Annales Societatis Geologorum Poloniae (2015), vol. 85: 627–635. doi: http://dx.doi.org/10.14241/asgp.2015.024

AGE AND CORRELATION OF LATE TRIASSIC TETRAPODS FROM SOUTHERN POLAND

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Lucas, S. G., 2015. Age and correlation of Late Triassic tetrapods from southern Poland. *Annales Societatis Geologorum Poloniae*, 85: 627–635.

Abstract: Age assignments of Triassic tetrapod fossils can be achieved by direct reference to a scheme of Triassic land-vertebrate faunachrons (LVFs) that correlates Triassic tetrapod fossil assemblages to each other based solely on the tetrapod fossils. Correlation of Triassic tetrapod assemblages to the standard global chronostratigraphic scale (SGCS, the "marine timescale") is a separate cross correlation between the vertebrate biochronology and marine biochronology that usually relies on other data (e. g., palynostratigraphy, magnetostratigraphy, radioisotopic ages) to be completed. Late Triassic tetrapod fossils in southern Poland are found at two stratigraphic positions, the Krasiejów and Lisowice levels. The tetrapod assemblage of the Krasiejów level is assigned to the early Adamanian LVF based primarily on the stratigraphic overlap of the phytosaur *Parasuchus* with the Adamanian index aetosaur *Stagonolepis*. The amphibians *Cyclotosaurus* and *Gerrothorax*, a *Proterochersis*-like turtle and the aetosaur *Paratypothorax* from the Lisowice level indicate it is assignable to the Revueltian LVF. Cross correlations to the SGCS are less definitive, but suggest that the Krasiejów level is late Carnian and the Lisowice level is early/middle Norian. However, this correlation of the Krasiejów level is confounded by disagreements over correlation of the marine Carnian–Norian boundary to nonmarine strata. Indeed, the possibility that the Krasiejów tetrapods fill a gap in the early Norian record of tetrapods merits consideration. Such difficulties emphasize the value of correlating tetrapod assemblages to each other using a land-vertebrate biostratigraphy/biochronology, instead of immediately attempting the more problematic correlation to the SGCS.

Key words: Late Triassic, Poland, land-vertebrate faunachron, Krasiejów level, Lisowice level, Adamanian, Revueltian.

Manuscript received 31 March 2015, accepted 28 May 2015

INTRODUCTION

Triassic tetrapod (amphibian and reptile) fossils are known from across what was the Pangean supercontinent and have long been used in biostratigraphy and biochronology, a tradition extending back to at least the 1870s. Lucas (1990) advocated developing a global Triassic timescale based on tetrapod evolution (also see Lucas and Hunt, 1993), and subsequently Lucas (1998, 2010) presented a comprehensive global Triassic tetrapod biochronology (Fig. 1). This biochronological timescale divides the Triassic into eight time intervals (land-vertebrate faunachrons, LVFs) based on biochronological data that represent tetrapod evolutionary events. This scheme has been tested and refined for nearly two decades and was last reviewed by Lucas (2010).

Before 2000, little was known of Polish Late Triassic tetrapods, so reviews of Triassic tetrapod biostratigraphy/biochronology before that time (e.g., Lucas, 1998, 1999) made no mention of Polish Triassic tetrapods. However, this changed radically with the discovery of two extensive bonebeds and other tetrapod occurrences in southern Poland (Silesia) of Late Triassic age (Fig. 2). These bonebeds now rank among the most important Late Triassic tetrapod localities known.

Elsewhere in this volume, Szulc *et al.* (2015) review in detail the stratigraphic context of Late Triassic tetrapod fossils from Poland, and I follow their review in identifying two narrow stratigraphic intervals that produce these fossils, the Krasiejów and Lisowice levels (Fig. 2). Published age assignments for both levels, which have mostly been correlated directly to the marine timescale, are controversial (Szulc *et al.*, 2015). Here, I discuss the age of the Silesian Upper Triassic tetrapod-fossil-producing levels with regard to the tetrapod biochronology of the Late Triassic and then, separately, with regard to the standard global chronostratigraphic scale (SGCS).

