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LOST NORIAN FLUVIAL TRACKS: SEDIMENTOLOGY AND STRATIGRAPHY OF THE UPPER TRIASSIC COARSE-GRAINED DEPOSITS IN KAMIENICA ŚLĄSKA (UPPER SILESIA, SOUTHERN POLAND)

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Abstract: In the Triassic–Jurassic boundary profiles of the Upper Silesian region, there are locally developed coarse clastic deposits, commonly known as the Połomia Gravels, Połomia Beds or "Połomia Formation" (informal name). Due to the lack of reliable stratigraphic tools, the chronostratigraphic position of these deposits remains one of the most controversial aspects of the Triassic–Jurassic lithostratigraphy in the region. Sparse biostratigraphic data from the overlying and underlying deposits indicate a wide range of ages, from the Late Triassic to Early Jurassic. This paper presents the results of sedimentological, petrographical and palynological analyses of the coarse-grained deposits from the Kamienica Śląska gravel pit, which is currently one of the biggest facilities of this type in Upper Silesia. The outcrop section, with a total thickness of up to 20 m, is dominated by friable, light grey to beige and locally dark grey, large-scale planar to trough cross-stratified conglomerates and coarse-grained sandstones with subordinate thin interbeds of grey and reddish brown mudstones. Three facies associations have been distinguished, representing a main channel belt, secondary channels and floodplains subenvironments. Facies analysis points to a braided river tract with localised floodplain sediments. The grain composition of the Kamienica Śląska gravel/conglomerate is less diversified than that of the polymictic typical Połomia Beds of the Myszków area and resembles oligomictic conglomerates known from the Grabowa Formation of the Norian age and/or conglomerates of the Gorzów Beds of Rhaetian age, which also occur on the studied region. Palynological analysis of mudstone interbeds within the conglomeratic deposits shows the presence of miospores guiding and characteristic for subzone c of the *Corollina meyeriana* zone of the late Norian–early Rhaetian age. The appearance of the coarse-grained deposits in late Norian could be associated with the development of a long-reach braided fluvial tract, draining the S and SE part of the Sudetian-Malopolska-Lublin land (S-M-L land) in response to the tectonic rearrangement in the source area and gradual climatic change from semi-arid to humid in the Rhaetian.

Key words: Upper Norian–lower Rhaetian, braided river alluvium, facies analysis, sedimentology, palynology, regional correlation.

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INTRODUCTION

When starting the palynological study of the mudstone intercalations from the Kamienica Śląska gravel pit, the authors assumed that they were dealing with the Połomia Beds or the informally called Połomia formation (e.g., Unrug and Calikowski, 1960; Jakubowski, 1977; Nita and Nita, 2014), which are typical gravel-dominated deposits known in the Kraków-Wieluń area of southern Poland (Fig. 1A). In the regional literature, the age of the Połomia formation ranges from the Late Triassic (Norian, e.g., Deczkowski, 1997) to Early Jurassic/Toarcian (e.g., Marcinkiewicz, 1960; Jakubowski, 1977; Kopik, 1998; Fig. 2). The highly regionalised and patchy distribution of the Połomia formation in southern Poland and its lack of fossil fauna or flora in the known sections have long hampered a precise stratigraphic correlation of this unit across the region.

For many years, lithostratigraphy was thus used as the only available method for regional correlation, with the clast composition of the conglomerates as the main criterion. The Połomia gravels are polymictic, with numerous pebbles of polymictic conglomerates, siliceous hematite and diverse limestone types (e.g., Unrug and Calikowski, 1960; Jakubowski, 1977), whereas these clast lithologies are less frequent or absent in the older conglomerates (e.g., the Norian Grabowa Formation; see Jewuła *et al.,* 2019). To resolve the problem of the stratigraphical position of the conglomeratic deposits in the Kamienica Śląska gravel pit (Fig. 1B), presumed to be a part of the Połomia formation (Nita and Nita, 2014), the petrographic and palynological analyses were applied – with preliminary results reported by Fijałkowska-Mader and Paszkowski (2016).

The deposits were also analysed sedimentologically to reconstruct their sedimentary environment. The results were then put into a broader palaeoenvironmental context in an attempt to link the signal of allogenic controls, such as climate changes and distant tectonic processes, with the sedimentary evolution of the Late Triassic Germanic Basin in its Polish part.

GEOLOGICAL SETTING

The Upper Triassic in southern Poland was deposited in the southeastern part of the vast epicontinental Central European Basin (CEB), also known as the Germanic Basin, which occupied most of the central and partly Western Europe. The semi-arid and arid climatic conditions in the Late Triassic, controlled by the megamonsoonal circulation system from the Tethys (Kutzbach, 1994; Reinhardt and Ricken, 2000), resulted in deposition of predominantly fine-grained deposits, with local evaporites in the central part of the CEB (Deczkowski and Franczyk, 1988; Feist-Burkhardt *et al*., 2008). Coarse-grained fluvial deposits, conglomerates and coarse-grained sandstones, are more common in the marginal parts of the basin (Feist-Burkhardt *et al.*, 2008). Numerous small outcrops of these deposits, with the Kamienica Ślaska gravel pit as the largest, are scattered in the NW Upper Silesia (mostly around Błędów and Ponoszów; Fig. 1A) and ascribed to different informal and formal lithostratigraphic units (Gorzów Beds, Grabowa Formation or Połomia formation). These deposits were variously labelled as the Połomia Beds, Połomia gravels or Połomia Formation (Unrug and Calikowski, 1960; Jakubowski, 1977).

To determine the age of the Połomia formation, palynostratigraphical research was carried out in the 1950s and 1960s on the adjoining units of Gorzów Beds, Blanowice Beds and Sub-coal Beds (Fig. 2). However, the results appeared inconclusive, indicating a range of ages (e.g., Rogalska, 1954, 1962; Marcinkiewicz, 1957, 1960, 1971; Marcinkiewicz *et al.,* 1960). Therefore, the criterion used so far for distinguishing older conglomerates/gravels of the Rhaetian Gorzów Beds (*sensu* Jakubowski, 1977) and Norian Grabowa Formation from the younger Połomia formation remained the petrographic composition of gravel clasts. The gravels of the Połomia formation are polymictic, as opposed to the oligomictic, quartz- and quartzite-dominated gravels in the Gorzów Beds and Grabowa Formation (e.g., Znosko, 1955; Unrug and Calikowski, 1960; Jakubowski, 1977; Szulc and Racki 2015; Szulc *et al*., 2015a). Little consideration was given to the gravel varied provenance and possible regional climate changes. Jewuła *et al.* (2019) suggested that the presence of conglomerates in the Grabowa Formation in the Patoka 1 borehole (Fig. 1A) may be related to a mid-Norian climatic pluvial phase.

Besides petrographic and palynological analysis, an essential aspect of age research of the Kamienica Śląska gravelly deposits was to determine the stratigraphy of the underlying beds, which are not exposed in the gravel pit itself. Based on the data from adjacent boreholes Kamienica-1 (3BN; Fig. 1B; Köppen, 1997) and Lubsza 2BN (data from National Geological Archive), the package of conglomerates and sandstones, which presumably can be correlated with those outcropping in the Kamienica Śląska quarry, is situated approximately 100–120 m above the top of the Schilfsandstein interval, which can be regarded as an important correlation marker in the area. Moreover, in both wellbores, short (< 5 m thick) intervals of Woźniki limestone were described below the sandstones and conglomerates, which could narrow down the stratigraphic range of the middle and upper Norian (the Patoka Member of the Grabowa Formation; see Szulc *et al.*, 2006, 2015a). In the Czarny Las borehole (Fig. 1A), conglomerates and sandstones sit on evaporite-bearing claystones (Szulc, 2007), which could indicate the presence of the Ozimek Member of Grabowa Formation, correlatable with the wide-spread Keuper facies of the Upper Gypsum Beds (Szulc, 2007; Szulc and Racki, 2015; Szulc *et al.,* 2015a, b).

MATERIAL AND METHODS

The Kamienica outcrop is an active open-cast gravel pit located 3.5 km northwest of the town of Woźniki. For most of the outcrop section, the bulk thickness of the exposed deposits (~20 m) is dominated by friable, light grey to beige, locally dark grey, large-scale cross-stratified conglomerates and coarse-grained sandstones (Fig. 3, see details below). The entire vertical section has been described in detail. Sedimentological characterisation of the deposits included a detailed description of sediment colour, texture (grain size and sorting), sedimentary structures and presence of carbonates. The transport directions indicated by sedimentary structures have also been noted. Special attention was given to fine-grained sediments within the otherwise coarse-grained succession and to the composition of clasts in the conglomeratic deposits.

Gravel compositional analysis was performed to quantify lithological groups of the 16–56 mm clast-size fraction (pebbles). A bulk gravel sample from the main channel facies association was sieved to separate gravel clasts from the coarse-sand matrix. The individual clasts (484 pebbles) were then classified into groups according to their lithology.

One palynological sample was taken from each mudstone horizon (Fig. 3). The sample material was treated according to the method described by Orłowska-Zwolińska (1983). The rock samples, 30–50 g in weight, were first disintegrated mechanically and then treated with 10% HCl and 40% HF in a cold state for 6–7 days. Afterwards, the samples

