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THE 'LADINIAN–CARNIAN TERRIGENOUS INVASION' REVISITED: CLUES FROM THE PETROGRAPHY OF SANDSTONES AND SHALES IN NORTHWESTERN BULGARIA

Athanas Chatalov

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Abstract

Increased siliciclastic influx caused temporary cessation of the carbonate sedimentation on a NW Tethyan ramp around the Middle/Late Triassic boundary. This regional 'Ladinian–Carnian terrigenous invasion' has been formerly interpreted as a result of intensive tectonic activity in the sourceland. However, new petrographic data from sandstones and shales outcropping in NW Bulgaria reveal that the major control was climate humidification. The latter is evidenced by the high quartz/feldspar ratio, very low amount of plagioclase, lithic grains and unstable detrital minerals, traces of corrosion in many quartz grains, and authigenic glauconite formation in the sandstones as well as the abundance of phytoclasts and presence of amber in the shales (plus a hygrophytic affinity of the spore-pollen assemblage as determined in a previous research). The significant climate change was most likely associated with the 'Ladinian–Carnian humid interval' which has been recognized in Tethyan and Peri-Tethyan successions across Europe and explained as a consequence of intense volcanism. The termination of massive siliciclastic input was followed by renewed carbonate deposition in the ramp environment indicating a rapid return to arid climatic conditions before the onset of the global 'Carnian Pluvial Event'.

Key words: siliciclastic influx, carbonate ramp, quartzose sandstones, phytoclasts, amber, humid climate

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Introduction. Temporary shutdown of carbonate factories and demise of carbonate platforms are controlled by the interplay of various extrinsic and intrinsic factors. For example, cessation of marine carbonate production may be caused by increased terrigenous runoff which is directly influenced by climatic conditions and/or tectonic regime in the hinterland, and also by sea-level changes [1]. In particular, the establishment of warmer and humid conditions has a major effect on source areas by enhancing chemical weathering and fluvial runoff. Periods of wet–dry climate with highly seasonal rainfall are characterized by greatest siliciclastic input into sedimentary basins [2]. Short-term and long-term shifts from carbonate to siliciclastic sedimentation (and vice versa) are a common characteristic of marine depositional systems and many examples in the geological record have been explained mainly by climate changes.

The present study re-examines the massive siliciclastic influx into a Triassic carbonate ramp from the NW Tethys area that temporarily suffocated the carbonate factory around the Middle/Late Triassic boundary. This sudden change in the depositional style has been named 'Ladinian–Carnian terrigenous invasion' and interpreted as a result of intensive tectonic activity in the sourceland [3]. It has been also noted that the northwestern zone (i.e., NW Bulgaria) remained unaffected [3]. New petrographic data from upper Ladinian–lower Carnian sandstones and shales outcropping in this part of the country are used to revisit the fundamental controls on the siliciclastic input and the interruption of marine carbonate sedimentation.

Geological and stratigraphic setting. The exposed Triassic sedimentary rocks in NW Bulgaria occur in the West Balkan Tectonic Zone and are assigned to the Balkanide (facies) type of Triassic. The whole succession corresponds to a 2nd-order transgressive–regressive stratigraphic cycle. Marine sediments were deposited from the Early to Late Triassic on a carbonate ramp located in the subtropical belt on the NW shelf area of the Tethys Ocean. Lithostratigraphically, these strata are referred to as Iskar Carbonate Group (up to 500 m thick) and consist almost entirely of limestones and dolostones. Sandstones and shales were mainly deposited during the second progradational stage in the ramp development. The siliciclastic rocks are included in the volume of the Mitrovtsi Formation [4] and the argillaceous-sandy formation, the latter forming the middle part of the Rusinovdel Formation [5]. A palynological analysis of shales from the lower levels of the Mitrovtsi Formation indicated late Ladinian (Longobardian) age [6], and the upper part of the unit belongs to the lower Carnian (Julian) stage as determined on the basis of bivalve fauna [4]. The presumed age of the argillaceous-sandstone formation deposits is early Carnian [5]. The Mitrovtsi Formation is correlated with the argillaceous-sandstone formation in the scheme of Triassic lithostratigraphic units in North Bulgaria [7].