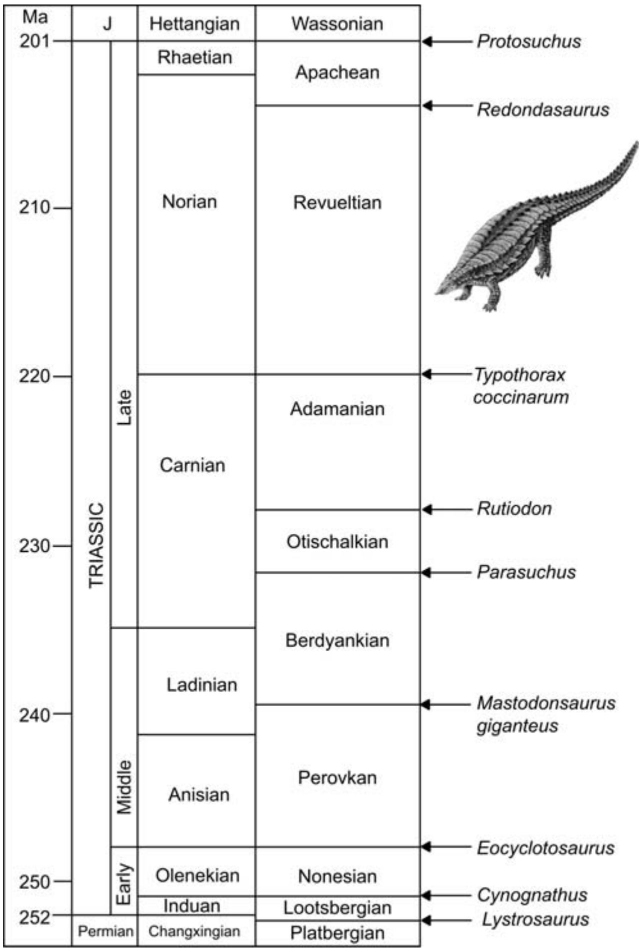

Fig. 1. The Triassic timescale based on tetrapod biostratigraphy and biochronology. Triassic SGCS based on Lucas *et al.* (2012) and Ogg *et al.* (2014). Modified from Lucas (2010).

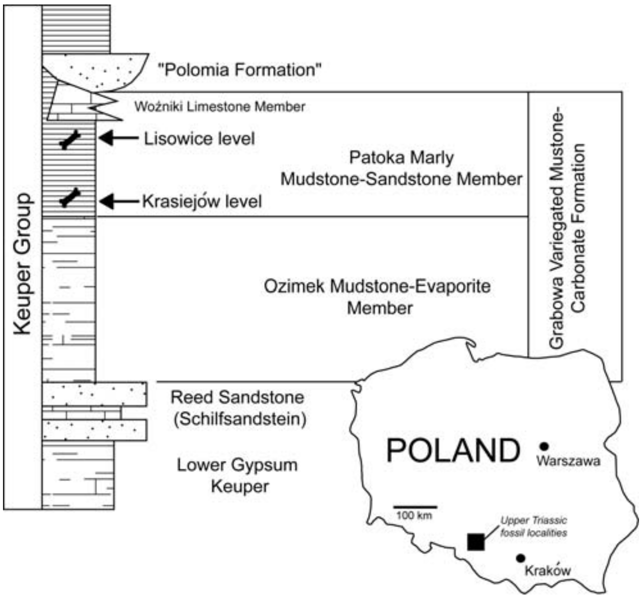

Fig. 2. Stratigraphic distribution of the two vertebrate-fossil-bearing levels in the Upper Triassic of Silesia (after Szulc *et al.*, 2015, fig. 2) and index map of Poland showing location of area with fossil localities.

CORRELATION AND CROSS CORRELATION

Land-vertebrate faunachrons (LVFs) are biochronological units, and their beginnings are defined by biochronological events (Lucas, 1998, 2010). Each LVF begins with the FAD (first appearance datum) of a tetrapod index taxon, usually a genus, though species are used if they provide greater biochronologic resolution (Fig. 1). In so doing, the end of an LVF is defined by the beginning of the succeeding LVF, which is the FAD of another tetrapod index taxon. This is a precise way to define LVF boundaries, so LVFs are interval biochrons.

A distinctive assemblage of vertebrate fossils characterizes each LVF. This tetrapod assemblage is the primary basis for characterization of the LVF. Index fossils of LVFs meet the criteria of true index fossils (temporally restricted, common, widespread, easily identified) and do not include endemic or rare taxa that happen to be restricted to a LVF, usually as single records. The tetrapod biochronology of the Triassic is a timescale independent of the SGCS (Fig. 1).

The Chinle Group strata of the American Southwest yield the best studied and most complete fossil record of Upper Triassic tetrapods (e.g., Lucas, 1993, 1997; Long and Murry, 1995; Lucas and Huber, 2003). The Chinle Group tetrapod fossil record thus provided the basis for definition of the four Late Triassic LVFs: Otischalkian, Adamanian, Revueltian and Apachean (Fig. 1). Of great importance, tetrapod fossil assemblages from Texas (Otischalkian characteristic assemblage), Arizona (Adamanian characteristic assemblage) and New Mexico (Revueltian and Apachean characteristic assemblages) are stratigraphically superposed and thus are time successive (e.g., Lucas 1993, 1997; Lucas and Hunt, 1993; Lucas *et al.*, 2007b; Spielmann and Lucas, 2012). The Chinle assemblages yield phytosaurs, aetosaurs and metoposaurs useful for broad correlation, and a burgeoning microvertebrate biostratigraphy also supports the macrovertebrate-based correlation (Lucas, 2010).

