Cambrian strata were deposited within separated pull-apart basins is the widely accepted model (e.g., Buschmann et al., 1995, 2006; Linnemann et al., 2000, Murphy et al., 2004). However, such an assumption of isolated depocenters is not supported by the paleontological data. The demonstrated paleogeographic relationships of the German Early Cambrian benthic fossil

assemblages cannot be explained if they lived in isolated sedimentary basins. In contrast, the wide geographical distribution, especially of the German trilobite and archaeocyathan taxa, needs not only open-marine conditions but also long-duration migration paths for faunal exchange between the German and the French, Spanish, Portuguese, and Moroccan depocenters, at least (Sdzuy, 1972; Elicki and Debrenne, 1993; Geyer and Elicki, 1995; Álvaro et al., 1998; Liñán et al., 2004). The trilobites and the small shelly fossils of the Görlitz syncline may further suggest long-distance relationships to the other edge of the Paleotethys (see above). Of course, there are doubtless endemic elements in the Cambrian faunas from the Mediterranean (e.g., Sdzuy, 1972; Álvaro et al., 2003). But these do not indicate distinct paleogeographical isolation. Spatial separation of assemblages (and so of genetic information) can also be caused by other, but rather locally acting factors (e.g., temperature, temperature variations, available nutrients, turbidity, water-currents and circulation, environment stability, substrate consistency, direction of coastlines; Dodd and Stanton, 1990). Genetic alterations (mutations) of species in such “separated” communities (e.g., caused by the generally stronger cosmic radiation and the relatively unprotected exposure of organisms within the shallow-water habitats) may result in speciation of new, but now endemic, elements. Such separating outer factors would selectively affect different groups of an assemblage, which can lead to different speciation rates within the “separated” area and can explain the co-occurrence of endemic and non-endemic taxa. There are recent examples for the occurrence of adjoining biotic assemblages containing endemic and non-endemic elements in shortest distance to one another, on the same shelf, without any geographical separation (Sverdrup et al., 1942; Valentine, 1973). In fact, each province or realm, or any biogeographical area, is characterized by a distinct collection of endemic species, and the borders between those regions are usually distinct.

A second argument for deposition of the German Cambrian sediments within limited basins should be the seemingly local occurrence of the former in contrast to the succeeding widely distributed Ordovician strata (Linnemann and Buschmann, 1995; Linnemann and Schauer, 1999; Linnemann, 2003). However, some widespread late Middle Cambrian to Early Ordovician phases of uplift and denudation are indicated for different regions of western Perigondwana (e.g., Courtessole, 1973; Bechstädt and Boni, 1994; Linnemann and Buschmann, 1995; Gutiérrez-Marco et al., 2002; Leone et al., 2002). So, not only for Germany but also for the Cambrian succession in Sardinia, for instance, significant erosion of sediments is reported (in Sardinia up to ~2000 m; Bechstädt and Boni, 1994). That level of erosion suggests that the intensities of uplift and denudation have been regionally very different.

A further argument against Cambrian deposition in regionally limited basins could be the amazing accordance and continuity of coeval sedimentary facies patterns. Very similar sedimentary successions from Morocco via Portugal, Spain, France, Sardinia, and Germany up to Turkey are highly comparable, which means they are similar over the whole of central Perigondwana (=European

shelf sensu Courjault-Radé et al., 1992) (Dean and Monod, 1970; Bechstädt et al., 1988; Courjault-Radé, 1988; Courjault-Radé et al., 1991; Pillola, 1993; Bechstädt and Boni, 1994; Elicki, 1994; Liñán et al., 1996, 2002; Álvaro et al., 1999; Fernández-Remolar, 1999; Göncüoğlu and Kozlu, 2000; Sarmiento et al., 2001).

The synthesis of these three points (very active faunal exchange, successively strong but regionally different uplift and denudation, and widely consistent facies realms) supports a modified model of a rather consistent and simply more or less differentiated European shelf of Gondwana, probably containing some areas of higher subsidence (intra-shelf basins). The latter and the different degree of erosion explain the sometimes impressive thicknesses of the preserved sedimentary successions. Thus, the currently interpreted central and southern European terranes represent fragmentary preserved areas of an originally rather consistent central peri-Gondwanan shelf in the Cambrian—a model that may also be extrapolated to the Middle Cambrian (Sdzuy, 1957b, 1962, 1970, 2000; Sdzuy et al., 1999). The content, the coinciding evolution patterns, and the paleogeographic relationships of Perigondwana’s Early to Middle Cambrian faunas demonstrate that a separation and evolution of terranes had not started before the end of the Cambrian or the start of the Early Ordovician. For the Early and Middle Cambrian times at least, a slightly differentiated shelf configuration of central Perigondwana without isolated areas fits best with the paleontological and sedimentological data.