Material and methods. The siliciclastic rocks were studied in two outcrops of the Mitrovtsi Formation in the Shiroka planina Mountain (the gullies Golyama

Kratchina and Cheshmichki dol), and two outcrops of the argillaceous-sandstone formation in the Koznitsa Mountain (west of Druzhevo village) and in the Vratsa Mountain (south of Milanovo village), respectively (Fig. 1). Twenty-one samples

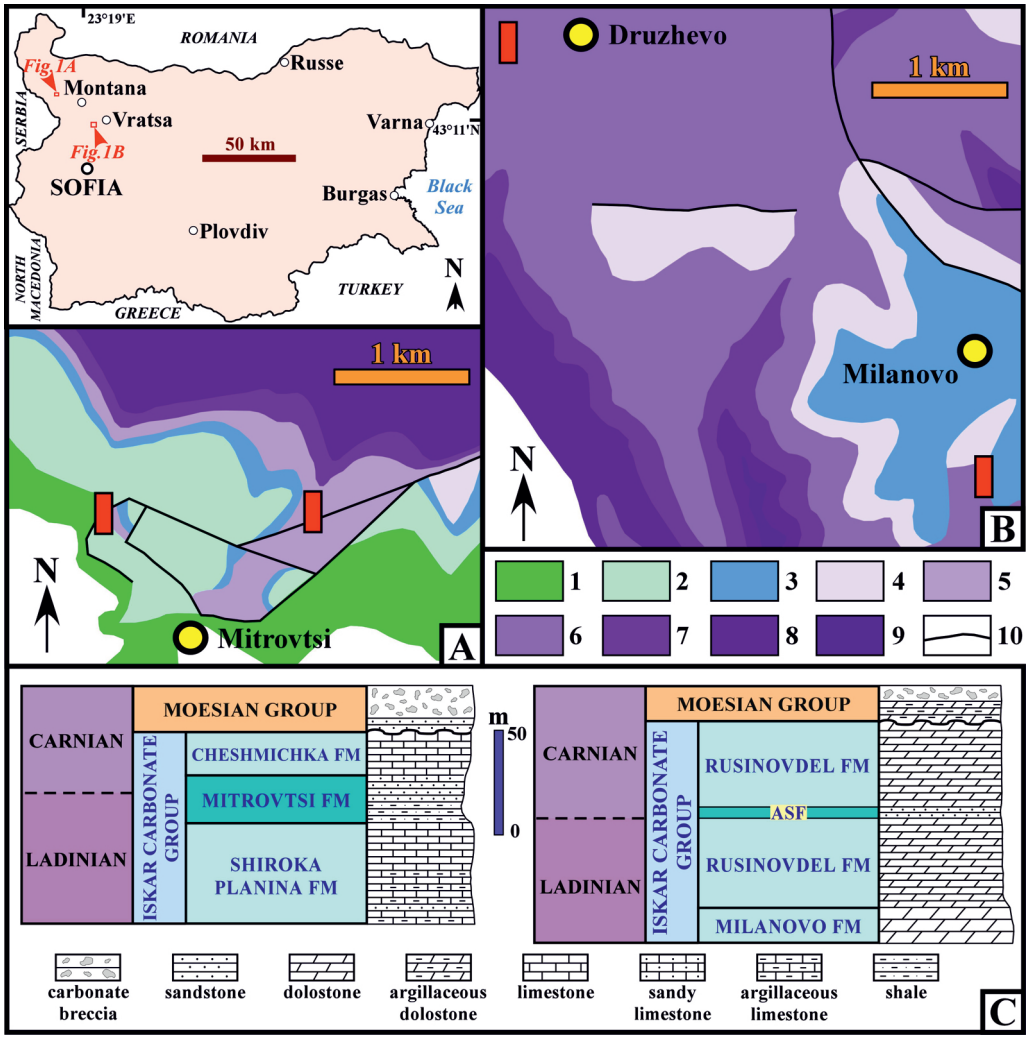


Fig. 1. A, B – Geological maps of the two study areas (from [8, 9]) with location of the sampled outcrops (Golyama Kratchina 43°45′N 22°93′E, Cheshmichki dol 43°45′N 22°95′E, Druzhevo 43°14′N 23°34′E, Milanovo 43°10′N 23°39′) shown by red rectangles. Legend: 1 – Lower Cretaceous rocks, 2 – Upper Jurassic–Lower Cretaceous rocks, 3 – Jurassic rocks, 4 – Komshtitsa Formation (Carnian–Norian?), 5 – Cheshmichka Formation (Carnian), Mitrovtsi Formation (Ladinian–Carnian), Shirokaplanina Formation (Ladinian), 6 – Rusinovdel Formation (Ladinian–Carnian), 7 – Toshkovdol Formation, Milanovo Formation (Anisian–Ladinian), 8 – Babina Formation (Anisian), 9 – Mogilata Formation (Olenekian–Anisian), 10 – fault. C – Stratigraphic and lithologic logs based on data from [4–6]. Abbreviation: ASF – argillaceous-sandstone formation

from sandstones of both units and five samples from shales of the Mitrovtsi Formation were collected for preparation of standard thin-sections and observation on transmitting light-microscope. Framework mineral composition of the sandstones was quantified by point-counting of 300 detrital sand-sized grains per thin-section. The original feldspar contents were corrected following McBride [10] and the ternary QFL diagram proposed by Garzanti [11] was used for petrographic classification.

Petrography. The medium-bedded to thick-bedded sandstones have massive structure and dark grey, brownish-grey, rusty-brownish and greenish-grey rock colours (Fig. 2a, b). Bivalve shells (Fig. 2c) and straight dark-coloured burrows (Fig. 2d) are locally observed in deposits of the Mitrovtsi Formation, and the presence of plant debris is a typical feature. Under the microscope, the sandstones from the Shiroka planina Mountain and the Druzhevo outcrop show moderately sorted texture with very fine to fine sand grains having generally low