Use of a tetrapod biochronology that assigns ages and correlates based on the tetrapods, themselves, frees vertebrate biostratigraphers from attempting to correlate tetrapods directly to the SGCS. This is best exemplified by the North American land-mammal "ages," a set of biochronological units created by Wood *et al.* (1941) to organize Cenozoic, mammal-dominated assemblages, primarily from western North America. As an example, in that scheme a fossil mammal assemblage can be assigned to the Barstovian land-mammal "age," and correlation within the Barstovian can be based only on the known distribution of the mammal fossils. The question of correlating the Barstovian to the SGCS is a separate problem not resolved by mammalian biochronology. Instead, magnetostratigraphy and radioisotopic ages indicate the Barstovian spans ~12.5–15.5 Ma, so it is overlaps the Langhian and Serravalian marine stages of the Miocene on the SGCS (Tedford *et al.*, 2004). No vertebrate biostratigrapher tries to make that correlation (which I call a cross correlation) based on mammals, and in the literature of North American mammalian biochronology, Barstovian is often used with little or no reference to cross correlation to the SGCS.

The important lesson is that a vertebrate biochronological scheme allows ages to be assigned and correlations to be determined by the vertebrates, themselves. Of course, these correlations are based on biostratigraphic data that is inherently incomplete, so that the actual temporal ranges of the taxa being used to correlate are not established with certainty. The correlation to the SGCS is a separate cross correlation between the vertebrate biochronology and marine biochronology that usually relies on other data (e.g., palynostratigraphy, magnetostratigraphy, radioisotopic ages) to be completed. In some places, a terrestrial/freshwater fossil vertebrate is found displaced in marine deposits, which allows some direct cross correlation of vertebrate taxa to the SGCS, but typically that cross correlation relies wholly on non-vertebrate-fossil data.

POLISH LATE TRIASSIC TETRAPODS

The Polish fossil record of Late Triassic tetrapods advanced greatly during the 1990s, when scientific study of the extensive bonebed in the Krasiejów clay pity near Opole began, and much has been published since (see especially the reviews by Dzik and Sulej, 2007, and Szulc *et al.*, 2015).

Dzik *et al.* (2008) announced the discovery of a second, stratigraphically higher Upper Triassic bonebed at the Lipie Śląskie clay pit near Lubliniec. This bonebed yields an assemblage dominated by dicynodonts and archosaurs. There are three other approximately correlative fossil vertebrate localities in Silesia. Another bonebed in the Woźniki clay pit yields vertebrates similar to those from Lipie Śląskie (Sulej *et al.*, 2011). Sulej *et al.* (2011) correlated the Woź- niki assemblage with the Krasiejów locality, but Szulc *et al.* (2015) argue convincingly that the Woźniki assemblage and the Lipie Śląskie assemblage are stratigraphically equivalent and subsume it under what they call the Lisowice level (Fig. 2).

Bones from Poręba were discovered in 2008 and include amphibians, turtles, and aetosaurs, among others, and have in part been described (Sulej *et al.*, 2012; Niedźwiedzki *et al.*, 2014). This locality, and very recently discovered bones from another locality at Zawiercie, are stratigraphically equated to Lipie Śląskie (e.g., Racki, 2010; Szulc *et al.*, 2015b). Thus, the Lisowice level comprises the fossil vertebrate localities at Lipie Śląskie, Woźniki, Poręba and Zawiercie.

PREVIOUSLY ASSIGNED AGES AND CORRELATIONS

There have been two different sets of age assignments of the Krasiejów and the Lisowice levels, one by Dzik and collaborators (e.g., Dzik and Sulej, 2007; also see Pieńkowski *et al.*, 2014) and the other by Szulc *et al.* (2015). These are almost exclusively direct correlations to the SGCS. Lucas *et al.* (2007a) and Lucas (2010) correlated the Krasiejów level directly to the tetrapod biochronology, and Szulc *et al.* (2015) did so with the Lisowice level.

Szulc *et al.* (2015) present a detailed review of these and other age assignments, especially those based on data other than vertebrate biochronology, obviating the need for an extensive review here. Nevertheless, some of these age assignments are discussed below, especially to the extent that they agree or disagree with the correlations advocated here.

CORRELATION TO LATE TRIASSIC LVFS

Krasiejów level

The Krasiejów level includes the following biochronogically significant tetrapod taxa: the amphibians *Cyclotosaurus* and *Metoposaurus*, the phytosaur *Parasuchus* ("*Paleorhinus*"), and the aetosaur *Stagonolepis* (e.g., Dzik and Sulej 2007; Lucas *et al.*, 2007a; Sulej, 2010; Szulc *et al.*, 2015). Lucas *et al.* (2007a) published the first explicit correlation of the Krasiejów level to the Triassic LFVs, assigning it an Otischalkian age. This followed the long held idea that the phytosaur *Parasuchus* is a robust index taxon of the Otischalkian LVF (Hunt and Lucas, 1991; Lucas *et al.*, 2007a).

