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Neptunian dykes penetrating the Lower Jurassic Dudziniec Formation in the autochthonous High-Tatric succession, Tatra Mountains, Western Carpathians, Poland

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ABSTRACT:

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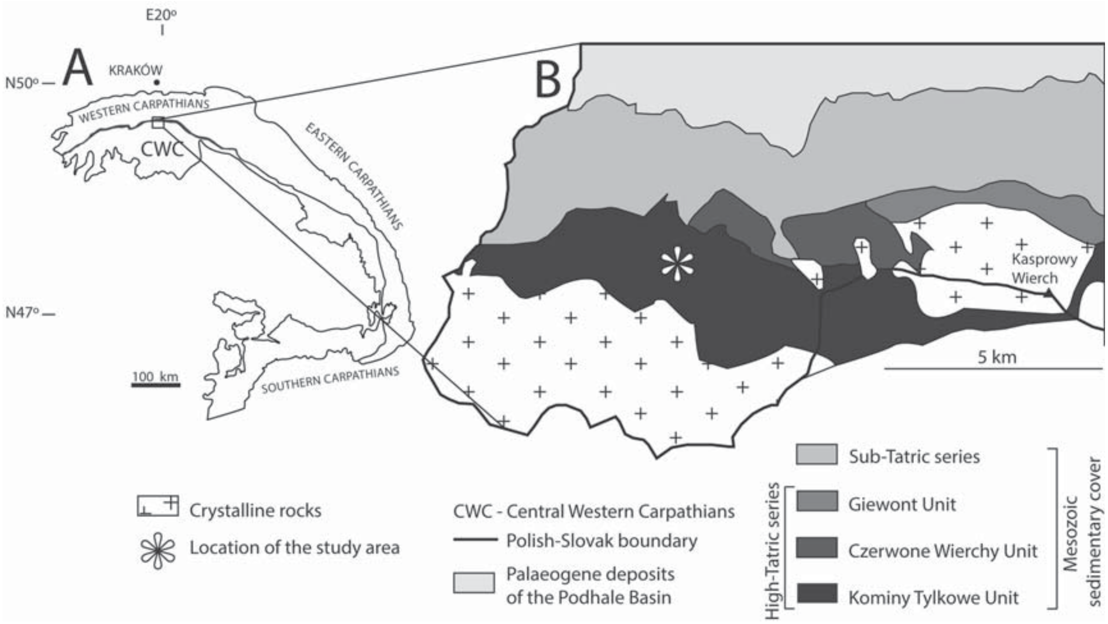
The Lower Jurassic to Aalenian carbonate-clastic Dudziniec Formation exposed in the autochthonous unit of the Tatra Mountains (Kościeliska Valley) hosts neptunian dykes filled with various deposits. The development of the fissures took place in multiple stages, with the same fractures opening several times, as is indicated by their architecture, occurrence of internal breccias and arrangement of the infilling sediments. Various types of internal deposits were derived in a different manner and from different sources. Fine carbonate sediments, represented by variously coloured pelitic limestones, calcilutites and fine calcarenites, most probably come from uplifted and corroded carbonate massifs (possibly from the allochthonous units of the High-Tatric succession). Products of weathering, both in dissolved form and as small particles, were washed into the sedimentary basin of the autochthonous unit, and redeposited within the dykes. The sandy varieties of the infillings, represented by red, ferruginous calcareous sandstones, come directly from the host rocks or from loose sediments present on the sea bottom at the time of fracturing. The most probable age of the infilling sediments is Sinemurian to Pliensbachian. The occurrence of dykes of this age is yet another feature confirming that the sedimentary development of the Lower Jurassic sandy-carbonate facies in the autochthonous unit was strongly influenced by synsedimentary tectonic activity, such as block-faulting.

Key words: Neptunian dykes; Dudziniec Formation; Lower Jurassic; High-Tatric succession; Tatra Mountains.