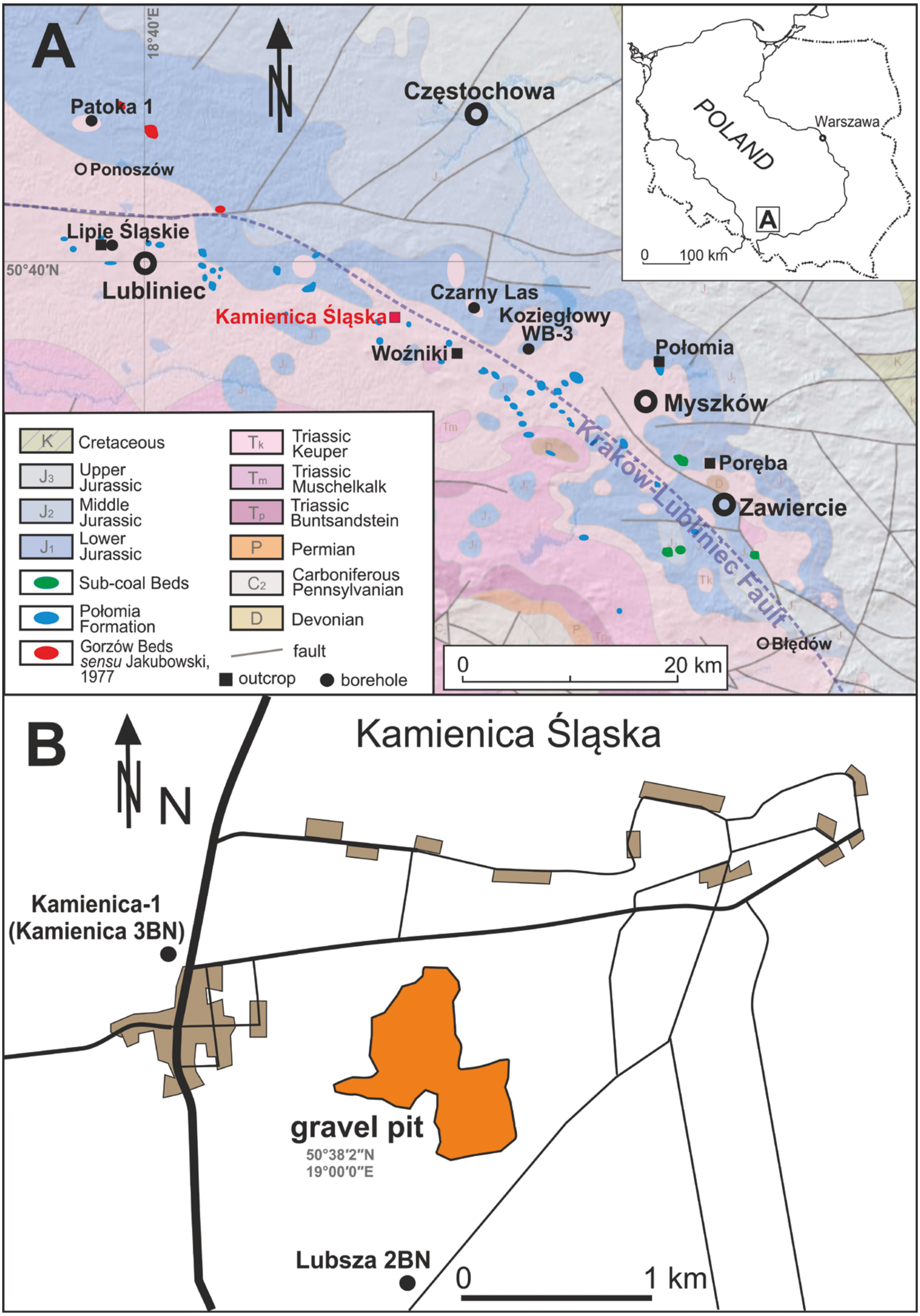
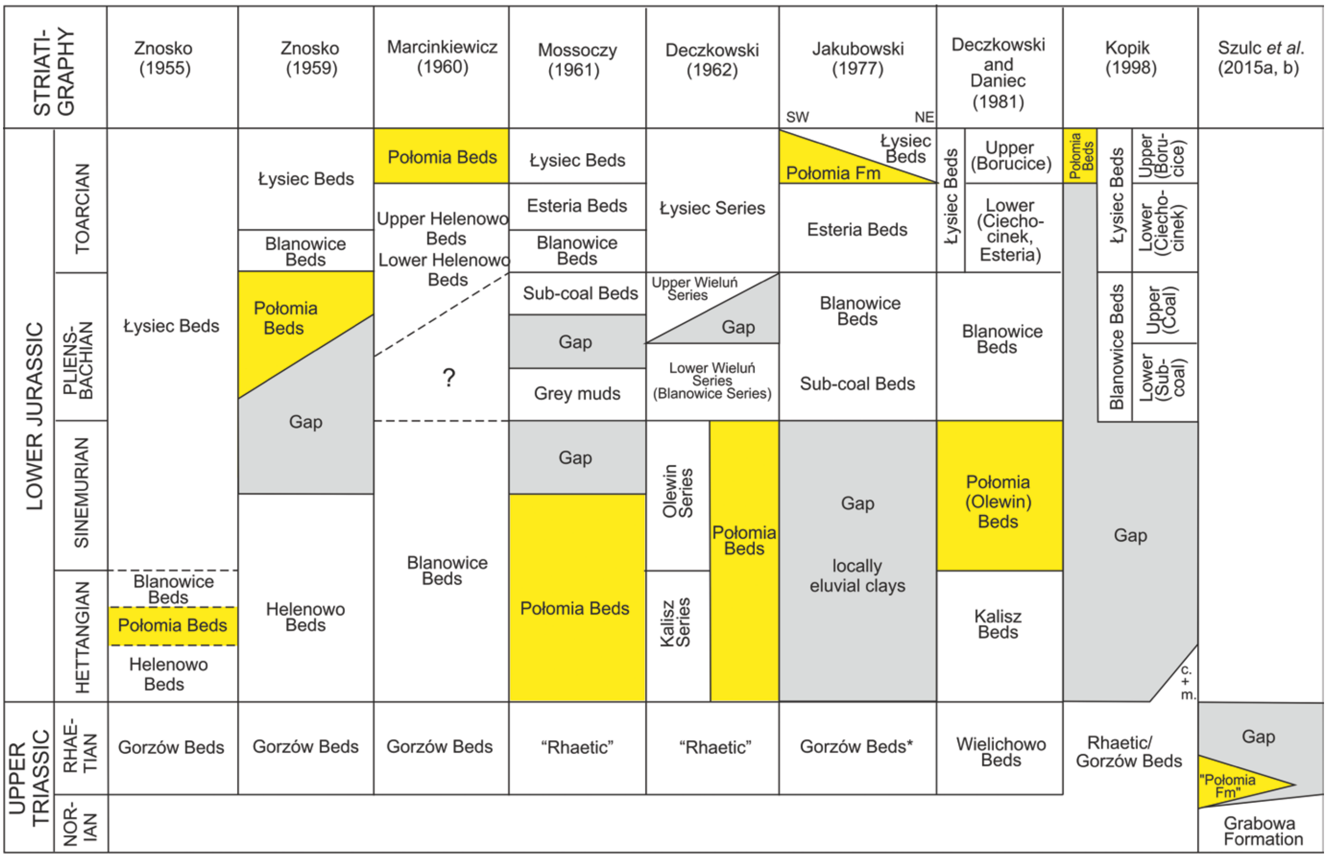


Fig. 1. Location of the study area. **A**. Location of the village of Kamienica Śląska and other occurrences of the late Triassic–early Jurassic coarse clastic deposits in outcrops and boreholes (after Jakubowski, 1977), with the Kraków-Lubliniec Fault after Szulc *et al*. (2006). Background geological map from www.pgi.gov.pl. **B**. Location of the gravel pit and two adjacent boreholes (BN) in Kamienica Śląska. Lithological descriptions of the borehole cores are available in Köppen (1997) and at the National Geological Archive website.



* According to the present authors, the Gorzów Beds of Jakubowski (1977) should be correlated to the Grabowa Formation of Szulc *et al.* (2015a, b)

Fig. 2. Review of the Upper Triassic–Lower Jurassic lithostratigraphy in the Upper Silesia region according to different authors. Note the variable position of the Połomia lithostratigraphic unit (highlighted in yellow).

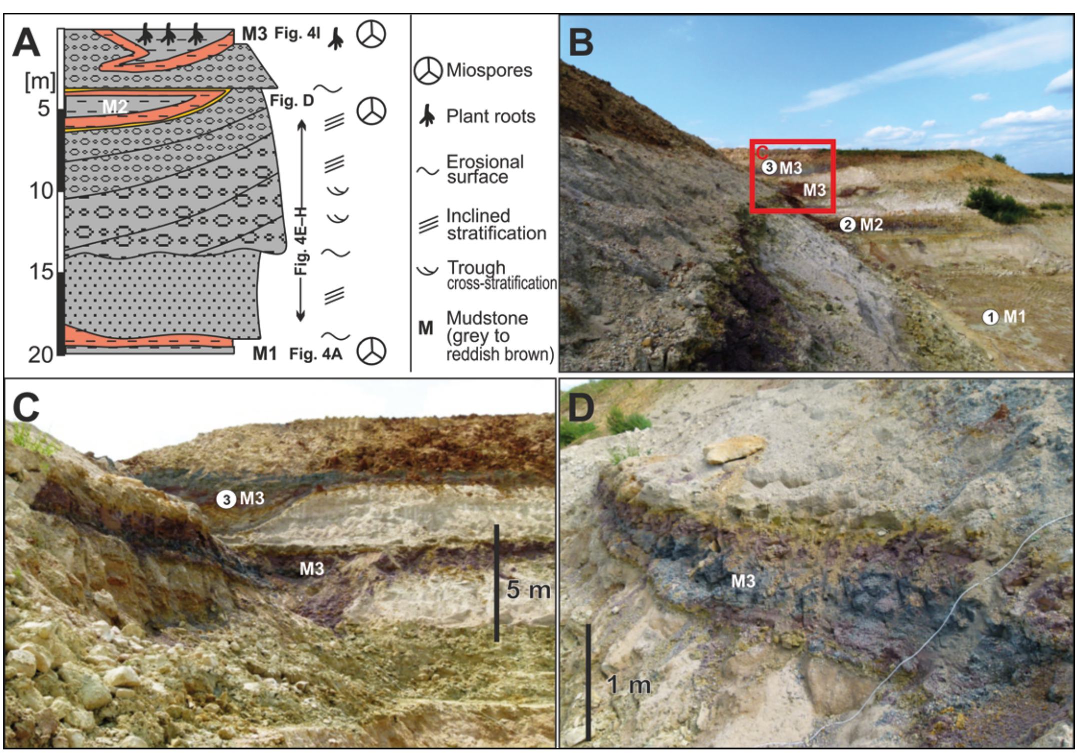


Fig. 3. The gravel pit in Kamienica Śląska. **A**. Sedimentological composite log of the gravel-pit outcrop. **B**. Broad view of the pit western wall with the three mudstone interbeds (M1–M3) and location of palynological samples (1–3). **C**. Enlarged part of figure B (see the red frame therein). **D**. Close-up view of the mudstone bed M3. Note the upward change of mudstone colour, indicating post-depositional oxidation of the mud.

(solid residues) were washed with water, treated at 70°C for 2 hours with 10% HCl and poured into a heavy liquid mixture of CdJ_2+KJ_2 (specific weight 2.1 g/cm^3). The resulting residue was then mounted in glycerine gel on thin-section glasses. The palynological quantitative analysis was based on the counting of all miospore specimens recognised in the thin-section slide and normalising their counts to 100%. Microscopic analyses were performed using a Leitz Laborlux microscope.

RESULTS

Sedimentary facies associations

The gravelly-sandy succession, up to 20 m in exposed thickness, is underlain and overlain by mudstones. The lower mudstone, massive and greyish yellow-green (5GY 7/2) in colour, has an erosional top (Fig. 4A). The upper mudstone has a sharp non-erosional base, is massive and shows upward colour changes from pale yellowish-orange (10YR 8/6) to greyish yellow-green (5GY 7/2) and further to moderate red (5R 5/4) and moderate brown (5YR 3/4). This mudstone unit is intercalated with two planar-stratified sandstone beds (Fig. 4B). The top of the lower sandstone bed (80 cm thick) is erosionally scoured, and the scour niche is filled with a massive mudstone. The mudstone is erosionally overlain by the second sandstone bed (60 cm thick).

Three facies associations have been distinguished in the succession profile. They are described below and interpretively labelled as a main channel, secondary channel and floodplain deposits.

Main channel facies association

This facies assemblage, about 3 m thick, consists of conglomeratic beds 0.7 to 1.3 m in thickness (Fig. 4C, D). The conglomerates are poorly sorted, matrix- to clast-supported and dominated by granule size fraction (Fig. 4E). Granules commonly dominate up to 80% of the bed thickness, passing upwards into coarse sand. Gravel clasts are generally well rounded and lithologically dominated by vein quartz. Subordinate lithologies include sandstone (quartzite and glauconitic sandstone), conglomerate (with jaspilite clasts up to 10 cm), carbonate rock (limestone and potentially redeposited calcrete), weathered crystalline rocks and silicified plant fragments (Fig. 4F, G). Some beds contain mudstone intraclasts, up to 20 cm in size, lithologically similar to the underlying mudstone (Fig. 4H). The conglomerate matrix is a poorly sorted coarse-grained sand with a mineral composition compatible with that of the gravel fraction.