However, Lucas (2010) concluded that North American and European records of the characteristic Adamanian aetosaur *Stagonolepi*s indicate that some *Parasuchu*s records should be considered early Adamanian in age. Thus, if all *Stagonolepis* records are regarded as Adamanian (as they were by Lucas 1998), then records of *Parasuchus* from the German Kieselsandstein and Blasensandstein (this includes, by my taxonomy, phytosaurs termed *Paleorhinus* and *Ebrachosuchus* by Butler *et al.*, 2014) and the Polish Krasiejów locality are Adamanian. This is also consistent with the Chinle Group record of *Parasuchus* at the *Placerias*/Downs quarries in the Bluewater Creek Formation in eastern Arizona, in what I have regarded as oldest Adamanian strata in the Chinle Group (Lucas, 2010). Thus, recognizing that *Parasuchus* records are not strictly Otischalkian (some are early Adamanian), and that *Stagonolepis* records are strictly Adamanian, clarifies correlation in the Otischalkian–Adamanian interval.

In Germany, the Schilfsandstein (Stuttgart Formation) produces *Metoposaurus* and *Parasuchus* but lacks *Stagonolepis*, so it has been assigned an Otischalkian age (Lucas 1998, 1999, 2010; Fig. 3). Stratigraphically higher, the stratigraphic interval between the Schilfsandstein and the Stubensandstein (the classic Rote Wand, Lehrberg Schichten, Blasensandstein and Kieselsandandstein; Fig. 3) produces *Stagonolepis*, *Parasuchus* and *Metoposaurus*, and is assigned an Adamanian age (Lucas, 2010; Fig. 3). Milner and Schoch (2004) claimed the presence of *Metoposaurus* in the Revueltian Stubensandstein of Germany, They based this claim on a skull acquired by the British Museum in 1862, listed in the museum records as coming from "the Middle Keuper near Stuttgart, Württemburg." Fraas (1889, p. 137) stated the skull came from "Feuerbacher Heide bei Stuttgart" and provided a brief description of the skull, which had never been illustrated. Despite this description, Milner and Schoch (2004, p. 244) stated that "it is questionable if Fraas ever saw the specimen." Feuerbacher Heide was a small community that is now part of greater Stuttgart, where stone quarries in the Schilfsandstein yielded many tetrapod specimens including *Metoposaurus*, the phytosaur *Zanclo-*