ACKNOWLEDGMENTS

Many thanks for useful help in the field, for many discussions, and for critical remarks go to Gerd Geyer (Würzburg, Germany), Eladio Liñán (Zaragoza, Spain), Andrey Zhuravlev (Moscow, Russia), and Thomas Wotte and Bernd Buschmann (both Freiberg, Germany). The work was generously supported by the German Research Foundation (research project EL 144/1, 144/12 and Schn 408/1).

REFERENCES CITED

- Álvaro, J.J., Liñán, E., and Vizcaíno, D., 1998, Biostratigraphical significance of the genus *Ferralsia* (Lower Cambrian, Trilobita): *Geobios*, v. 31, no. 4, p. 499–504, doi: 10.1016/S0016-6995(98)80121-6.
- Álvaro, J.J., Vizcaíno, D., and Vennin, E., 1999, Trilobite diversity patterns in the Middle Cambrian of southwestern Europe: A comparative study: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 151, p. 241–254, doi: 10.1016/S0031-0182(99)00033-4.
- Álvaro, J.J., Elicki, O., Geyer, G., Rushton, A.W.A., and Shergold, J.H., 2003, Palaeogeographical controls on the Cambrian trilobite immigration and evolutionary patterns reported in the western Gondwana margin: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 195, no. 1–2, p. 5–35, doi: 10.1016/S0031-0182(03)00300-6.
- Bechstädt, T., and Boni, M., 1994, Controls on the evolution of the Cambrian carbonate platform in Bechstädt, T., and Boni, M., eds., *Sedimentological, stratigraphical and ore deposits field guide of the autochthonous Cambro-Ordovician of southwestern Sardinia: Memorie descrittive della carta geologica d’Italia*, v. XLVIII: Rome, Servizio Geologico Nazionale, 434 p.
- Bechstädt, T., Schledding, T., and Selg, M., 1988, Rise and fall of an isolated, unstable carbonate platform: The Cambrian of southwestern Sardinia: *Geologische Rundschau*, v. 77, no. 2, p. 389–416, doi: 10.1007/BF01832387.