Clast fabric in granule-dominate gravel is difficult to recognize and seems chaotic, but pebbles locally show a “rolling” imbrication. The conglomerate beds are subhorizontal and show tabular, planar tangential cross-stratification, only locally trough cross-stratification. This kind of depositional architecture indicates vertical stacking of 2D and subordinate 3D gravelly dunes, which – in a terrestrial setting – suggests the infill of a major braided-river channel (Miall, 1978, 1996; Nemec, 1992; Bridge, 2003). The river channel at the study site was not deeper than 1.5 m. Measurements of cross-strata indicate local river transport towards the NW.

Secondary channel facies association

This facies assemblage, about 10 m thick, comprises poorly sorted coarse-grained sandstones with scattered gravel clasts up to 3 cm in size. The content of granule and pebble fraction is similar as in the previous facies association. Beds are 30 to 70 cm thick (Fig. 4I, J), roughly tabular, with erosional lower boundaries commonly paved with a gravel lag (Fig. 4J). The beds show large-scale planar tangential and trough cross-stratification, with the latter more common than in the previous facies association.

This depositional architecture indicates vertical stacking of 3D and subordinate 2D gravelly sand dunes, which suggests the infill of a braided-river channel (Miall, 1978, 1996). This channel at the study site was smaller, about 1 m deep, and more sand-prone. It probably represented a subsidiary branch of a laterally shifting, anabranching fluvial system (*sensu* Nanson and Knighton, 1996). Visual estimates suggest transport direction comparable to that of the adjoining main channel.

Floodplain facies association

The sandy-gravelly succession contains three mudstone interbeds, up to 2 m thick (labelled M1–M3 in Fig. 3). The mudstones are either dark grey or light red, or are yellowish where weathered. They are highly calcareous. The contact between mudstone and the underlying conglomerate or sandstone is lithologically sharp, but non-erosional. The mudstone upper boundary is erosional. Planar parallel lamination, highlighted by subtle variation in grain size, is common in the lower part of the mudstone beds. The uppermost part of the mudstone bed M3 shows poorly preserved, coalified plant-root traces, or rhizoids (Fig. 4K).

In the environmental context of a laterally shifting fluvial system, the mudstone units with their considerable thickness are interpreted as overbank floodplain deposits (Bridge, 2003). The floodplain areas were short-lived, occupying abandoned fluvial tracts (cf. Nemec, 1992), and were at least partly vegetated – which bears some regional climatic implications. Coalified plant roots (Fig. 3I) indicate humid, water-soaked palaeosols, but insufficiently covered with water to promote peat-forming conditions (Retallack, 2008).

Gravel clast composition

The gravel clast lithological composition is dominated by vein quartz (50.4%), followed by metaquartzite (15.5%) and quartz arenites (8.1%) (Tab. 1). Fragments of the Woźniki Limestone (uppermost mid-Keuper) make up to 6% of the analysed clasts. Dark flints, metacherts, quartz granule conglomerates and jaspilities constitute less than 5% of the gravel clasts population. Minor clast components (with less than ten pebbles found) include volcanic rocks, silcrete, lydites, greywackes, flints, silicified limestones with Mississippian foraminifers, silicified carbonate with gypsum pseudomorphs, silicified peat and silicified coquina.

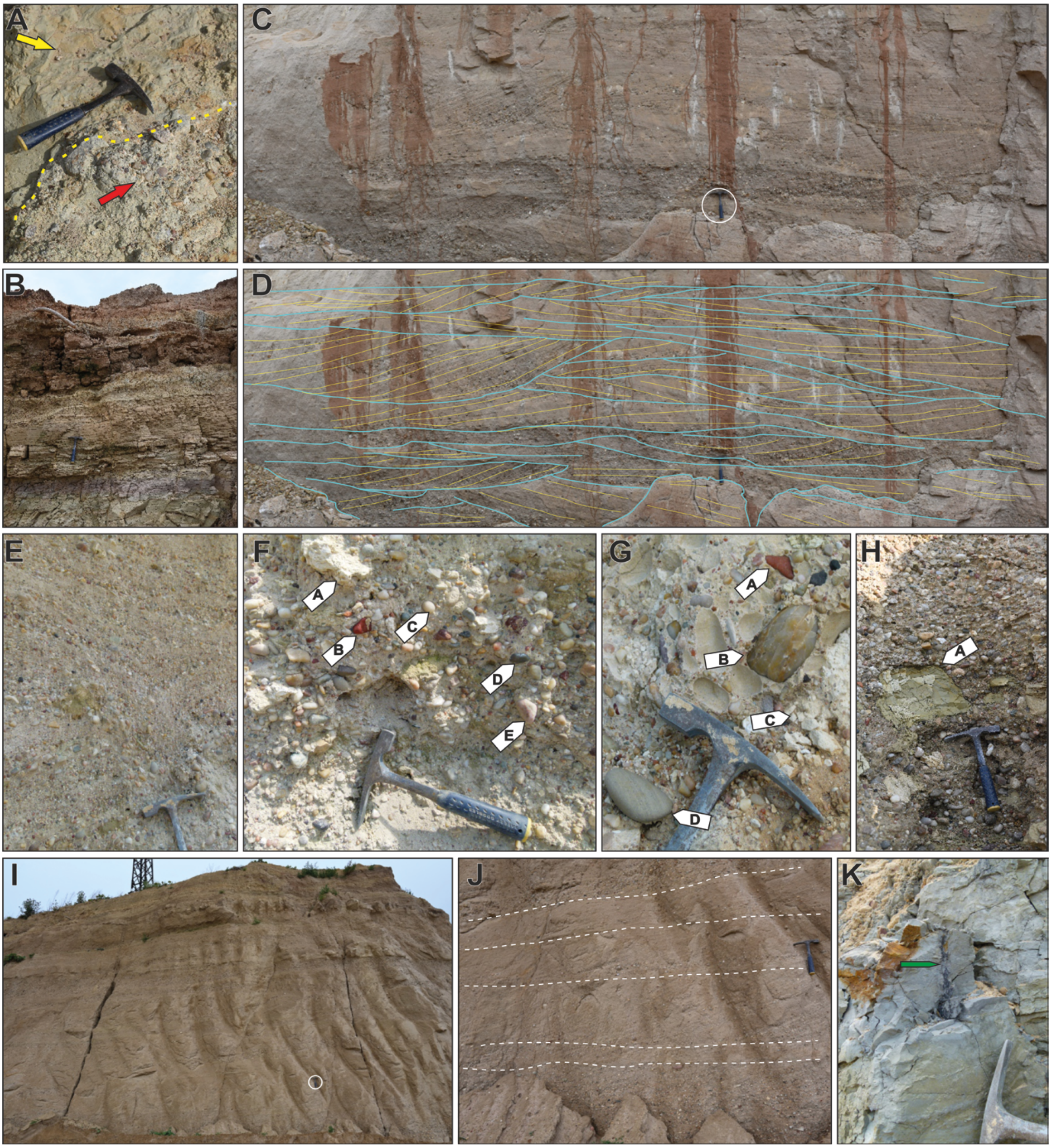


Fig. 4. Sedimentary features recognised in the gravel pit in Kamienica Śląska. **A**. Contact of the mudstone bed M1 (yellow arrow) with the underlying conglomerate (red arrow). **B**. Intercalation of planar-stratified sandstone within the mudstone bed M3. **C**. Cross-stratified conglomerates and sandstones of the main channel facies association. **D**. A corresponding line-drawing with the yellow lines representing stratification and the blue lines erosional cross-set bases. **E**. Cross-stratified conglomerates of the main channel facies association. **F**. Close-up view of the channel-fill oligomictic conglomerate with well-rounded clasts of A – Woźniki Limestone, B – jaspilite (recycled from Ediacaran oligomictic conglomerate?), C – vein quartz, D – metalydite, and E – quartz arenite. **G**. Close-up view of poorly sorted conglomerate with rounded clasts of A – jaspilite, B – vein quartz, C – Upper Triassic? marl (broken), and D – laminated quartz arenite. **H**. Close-up view of conglomerate with sub-rounded large mudstone intraclasts (arrow A). **I**. Broad outcrop view of the secondary channels facies associations. Note the dominance of poorly sorted coarse-grained sandstones with scattered pebbles. **J**. Close-up view of the secondary channel facies associations. Note the channel lags (at the bottom and top) composed of granules and pebbles, and the vertically stacked sets (dashed lines) of planar tangential cross-strata. **K**. In-situ carbonaceous plant rootlet in the upper part of the mudstone bed M3. The hammer (scale) is 35 cm long.

The deposits of the fluvial system indicate a lowland-type anabranching braided river, rather than a basin-margin alluvial fan (cf. Nemec, 1992; Miall, 1996; Nanson and Knighton, 1996), but the sediment grain-size range and high mineralogical maturity may seem poorly compatible. Gravel-bed rivers tend to form close to their source area, whereas high sediment maturity may indicate a long-distance transport. In our interpretation, the fluvial drainage system in the Kamienica Ślaska area was located relatively close to its sourcing terrain, but involved a recycling of older mature gravelly sediments (see further discussion in the text).

Palynological analysis

Relatively rich miospore assemblages were yielded by samples 2 and 3, taken from the middle (M2) and upper (M3) mudstone layers (Fig. 3A), respectively. They are dominated by circumpollen *Classpollis* (al. *Corollina*) *meyeriana* (Klaus) de Jesrey (Figs 5B–D, 7M–O; Tab. 2). Common are also other pollens (Tab. 2). Spores make up 35% of the studied assemblages and are dominated by *Todisporites* (Fig. 7A, B) and *Deltoidospora* specimens (Fig. 5A; Tab. 2). In sample 2, relatively abundant are degraded and/or reworked palynomorphs, including Palaeozoic chitinozoa (Fig. 6U), spores (Fig. 6M, N) and bisaccate pollen (Fig. 6P–S), with spores making up 19% and pollen 6% of the spectrum. The percentage of reworked spores decreases to 5% and reworked pollen to below 1% in sample 3.

The assemblages are dominated by conifer pollen, regarded as xerophytic forms (Visscher and van der Zwan, 1980). The pollen assemblage represents subzone c of the *Corollina meyeriana* palynological zone defined by Orłowska-Zwolińska (1983, 1985) from the upper part of the Zbąszynek Beds (latest Norian–early Rhaetian). It differs from spectra of the older subzone b of the *Corollina meyeriana* palynozone (documented in the nearby Czarny Las borehole; Figs 1, 8; Fijałkowska-Mader *et al.*, 2015) by the presence of *Rhaetipollis germanicus* species and its stratigraphic range is considered to be the late Norian–Rhaetian (Cirilli, 2010).

Based on the palynostratigraphic data, the sedimentary succession in the Kamienica Śląska gravel pit would then represent a late Norian–Rhaetian pluvial climatic episode in the Upper Silesia region. In the regional stratigraphic context, this pluvial episode was preceded by a mid-Norian pluvial episode and subsequently followed by a Rhaetian pluvial episode (Fig. 9), as discussed further below.