INTRODUCTION

The very first scientific interests of the late Professor Andrzej Radwański, marking the onset of his splendid academic carrier, concentrated on topics strictly connected with the scope of this paper. His Master of Science thesis, prepared at the Faculty of Geology, University of Warsaw, was devoted to the studies of the High-Tatric Lower Jurassic (so-called Liassic) deposits in the Chochołowska and Kościeliska valleys, which today, after the introduction of a formal lithostratigraphic division of the Jurassic of the Tatra Mountains (Lefeld *et al.* 1985), are referred to as the Dudziniec Formation. Originally, as a student of petrology, Prof. Radwański focused on the petrography of the Lower Jurassic carbonate-clastic sediments (Radwański 1959a). However, already at that time his later devotion to the studies of dynamic processes and to sedimentology found its reflection in the published interpretation of littoral structures from the base of the Jurassic, exposed in the Smytnia Valley (Radwański 1959b). He described a cliff struc-



Text-fig. 1. Geographic location of the study area. A – position of the Tatra Mountains in the Carpathians; B – structural map of the western part of the Polish section of the Tatra Massif

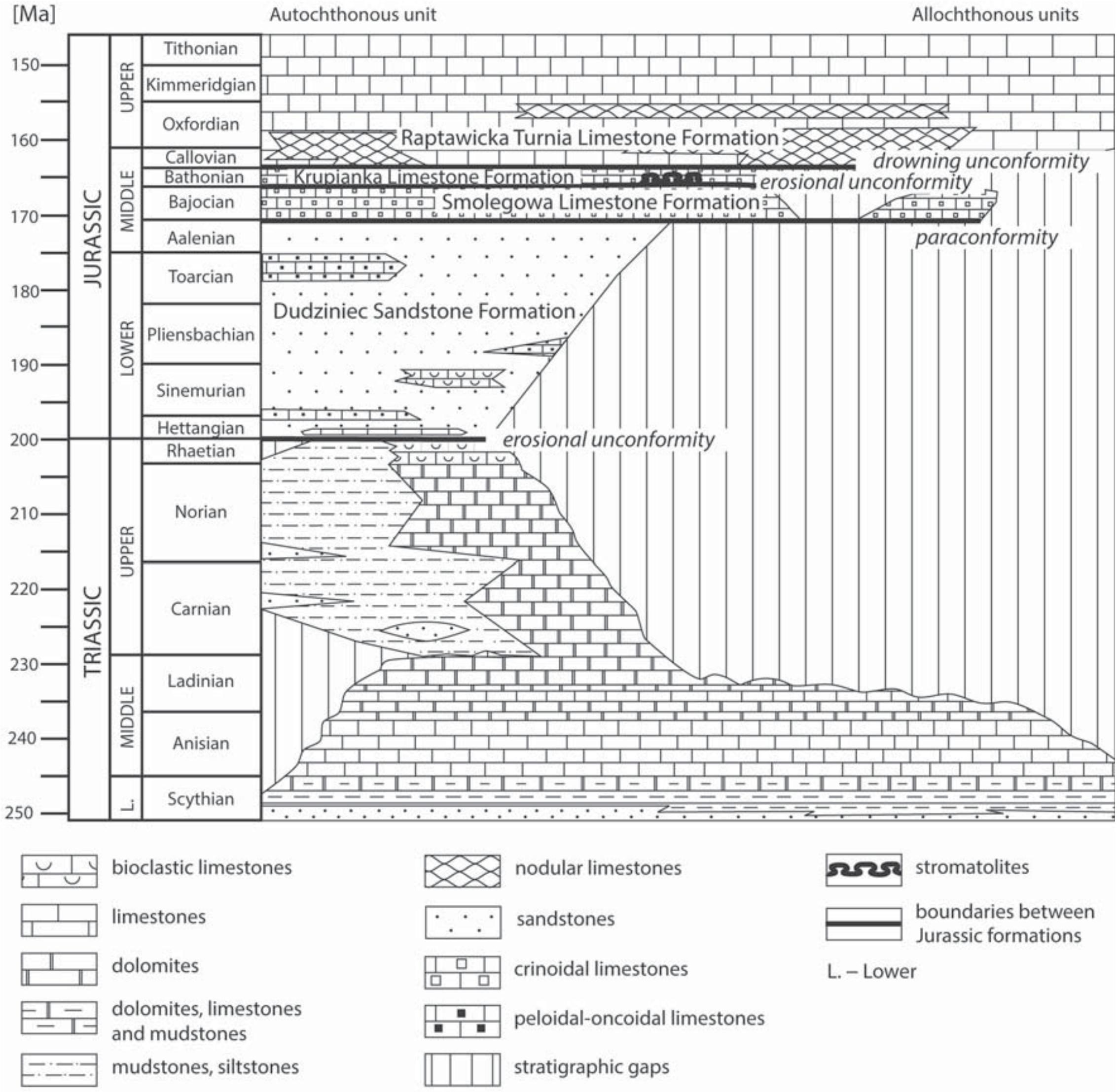
ture that developed as a result of abrasion, which took place during the Early Jurassic sea transgression, as well as clastic dykes and veins that penetrate the topmost part of the Triassic, and which are filled with Lower Jurassic material. This description of fissures remains, up to date, the only thorough investigation of sedimentary dykes filled with sediments of the Dudziniec Formation reported from the High-Tatric succession of the Tatra Mountains. In the present paper neptunian dykes are described that are developed within the Dudziniec Formation, therefore higher in the lithological succession than those presented by Radwański (1959a, b), but most probably also hosting sediments derived from the Lower Jurassic.