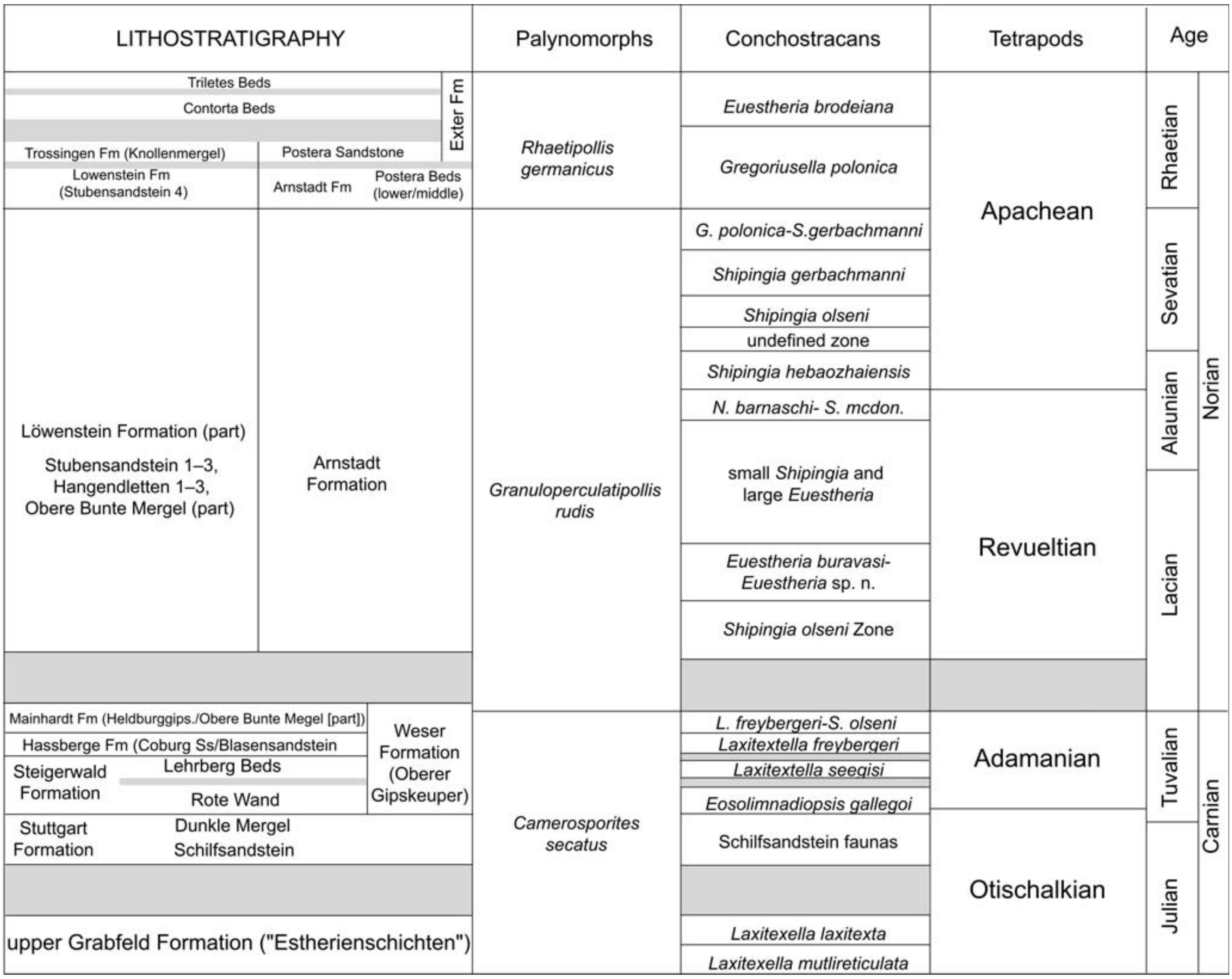

Fig. 3. Biostratigraphy of the Carnian–Norian boundary interval in the Keuper section of the Germanic Basin. Based primarily on Kozur and Bachmann (2008), Kozur and Weems (2010), Kuerschner and Herngreen (2010) and Lucas (2010). Modified from Lucas *et al.* (2012).

don arenaceus and the sphenosuchian *Dyoplax* (e.g., Hunt, 1993; Lucas *et al.*, 1998; Hungerbühler, 2001). Thus, it makes eminent sense for the British Museum metoposaur skull to have come from a stone quarry at Feuerbacher Heide, as stated by Fraas, who had a detailed firsthand knowledge of the Feuerbacher localities and fossils.

Nevertheless, Milner and Schoch (2004) claimed that the BMNH skull came from the Middle Stubensandstein at Aixheim. They based this conclusion on the preservation of the specimen, stating that the "three dimensional creamy-white bone" and "green coarse sandstone" of the BMNH specimen excludes its provenance as Schilfsandstein. However, not all specimens from the Schilfsandstein are black, crushed bone as Milner and Schoch (2004) claim (see for example, the type of *Zanclodon arenaceus*: Hungerbühler, 2001b, figs 1, 2), and "green coarse sandstone" does not exclude the Schilfsandstein lithologically.

Indeed, the original locality data with the British Museum skull preclude its provenance as middle Stubensandstein at Aixheim. Thus, Aixheim is not near Stuttgart, it is ~90 km to the SSW (Hungerbühler, 1998, fig. 1). In 1862, Aixheim would have been at least a two-day journey by horse from Stuttgart, and thus would not have been described as "near Stuttgart." Furthermore, the original attribution to the "Middle Keuper" excludes the Stubensandstein, as the Schilfsandstein was traditionally considered Middle Keuper in Baden-Württemberg (Geyer and Gwinner, 1991). Finally, no well provenanced German metoposaur has ever been found in the Stubensandstein; all are from the Schilfsandstein-Lehrberg Schichten interval (Lucas, 1999). Thus, I conclude that Milner and Schoch's (2004) claim that the British Museum skull is from the Stubensandstein, and thus Revueltian in age, is based on specious reasoning and reject it (also see Lucas *et al.*, 2007b).

I thus follow Lucas (2010) and continue to regard the Krasiejów level as early Adamanian. Particularly compelling is that the vertebrate biochronology correlates it to the Adamanian stratigraphic interval between the Schilfsandstein and Stubensandstein in Germany.

Lisowice level

Biochronologically significant tetrapod taxa reported and/or documented from the Lisowice level include the am-