- Bengtson, S., Conway Morris, S., Cooper, B.J., Jell, P.A., and Runnegar, B.N., 1990, Early Cambrian fossils from South Australia: Brisbane, Association of Australasian Palaeontologists Memoir 9, 364 p.
- Blumenstengel, H., 1980, Zur Paläontologie und Biostratigraphie der Heinersdorfer Serie (Kambrium) im Thüringer Schiefergebirge: Freiburger Forschungshefte, v. C348, p. 61–68.
- Brasier, M.D., 1989a, Towards a biostratigraphy of the earliest skeletal biotas, in Cowie, J.W., and Brasier, M.D., eds., The Precambrian-Cambrian boundary: Oxford, Clarendon Press, p. 117–165.
- Brasier, M.D., 1989b, China and the Palaeoethyan belt (India, Pakistan, Iran, Kazakhstan, and Mongolia), in Cowie, J.W., and Brasier, M.D., eds., The Precambrian-Cambrian boundary: Oxford, Clarendon Press, p. 40–74.
- Brasier, M.D., 1990, Nutrients in the early Cambrian: *Nature*, v. 347, no. 6293, p. 521–522, doi: 10.1038/347521b0.
- Brasier, M.D., 1992, Nutrient-enriched waters in the early skeletal fossil record: *Journal of the Geological Society of London*, v. 149, p. 621–629.
- Brause, H., 1969, Das verdeckte Altpaläozoikum der Lausitz und seine regionale Stellung: Abhandlungen der Deutschen Akademie der Wissenschaften, Klasse Bergbau, Hüttenwesen und Montangeologie, v. 1968, no. 1, p. 1–143.
- Brock, G.A., Engelbretsen, M.J., Jago, J.B., Kruse, P.D., Lauri, J.R., Shergold, J.H., Shi, G.R., and Sorauf, J.E., 2000, Palaeobiogeographic affinities of Australian Cambrian faunas, in Wright, A.J., Young, G.C., Talent, J.A., and Lauri, J.R., eds., Palaeobiogeography of Australian faunas and floras: Brisbane, Association of Australasian Palaeontologists Memoir 23, p. 1–61.
- Buschmann, B., Linnemann, U., Schneider, J., and Süß, T., 1995, Die cadomische Entwicklung im Untergrund der Torgau-Doberluger Synklinale: Zeitschrift für geologische Wissenschaften, v. 23, no. 5–6, p. 729–749.
- Buschmann, B., Elicki, O., and Jonas, P., 2006, The Cadomian unconformity in the Saxo-Thuringian Zone, Germany: Palaeogeographic affinities of Ediacaran (terminal Neoproterozoic) and Cambrian strata: *Precambrian Research*, v. 147, p. 387–403.
- Courjault-Radé, P., 1988, Analyse sédimentologique de la formation de l'Orbiel ("alternance grés-calcaires" autc., Cambrian inférieur). Evolution tectono-sédimentaire et climatique (versant sud de la Montagne Noire, Massif central, France): *Bulletin de la Société Géologique de France*, v. 8, no. 6, p. 1003–1013.
- Courjault-Radé, P., Gandin, A., Debrenne, F., and Doré, F., 1991, Geodynamic control on Lower Cambrian sedimentation in Normandy, Montagne Noire (France) and Sardinia (Italy), *Geologia del Basamento Italiano—Convegno in memoria di Tommaso Coccozza*, Siena, March 21–22, 1991, Abstracts: Siena, Università degli studi, p. 145–147.
- Courjault-Radé, P., Debrenne, F., and Gandin, A., 1992, Palaeogeographic and geodynamic evolution of the Gondwana continental margins during the Cambrian: *Terra Nova*, v. 4, p. 657–667.
- Courtessole, R., 1973, Le Cambrien moyen de la Montagne Noire—Biostratigraphie: *Imprim d'Oc*, Toulouse, 248 p.
- Dean, W.T., and Monod, O., 1970, The lower Palaeozoic stratigraphy and faunas of the Taurus Mountains near Beysehir, Turkey—I. Stratigraphy: *Bulletin of the British Museum (Natural History): Geology*, v. 19, no. 8, p. 413–426.
- Debrenne, F., and Zhuravlev, A.Yu., 1997, Cambrian food web: A brief review: *Geobios*, no. 20, p. 181–188.
- Dodd, J.R., and Stanton, R.J., Jr., 1990, Paleocology—Concepts and applications: New York, Chichester, Brisbane, Toronto, Singapore, Wiley & Sons, 502 p.
- Elicki, O., 1992, Faziesanalyse der unterkambrischen Karbonate Deutschlands [Ph.D. thesis]: Freiberg, Freiberg University, 121 p.
- Elicki, O., 1994, Lower Cambrian carbonates from eastern Germany: Palaeontology, stratigraphy and palaeogeography: *Neues Jahrbuch für Geologie und Paläontologie*, Abhandlungen, v. 191, no. 1, p. 69–93.
- Elicki, O., 1996, Die Gastropoden und Monoplacophoren der unterkambrischen Görlitz Fauna: *Freiburger Forschungshefte*, v. C464, p. 145–173.
- Elicki, O., 1997, Biostratigraphic data of the German Cambrian—Present state of knowledge: *Freiburger Forschungshefte*, v. C466, p. 155–165.
- Elicki, O., 1998, First report of *Halkieria* and enigmatic globular fossils from the central European Marianian (Lower Cambrian, Görlitz syncline, Germany): *Revista Española de Paleontología*, número extraordinario, Homenaje al Prof. Gonzalo Vidal, p. 51–64.
- Elicki, O., 1999a, Beitrag zur Lithofazies und zur Lithostratigraphie im Unterkambrium von Doberlug-Torgau: *Freiburger Forschungshefte*, v. C481, p. 107–119.