Professor Radwański continued his intensive works in the Tatra Mountains until his PhD in 1964, the thesis of which was devoted to the petrography and sedimentology of the High-Tatric Rhaetic (Radwański 1968). Unfortunately, later during his career, he switched to other topics and areas, stating that "*he will never come back to work in this cursed mountain range where it always rains*". Time proved that he kept his promise.

GEOLOGICAL SETTING

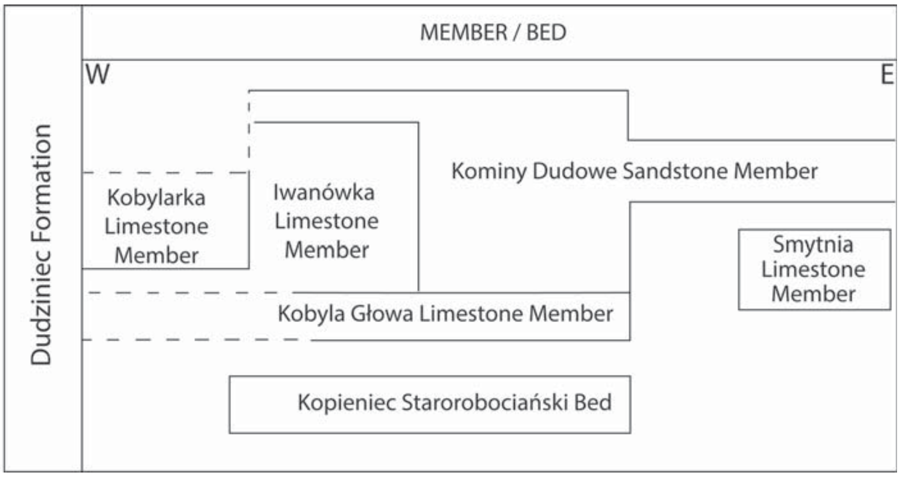
The Tatra Mountains are located in the Central Western Carpathians (CWC) (Text-fig. 1A). The massif is composed of a Variscan crystalline core and a Permo-Mesozoic sedimentary cover, which due to the tilting of the whole structure is exposed mainly on its northern slopes. The sedimentary rocks represent two major successions (or series) differing in their facies development and completeness – High-Tatric and Sub-Tatric (Text-fig. 1B). The High-Tatric succession, exposed in the topographically higher parts of the mountains, is of both autochthonous and allochthonous character, and is represented mainly by shallow-water deposits with numerous stratigraphic gaps, whereas the Sub-Tatric succession, preserved as nappes, is developed mainly in deeper facies and is more complete. These series correspond respectively to the Tatric Unit (High-Tatric) and to the Fatric and Hronic units (Sub-Tatric), referred to as major palaeogeographical units of the CWC (Andrusov *et al.* 1973; Kotański 1979).