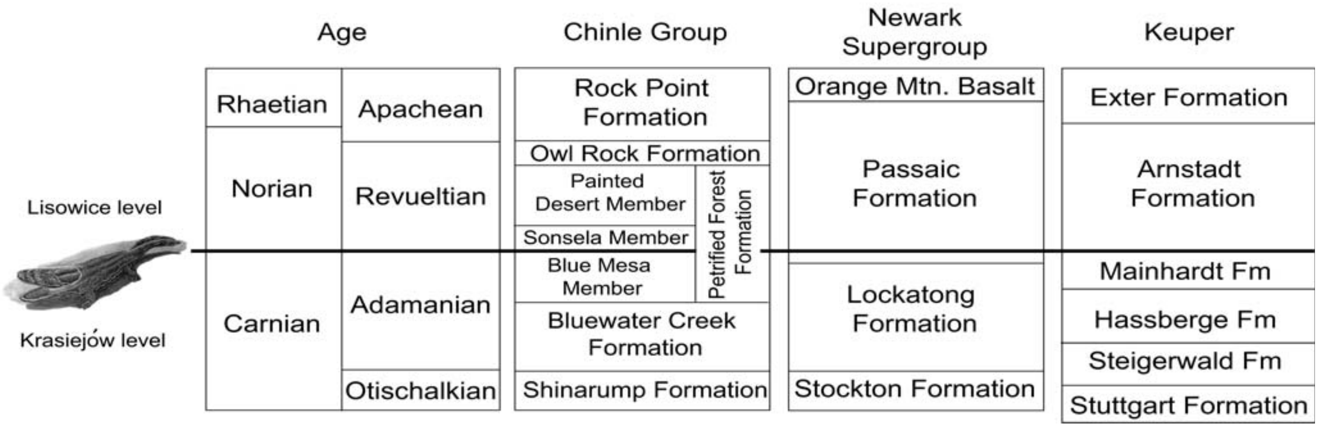

Fig. 4. Nonmarine correlation of the Carnian–Norian boundary (after Lucas *et al.*, 2012) showing correlation of Krasiejów and Lisowice levels proposed here.

phibians *Cyclotosaurus* and *Gerrothorax*, the turtle cf. *Proterochersis*, an aetosaur I judge to be *Paratypothorax* (compare the osteoderms illustrated in Sulej *et al.*, 2012 with those of *Paratypothorax* illustrated by Long and Murry, 1995 and Lucas *et al.*, 2006) and a large dicynodont (Dzik *et al.*, 2008; Sulej *et al.*, 2012; Niedźwiedzki *et al.*, 2012, 2014; Świło *et al.*, 2014). Szulc *et al.* (2015) represents the first explicit correlation of the Lipie Śląskie boned to the Triassic LVFs, assigning it a Revueltian age.

Late Triassic dicynodont records are of Otischalkian–Adamanian age, except for one Revueltian? record from Argentina (Lucas and Wild, 1995; Lucas, 2010). (There is a putative Cretaceous record from Australia (Thulborn and Turner, 2003), but its reliability is questionable.) In Germany, the best known and most diverse Keuper tetrapod assemblage is that of the Lower Stubensandstein (Löwenstein Formation). This Revueltian-age assemblage (Lucas, 1999, 2010) includes the amphibians *Cyclotosaurus* and *Gerrothorax*, the earliest European turtles (including *Proterochersis*), and the aetosaur *Paratypothorax* (e.g., Lucas, 1998, 1999, 2010). These taxa support correlation of the vertebrate fossils from the Lisowice level is to the Lower Stubensandstein assemblage and thus indicate a Revueltian age (Szulc *et al.*, 2015).

Some of the vertebrates of the Lisowice level have been used to advocate a younger age ("Rhaetian," which would be an Apachean age in the land-vertebrate biochronology: Fig. 1). However, these are correlations based on perceived stage of evolution or on poorly known taxa with few records (the mammaliaform tooth from Lipie Śląskie assigned to *Hallauthe- rium*). Instead, I favor correlations based on well-established and long-studied index taxa such as amphibians and aetosaurs.

CORRELATION TO THE SGCS

Records of nonmarine Triassic tetrapods in marine strata (Lucas and Heckert 2000), palynostratigraphy, conchostracan biostratigraphy, magnetostratigraphy and radioisotopic ages provide some basis for correlation of the LVFs to the standard global chronostratigraphic scale (Fig. 1). Nevertheless, reliable data for this cross correlation remain relatively sparse, so the correlation of the LVFs to the SGCS is still imprecise in many time intervals. Thus, the cross correlations shown here (Figs 1, 4) are open to improvement and/or modification.

Krasiejów level

If we accept the cross correlation of the LVFS to the SGCS advocated by Lucas (2010), then the Krasiejów level is late Carnian. Most published direct correlations to the SGCS have assigned the Krasiejów level to the Carnian (e.g., Dzik and Sulej, 2007), but Szulc *et al.* (2015a, b; also see Szulc, 2005), largely based on palynostratigraphy, assigned it to the Norian.

I cross correlate the Adamanian to the late Carnian age based on palynostratigraphy, conchostracan biostratigraphy, sequence stratigraphy and magnetostratigraphy (Lucas *et al.*, 2012). Kozur and Weems (2007, 2010) and Lucas et al. (2012) discussed at length the biostratigraphic evidence to support a late Carnian (Tuvalian) correlation of the Adamanian, and I briefly review it below. However, some magnetostratigraphic correlations, notably by Muttoni *et al.* (2004), repeated recently by Maron *et al.* (2015), places the Norian base much lower in nonmarine strata than did Lucas *et al.* (2012).