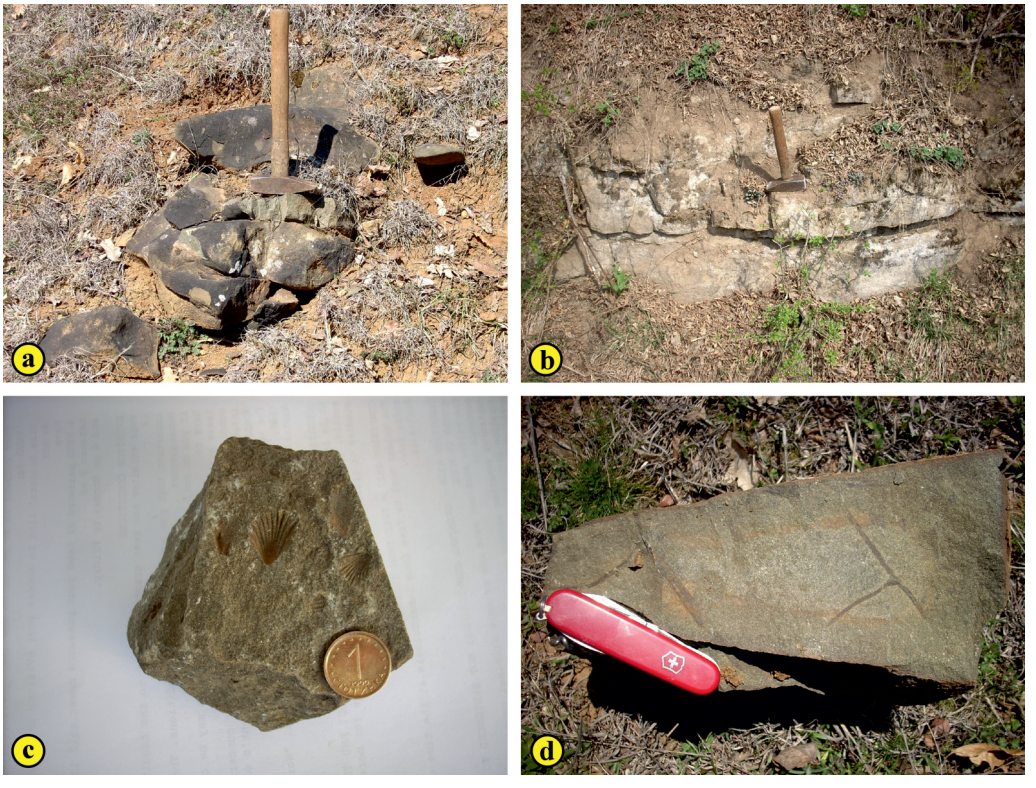


Fig. 2. Macroscopic features of sandstones of the Mitrovtsi Formation in the Cheshmichki dol gully (a, c, d) and the argillaceous-sandstone formation south of Milanovo village (b): a – Greenish-grey rocks with massive structure. Scale: hammer is 33 cm long; b – Medium-bedded dark grey sandstones; c – Bivalve shells. Scale: coin diameter is 16 mm; d – Dark-coloured straight burrows. Scale: knife is 8.5 cm long