The High-Tatric succession consists of three major tectonic units – the autochthonous Kominy Tylkowe Unit and the allochthonous (foldic) Czerwone Wierchy and Giewont units (Text-fig. 1B). The autochthonous unit embraces also the so-called parautochthonous folds, with the sediments detached from the basement and moved on small distances, but palaeogeographically still representing the same area. The foldic units are overthrusted northwards to form the High-Tatric nappes (Jurewicz 2005, 2012), and in terms of palaeogeography represent areas located south of the autochthonous domain.



Text-fig. 2. Simplified stratigraphic succession of the High-Tatric series (after Uchman 2014, modified)

The autochthonous unit represents the most complete succession of the High-Tatric succession, whereas the parautochthonous folds and the allochthonous units are less complete and contain large stratigraphic gaps (Text-fig. 2). The most important difference is the occurrence of the Lower Jurassic Dudziniec Formation in the autochthonous series, and its absence elsewhere. In the Czerwone Wierchy and Giewont units, the Triassic is directly overlain by the Smolegowa (Bajocian; white crinoidal limestones), the Krupianka (Bathonian; mainly red crinoidal limestones) or even the Raptawicka Turnia (starting with Callovian; wavy bedded limestones) formations. The Smolegowa and particularly the Krupianka formations are usually laterally discontinuous and are preserved as lenticular bodies. Commonly the only indication of the deposition of sediments of particular formations in a given area is their occurrence in neptunian dykes (Łuczyński 2001a, 2002). Based on the spatial relations between particular Jurassic lithosomes, and on the occurrence of stratigraphic gaps between particular units, four main types of Jurassic unconformities have been discerned in the High-Tatric succession (Jezierska and Łuczyński 2016). In stratigraphical order these are: base of the Dudziniec Formation (erosional unconformity), base of the Smolegowa Formation (paraconformity), base of the Krupianka Formation (erosional unconformity) and



Text-fig. 3. Subdivision of the Dudziniec Formation (after Lefeld *et al.* 1985, modified)

base of the Raptawicka Turnia Formation (drowning unconformity). Recurring episodes of erosion modified the previously developed unconformity surfaces, which resulted in the complex architecture of the Triassic/Jurassic contact, as well as between particular Jurassic lithosomes. Neptunian dykes filled with various Jurassic sediments usually penetrate downwards from these unconformity surfaces.

The Dudziniec Formation, hosting the dykes described in this paper, occurs only in the Kominy Tylkowe Unit and is developed in a wide range of sandy-carbonate facies. The Lower Jurassic limestone and sandstone sequences of the High-Tatric succession were described among others by Horwitz and Rabowski (1922), Siemiradzki (1923), Rabowski (1954, 1959), Kotański (1959), Radwański (1959a), Z. Wójcik (1959), K. Wójcik (1979, 1981) and Jezierska *et al.* (2016). The detrital material contains quartz grains, carbonate lithoclasts and bioclasts (bivalves, crinoids, brachiopods and belemnites). Based on the belemnite and brachiopod faunas, the age of the formation has been determined as Sinemurian–Aalenian (Horwitz and Rabowski 1922; Lefeld *et al.* 1985). Several members or beds are distinguished within the formation (Lefeld *et al.* 1985; Text-fig. 3): (i) Kopieniec Starorobociański Bed – thin to medium-bedded, grey, dark-grey or blue-grey sandy limestones, (ii) Kobyla Głowa Limestone Member – medium-bedded, dark-grey encrinites with small amounts of clastic admixture, (iii) Kobylarka Limestone Member – massive grey encrinites, (iv) Smytnia Limestone Member – poorly bedded grey to dark-grey and black limestones containing brachiopods and bivalves, (v) Iwanówka Limestone Member – thin to medium-bedded, grey to black encrinites with an admixture of quartz, and Triassic dolomites, alternating with spiculites, and (vi) Kominy Dudowe Sandstone Member – medium-bedded, light-grey, pinkish-grey and yellowish conglomeratic-quartzitic sandstones, calcareous in places. Generally, the Dudziniec Formation is represented by shallower, more proximal and more coarse-grained sandy-crinoidal facies in the eastern area of its exposures (Kościeliska Valley; Staśkiewicz 2015; Jezierska *et al.* 2016), and by deeper, more distal and finer facies with spiculites on the west (Chochołowska Valley; K. Wójcik 1979, 1981).