Table 1

Gravel clast composition of the main channel facies association in the Kamienica Śląska succession.

Lithology	Number of clasts	%
Vein quartz	244	50.4
Metaquartzite	75	15.5
Quartz arenite	39	8.1
Woźniki limestone	29	6.0
Flint	22	4.5
Metachert	14	2.9
Granule grained quartz conglomerate	12	2.5
Jaspilite	11	2.3
Volcanic clast	6	1.2
Silcrete	6	1.2
Lydite	5	1.0
Greywacke	5	1.0
Flint with fossils	4	0.8
Silicified Mississipian forams limestone	3	0.6
Silicified mudstone	3	0.6
Spiculites with microfossils	2	0.4
Silicified carbonate with gypsum pseudomorphs	2	0.4
Silicified peat	1	0.2
Silicified coquina with orthocone	1	0.2
Total	484	100

DISCUSSION

The literature controversy regarding the age of the transitional Triassic–Jurassic (*sensu lato*) coarse-grained sediments in the Upper Silesia has lasted for nearly a century (Fig. 2). The determining of the stratigraphic position of these deposits is crucial, as they may help to understand the environmental response of Central European continental settings to global events in the latest Triassic and early Jurassic. The Triassic–Jurassic transition witnessed numerous global events, such as the initial phases of the opening of the Atlantic Ocean with emplacement of the Central Atlantic Magmatic Province (CAMP; e.g., Whalen *et al.*, 2015), reorganisation in the Tethys domain (e.g., Szulc, 2000), biotic turnovers and extinctions (e.g., Ruhl *et al.*, 2011), and intensification of the large monsoonal circulation in the Pangea (Kutzbach and Gallimore, 1989; Kutzbach, 1994; Reinhardt and Ricken, 2000). All those events are well recorded in marine environments, but their record in the continental settings is considerably sparser and deserves more attention in palaeoenvironmental studies.

Sedimentological analysis of the gravel-sand deposits in Kamienica Śląska indicates a lowland fluvial drainage system of laterally shifting braided channels. The depth of the main, gravel-prone palaeochannel and its cross-stratified infill facies imply a major river branch with subcritical discharges in the upper range of the lower flow regime (Harms *et al.,* 1982). Occurrences of low-angle cross-stratification may represent washed-out dunes and antidunes, which generally form at the transition from subcritical to supercritical unidirectional flow (Kędzior and Popa, 2018). The secondary, shallower palaeochannel suggests a subsidiary branch of an anabranching river system, filled with sandy dunes in the upper range of the lower flow regime (Harms *et al.,* 1982).

Table 2

Miospore frequency in the assemblages collected from mudstone interbeds in the Kamienica Śląska success.

	Dominated >20%	Common 5–20%	Not numerous 1–5%	Rare <1%
pollen	*Calssopollis meyeriana* (Figs 5B–D, 5T, 7M–O)	*Monosulcites minimus* (Figs 5H, 7T), *Vallasporites ignaci* (Figs 4M, 6U), *Enzonalasporites manifestus* (Fig. 6R), *E. vigens* (Fig. 4K), *E.* cf. *vigens* (Fig. 6S), *E.* sp. (Fig. 4L), *Brachysaccus neomundanus* (Figs 4O, 7C)	*Triadispora polonica* (Fig. 7H), *T.* sp. (Figs 4S, 7I), *Labiisporites triassicus* (Fig. 7J), *Riccisporites tuberculatus* (Fig. 7S), *Ovalipollis luncensis* (Fig. 7A), *O. ovalis* (Figs 4N, 5O, 7B), *Monosulcites minimus* (Fig. 7T)	*Protohaploxypinus* sp. (Fig. 5P), *Patinasporites* cf. *densus* (Fig. 6T), *Alisporites* sp. (Figs 4R, 5R), aff. *Brachysaccus* sp. (Fig. 7D), *Parillinites* sp. (Fig. 7E), *Falcisporites* sp. (Fig. 7F), *Cedripites* sp. (Fig. 4P), aff. *Piceapollnites* sp. (Fig. 7G), *Vallasporites ignaci* (Fig. 6U), *Duplicisporites granulatus* (Fig. 7L), *Rhaetipollis germanicus* (Figs 5E, F, 7R), *Classopollis torosus* (Fig. 7P), *Monosulcites punctatus* (Fig. 7U), *M.* sp. (Fig. 5I), *Ephedripites* sp. (Fig. 5J), *Sphaeripollenites* sp. (Fig. 5K), polysaccate pollen (Fig. 4T, U)
spores		*Todisporites cinctus* (Fig. 6A), *T. minor* (Fig. 6B), *Deltoidospora* cf. *toralis* (Fig. 4A)	*Nevesisporites limatulus* al. *Gordonispora fosulata* (Figs 4G, 6L, 4G), *Lycopodiumsporites* cf. *reticulumsporites* (Fig. 6F), *L.* sp. (Fig. 6G), *Lycopodiacidites* sp. (Fig. 6H), aff. *L.* sp. (4D), *Densosporites* spp. (Fig. 6M, N), *Carnisporites* cf. *granulatus* (Fig. 6K), *C. mesozoicus* (Fig. 4B), C. spp. (Figs 4C, 6K)	*Verrucosisporites* sp. (Fig. 6D), *Baculatisporites* sp. (Fig. 4E), aff. *Conbaculatisporites* sp. (Fig. 6J), aff. *Conbaculatisporites* sp. (Fig. 6J), *Anapiculatisporites telephorus* (Fig. 4F), *Apiculatisporites* sp. (Fig. 6C), aff. *Taurocusporites* sp. (Figs 4H, 6E), *Heliosporites* cf. *altmarkensis* (Fig. 6I), *Polycingulatisporites* sp. (Fig. 4J), *Kraeuselisporites* cf. *cooksonae* (Fig. 4I), aff. *K.* sp. (Fig. 6O), aff. *Densosporites* sp. (Fig. 6N), aff. *Perotrilites* sp. (Fig. 6P)

The intervening mudstone units, M1–M3, represent overbank floodplain ponds that were temporarily extending over the abandoned branches of laterally shifting channels (cf. Nemec, 1992; Miall, 1996). These ponds locally hosted vegetation and were becoming anoxic due to the accumulation of organic matter, which aided the preservation of palynological material. Large mudstone intraclasts in channel-fill deposits indicate incision of the shifting river channels. The incision would temporarily lower the local groundwater level and cause post-depositional oxidation of the shallow muddy ponds or their margins; hence the yellowish to reddish shades of the mudstone colour in certain horizons (Fig. 3D). The lateral shifting of channels apparently caused short-term groundwater table oscillations on a local scale.

Lack of *in-situ* volcanic rocks and/or tuffs in the studied area hamper obtaining precise geochronology. Detrital zircon analyses were conducted on samples from the Lower Keuper and Carnian Schilfsandstein sandstones in the Koziegłowy borehole (Figs 1A, 8) by Köppen (1997) and from the Norian in Lipie Śląskie (Lisowice; Figs 1A, 8) by Kowal-Linka *et al.* (2019). In the latter paper, the age of the youngest zircon found in a fluvial channel-fill sandstone appeared to be no older than 211 (± 3) Ma (middle Norian). No other geochronological age determinations are available for the uppermost Triassic sediments in this area.

The correlation of the miospore assemblage from Kamienica Śląska with the subzone c of the *Corollina meyeriana* zone would indicate a late Norian–early Rhaetian age of the deposition. The precise determination of the age of the subzone c remains difficult due to unresolved problems with the position of the Norian-Rhaetian boundary in the Germanic Basin. For instance, Kürscher and Herngreen (2010) correlated the whole zone *C. meyeriana* with the Norian zone *Granuloperculatipollis rudis* in their Figure 2, but its subzone c with the Rhaetian zone *Rhaetipollis germanicus* in their text (p. 76). Szulc *et al.* (2015b, fig. 18), in contrast, suggested a late Norian age for this subzone. Based on the pollen evidence of *R. germanicus* Schulz, Fijałkowska-Mader *et al.* (2015) have correlated subzone c with the lower part of the Rhaetian *R. germanicus* zone of Herngreen (Kürscher and Herngreen, 2010). The youngest zircon dating of the sandstones from the Lipie Śląskie (Lisowice), correlated with the older subzone b of biozone *C. meyeriana* (Fijałkowska-Mader *et al.*, 2015), gave the

