The Permian-Triassic boundary and Early Triassic sedimentation in Western European basins: an overview

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Abstract

At the scale of the peri-Tethyan basins of western Europe, the “Buntsandstein” continental lithostratigraphic units are frequently attributed to the “Permian-Triassic” because, in most cases, the lack of any “Scythian” (i.e. Early Triassic) biochronological evidence makes it very difficult to attribute the basal beds of the cycle to the Permian or to the Triassic. A careful recognition of unconformities and sedimentary indications of clearly arid climate provide powerful tools for correlation within non-marine successions that are devoid of any biostratigraphic markers, at least on the scale of the West European Plate.

From a review of the “Buntsandstein” series of several basins we can characterize the Permian-Triassic boundary and the beginning of Triassic sedimentation at the scale of Western Europe. We clearly show that, except for the Central Germanic Basin, an unconformity can be observed between the Permian and the Triassic. Apart from the Germanic Basin, there is a total lack of typically “Scythian” fossils in the rest of West European basins, and the oldest biochronological markers yielded by these units are palynomorphs allowing to assign an Anisian age generally to the upper part of the “Buntsandstein”, but also its lowermost in a few cases. In the peri-Tethyan basins of western Europe, the Permian-Triassic boundary corresponds to an unconformity overlain by conglomerates containing ventifacts (followed by fluvial sandstones, sometimes rich in paleosols and sometimes totally devoid), which are attributed mainly to the lower Olenekian, i.e. Smithian. Alternatively, the succession passes up directly into fluvial sandstones containing the first paleosols, and then plant debris and palynomorphs attributed to the Anisian. In this way, the lack of typically Early Triassic fossils in most of the peri-Tethyan basins, at the scale of the west European Plate, can be explained by a true stratigraphic hiatus in the earliest Triassic (i.e. Induan) and by arid conditions unfavourable for the development of flora and fauna and their preservation during the Olenekian.

Keywords: Permian-Triassic boundary, Early-Middle Triassic, Western Europe basins, Scythian, Anisian.
Resumen

En las cuencas peritéticas de Europa occidental, la unidad litoestratigráfica continental “Buntsandstein” es frecuentemente atribuida al “Pérmico-Triásico”, porque, en la mayoría de los casos, la falta de elementos biocronológicos “scythienses” complica la atribución de los niveles basales al Pérmico o al Triásico. Un cuidadoso examen de las discordancias, y el uso de indicadores sedimentarios de climas claramente áridos constituyen herramientas fundamentales para la correlación de estas unidades no marinas, desprovistas de cualquier marcador bioestratigráfico, al menos en el Oeste de la Placa Europea.

La revisión de las series “Buntsandstein” de varias cuencas nos ha permitido caracterizar el límite Pérmico-Triásico y el comienzo de la sedimentación durante el Triásico inferior en el oeste de Europa, demostrando claramente que, excepto en la Cuenca Germánica, se puede observar una discordancia entre las series pérmicas y triásicas. Excepto en esta Cuenca Germánica, existe una falta total de fósiles típicamente “scythienses”, y los elementos bioestratigráficos más antiguos encontrados son conjuntos de palinomorfo que permiten asignar a los niveles superiores de las series “Buntsandstein” una edad Anisiense, en algunos cortes los niveles inferiores. En las cuencas peritéticas de Europa occidental, el límite Pérmico-Triásico se corresponde con una discordancia que se recubre por conglomerados con ventifactos (seguidos por areniscas fluviales, a veces ricas en paleosuelos y a veces totalmente desprovistas de ellos), atribuidos principalmente a Olenekian inferior (Smithien), o directamente areniscas fluviales donde aparecen los primeros paleosuelos, así como restos de plantas y palinomorfos, atribuidos al Anisiense. De esta forma en el Oeste de la Placa Europea, la falta de fósiles característicos del Triásico Inferior, en la mayoría de las cuencas peritéticas, puede explicarse por un importante hiato estratigráfico durante el Triásico Inferior (Induense) y por unas condiciones áridas, desfavorables para la vida y la preservación de fósiles durante el Olenekian.