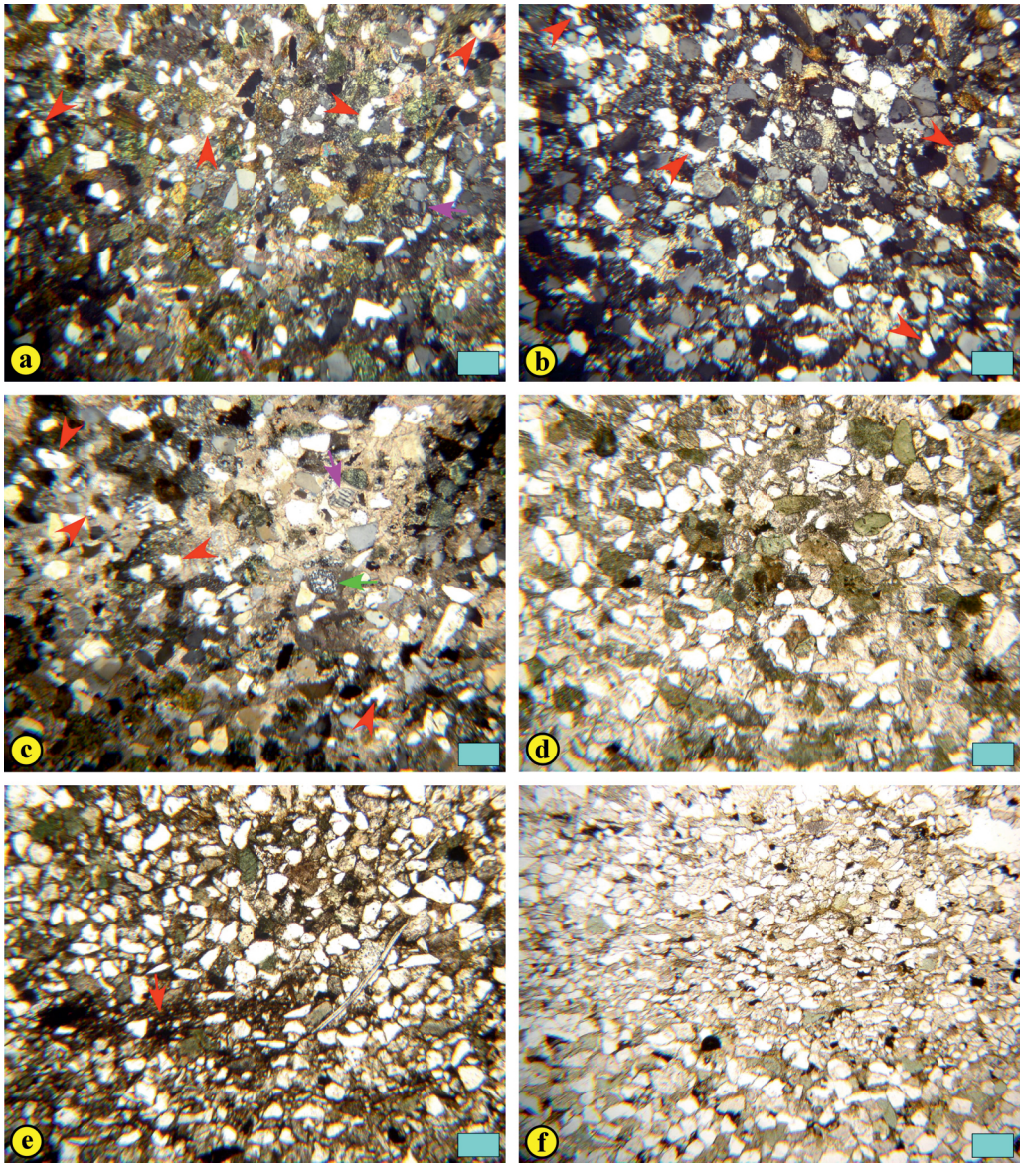