- Elicki, O., 1999b, Palaeoecological significance of calcimicrobial communities during ramp evolution: An example from the Lower Cambrian of Germany: *Facies*, v. 41, p. 27–40.
- Elicki, O., 2003, Das Kambrium Sachsens: Veröffentlichungen des Museums für Naturkunde Chemnitz, v. 26, p. 41–62.
- Elicki, O., 2005, The utility of late Early to Middle Cambrian small shelly fossils from the western Mediterranean: *Geosciences Journal*, v. 9, p. 161–171.
- Elicki, O., and Debrenne, F., 1993, The Archaeocyatha of Germany: *Freiburger Forschungshefte*, v. C450, p. 3–40.
- Elicki, O., and Schneider, J., 1992, Lower Cambrian (Atdabanian/Botomian) shallow-marine carbonates of the Görlitz syncline (Saxony/Germany): *Facies*, v. 26, p. 55–66.
- Elicki, O., and Wotte, Th., 2003, Cambroclaves from the Cambrian of Sardinia (Italy) and Germany: Constraints for the architecture of western Gondwana and the palaeogeographical and paleoecological potential of cambroclaves: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 195, p. 55–71, doi: 10.1016/S0031-0182(03)00302-X.
- Fernández-Remolar, D.C., 1999, Las calizas fosforíticas del Ovetiense Inferior de la Sierra de Córdoba, España: *Boletín de la Real Sociedad Española de Historia Natural, Sección Geológica*, v. 95, p. 15–45.
- Franke, W., 1984, Variszischer Deckenbau im Raume der Münchberger Gneismasse—abgeleitet aus der Fazies, Deformation und Metamorphose im umgebenden Paläozoikum: *Geotektonische Forschungen*, v. 68, p. 1–253.
- Freyer, G., 1977, Das Unterkambrium von Görlitz, seine geologische Erforschung und Fossilführung—ein Überblick: *Abhandlungen und Berichte des Naturkundemuseums Görlitz*, v. 51, no. 7, p. 18–29.
- Freyer, G., 1981a, Die unterkambrische Brachiopodenfauna des Görlitzer Schiefergebirges: *Abhandlungen und Berichte des Naturkundemuseums Görlitz*, v. 54, no. 5, p. 1–20.
- Freyer, G., 1981b, Die Cruzianen von Hainichen bei Borna und das Alter ihrer Fundschichten: *Freiburger Forschungshefte*, v. C363, p. 51–55.
- Freyer, G., and Suhr, P., 1987, Über Archaeocyathinen-Funde und den lithologischen Aufbau des Unterkambriums im Gebiet von Torgau: *Zeitschrift für geologische Wissenschaften*, v. 15, no. 6, p. 665–680.
- Freyer, G., and Suhr, P., 1992, Über Algengemeinschaften aus der unterkambrischen Zwethauer Folge des Gebietes von Torgau: *Freiburger Forschungshefte*, v. C445, p. 49–65.
- Geyer, G., and Elicki, O., 1995, Lower Cambrian trilobites from the Görlitz Synclinorium (Germany)—Review and new results: *Paläontologische Zeitschrift*, v. 69, no. 1–2, p. 87–119.
- Geyer, G., and Landing, E., 2004, A unified Lower–Middle Cambrian chronostratigraphy for West Gondwana: *Acta Geologica Polonica*, v. 54, no. 2, p. 179–218.
- Göncüoğlu, M.C., and Kozlu, H., 2000, Early Paleozoic evolution of NW Gondwanaland: Data from southern Turkey and surrounding regions: *Gondwana Research*, v. 3, p. 315–323, doi: 10.1016/S1342-937X(05)70290-2.
- Göthel, M., 2001, Das autochthone und allochthone Paläozoikum des "Görlitzer Schiefergebirges" (Mitteleuropäische Varisziden, Deutschland): *Zeitschrift für geologische Wissenschaften*, v. 29, no. 1–2, p. 55–73.
- Gozaló, R., and Hinz-Schallreuter, I., 2002, Biostratigraphy and palaeobiogeography of the Cambrian genus *Hipponicharion* (Ostracoda): *Paläontologische Zeitschrift*, v. 76, no. 1, p. 65–74.
- Gubanov, A.P., 2002, Early Cambrian palaeogeography and the probable Iberia-Siberia connection: *Tectonophysics*, v. 352, p. 153–168, doi: 10.1016/S0040-1951(02)00194-4.
- Gubanov, A.P., Skovsted, C.B., and Peel, J.S., 2004a, *Anabarella australis* (Mollusca, Helcionelloida) from the Lower Cambrian of Greenland: *Geobios*, v. 37, p. 719–724, doi: 10.1016/j.geobios.2003.05.009.
- Gubanov, A.P., Fernández-Remolar, D.C., and Peel, J.S., 2004b, Early Cambrian molluscs from Sierra de Córdoba (Spain): *Geobios*, v. 37, p. 199–215, doi: 10.1016/j.geobios.2003.04.003.
- Gutiérrez-Marco, J.C., Robardet, M., Rábano, I., Sarmiento, G.N., San José Lancha, M.Á., Araújo, P.H., and Pieren Pidal, A.P., 2002, Ordovician, in Gibbons, W., and Moreno, T., eds., *The geology of Spain*: London, Geological Society of London, p. 31–49.
- Jiang, Z., 1992, The Lower Cambrian fossil record of China, in Lipps, J.H., and Signor, P.W., eds., *Origin and early evolution of the metazoan*: New York and London, Plenum Press, p. 311–333.
- Jonas, P., Buschmann, B., and Gaitzsch, B., 2000, Unterkambrischer und unterkarboner Vulkanismus der Torgau-Doberluger Synklinale (NE Saxothuringische Zone): *Zeitschrift für geologische Wissenschaften*, v. 28, no. 1–2, p. 157–175.
- Kemnitz, H., Romer, R.L., and Oncken, O., 2002, Gondwana break-up and the northern margin of the Saxothuringian belt (Variscides of central Europe):