Palabras clave: Límite Pérmico-Triásico, Triásico Inferior-Medio, cuencas de Europa occidental, Scythiense, Anisiense

1. Introduction

At the scale of the western Europe peri-Tethyan basins, the lowermost part of the Mesozoic sedimentary cycle is composed of continental deposits generally described as “Buntsandstein”. A “Permian-Triassic” age has often been proposed for this lithostratigraphic unit because, in most cases, the lack of any “Scythian” (i.e. Early Triassic) biochronological evidence makes it very difficult to attribute its basal beds to either the Permian or the Triassic. The oldest Triassic fossils, generally yielded by the upper part of the “Buntsandstein” but also its lowermost in a few cases, are attributed there to the Anisian. Nevertheless, the lack of typically Early Triassic fossil remains can be explained either by environmental conditions (i.e. “desert” environments) unfavourable for the development and preservation of a fauna/flora, or by a true stratigraphic gap.

Throughout the northern hemisphere, where continuity can be demonstrated between the Permian and Triassic, there is no evidence for a sudden collapse of the terrestrial ecosystems. The climate seems to have evolved towards rather more humid conditions during the Griesbachian Stage (e.g. Fuglewicz 1980; Kozur 2003); the macroflora continues to exhibit a predominantly Permian character, while the palynoflora is transitional (Shu and Norris, 1999; Lozovsky et al., 2001). This explains why we should expect a more or less significant hiatus when outcrops display an abrupt change in depositional style or palaeoclimatic conditions at the Permian-Triassic boundary (Durand, 2006). Consequently, a careful recognition of unconformities, and the use of sedimentary indicators of a clearly arid climate can provide powerful tools for correlations. This applies at least on the scale of the West European Plate, within the non-marine successions devoid of any biostratigraphic markers that straddle the Permian-Triassic boundary.

The aim of this paper is to characterize the Permian-Triassic boundary and the onset of early Triassic sedimentation at the scale of Western Europe, based on a review of the “Buntsandstein” series of several European basins (Fig. 1).

2. The Permian-Triassic boundary in Western European basins

During the Late Permian, exceptional falls of global sea level (Ross and Ross, 1987; Hallam and Wignall, 1999; Seidler, 2000; Heydari et al., 2001) led to more or less deep erosion in most western European basins. Moreover, paleontologists recognize the end-Permian as representing the major Phanerozoic mass extinction episode. During the earliest Triassic, these areas under erosion were bypassed by sediments, and the time gap corresponding to the sub-Triassic unconformity increased progressively towards the edges of the basin (Durand, 2006). Indeed, the only localities on the West European Plate where continuity of sedimentation can be proven correspond to the deepest part of the endorific central European basin, i.e. the Germanic Basin (Nawrocki, 2004).
2.2. Southeast France

The major criterion used to define the “Buntsandstein” in France is the clear change from local drainage systems in several distinct basins, a characteristic feature of the Permian palaeogeography, to a single widespread system that is typical of the Triassic. In the Provence Trough, which borders the Variscan Maures Massif, the main palaeocurrents directions of the “Buntsandstein” are locally even opposite to those observed in the Permian (Durand et al., 1989; Durand, 1993). In this area, the sub-“Buntsandstein” surface can be likened to the Permian-Triassic boundary (PTB) (Table 1) by comparison with the very similar stratigraphical relationships observed in some marginal parts (south of the Vosges massif) of the Germanic Basin (Durand, 2006). The uppermost unit below the PTB (La Motte pelitic Formation of the Bas-Argens basin, called Fabregas Fm. in the Toulon area) made up of playa deposits, yields vertebrate tracks of Guadalupian age (Gand and Durand, 2006). The PTB exhibits three types of contact according to the location, ranging from the central axis to the margins of the depositional area:
Table 1.- Stratigraphic comparison between different Permian-Triassic formations of Western Europe. Without scale.

Tabla 1.- Comparación estratigráfica entre diferentes formaciones del Pérmico-Triásico del Oeste de Europa. Sin escala.
Fig. 2.- A) Sedimentary geometry and lithology of the Lower Triassic stratigraphic cycles, along a transect between the area south of Orléans (Bertray well) and the Rhine Graben (Soultz-sous-Forêts well) inferred from well-log analysis: (1) Correlations from Variscan basement or pre-Triassic deposits to the Hardegsen unconformity, (2) Correlations from the Hardegsen unconformity to the basal anhydrite bed of the “Couches grises” Formation defined in the eastern part of the Paris Basin (middle part of the Middle Muschelkalk, Table 1). (B) Transect location. (Modified after Bourquin et al., 2006)