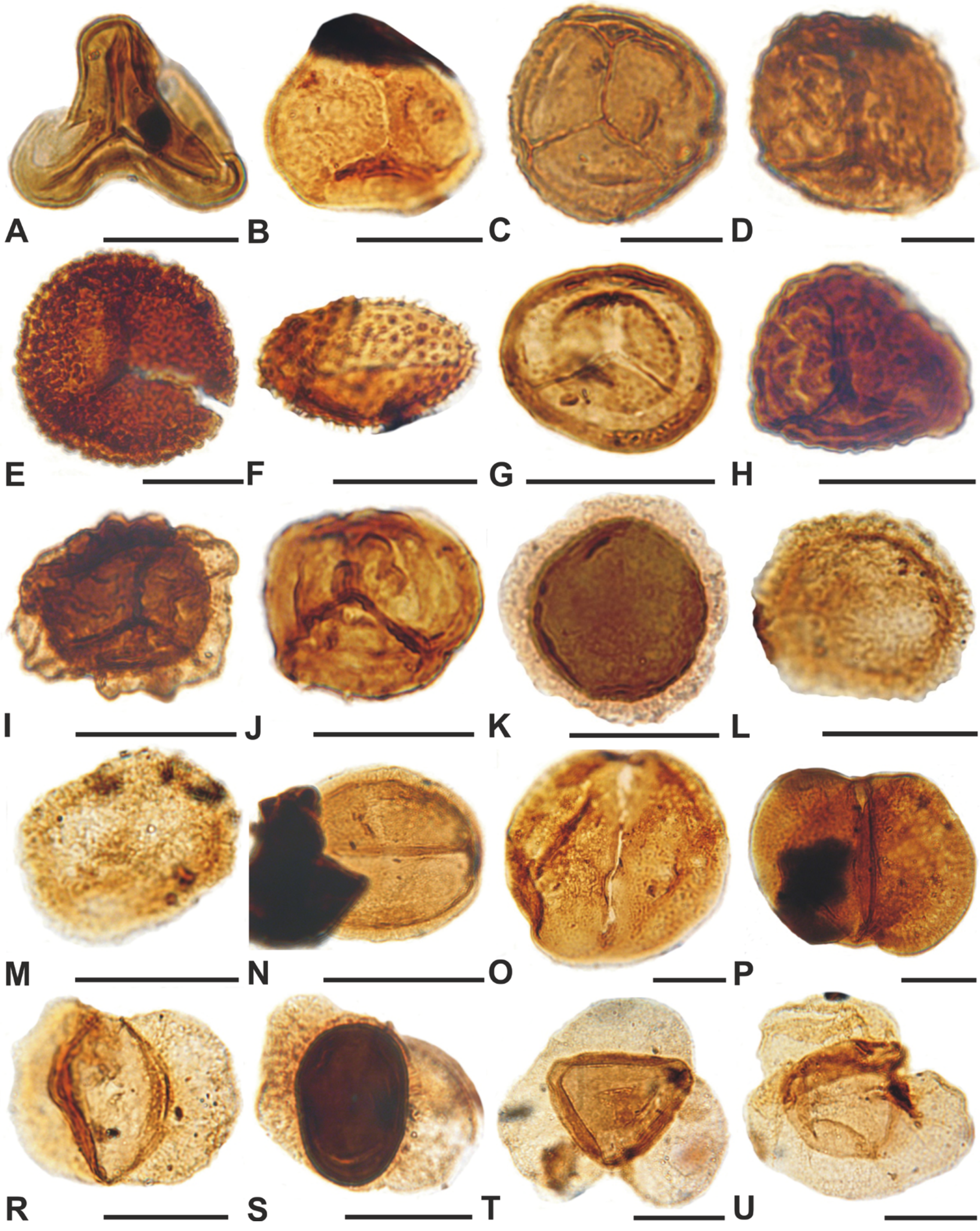


Fig. 5. Miospores from sample 2 (mudstone bed M2 in Fig. 3). The scale bar is 30 µm. **A**. *Deltoidospora* cf. *toralis* (Leschik) Lund, slide 1 (s1), J41/1. **B**. *Carnisporites* cf. *mesozoicus* (Klaus) Mädler, H49. **C**. *Carnisporites* sp., s1, W40/2. **D**. aff. *Lycopodiacidites* sp., s2, O32/2. **E**. *Baculatisporites* sp., s1, V40/2. **F**. *Anapiculatisporites telephorus* Pautsch**.** **G**. *Nevesisporites limatulus* Playford al. *Gordonispora fossulata* (Balme) Van der Eem, s2, T46/2. **H**. aff. *Taurocusporites* sp., s2, R48/4. **I**. *Kraeuselisporites* cf. *cooksonae* (Klaus) Dettmann, s1, V33/1. **J**. *Polycingulatisporites* sp., s1, R40. **K**. *Enzonalasporites vigens* Leschik, s2, M28/2. **L**. *Enzonalasporites* sp., s1, S41/4. **M**. *Vallasporites ignacii* Leschik, s2, T43/1. **N**. *Ovalipollis ovalis* Krutzsch, s1, S32/3. **O**. *Brachysaccus neomundanus* (Leschik) Mädler, s2, V46/1. **P**. *Cedripites* sp., s1, J34,3. **R**. *Alisporites* sp., s1, R28/1. **S**. *Triadispora* sp., s1, R29/2. **T**, **U**. Polysaccate pollen grain; respectively: s2, S40/1 and s1, U39/3.

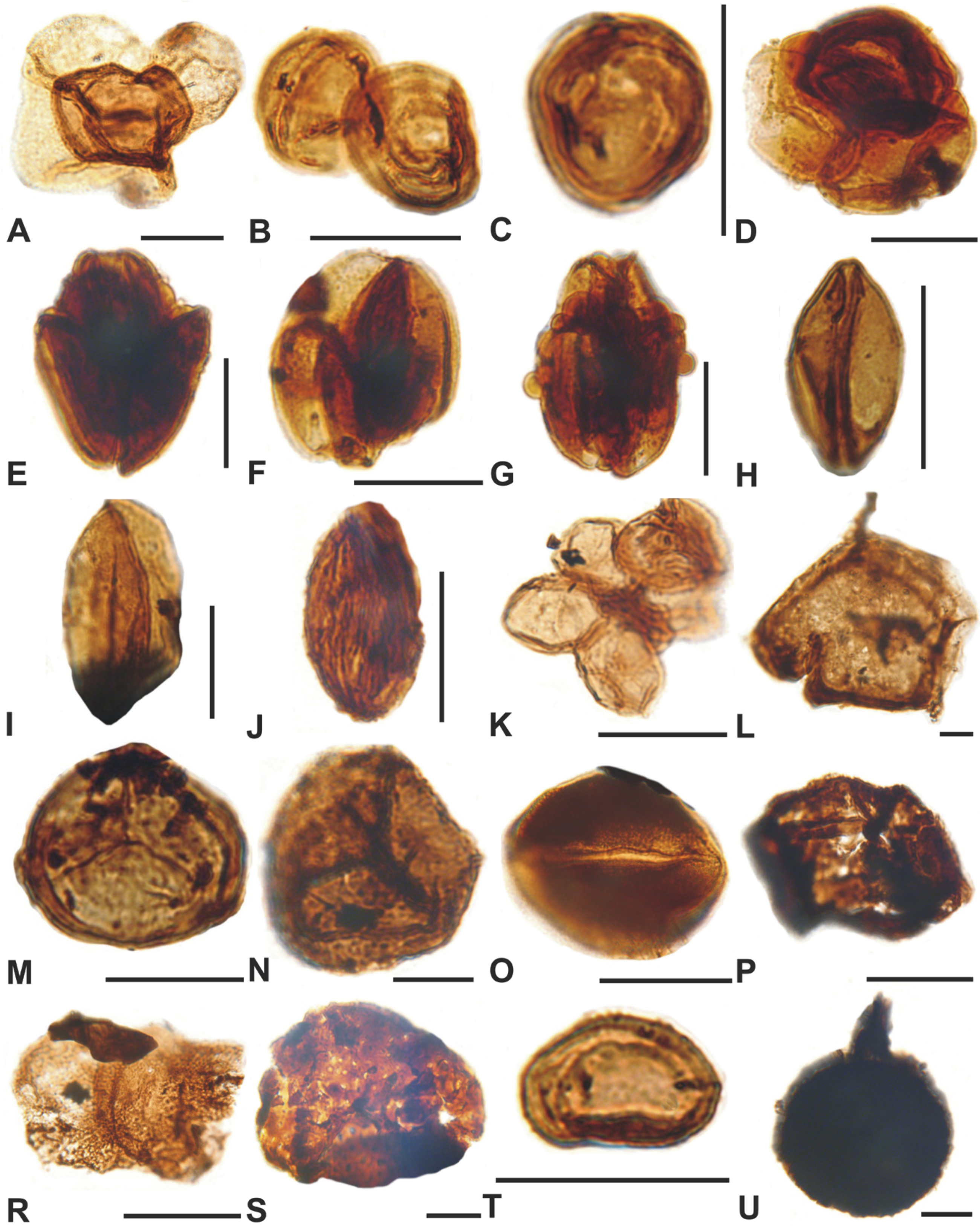


Fig. 6. Miospores from sample 2 (mudstone bed M2 in Fig. 3). The scale bar is 30 µm. **A**. Polysaccate pollen grain, s1, U41/1. **B–D**. *Classopollis meyeriana* (Klaus) de Jersey: B – s1, J31/2; C – s2; D (tetrad) – s2, L39. **E**, **F**. *Rhaetipollis germanicus* Schulz (tetrad): E – s1, N36/2; F – s1, Q21,3. **G**. aff. *Riccisporites* sp. (tetrad), s2, K40,2. **H**. *Monosulcites minimus* Cookson, s2, G36/4. **I**. *Monosulcites* sp., s2, R44. **J**. *Ephedripites* sp., s2, V36/1. **K.** *Sphaeripollenites* sp. (not separated pollen), s1, W27/2. **L**. Alga?, s2, J47/2. Photos **M–U**: stronger coalified and degraded and/or reworked? forms. **M**, **N**. Sporites indet.: M – s1, U34/2; N – s1, F34/3. **O**. *Ovalipollis ovalis* Krutzsch, s2, R46/1. **P**. *Protohaploxypinus* sp., s2, G46. **R**. *Alisporites* sp., s2, P36/3. **S.** Disaccites indet., s1, F45/4. **T**. *Classopollis meyeriana* (Klaus) de Jersey, s1, E44/1. **U**. Chitinozoa indet., s1. S37/2.