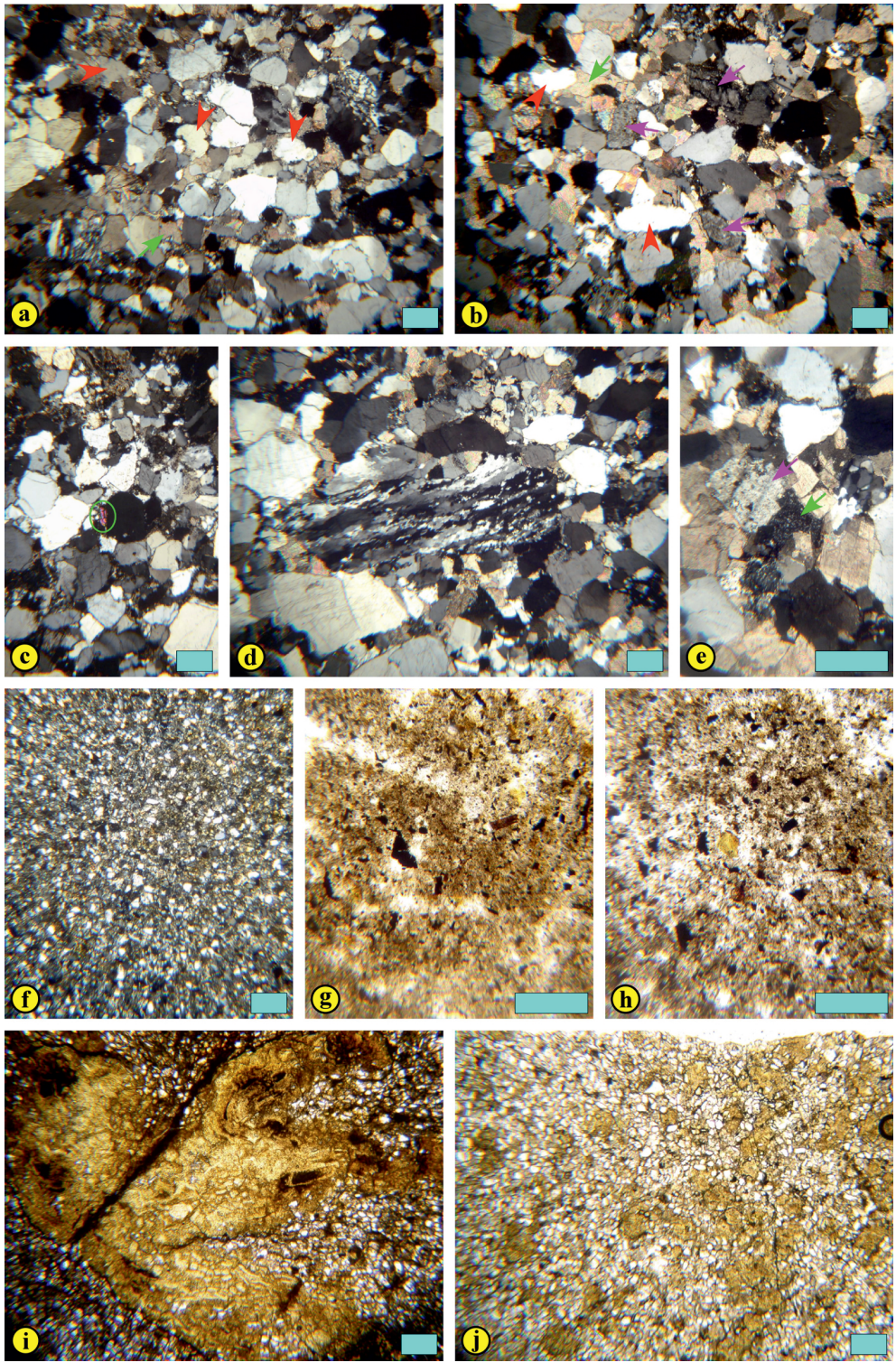