Fig. 2.- A) Geometrías y litología de los ciclos estratigráficos del Triásico Inferior, a lo largo del transecto entre el área Sur de Orléans (sondeo de Bertray) y el Graben del Rin (sondeo de Soultz-sous-Forêts) deducidas del análisis de los testigos de sondeo: (1) Correlación desde el basamento Varisico o los depósitos pre-Triásicos a la discordancia Hardegsen, (2) Correlación desde la discordancia Hardegsen a la capa de anhidrita de la base de la Formación “Couches grises” definida al este de la Cuenca de Paris (parte media del Muschelkalk medio, Table 1). (B) Localización del transecto. (Modificada de Bourquin et al., 2006)
(2002). Nevertheless, in Minorca, the lowermost of Sciunach (2001) applied the term “Buntsandstein” only to the upper part (units 3 and 4) of the “Verrucano Sardo” (Gasperi and Gelmini, 1980) which encompasses all the post-Autunian siliciclastic succession. The so-called “Lower Buntsandstein” of Sciunnach (i.e. Cala del Vino Formation, Cassinis et al., 2003) can be correlated with the Permian St-Mandrier Formation (more than 700 m thick) of the Toulon area (Fig. 2). Costamagna and Barca (2002) use the term “Buntsandstein” for the whole “Verrucano Sardo”. Conversely, Cassinis et al. (2003), use the same concept as in Provence, restricting the “Buntsandstein” to the uppermost part of the succession starting from the “Conglomerato del Porticciolo”.

2.5. Bulgaria

In NW Bulgaria, the Petrohan terrigenous Group can be regarded as the “Buntsandstein” facies of the Peri-Tethyan.
3.1. Germanic Basin

Detailed stratigraphic studies on the western margin of the Germanic Basin and a comparison with other parts of this basin allow us to propose correlations of the Triassic “Buntsandstein” on either side of the Rhine Graben (Fig. 4; Bourquin et al., 2006).

At the beginning of the Early Triassic (Induan), the sedimentation area was restricted to the central part of the Germanic Basin: the Lower Buntsandstein formations, which characterize a playa system, do not have any equivalents on the western margin of the basin (Geluk, 2005). Succeeding marginal-marine evaporites these deposits express the regressive tendency of the uppermost Zechstein (“Bröckelschiefer” = Fulda Formation), which continues into the Lower Buntsandstein (Aigner and Bachmann, 1992). The slightly angular unconformity at the base of the Upper “Bröckelschiefer” was caused by non-deposition or erosion of the uppermost Zechstein at the basin margin (Röhling, 1991, Szurlies et al., 2003).

During the lower Olenekian (Smithian), in the northwestern peri-Tethys domain, fluvial deposits are preserved in a large endoreic basin under arid climatic conditions (Fig. 5). In the western part of the Germanic basin, the sedimentation is characterized by braided fluvial systems passing laterally, toward the central part, into more or less ephemeral lakes (Richter-Bernburg, 1974; Röhling, 1991; Aigner and Bachmann, 1992; van der Zwan and Spaak, 1992; Geluk, 2005) and aeolian deposits (Clemmensen, 1979; Ulicny, 2004). In the northern Germanic Basin, alluvial fan deposits are described that are fed by catch-
ment areas from the Fennoscandian Massif (Goldsmith et al., 2003). At the southwestern margin of the Germanic basin, combined sedimentological and well-log studies show that sandstones (“Grès vosgien”) and conglomeratic facies (“Conglomérat basal” and “Conglomérat principal”) were deposited on a very large alluvial plain that onlapped the basement topography (Durand, 1978; Durand et al., 1994; Bourquin et al., 2006). The facies analysis allows us to recognize deposits laid down by a major bed-load river within an arid alluvial plain without vegetation. The arid climate prevailing in the sedimentation area is attested by the presence of many wind-worn pebbles and cobbles (ventifacts), not only concentrated in the conglomeratic layers, but also scattered here and there throughout the “Grès vosgien” Fm. (Durand et al., 1994).