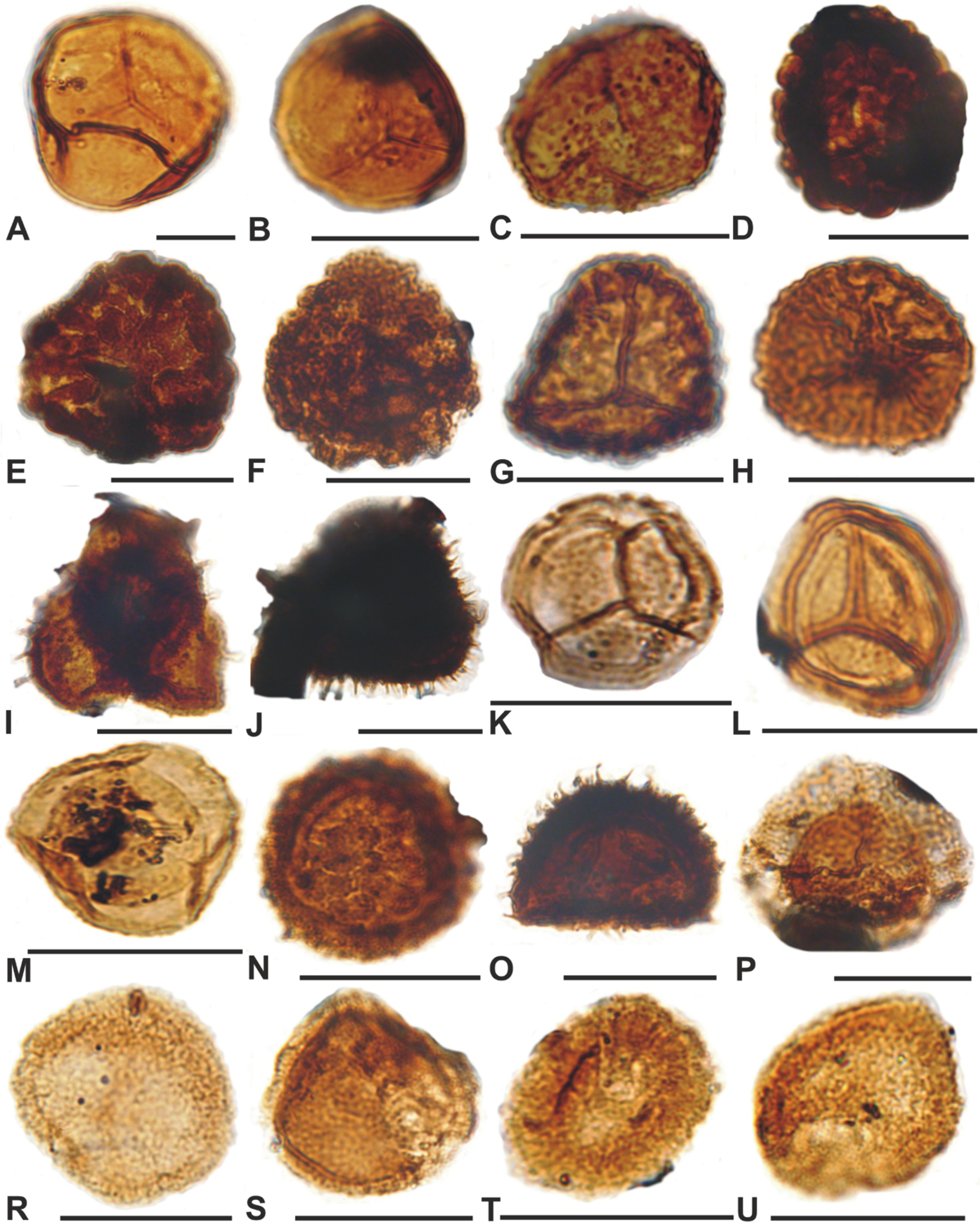


Fig. 7. Miospores from sample 3 (mudstone bed M3 in Fig. 3). The scale bar is 30 μm. **A.** *Todisporites cinctus* (Maliavkina) Orłowska-Zwolińska, s2, V31/2. **B**. *Todisporites minor* Couper , s2, L36/3. **C**. *Apicuatisporites* sp., s2, O35/2. **D**. *Verrucosisporites* sp., s2, N37/1. **E**. aff. *Taurocusporites* sp., s2, T44/3. **F**. *Lycopodiumsporites* cf. *reticulumsporites* (Rouse) Dettmann, s2, E38. **G**. *Lycopodiumsporites* sp., p2, J38/3. **H**. *Lycopodiacidites* sp., s1, K33. **I**. *Heliosporites* cf. *altmarkensis* Schulz (tetrad), s2, L44/2. **J**. aff. *Conbaculatisporites* sp., s2, H35. **K.** *Carnisporites* cf. *granulatus* Schulz, s1, K31/1. **L**. *Nevesisporites limatulus* Playford al. *Gordonispora fossulata* (Balme) Van der Eem, s2, U30/1. **M**. *Desnsosporites* sp., s1, S39/1. **N**. aff. *Densosporites* sp., p2, G37/2. **O**. aff. *Kraeuselisporites* sp., s2, J46/3. **P**. aff. *Perotrilites* sp., s2, M45/3. **R**. *Enzonalasporites manifestus* Leschik, s1, N33. **S**. *Enzonalasporites* cf. *vigens* Leschik, s2, J35/2. **T.** *Patinasporites* cf. *densus* Leschik, s2, M39/4. **U.** *Vallasporites ignacii* Leschik, s2, H35.

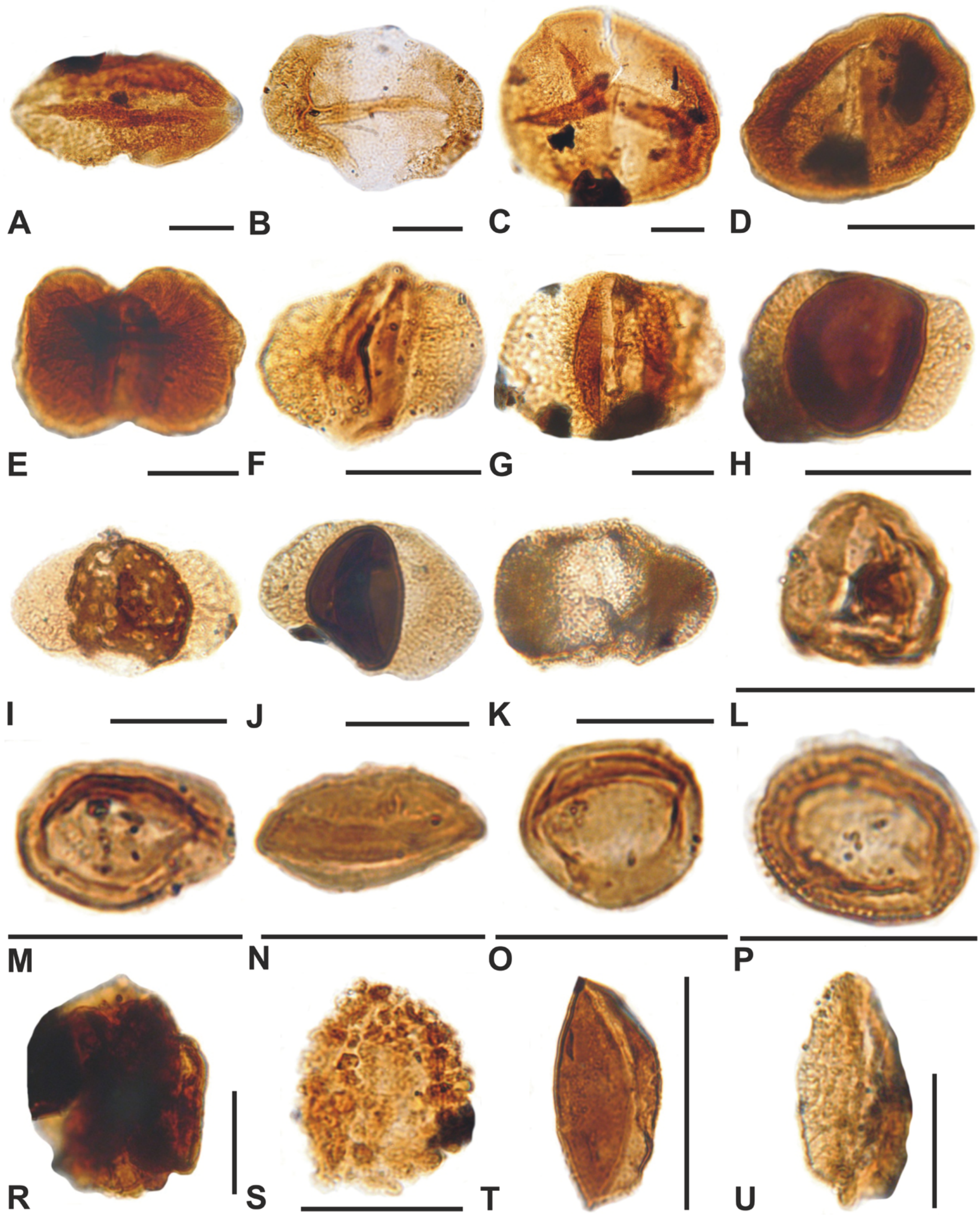


Fig. 8. Miospores from sample 3 (mudstone bed M3 in Fig. 3). The scale bar is 30 μm. **A**. *Ovalipollis lunzensis* Klaus, s2, J31/1. *Ovalipollis ovalis* Krutzsch, s2, G31/1. **C**. *Brachysporites neomundanus* (Leschik) Mädler, s1, J36/2. **D**. aff. *Brachysaccus* sp., s1, S44/4. **E**. *Parillinites* sp., s2, U30/3. **F**. *Falcisporites* sp., s2, S36/3. **G**. aff. *Piceapollenites* sp., s2, N33/3. **H**. *Tridispora polonica* Brugman, s2, P42/4. **I**. *Triadispora* sp., s2, N31/3. **J**. *Labiisporites triassicus* Orłowska-Zwolińska, s1, J36/2. **K**. Disaccites indet., s1, D35. **L**. *Duplicisporites granulatus* Leschik, s2, V46/3. **M–O**. *Classopollis meyeriana* (Klaus) de Jersey, with: **M** – s1, N27/2; **N** – s2, Q33/1; **O** – s2, T44/3. **P**. *Classopollis torosus* (Reissinger) Couper, s2, J44/3. **R**. *Rhaetipollis germanicus* Schulz (tetrad), s2, J36. **S**. *Riccisporites tuberculatus* Lundblad, s2, P35/2. **T**. *Monosulcites minimus* Cookson, s2, P36/2. **U**. *Monosulcites punctatus* Orłowska-Zwolińska, s2, G36/4.

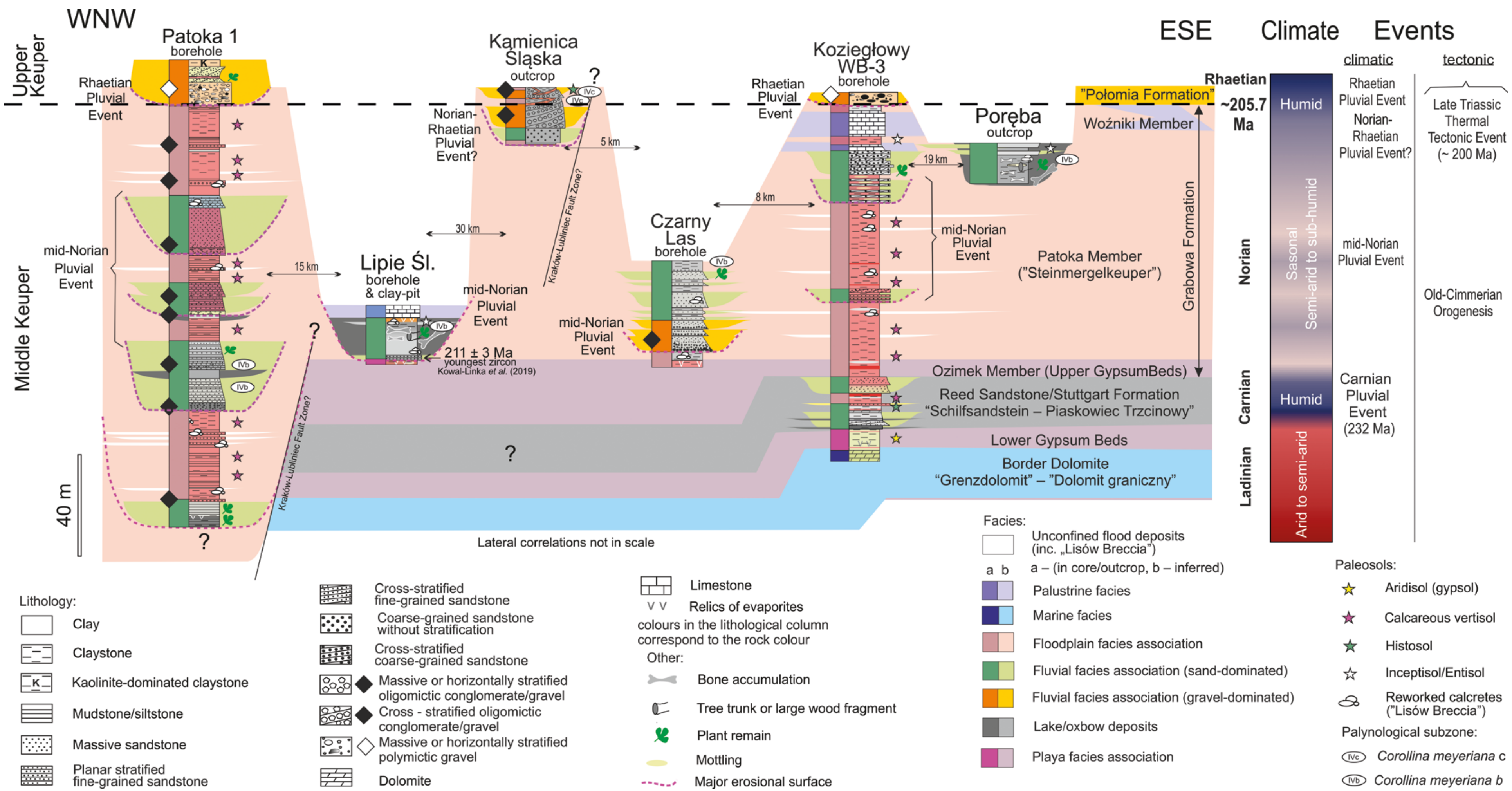


Fig. 9. Interpretation of the Upper Triassic lithostratigraphy in the Upper Silesia region on a background of climatic and tectonic events (modified from Szulc *et al*., 2015a and Jewuła, 2021).

age of 211 (± 3) Ma as the most conservative estimation (Kowal-Linka *et al*., 2019; Fig. 8). Therefore, the deposition of the coarse-grained sediments of the Grabowa Formation (e.g., in the Czarny Las borehole section, where the subzone b of *C. meyeriana* zone was also recognised) could have commenced in the mid-Norian and continued towards the Rhaetian time. The age of the younger, polymictic conglomerates (classical Połomia Beds) remains an open question, although there are some indirect premises indicating a Rhaetian to earliest Jurassic age of deposition.