- International Journal of Earth Sciences, v. 91, p. 246–259, doi: 10.1007/s005310100209.
- Landing, E., Nowlan, G.S., and Fletcher, T.P., 1980, A microfauna associated with Early Cambrian trilobites of the *Callavia* zone, northern Antigonish Highlands, Nova Scotia: Canadian Journal of Earth Sciences, v. 17, p. 400–418.
- Leone, F., Ferretti, A., Hammann, W., Loi, A., Pillola, G.L., and Serpagli, E., 2002, A general view on the post-Sardic Ordovician sequence from SW Sardinia: Rendiconti della Società Paleontologica Italiana, v. 1, p. 51–68.
- Liñán, E., Gámez Vintaned, J.A., and Gozalo, R., 1996, II. Field Conference of the Cambrian Stage Subdivision Working Groups, International Subcommittee on Cambrian Stratigraphy, Zaragoza, Spain, September 13–21, Field trip guide and abstracts: Zaragoza, Spain, Universidad de Zaragoza, 129 p.
- Liñán, E., Gozalo, R., Palacios, T., Gámez Vintaned, J.A., Ugidos, J.M., and Mayoral, E., 2002, Cambrian, in Gibbons, W., and Moreno, T., eds., The geology of Spain: London, Geological Society of London, p. 17–29.
- Liñán, E., Perejón, A., Gozalo, R., Moreno-Eiris, E., and de Oliveira, J.T., 2004, The Cambrian system of Iberia: Madrid, Publicaciones del Instituto Geológico y Minero de España, Ser. Cuadernos del Museo Geominero, v. 3, 63 p.
- Linnemann, U., 2003, Sedimentation und geotektonischer Rahmen der Bekenentwicklung im Saxothuringikum (Neoproterozoikum–Unterkarbon): Geologica Saxonica, v. 48/49, p. 71–110.
- Linnemann, U., and Buschmann, B., 1995, Die cadomische Diskordanz im Saxothuringikum (oberkambrisch-tremadocische overlap-Sequenzen): Zeitschrift für geologische Wissenschaften, v. 23, no. 5–6, p. 707–727.
- Linnemann, U., and Schauer, M., 1999, Die Entstehung der Elbezone vor dem Hintergrund der cadomischen und variszischen Geschichte des Saxothuringischen Terranes—Konsequenzen aus einer abgedeckten geologischen Karte: Zeitschrift für geologische Wissenschaften, v. 27, no. 5–6, p. 529–561.
- Linnemann, U., Gehmlich, M., Tichomirowa, M., Buschmann, B., Nasdala, L., Jonas, P., Lützner, H., and Bombach, K., 2000, From Cadomian subduction to Early Palaeozoic rifting: The evolution of Saxo-Thuringia at the margin of Gondwana in the light of single zircon geochronology and basin development (central European Variscides, Germany), in Franke, W., Haak, V., Oncken, O., and Tanner, D., eds., Orogenic processes: Quantification and modelling in the Variscan belt: London, Geological Society of London, Special Publication 179, p. 131–153.
- Mambetov, A.M., and Repina, L.N., 1979, The Lower Cambrian of the Talasskiy Alatau and its correlation with the sections of Maly Karatau and the Siberian platform, in Zhuravleva, I.T., and Meshkova, N.P., eds., Biostratigraphy and palaeontology of the Lower Cambrian of Siberia: Moscow, Nauka, p. 98–138 (in Russian).
- Murphy, J.B., Pisarevsky, S.A., Nance, R.D., and Keppie, J.D., 2004, Neoproterozoic–Early Paleozoic evolution of peri-Gondwanan terranes: Implications for Laurentia–Gondwana connections: International Journal of Earth Sciences, v. 93, p. 659–682, doi: 10.1007/s00531-004-0412-9.