The fluvial channels seem to be very wide, and they are divided during low-water stages into numerous distributaries separated by temporary islands with aeolian deposits and ephemeral ponds that allowed only a very limited development of subaquatic life. Although many distributaries display periods of inactivity that reflect their ephemeral character, the occurrence of deflation lags bounding the fluvial systems in the middle of the “Grès vosgien” Fm. indicates frequent wind reworking of fluvial deposits. The upper “Grès vosgien” Fm. is essentially characterized by playa-lake deposits (Karlstal Formation in the Palatinate) that directly overlie the basement to the west. These deposits mark the maximum flooding episode of the first major cycle, which is well recognized on well-log data in the Early Triassic succession (Fig. 4). The maximum
flooding surface (MFS) of the major stratigraphic cycle defined in the Paris Basin appears equivalent to the MFS observed within the Volpriehausen Formation (Aigner and Bachmann, 1992; Aigner et al., 1999), where brackish-marine fauna is present in the central part of the Germanic Basin (Richter-Bernburg, 1974, Roman, 2004). At the basin scale, the sandstones facies that developed after this playa episode show a progradational pattern. The upper part of the “Conglomérat principal” Formation does not exceed a thickness of 20 m on outcrops in the Vosges area, and shows a great extension to the east. In Lorraine, the top of the Middle Buntsandstein is marked by a major sedimentary break associated with a period of by-pass and development of the first paleosols (i.e. “Zone limite violette”, Müller, 1954; Ortalam, 1967; Gall et al., 1977). This episode could be coeval with the deposition of the Hardegsen Formation, where the evidence of biological activity (ichnites, rhizolites and palynomorphs) rules out any correlation with the “Conglomérat principal” Fm. laid down under arid conditions. The ‘Conglomérat principal’ Fm. rarely occurs at outcrop north of the Vosges Massif, near the German Frontier. Here, it is truncated by a major discontinuity referred to as the “Hardegsen unconformity”, which even cuts locally into the “Grès vosgien” Fm. This unconformity expresses the onset of one of the most pronounced extensional tectonic events observed in the German Triassic (Trushem, 1961, 1963; Wolburg, 1968; Röbling, 1991).

Above the Hardegsen unconformity, the Triassic deposits show an onlap relationship, which implies some tectonic activity just before the renewal of fluvial sedimentation. Moreover, the siliciclastic material includes micas, large feldspars and, angular quartz that provide evidence for reactivation of the source area. The fluvial sedimentation shows an enhanced development of floodplains with preservation of paleosols. The only biostratigraphic evidence in this Upper “Buntsandstein” cycle is provided by the “Grès à Voltzia”, where macrofauna and palynoflora allow the attribution of a lower to middle Anisian age according to location (Durand and Jurain, 1969; Gall, 1971). The “Grès à Voltzia” evolves eastwards and upwards into deposits with increasingly marine affinity (“Grès coquiller” and “Complexe de Volmunster”, “Dolomie à Myophoria orbicularis”). This fluvial system is a lateral equivalent of marine deposits attributed to the Lower Muschelkalk in Germany (Fig. 4), and is preserved in an exoreic basin. Fluvial systems appear to collapse suddenly at the beginning of the evaporitic episode corresponding to the Middle Muschelkalk (“Couches rouges”, “Couches grises” and “Couches blanches”), which precedes the deposition of marine carbonates during the Ladinian (Table 1). The vertical passage from the “Couches intermédiaires” to the Ladinian marine limestones characterizes a general backstepping trend, in which the maximum flooding surface (MFS) is located at the top of the “Calcaires à Cératites” Formation dated as Ladinian (Duringer and Hagdorn, 1987).

3.2. Southeast France

The deposits referred to as “Buntsandstein” are much thinner (maximum 80 m) in the Provence Trough than in the northern Vosges area. Along the basin axis, a basal quartz conglomerate up to 8 m thick (“Poudingue de Port-Issol” Formation) overlies the sub-“Buntsandstein” unconformity that is thought to represent the PTP. The vast majority of the pebbles are well rounded by long fluvial transport, but many display secondary ridges and facets shaped by wind-blown sand (ventifacts). The contact with the main unit (“Grès de Gonfaron” Formation) is very sharp and marked by the sudden appearance of caliche nodules, sometimes reworked and sometimes in situ. These mainly fluvial sandstones pass upwards, in the more distal area (Toulon), into terminal fan and playa deposits. Besides the caliche horizons, there is relatively frequent evidence of biological activity, e.g.: vegetation-induced primary sedimentary structures (Rygel et al., 2004) and trace fossils, mainly corresponding to invertebrate burrows (Scoyenia, Beaconites, Phycodes, Arenticoloides, etc). Nevertheless, the only palaeontological remains that enable dating of this unit are palynomorphs from the uppermost part, which allow the assignment of an early Anisian age (Adloff, in Durand et al., 1989). Occasional occurrences of tetrapod footprints have also been recorded. Although these trace fossils are much less constraining for age determination than palynomorphs, their stratigraphic ranges nonetheless encompass the early Anisian (Demathieu and Durand 1991).