Lisowice level

If we accept the cross correlation of the LVFS to the SGCS advocated by Lucas (2010), then the Lisowice level is early-middle Norian. In contrast, Dzik and collaborators assigned the Lisowice level a late Norian and/or Rhaetian age (e.g., Dzik *et al.*, 2008; Niedźwiedzki *et al.*, 2012; Sulej *et al.*, 2012; Świło *et al.*, 2014). This prompted Dzik *et al.* (2008) to argue that the apparently diachronous (anomalously young) occurrence of some vertebrate taxa at the Lipie Śląskie locality indicates very different vertebrate communities lived at the same time in different parts of the Central European Triassic basin. However, the Lisowice level shares vertebrate taxa with Revueltian strata elsewhere, which are convincingly cross correlated to the early-middle Norian. Indeed, correlating the Lisowice level to the early-middle Norian (Revueltian) based on shared index taxa is more parsimonious than arguing for great diachroneity of tetrapod taxa that lived in a single depositional basin.

Furthermore, Szulc *et al.* (2015) review the basis for a Rhaetian correlation of the Lisowice level and demonstrate that it is dubious. All biostratigraphic data, particularly palynostratigraphy and land-vertebrate biochronology, agree that the Lisowice level is either early or middle Norian (Szulc *et al.*, 2015).

DISCUSSION

Lithostratigraphic considerations

An important lithostratigraphic datum in the Triassic section in Silesia is the Reed Sandstone, which has long been known to be the Polish expression of the Schilfsandstein (Stuttgart Formation; Fig. 2). The Schilfsandstein has a well established early Carnian (Julian) age in Germany (e.g., Kozur and Bachmann, 2008). In Silesia, the early Carnian Reed Sandstone is stratigraphically below the Krasiejów and Lisowice levels (Fig. 2), so it sets a maximum age for these bone-bearing intervals. More importantly, equivalence of the Schilfsandstein and Reed Sandstone invites comparison of the Keuper section above the Schilfsandstein in Germany and above the Reed Sandstone in Poland. Such comparison might be used to infer some lithostratigraphic constraints on correlation of the German and the Polish sections (Szulc *et al.*, 2015).

In southern Poland, the strata that contain the Krasiejów and Lisowice levels are a relatively thin, mudstone-dominated section (Fig. 2). They resemble some parts of the post-Schilfsandstein Keuper in Germany (notably parts of the mudstone-dominated units) but are much thinner and lack the stratigraphic architecture of the German section. Most notable is the absence of a substantial sandstone interval in Silesia, the Stubensandstein of the German section.

My correlations of the Krasiejów and Lisowice levels indicate that the approximately 30-m-thick, mudstone-dominated section that they encompass ranges from late Carnian through early-middle Norian, which equates it to much of the Weser Formation (Oberer Gipskeuper) through much of the Löwenstein Formation in the German section (Fig. 2). This correlation suggests that the Polish section is a condensed and likely hiatus-laden correlative of a significant portion of the German Keuper.

In contrast, Szulc *et al.* (2015) advocate an early to middle Norian age for both the Krasiejów and Lisowice levels, which greatly reduces the time interval between the bone-bearing levels. This would correlate the Silesian bone-bearing interval to only part of the Löwenstein Formation. Indeed, Szulc (2005) and Szulc *et al.* (2015b) propose an overall continuous deposition of the Silesian Keuper section, in contrast to "the main Eo-Cimmerian disconformity" usually identified at or near the Norian base in the western Germanic Basin. If so, early Norian vertebrate faunas may be totally absent from Germany, and the Krasiejów fauna may fill the hiatus, and thus represent an otherwise unrecorded early Norian tetrapod assemblage.

Palynostratigraphy

Palynozonation of the Silesian Upper Triassic is based primarily on the work of Orłowska-Zwolińska (1983, 1985). In her zonation, the Krasiejów level is in her subzone IVa, and the Lisowice level is in subzone IVb of her "*Corollina meyeriana* Zone." Kuerschner and Herngreen (2010) reviewed the palynozonation of Orłowska-Zwolińska to place the Carnian–Norian boundary within her "*Corollina meyeriana* Zone," in the lower part of her subzone IVa. Cirilli (2010, fig. 2), however, suggested the Norian base is at the base of the "*Corollina meyeriana* Zone" by indicating in the figure the FAD of *Classopollis meyerianus* (= *Corollina meryeriana*) at the base of the Norian. However, in her text, Cirilli (2010, p. 289) contradicted this by stating that the Carnian–Norian boundary is within the "*Corollina meyeriana* Zone" of Orłowska-Zwolińska.

My assignment of a late Carnian age to the Krasiejów level is consistent with the placement of the Carnian–Norian boundary of Kuerschner and Herngreen (2010). However, as Szulc *et al.* (2015b) note, there is some uncertainty and imprecision in placing the base of the Norian with regard to the palynozonation of Orłowska-Zwolińska. This is part of the basis for their argument that the Krasiejów level is Norian. Clearly, palynological correlation of the Carnian–Norian boundary in the Silesian section is imprecise, debatable and should be improved.