Fig. 3. Quartzose sandstones from the Shiroka planina Mountain (a, c–e) and the Druzhevo outcrop (b, f): a–c Moderately sorted texture with predominant subangular to subrounded, monocrystalline quartz grains. Many of the latter show traces of corrosion (etch pits and embayments – red arrows). Plagioclase and microcline grains are indicated by magenta arrows and chert fragment is indicated by green arrow; d – Abundant green and brownish-green glauconite pellets; e – Streak of amorphous organic matter (arrow); f – Detrital grains and glauconite pellets showing laminar arrangement by size. Note the presence of opaque phytoclasts. Photomicrographs a–c are in cross-polarized light and the rest are in plane-polarised light. Scale bar is 0.3 mm long

degree of roundness (Fig. 3a–c). The dominant quartz comprises monocrystalline grains (mostly with non-undulatory extinction) and very scarce polycrystalline grains. Many quartz grains show traces of corrosion, i.e., etch pits and embayments. The feldspar grains (microcline, perthite and rare plagioclase) are locally replaced by kaolinite (forming grain-shaped patches) or carbonate (forming pseudomorphs). Green and brownish-green (para)autochthonous glauconite pellets occur in most samples (Fig. 3d). Other minor constituents include muscovite, biotite and chlorite flakes, chert lithics, rip-up mudclasts and heavy mineral grains (zircon, tourmaline). Amorphous organic matter (Fig. 3e) and small phytoclasts are also present. The groundmass is represented by clay matrix and/or calcite cement. In few samples, the detrital grains and glauconite pellets have distinct laminar arrangement by size (Fig. 3f). The sandstones from the Milanovo outcrop show some specific textural features, e.g., poorer sorting (very fine to coarse sand), slightly higher amount of polycrystalline quartz and feldspar grains, lack of glauconite, mica and organic matter, presence of fine to medium crystalline dolomite cement, and stronger compaction (Fig. 4a–e). According to the relative amount of quartz (87–93%), feldspar (7–13%) and lithic grains (< 1%) all sandstones are classified as quartzose and feldspatho-quartzose (quartz-rich).