3.3. Spain

The most important expression of Early Triassic sedimentation in Spain is represented by the Cañizar Formation (or its equivalents). This unit is characterized by amalgamated sequences of braided systems that are almost devoid of fines and lacking any palaeoflora except at the top (López-Gómez and Arche, 1994). As defined above, its basal unit (Chequilla Conglomerate Member) is composed of conglomerates yielding ventifacts (Durand, in Arche and López-Gómez, 2005). The Cañizar Fm. is capped by paleosols and iron-rich crusts that represent a break in sedimentation with subaerial emergence of re-
4. Correlation and discussion

At the scale of Western Europe we clearly show that, except from the Central Germanic Basin, an unconformity can be observed between the Permian and the Triassic deposits. The main question is the age of the earliest Triassic sediments. Except for the Germanic Basin, there is a total lack of typically “Scythian” fossils, and the oldest biochronological evidence yielded by these rocks are palynomorphs, found more or less high in the sections, that provide an early Anisian age. In the particular instance of the Lodève basin (Languedoc, SE France), the very basal bed of the “Buntsandstein” contains palynomorphs ascribed to the middle Anisian (Broutin et al., 1992; Diez, 2000).

Within the Germanic Basin, rocks of Induan and Olenekian age have been recognized by magnetostratigraphy (Szurlicz, 2004) and biostratigraphy (Kozur and Bachmann, 2005; see also discussion in Durand, 2006).

In other respects, recent studies from palaeoenvironmental reconstructions allow us to simulate climate conditions during the Olenekian period (Péron et al., 2005). The present study is focused on Western Europe, where sedimentological and stratigraphic data can be used to check the results of climate simulation against geological data. The main result is that climatic conditions in the sedimentary basins were very arid, while the sediment and water supply came from the adjacent relief (Fig. 6). Although these arid conditions prevailed at the European scale, seasonal changes are inferred in North Africa, showing alternating periods of aridity and precipitation. In this context, we can readily explain the presence of aeolian features (dunes or ventifacts) at a large scale.

On the western margin of the Germanic Basin, the Triassic deposits formed under arid conditions are attributed mainly to the lower Olenekian, i.e. Smithian (Durand, 2006). They are made up of 300 m of sandy alluvium laid down by a major braided river in an arid basin with some aeolian and very few floodplain deposits, lacking any paleosols (“Conglomerat basal”, “Grès vosgien” and “Conglomerat principal”).

Above this arid fluvial facies, the upper Olenekian, i.e. Spathian, is marked by a major sedimentary break characterized by the formation of a planation surface and preservation of the lowermost paleosols, followed by the tectonically induced Hardgegson unconformity. During
the Hardegsen Phase, a major structural event occurred in NW Europe (Geluk and Röhling, 1997), leading to the formation of rift systems in NW Germany (Best et al., 1983; Röhling, 1991). In the Germanic Basin, the base of the Solling Formation corresponds to the erosional interval of the Hardegsen unconformity, during which 100 m of Middle Buntsandstein deposits were locally eroded (Aigner and Bachmann, 1992). Moreover Geluk (1998) shows that the base of the Solling Formation becomes progressively younger to the west, accompanied by a decrease in thickness. In the present study, this formation appears to be missing due to non-deposition or erosion. The Solling sandstones preserved in the basin could be equivalent to an episode of sediment by-pass at the basin margin (Bourquin et al., 2006). Above the Solling Formation, the Röt Formation, corresponding to evaporitic marine and sabkha deposits, representing the earliest Triassic occurrence of halite deposition in the Germanic Basin. In the western part of the Germanic Basin, after the major Hardegsen unconformity, the Triassic fluvial suc-
cession is characterized by a major retrogradational trend from fluvial deposits (from low sinuosity rivers with well developed floodplain and paleosol, “Couches intermédiaires” and “Grès à Voltzia”), dated as Anisian, to shallow marine deposits of the Ladinian (Durand, 1978; Bourquin et al., 2006), reflecting the connection of the Germanic Basin with the Tethys Ocean (Dercourt et al., 1993). These fluvial systems are the lateral equivalents of sabkha and marine environments in the Central Germanic Basin.

In the other western Europe peri-Tethyan basins (Table 1), the Permian-Triassic boundary corresponds to an unconformity that is overlain either by conglomerates containing ventifacts (followed by fluvial sandstones sometimes rich and sometimes totally lacking in paleosols) or directly by fluvial sandstones with the first occurrence of paleosols, and then plants debris and palynomorphs.