The palynological correlations, however, are much more definitive regarding the age of the Lisowice level. It is in zone IVb of Orłowska-Zwolińska, agreed on by all to be Norian.

Conchostracan biostratigraphy

Kozur and Weems (2005, 2007, 2010) developed a detailed conchostracan biostratigraphy for the nonmarine Triassic of Europe and North America. This is cross correlated to the SGCS primarily based on the German Triassic section. In evaluating the Upper Triassic conchostracan record in Silesia, Kozur and Weems (2010) assigned the Krasiejów level to their late Carnian *Laxitextella seegisi* Zone and the Lisowice level to their early Rhaetian *Gregoriusella polonica* Zone. To my knowledge, *Laxitextella* has no Norian records, so this conchostracan genus at Krasiejów indicates a Carnian age, though the early Norian hiatus in the German section may affect this conclusion. Thus, it is difficult to question Kozur and Weems' (2010) cross correlation of the Krasiejów level, which is consistent with the vertebrate biochronological data and supported by at least one view of the palynostratigraphy. However, assigning the Lisowice level a Rhaetian age based on conchostracans contradicts the cross correlation based on tetrapod biochronology and palynostratigraphy (see comment by Nitsch in Szulc *et al.*, 2015).

It is beyond the scope of this paper to re-evaluate the conchostracan biostratigraphy of Kozur and Weems, but this extensive biostratigraphic scheme needs further testing. Such testing has begun in the Early Triassic (e.g., Becker, 2015) and problems with the Late Triassic correlations are discussed by Maron *et al.* (2015) and Weems and Lucas (2015).

The long Norian

The Late Triassic timescale is poorly constrained due largely to the dearth of reliable radioisotopic ages that can be related precisely to biostratigraphy combined with evident contradictions between biostratigraphic and magnetostratigraphic correlations. These problems are most apparent with regard to the age and correlation of the Carnian–Norian boundary (base of the Norian stage). Lucas *et al.* (2012) reviewed the available age data pertaining to the Carnian–Norian boundary to conclude that the "long Norian" in current use by many workers, which places the Carnian–Norian boundary at ~ 228 Ma, is incorrect. The evidence supports a Norian stage that is much shorter than proposed by these workers, so the Carnian–Norian boundary is considerably younger than this, close to 220 Ma in age (Fig. 1).

Critical to this conclusion is the correlation of the Carnian–Norian boundary in nonmarine strata of Europe and North America, and its integration with existing radioisotopic ages and magnetostratigraphy. Three biostratigraphic datasets (palynomorphs, conchostracans and tetrapods) reliably identify the same position for the Carnian–Norian boundary (within normal limits of biostratigraphic resolution) in nonmarine strata of the Chinle Group (American Southwest), Newark Supergroup (eastern USA and Canada) and the German Keuper. In recent years a correlation based solely on magnetostratigraphy has been proposed between the Pizzo Mondello section in Sicily and the Newark section (Muttoni *et al.*, 2004). Lucas *et al.* (2012) concluded that this correlation, which ignores robust biostratigraphic data, places the Norian base much too low in the Newark Basin section, yet it became the primary justification for placing the Carnian–Norian boundary at ~228 Ma (based on Newark cyclostratigraphy).

Nevertheless, the "long Norian," if accepted, cross correlates the Adamanian to the Norian, which would make the Krasiejów level Norian, as Szulc *et al.* (2015b) conclude. Furthermore, the possibility that the Carnian–Norian boundary correlates to a level within the Adamanian, and that the Krasiejów level is younger than the Norian base should be considered. In these ways, a Norian age for the Krasiejów level is possible. However, my analysis of the available data suggests this is unlikely, so I regard the Krasiejów level as late Carnian.

CONCLUSIONS

1. In southern Poland (Silesia), Upper Triassic tetrapod fossils are known from two narrow stratigraphic intervals, the Krasiejów level and the Lisowice level.
2. Tetrapod index taxa support assigning an early Adamanian age to the Krasiejów level.
3. Tetrapod index taxa support assigning a Revueltian age to the Lisowice level.
4. Cross correlation to the SGCS indicates that the Adamanian Krasiejów level is late Carnian, whereas the Revueltian Lisowice level is early-middle Norian.
5. These correlations imply that the Silesian Upper Triassic section is a condensed and likely hiatus-laden correlative of a significant portion of the German Keuper.
6. Nevertheless, uncertainties with regard to biostratigraphic ranges and correlations of tetrapod, palynomorphs and conchostracans, as well as disagreement about the duration of the Norian, make it possible that the Krasiejów level is Norian. In contrast to other data, conchostracan-based cross correlations indicate the Lisowice level is Rhaetian, and should be re-examined.

Acknowledgments

I thank Grzegorz Racki and Joachim Szulc for inviting this contribution, and for educating me about many details of the Silesian Upper Triassic. Grzegorz Racki and Cesar Leandro Schultz provided helpful reviews that improved the manuscript.

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