The dark grey shales of the Mitrovtsi Formation consist of abundant clay matrix and variable amount (10–40%) of quartz silt (Fig. 4f), the latter locally infilling small circular burrows. The random distribution and angular to subrounded shape of the quartz grains indicate detrital origin. Diverse forms of organic matter are distinguished including: opaque, semi-opaque and translucent phytoclasts (lath-shaped, irregular, equidimensional) (Fig. 4g, h), amorphous organic matter, subspherical clusters of microspores(?), large fragments (with ghostly cellular structure) and small droplets of yellow-brownish resin (Fig. 4i, j). Other very minor components are feldspar, glauconite and phosphate grains plus muscovite and chlorite flakes.

Interpretation and discussion. Upper Ladinian–lower Carnian siliciclastic deposits occur in most of the areas with exposures of the Balkanide and Sub-Balkanide types of Triassic [3], including rocks of the Radomir Formation and Vasilyov Formation, but also in the subsurface of the Moesian Platform (western part – Mitrovtsi Formation, eastern part – Tulenovo Formation). The 'Ladinian–Carnian terrigenous invasion' is further recognized in NW Bulgaria as evidenced herein by the sandstones and shales of the Mitrovtsi Formation and the argillaceous-sandstone formation. This regional depositional event has been explained in general by intensive tectonic movements [3] which presumably caused uplifting and erosion of hinterland areas with rejuvenation of siliciclastic sources. However, no relevant tectonic activity is known so far from the territory of Bulgaria for this time interval which was characterized by a tectonically quiescent setting (passive continental margin), unlike elsewhere in the western Tethys (e.g., the Southern Alps).


a
b
c
d
e
f
g
h
i
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Sea-level change may have been a potential trigger of the sudden siliciclastic influx and the temporary cessation of carbonate production. For example, falling sea-level can lead to river systems incising and thus result in more terrigenous input to the marine basin [1]. A major eustatic sea-level drop occurred during the late Ladinian which is recorded in some regions of continental Europe as well as Svalbard, Arctic Canada, India, and Australia [12]. In this case, however, there is no convincing petrographic evidence (sedimentary structures, biota, non-skeletal carbonate grains, authigenic minerals) for a significant sea-level fall that was associated with the shift from carbonate to siliciclastic deposition. As for the (para)autochthonous glauconite in the sandstones, it cannot be considered a straightforward paleobathymetric indicator for marine environments, and furthermore, its formation is mainly associated with transgressive episodes [13].

Alternatively, climate humidification was a major control on the 'Ladinian–Carnian terrigenous invasion'. The high quartz/feldspar ratio and the very low amount of plagioclase, rock fragments and unstable detrital minerals in the sandstones suggest intense continental weathering and/or extensive sedimentary recycling [10], provided that there is no evidence for large-scale dissolution and/or replacement of the feldspar and lithic grains. The bulk of the detrital quartz displays angular to subrounded morphology and many grains show traces of corrosion (etch pits and embayments) implying that a warm and humid climatic regime in the source area caused chemical breakdown of feldspars (especially plagioclase) and unstable lithics. In addition, the formation of authigenic glauconite indicates an increased level of nutrients accompanying the influx of detrital particles. The enhanced continental weathering and terrestrial input during the warm and humid climatic interval provided the required reactive iron for glauconite authigenesis in the marine environment while the increased supply of organic matter favoured the establishment of weakly reducing conditions [13]. It should be noted, however, that despite the lack of quartz grains with abraded overgrowths and siliciclastic rock fragments, some quartz (also zircon and tourmaline) grains are well rounded suggesting recycled origin. The deposition of shales (Mitrovtsi Formation) indicates even more intense chemical weathering in the hinterland with development of soils and presence of vegetation [1]. The abundance of terrestrial plant remains