The difference in the gravel composition between the Grabowa unit (into which the authors include the Kamienica Śląska deposits) and the Połomia unit may indicate a change and/or enlargement of the catchment areas or a deeper erosional incision of fluvial network caused by the lowering of the regional base level. In general, the composition of gravelly deposits in the region rules out sediment derivation from the north, for instance, from the Scandinavian shield (Jewuła *et al.*, 2019). As suggested earlier by Unrug and Calikowski (1960), the most likely transport direction was from the south or southeast, probably from the so-called Cracow-Silesian Land of Deczkowski and Franczyk (1988; see also Deczkowski, 1997) or Sudetian-Małopolska-Lublin Land of Szulc (2000; Fig. 9). Our sedimentological observations from the Kamienica Śląska outcrop section are consistent with these directions of fluvial transport.

The compositional maturity of the Grabowa conglomerates (including the Kamienica Śląska deposits) may be explained by redeposition of older gravelly sediments, such as the Lower Triassic (Buntsandstein) or Carboniferous deposits occurring directly south of the Kamienica Śląska area (Fig. 1A). Erosion of carbonate rocks is manifested by the presence of limestone fragments (from both the local Woźniki Limestone and the older, Middle Triassic Muschelkalk limestones) and the sediment calcareous matrix. The reworked palynomorphs in the M2 and M3 mudstone units may also indicate redeposition of older fine-grained sediments.

The classical Połomia Beds, in contrast, have a more varied gravel composition, including fragments of silicified limestone with Palaeozoic fauna and silicified peat. Furthermore, the sediment matrix in the Połomia beds is non-calcareous, with silicified carbonates only in the gravel fraction. The polymictic grain composition may indicate the opening of a new fluvial route, draining – in addition to the Sudetian-Małopolska-Lublin Land – the areas located farther to the southeast. The fluvial drainage system might then extend backwards throughout the Lower San River Massif and the eastern part of the Pre-Carpathian-Moesian Massif, and possibly reach as far as the Dobrogea Coal Basins. The source areas could also be the Vindelician-Bohemian Massif (Konieczna *et al*., 2015) or the Brunovistulian unit (Kowal-Linka *et al*., 2022) as for the older Norian deposits in the Lipie Śląskie area (Fig. 9). The back-stepping extension of the fluvial drainage and the preservation of the conglomeratic alluvia in the region were probably instigated by a transtensional differential tectonic subsidence driven by the Kraków-Lubliniec Fault (Figs 1A, 9; see Morawska, 1997; Szulc *et al.*, 2006, 2015a, b; Jewuła *et al.,* 2019).

In addition to this likely tectonic control on sedimentation, the impact of regional climatic changes must also be considered. Climate-induced regional changes in the style of fluvial sedimentation have been recognised in both the Upper Triassic (Keuper) deposits and the Lower Jurassic (Liassic) deposits (e.g., Szulc, 2007; Gruszka and Zieliński, 2008; Bodzioch and Kowal-Linka, 2012; Pieńkowski *et al*., 2014; Jewuła *et al*., 2019; Kędzior *et al.*, 2021). Sedimentary characteristics of the Middle Keuper (Grabowa Formation) in the Silesia region indicate a dominance of a semi-arid climate with strong seasonality (Szulc, 2000, 2005; Szulc *et al.,* 2006, 2015a, b; Jewuła *et al*., 2019). The consensus is that a gradual climate humidification commenced in the mid-Norian and continued until the Jurassic (Feist-Burkhardt *et al.*, 2008). The relatively unweathered carbonate clasts in the Grabowa conglomerates may indicate a less intense chemical weathering than at the sedimentation time of the younger classical Połomia Beds, where the abundant kaolinised extra-basinal volcanic clasts indicate both an intense substrata erosion and an aggressive chemical weathering of immature siliciclastic debris in a highly seasonal semi-arid climate (e.g., Szulc, 2007; Brański, 2014; Środoń *et al*., 2014; Jewuła *et al*., 2019). Such seasonal climatic conditions, with a strong aridity component, at the deposition time of the Grabowa conglomerates seem supported by the dominance of xerophytic pollen (*Classopollis, Triadispora, Brachysaccus, Labiisporites*) in miospore spectra, indicating a semi-arid environment (Fijałkowska-Mader *et al*., 2021). The change of the fluvial pattern from the ephemeral anastomosing rivers of the Middle Keuper (Szulc, 2005; Gruszka and Zieliński, 2008; Bodzioch and Kowal-Linka, 2012; Jewuła *et al*., 2019; Kędzior *et al.*, 2021) to the perennial, anabranching braided rivers of the middle and the latest Norian can be related to regional pluvial events (Fig. 9). The most humid conditions and maximum backward extension of the fluvial drainage are likely recorded by the deposition of the polymictic Połomia Beds.

This linking of the Upper Silesia coarse-grained alluvia of the Triassic-Jurassic transition with regional climatic changes (Fig. 9) is hypothetical, but the regional climate shift towards more humid conditions seems evident. The climate shift could be due to the gradual movement of Europe towards mid-latitudes or to the development of greenhouse conditions with an increased moist air delivery (see discussion by Huynh and Poulsen, 2005).

CONCLUSIONS

Sedimentary facies analysis of the gravelly deposits in the Kamienica Śląska open-pit mine indicates a perennial, anabranching and laterally shifting braided-river system with short-term intercalations of muddy floodplain ponds. The mature gravel, dominated by vein quartz and quartzite components, resembles that of the Norian Grabowa Formation, but differs from gravels of the Połomia Beds, which are distinctly polymictic. A backward extension and/or deeper incision of the regional drainage system are inferred on this basis.

The palynological material from two mudstone interbeds in the Kamienica Śląska outcrop section indicates subzone c of the *Corollina meyeriana* palynozone, which implies a late Norian to Rhaetian age of the deposits. The two interbeds differ in their content of redeposited/reworked palynomorphs, which seems to reflect the lateral shifting of fluvial drainage system.

Based on the regional correlations of the Upper Triassic coarse-grained deposits in the Upper Silesia area, three climatic pluvial episodes are postulated for the mid-Norian, Norian–Rhaetian and Rhaetian.

The gravel composition difference between the Grabowa and Połomia units (with the appearance of kaolinised clasts) indicates progressive climate change from sub-humid to humid conditions, which agrees with the regional notion of a climatic humidification trend. The latest Norian experienced drier climatic spells, as indicated by the dominance of xerophytic palynomorphs in the mudstone interbeds in the Kamienica Śląska section.

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REFERENCES

Bodzioch, A. & Kowal-Linka, M., 2012. Unraveling the origin of the Late Triassic multitaxic bone accumulation at Krasiejów (S Poland) by diagenetic analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 346–347: 25–36.

Brański, P., 2014. Climatic disaster at the Triassic-Jurassic boundary – a clay minerals and major elements record from the Polish Basin. *Geological Quarterly*, 58: 291–310.

Bridge, J. S., 2003. *Rivers and Floodplains: Forms, Processes, and Sedimentary Record.* Blackwell Publishing, Malden, 491 pp.

Cirilli, S., 2010. Upper Triassic–lowermost Jurassic palynology and palynostratigraphy: a review. In: Lucas, S. G. (ed.), *The Triassic Time Scale. Geological Society, London, Special Publication,* 334: 285–314.

Dadlez, R., Marek, S. & Pokorski, J., 2000. *Mapa geologiczna Polski bez utworów kenozoiku 1:1 000 000*. Państwowy Instytut Geologiczny. Warszawa. [In Polish.]

Deczkowski, Z., 1962. Lias stratigraphy and lithology in the Kalisz-Częstochowa area. *Kwartalnik Geologiczny*, 6: 50–71. [In Polish, with English summary.]

Deczkowski, Z., 1997. Noryk i retyk. Formalne i nieformalne jednostki litostratygraficzne. In: Marek, S. & Pajchlowa, M. (eds), *The Epicontinental Permian and Mesozoic in Poland. Prace Państwowego Instytutu Geologicznego*, 153: 1–184. [In Polish, with English title.]

Deczkowski, Z. & Daniec, J., 1981. Rudy żelaza. In: Wiegomas, L. (ed.), *Surowce Mineralne Województwa Częstochowskiego.* Wydawnictwa Geologiczne. Warszawa, pp. 102–115. [In Polish.]

Deczkowski, Z. & Franczyk, M., 1988. Paleomiąższość, litofacje i paleotektonika noryku i retyku na Niżu Polskim. *Kwartalnik Geologiczny*, 32: 93–104. [In Polish, with English summary.]

Feist-Burkhardt, S., Götz, A. E., Szulc, J., Aigner, T., Borkhataria, R., Geluk, M., Haas, J., Hornung, J., Jordan, P., Kempf, O., Michalík, J., Nawrocki, J., Reinhardt, L., Ricken, W., Röhling, H. G., Ruffer, T., Török, A. & Zuhlke, R., 2008. Triassic. In: McCann, T. (ed.), *The Geology of Central Europe*. The Geological Society, London, pp. 749–821.

Fijałkowska-Mader, A., Heunisch, C. & Szulc, J., 2015. Palynostratigraphy and palynofacies of the Upper Silesian Keuper (southern Poland). *Annales Societatis Geologorum Poloniae*, 85: 637–661.

Fijałkowska-Mader, A., Jewuła, K. & Bodor, E., 2021. Record of the Carnian Pluvial Episode in the Polish microflora. *Palaeoworld*, 30: 106–125.

Fijałkowska-Mader, A. & Paszkowski, M., 2016. Palynostratigraphy of the Połomia Formation (southern Poland). In: Szydło, A., Krobicki, M. & Granoszewski, W. (eds), *17th Czech-Slovak-Polish Palaeontological Conference, Kraków 20–21 October 2016, Abstract Volume*, Polish Geological Institute – National Research Institute, Warszawa, p. 38.

Georgiev, G. & Botoucharov, N., 2007. Are there Middle Jurassic contourites in the Tarnovo depression (Southern Moesian platform margin)? *Geological Society, London, Special Publication*, 276: 283–298.

Gruszka, B. & Zieliński, T., 2008. Evidence for a very low-energy fluvial system: a case study from the dinosaur-bearing Upper Triassic rocks of Southern Poland. *Geological Quarterly*, 62: 415–432.

Harms, J. C., Southard, J. B. & Walker, R. G., 1982. *Structures and Sequences in Clastic Rocks. Lecture Notes, SEPM Short Course*, 9. Society of Economic Paleontologists and Mineralogists, Tulsa, 250 pp.

Huynh, T. T. & Poulsen, C. J., 2005. Rising atmospheric CO_2 as a possible trigger for the end-Triassic mass extinction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 217: 223–242.