In Spain, in the Castilian Branch of the Iberian Range, the hyper arid event, attributed herein to the Smithian, is recorded in the lower part of the Cañizar Formation; the top is marked by hiatuses and paleosols, which are possibly partly coeval with the German “Röt”. Within the Hoz del Gallo section, at about the first two thirds of the Rillo de Gallo Fm. (i.e. Canizar Fm) appears a condensed zone, about 3 m thick, with several weakly developed paleosols. The sudden drop in textural maturity from this level upwards could be regarded as a result of the Hardegsen movements in the catchment area, because a similar evolution is known in NE France, from the “Zone limite violette” paleosols to the “Couches intermédiaires” Formation (Table 1). In the Aragonian Branch, a gap is observed corresponding to the entire lower Triassic; the Permian-Triassic boundary is overlain by fluvial siliciclastics, including floodplain deposits and plant remains dated as Anisian.

In SE France (Provence) and in NW Sardinia, the “Poudingue de Port-Issol” and “Conglomerato del Porticciolo” formations can be attributed to the end of the arid lower Olenekian episode. Both conglomerates are overlain by fluvial sandstones with caliche nodules, which are dated as lower Anisian in their upper part. The top boundary of this conglomerate is sharp and could correspond to the Hardegsen unconformity.

In Bulgaria, the relationship of the thin basal conglomerate of the Noevtsi section with the overlying sandstones is reminiscent of the “Poudingue de Port-Issol” in Provence or the “Conglomerato del Porticciolo” in Nurra. By contrast, the basal conglomerate of the Smolyanovtsi section, which passes upwards into the Belogradchik Formation, strongly evokes, by its setting, the “Basal conglomerate” of the “Grès vosgien” in NE France or the Chequilla Member of the Cañizar Formation in central Spain, and thus could be a little older than that of Noevtsi (Table 1).

5. Conclusions

From this review of the “Buntsandstein” of several European basins we can characterize the Permian Triassic boundary and the onset of early Triassic sedimentation at the west European scale. We clearly show that, except from the Central Germanic Basin, an unconformity can be observed between the Permian and the Triassic. The main question is the age of the earliest Triassic sediments. Except in the Germanic Basin, there is a total lack of typi-
cally “Scythian” fossils, and the oldest biochronological markers provided by these series are palynomorphs yielding an early Anisian age.

In the western Europe peri-Tethyan basins (Table 1), the Permian-Triassic boundary corresponds to an unconformity that is overlain either by conglomerates containing ventifacts (followed by fluvial sandstones sometimes enriched and sometimes totally lacking in paleosols) or directly by fluvial sandstones with the first occurrence of paleosols, and then plant debris and palynomorphs. On the western margin of the Germanic Basin, the arid climate Triassic deposits are attributed mainly to the lower Olenekian, i.e. Smithian. Fluvial deposits with ventifacts (formed under arid conditions) are also described in other west European basins. Hence, this arid event seems not to be isolated in continental areas, but reflects arid climate conditions at the scale of Western Europe, as indicated by the climate simulation (Fig. 6). Moreover, an early Triassic arid episode is now indicated at the margins of Tethys (in the Lombardy Alps, Cassinis et al., this issue).

Thus, the lack of typically Early Triassic fossils can be explained not only by slow recovery after the Permian-Triassic biologic crisis (López-Gómez et al., 2005), but also by a true stratigraphic break during the Early Triassic (i.e. Induan) and/or by climatic conditions that were unfavourable for the development of flora and fauna during the lower Olenekian (i.e. ‘desert’ environments). The early Triassic arid episode could have a global origin as suggested by recent studies on early Triassic ammonoids (Brayard et al., 2006). Furthermore, it should be noticed that even in South Africa, last research provides evidence of a vegetated landscape during the earliest Triassic, and conversely of an aphytic interval from that time up to the Middle Triassic (Gastaldo et al., 2005).

The careful recognition of unconformities and the use of sedimentary indicators of clearly arid climate provide us powerful tools for correlation, within non-marine succession that are devoid of any biostratigraphic markers, at least on the scale of the West European Plate.

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References


Geluk, M.C. (1998): Palaeogeographic and structural develop-
ment of the Triassic in the Netherlands - new insights. Zentralblatt für Geologie und Paläontologie, Teil I, 1: 545-570.