Fig. 4. Feldspatho-quartzose (quartz-rich) sandstones from the Milanovo outcrop (a–e) and shales of the Mitrovtsi Formation (f–j): a, b – Poorly sorted detrital grains (quartz with etch pits and embayments – red arrows, feldspar – magenta arrows) cemented by fine to medium crystalline dolomite (green arrows); c – Zircon grain (encircled); d – Elongated polycrystalline quartz grain; e – Feldspar grain (magenta arrow) and kaolinite (green arrow); f – Detrital quartz silt in clay matrix; g, h – Amorphous organic matter and opaque to translucent phytoclasts with various shapes; i – Large resin fragment showing ghostly cellular structure; j – Abundant resin droplets (yellow-brownish). Photomicrographs a–f are in cross-polarized light and the rest are in plane-polarised light. Scale bar is 0.3 mm long

(phytoclasts) reflects a relative proximity of the marine depositional environment to the terrestrial source and is also consistent with increased continental runoff influenced by wet climate. Amber production in the Triassic has been linked to shifts from xerophytic to hygrophytic floras during humid events [14] and the newly found resin occurrence seems to be another evidence for such relationship. Last but not least, the palynological analysis of shales from the Mitrovtsi Formation indicates a hygrophytic affinity of the spore-pollen assemblage, and hence a late Ladinian humidity [6].

The predominantly arid to semi-arid climatic regime in the western Tethys during the Triassic was punctuated by regionally or locally manifested humid and subhumid phases, and also by small- to large-scale temperature variations [15,16]. A 'Ladinian–Carnian humid interval' has been recognized [15] coinciding with a short warming phase [16]. Lithological (siliciclastics, paleokarst, meteoric cements) and paleobotanical (macro- and palynoflora, amber) evidence for climate humidification comes mainly from the Southern Alps [14,17], but also from other Tethyan successions, e.g., the Mecsek Mountains in Hungary, the Polish Western Carpathians, the Peri-Tethyan Germanic Basin [18], and more remote areas, e.g., the central North Sea Basin [19]. The late Ladinian–early Carnian humid phase is best documented in the Southern Alps, where fluctuations in the rainfall intensity indicate seasonal conditions, interpreted as monsoonal climate [15, 17]. This humid interval might be the consequence of intense volcanism (known as the Italian Volcanic Centre) which has been largely recorded in the circum-Tethys area [16, 18]. Recently, Zhang et al. [20] presented integrated sedimentological evidence from continental deposits in North China suggesting a global response to the Ladinian–Carnian humid phase but also noted that the climate-driven enhancement of the hydrological cycle was related to regional volcanic activity.

The late Ladinian–early Carnian siliciclastic input had a detrimental effect on carbonate production in the ramp environment, e.g., by smothering and burying organisms, reducing light penetration and increasing nutrient levels [1], although it is evident that some carbonate-secreting organisms (thick-shelled bivalves) adapted to the sandy bottom substrate. The amount of terrigenous mud and sand strongly decreases in the overlying carbonates (bioclastic limestones of the Cheshmichka Formation and dolostones in the upper part of the Rusinovdel Formation) and thus indicates a rapid return to more arid climatic conditions during the remainder of the early Carnian before the onset of the most distinctive climate change in the Triassic, i.e., the global 'Carnian Pluvial Event' [15].

Conclusions. The regional 'Ladinian–Carnian terrigenous invasion' on a Triassic carbonate ramp in the NW Tethys is revisited on the basis of new petrographic data from siliciclastic rocks and published results from a previous palynological study of shales. It is suggested herein that the major control on the sudden terrigenous influx and temporary shutdown of the carbonate factory was related to humidification. This climatic phase is known from a number of Tethyan

and Peri-Tethyan successions in Europe under the name 'Ladinian–Carnian humid interval'. Further evidence on the provenance, tectonic setting and climate conditions can be obtained by studying the clay mineralogy and geochemistry (major oxides, trace and rare earth elements, isotopes) of the siliciclastic deposits.

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Faculty of Geology and Geography, Sofia University "St. Kliment Ohridski",
15 Tsar Osvoboditel Blvd, 1504 Sofia, Bulgaria
e-mail: `chatalov@gea.uni-sofia.bg`