Jakubowski, Z., 1977. Lower Jurassic sedimentation history of Cracow-Wieluń Upland and stratigraphic position of coarse clastic deposits. *Rocznik Polskiego Towarzystwa Geologicznego*, 47: 585–604. [In Polish, with English summary.]

Jewuła, K., 2021. *Depositional Environments and Facies Architecture of the Upper Permian–Lower Triassic and Upper Triassic Continental Successions in the SE Margin of Central European Basin (Holy Cross Mountains and Upper Silesia).* PhD Thesis, Institute of Geological Sciences, Polish Academy of Sciences, Kraków, 165 pp.

Jewuła, K., Matysik, M., Paszkowski, M. & Szulc, J., 2019. The Late Triassic development of playa-gilgai environments from Upper Silesia, southern Poland. *Sedimentary Geology*, 379: 25–45.

Kędzior, A. & Popa, M. E., 2018. An early Jurassic braided river system from Mehadia, south Carpathians, Romania. *Geological Quarterly*, 62: 415–432.

Kędzior, A., Widera, M. & Zieliński, T., 2021. Ancient and modern anastomosing rivers: insights from sedimentological and geomorphological case studies of the Triassic, Neogene and Holocene of Poland. *Geological Quarterly*, 65: 54, https://doi.org/10.7306/gq.1623

Konieczna, N., Belka, Z. & Dopieralska, J., 2015. Nd and Sr isotopic evidence for provenance of clastic material of the Upper Triassic rocks of Silesia, Poland. *Annales Societatis Geologorum Poloniae*, 85: 675–684.

Kopik, J., 1998. Lower and Middle Jurassic of the north-eastern margin of the Upper Silesian Coal Basin. *Biuletyn Państwowego Instytutu Geologicznego*, 378: 67–120. [In Polish, with English summary.]

Kowal-Linka, M., Jastrzębski, M., Krzemińska, E. & Czupyt, Z., 2022. The importance of parameter selection in studies of detrital zircon provenance: An example from Mesozoic deposits of the Bohemian Massif foreland (Poland). *Palaeogeography, Palaeoclimatology, Palaeoecology,* 599: 487–501.

Kowal-Linka, M., Krzemińska, E. & Czupyt, Z., 2019. The youngest detrital zircons from the Upper Triassic Lipie Śląskie (Lisowice) continental deposits (Poland): Implications for the maximum depositional age of the Lisowice bone-bearing horizon. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 514: 487–501.

Köppen, A., 1997. Faziesentwicklung in der fühen Obertrias Mitlleleuropas – ein sequenzstratigraphischer Vergleich. *Gaea Heidelbergensis*, 2: 1233.

Kutzbach, J. E., 1994. Idealized Pangean climates: Sensitivity to orbital change. In: Klein, G. D. (ed.), *Pangea: Paleoclimate, Tectonics, and Sedimentation During Accretion, Zenith, and Breakup of a Supercontinent*. *Geological Society of America, Special Paper*, 288: 41–55.

Kutzbach, J. E. & Gallimore, R. G., 1989. Pangaean climates: megamonsoons of the megacontinent. *Journal of Geophysical Research*, 94: 3341–3357.

Kürschner, W. M. & Herngreen, G. F. W., 2010. Triassic palynology of central and northwestern Europe: a review of palynological diversity patterns and biostratigraphic subdivisions. In: Lucas, S. G. (ed.), *The Triassic Time Scale*. *Geological Society, London, Special Publication*, 334: 263–283.

Marcinkiewicz, T., 1957. Megaspores of the Lias from Praszka, Zawiercie and Święty Krzyż Mountains. *Kwartalnik Geologiczny*, 1: 299–302. [In Polish, with English summary.]

Marcinkiewicz, T., 1960. Megaspore analysis of Jurassic sediments near Gorzów Śląski – Praszka (Cracow-Wieluń region). *Kwartalnik Geologiczny*, 4: 713–733. [In Polish, with English summary.]

Marcinkiewicz, T., 1971. The stratigraphy of the Rhaetian and Lias in Poland based on megaspore investigations. *Prace Instytutu Geologicznego*, 65: 5–57. [In Polish, with English summary.]

Marcinkiewicz, T., Orłowska, T. & Rogalska, M., 1960. Age of the Upper Helenów Beds (Lias) in view of mega- and microspore investigations (geological section Gorzów Śląski–Praszka). *Kwartalnik Geologiczny*, 4: 386–398. [In Polish, with English summary.]

Miall, A. D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In: Miall, E. D. (ed.), *Fluvial Sedimentology*. *Canadian Society of Petroleum Geologists Memoir,* 5: 597–604.

Miall, A. D., 1996. *The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis and Petroleum Geology*. Springer-Verlag, Berlin, 582 pp.

Morawska, A., 1997. The Lubliniec fracture zone: boundary of the Upper Silesian and Małopolska massifs, southern Poland. *Annales Societatis Geologorum Poloniae,* 67: 429–437.

Mossoczy, Z., 1961. New stratigraphical division of Lias in northern part of the Cracov-Częstochowa Jura. *Kwartalnik Geologiczny*, 5: 81–100. [In Polish, with English summary.]

Nanson, G. C. & Knighton, A. D., 1996. Anabranching rivers: their cause, character and classification. *Earth Surface Processes and Landforms*, 21: 217–239.

Nemec, W., 1992. Depositional controls on plant growth and peat accumulation in a braidplain delta environment: Helvetiafjellet Formation (Barremian–Aptian), Svalbard. In: McCabe, P. J. & Parrish, J. T. (eds), *Controls on the Distribution and Quality of Cretaceous Coals*. *Geological Society of America, Special Paper,* 267: 209–226.

Nita, J. & Nita, M., 2014. The geological values of the Woźniki municipality (Southern Poland). *Acta Geographica Silesiana*, 17: 49–62. [In Polish, with English summary.]

Orłowska-Zwolińska, T., 1983. Palynostratigraphy of the Upper part of Triassic epicontinental sediments in Poland. *Prace Instytutu Geologicznego*, 104: 5–89. [In Polish, with English summary.]

Orłowska-Zwolińska, T., 1985. Palynological zones of the Polish Epicontinental Triassic. *Bulletin of the Polish Academy of Sciences, Earth Sciences*, 33: 107–119.

Oszczypko, N., Uchman, A. & Bubniak, I., 2012. Foreland provenance of thick conglomerates in the early stage of Carpathian Foredeep development: the case of the Sloboda Conglomerate (Lower Miocene), western Ukraine. *Geological Quarterly*, 56: 789–802.

Pieńkowski, G., Niedźwiedzki, G. & Brański, P., 2014. Climatic reversals related to the Central Atlantic magmatic province caused the end-Triassic biotic crisis — Evidence from continental strata in Poland. In: Keller, G. & Kerr, C. A. (eds), *Volcanism, Impacts, and Mass Extinctions: Causes and Effects*. *Geological Society of America, Special Paper,* 505: 263–286.

Reinhardt, L. & Ricken, W., 2000. The stratigraphic and geochemical record of Playa Cycles: monitoring a Pangaean monsoon-like system (Triassic, Middle Keuper, S. Germany). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 161: 205–227.

Retallack, G. J., 2008. *Soils of the Past: An Introduction to Paleopedology. 3rd Edition*. John Wiley & Sons, London, 552 pp.

Rogalska, M., 1954. Spore and pollen analysis of the brown coal of the region of the so-called Blanowice Coal in Upper Silesia. *Biuletyn Instytutu Geologicznego*, 89: 5–46. [In Polish, with English summary.]

Rogalska, M., 1962. Spore and pollen grain analysis of Jurassic sediments in the northern part of the Cracow-Wieluń Cuesta. *Prace Instytutu Geologicznego*, 30: 495–507. [In Polish, with English summary.]

Ruhl, M., Bonis, R. N., Reichart, G. J., Sinninghe Damsté, J. S. & Kürschner, W. M., 2011. Atmospheric carbon injection linked to end-Triassic mass extinction. *Science*, 333: 430–434.

Stan, A. L. & Raileanu, A., 2003. Permian–Jurassic tectonic and depositional control on oil fields in the Central Moesian Platform, Romania. *AAPG Search and Discovery Article* #10046, DOI: 10.13140/2.1.2927.3608

Szulc, J., 2000. Middle Triassic evolution of the northern Peri-Tethys area as influenced by early opening of the Tethys Ocean. *Annales Societatis Geologorum Poloniae*, 70: 1–48.

Szulc, J., 2005. Sedimentary environments of the vertebrate-bearing Norian deposits from Krasiejów, Upper Silesia (Poland). *Hallesches Jahrbuch der Geowissenschaften*, B19: 161–170.

Szulc, J., 2007. Keuper. In: Szulc, J. & Becker, A. (eds), *Fieldtrip Guide, International Workshop on the Triassic of Southern Poland*. Polish Geological Society, Kraków, pp. 33–41.

Szulc, J., Gradziński, M., Lewandowska, A. & Heunisch, C., 2006. The Upper Triassic crenogenic limestones in Upper Silesia (southern Poland) and their paleoenvironmental context. In: Alonso-Zarza, A. M. & Tanner, L. H. (eds), *Paleoenvironmental Record and Applications of Calcretes and Palustrine Carbonates*. *Geological Society of America, Special Paper*, 416: 133–151.

Szulc, J. & Racki, G., 2015. The Grabowa Formation – the basic lithostratigraphic unit of the Keuper of Silesia. *Przegląd Geologiczny*, 63: 103–113. [In Polish, with English abstract.]

Szulc, J., Racki, G. & Jewuła, K., 2015a. Key aspects of the stratigraphy of the Upper Silesian Middle Keuper, southern Poland. *Annales Societatis Geologorum Poloniae*, 85: 557–586.

Szulc, J., Racki, G., Jewuła, K. & Środoń, J., 2015b. How many Upper Triassic bone-bearing levels are there in Upper Silesia (southern Poland)? A critical overview of stratigraphy and facies. *Annales Societatis Geologorum Poloniae*, 85: 587–627.

Środoń, J., Szulc, J., Anczkiewicz, A., Jewuła, K., Banaś, M. & Marynowski, L., 2014. Weathering, sedimentary, and diagenetic controls of mineral and geochemical characteristics of the vertebrate-bearing Silesian Keuper. *Clay Minerals*, 49: 569–594.

Unrug, R. & Calikowski, A., 1960. Sedimentation and petrology of the Połomia Beds. *Rocznik Polskiego Towarzystwa Geologicznego*, 30: 129–168. [In Polish, with English summary.]

Visscher, H. & van der Zwan, C. J., 1981. Palynology of the Circum-Mediterranean Triassic: phytogeographical and palaeoclimatological implications. *Geologische Rundschau*, 70: 625–634.

Whalen, L., Gazel, E., Vidito, C., Puffer, J., Bizimis, M., Henika, W. & Caddick, M. J., 2015. Supercontinental inheritance and its influence on supercontinental breakup: The Central Atlantic Magmatic Province and the breakup of Pangea. *Geochemistry, Geophysics, Geosystems*, 16: 3532–3554.

Znosko, J., 1955. Rhaetic and Lias between Cracow and Wieluń. *Prace Instytutu Geologicznego*, 14: 5–145. [In Polish, with English summary.]