- Nance, R.D., and Murphy, J.B., 1994, Contrasting basement isotopic signatures and the palinspastic restoration of peripheral orogens: Example from the Neoproterozoic Avalonian–Cadomian belt: Geology, v. 22, p. 617–620, doi: 10.1130/0091-7613(1994)022<0617:CBISAT>2.3.CO;2.
- Pillola, G.L., 1991, Trilobites du Cambrien inférieur du SW de la Sardaigne, Italie: Palaeontographica Italica, v. 78, p. 1–174.
- Pillola, G.L., 1993, The Lower Cambrian trilobite *Bigotina* and allied genera: Palaeontology, v. 34, no. 4, p. 855–881.
- Rožanov, A.Yu., and Zhuravlev, A.Yu., 1992, The Lower Cambrian fossil record of the Soviet Union, in Lipps, J.H., and Signor, P.W., eds., Origin and early evolution of the Metazoa: New York, London, Plenum Press, p. 205–309.
- Sarmiento, G.N., Fernández-Remolar, D., and Göncüoğlu, M.C., 2001, Cambrian small shelly fossils from the Cal Tepe Formation, Taurus Mountains, Turkey: Coloquios de Paleontología, v. 52, p. 117–134.
- Schwarzbach, M., 1934, Das Cambrium der Oberlausitz: Abhandlungen der Naturforschenden Gesellschaft Görlitz, v. 32, no. 2, p. 7–54.
- Sdzuy, K., 1957a, Revision der mittelkambrischen Trilobiten von Doberlug: Senckenbergiana Lethaea, v. 38, p. 7–28.
- Sdzuy, K., 1957b, Alter und tiergeographische Stellung des Mittelkambriums von Doberlug: Geologie, v. 6, no. 5, p. 465–475.
- Sdzuy, K., 1962, Neue kambrische Fossilien aus Bohrungen im Gebiet von Doberlug: Geologie, v. 11, no. 9, p. 1087–1101.
- Sdzuy, K., 1970, Mittelkambrische Fossilien aus neuen Bohrungen bei Doberlug und bei Delitzsch: Geologie, v. 19, no. 9, p. 1066–1085.
- Sdzuy, K., 1972, Das Kambrium der acadobaltischen Faunenprovinz—Gegenwärtiger Kenntnisstand und Probleme: Zentralblatt für Geologie und Paläontologie, Teil II, v. 1972, no. 1–2, p. 1–91.
- Sdzuy, K., 2000, Das Kambrium des Frankenwaldes: Senckenbergiana Lethaea, v. 79, p. 301–327.
- Sdzuy, K., Liñán, E., and Gozalo, R., 1999, The Leonian stage (early Middle Cambrian): A unit for Cambrian correlation in the Mediterranean subprovince: Geological Magazine, v. 136, p. 39–48, doi: 10.1017/S0016756899002241.
- Shergold, J.H., Feist, R., and Vizcaino, D., 2000, Early Late Cambrian trilobites of Australo-Sinian aspect from the Montagne Noire, southern France: Palaeontology, v. 43, p. 599–632, doi: 10.1111/1475-4983.00142.
- Sverdrup, H.V., Johnson, M.W., and Fleming, R.H., 1942, The oceans: Their physics, chemistry, and general biology: Englewood Cliffs, New Jersey, Prentice-Hall, 1087 p.
- Torsvik, T.H., Smethurst, M.A., Meert, J.G., Van der Voo, R., McKerrow, W.S., Brasier, M.D., Sturt, B.A., and Walderhaug, H.J., 1996, Continental break-up and collision in the Neoproterozoic and Palaeozoic—A tale of Baltica and Laurentia: Earth Science Reviews, v. 40, p. 229–258, doi: 10.1016/0012-8252(96)00008-6.
- Valentine, J.W., 1973, Evolutionary paleoecology of the marine biosphere: Englewood Cliffs, New Jersey, Prentice-Hall, 511 p.
- Walliser, O.H., 1958, *Rhombocorniculum comleyense* n. gen., n. sp: Paläontologische Zeitschrift, v. 32, p. 176–180.
- Wotte, Th., 2004, Nachweis und fazielle Position von reef mounds im Unterkambrium von Doberlug-Torgau: Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, v. 233, no. 3, p. 397–422.