JURASSIC NEPTUNIAN DYKES IN THE HIGH-TATRIC SERIES OF THE TATRA MOUNTAINS

The occurrence of dykes filled with sediments often provides a lot of valuable data on the developmental history and palaeogeography of the studied areas (e.g., Lehner 1991; Winterer and Sarti 1994; Matyszkiewicz *et al.* 2016) and yields unique stratigraphic and palaeontological information (Wendt 1971, 2017; Aubrecht and Kozur 1995; Schlögl *et al.* 2009). Commonly the infillings of dykes are the only preserved deposits representing particular stages of the given area's development (Jenkyns 1971; Jones 1992). Also in the High-Tatric area, in the normal stratigraphic succession, counterparts of dyke infillings are preserved usually only locally in the form of laterally discontinuous lenticular bodies, mostly as a result of Bajocian, Bathonian and post-Bathonian erosion. The Jurassic neptunian dykes described so far from the High-Tatric area are summarised here in order to give a general overview and as material for comparison.

The most common and best recognised Jurassic neptunian dykes in the High-Tatric succession are those filled with Bajocian Smolegowa limestones and Bathonian Krupianka limestones (Kotański 1959; Rabowski 1959; Wieczorek 2000; Łuczyński 2001a). Dykes of this age are present in all High-Tatric tectonic units. In the Czerwone Wierchy and Giewont units, they penetrate solely the Triassic (Anisian limestones and dolomites). In the parautochthonous folds (Rzędy pod Ciemniakiem) and in parts of the autochthonous unit (Chochołowska Valley) the dykes cut also the Dudziniec Formation, mainly its topmost part (Bagiński 1985; Łuczyński 2001a; Jezierski 2014). However, Wieczorek (2000, his fig. 4) mentions also dykes penetrating the lower parts of the Dudziniec Formation, as well as the Lower Jurassic of the Sub-Tatric succession.

The periods of formation of neptunian dykes filled with Middle Jurassic deposits mark episodes of intensive substrate fracturing, most probably associated with extensional tectonic movements. The occurrence of dykes in the lower part of the Dudziniec Formation and probably filled with Lower Jurassic material, described in this paper, may indicate that similar processes took place already in the Early Jurassic. Synsedimentary tectonics influenced the sedimentary development of the High-Tatric domain also in the Early Jurassic (Jezierska *et al.* 2016).

Two main categories of systems of neptunian dykes filled with Middle Jurassic deposits and penetrating the Triassic limestones and dolomites have been distinguished (for details see Łuczyński 2001a). *Group I* embraces dykes with sharp-edged walls and predominantly vertical structures, whereas *Group II* consists of dykes with smooth walls and running predominantly horizontally. Systems belonging to *Group I* are mostly filled with white and red crinoidal limestones, of the Smolegowa and Krupianka formations respectively, and by calcite cements. In some places, the Triassic substrate is so densely penetrated by fractures filled by sediments and cements as to form *in situ* internal breccias. The dykes of this group penetrate the substrate to depths not exceeding a dozen or so metres. *Group II* embraces structures filled with pure red micrite and those associated with pressure solution structures, with infillings showing a character of a solution residuum. Processes of pressure-solution and chemical compaction have strongly affected the sedimentary successions of the High-Tatric series, leading to the substantial thickness reduction of some lithosomes (Łuczyński 2001b), and also altered the internal structure and architecture of neptunian dykes, particularly those running horizontally. Systems of dykes belonging to *Group II* penetrate the substrate to greater depths, well exceeding 150 m. They commonly find their way along the heterogeneities of the host-rock and tend to run along bedding planes.

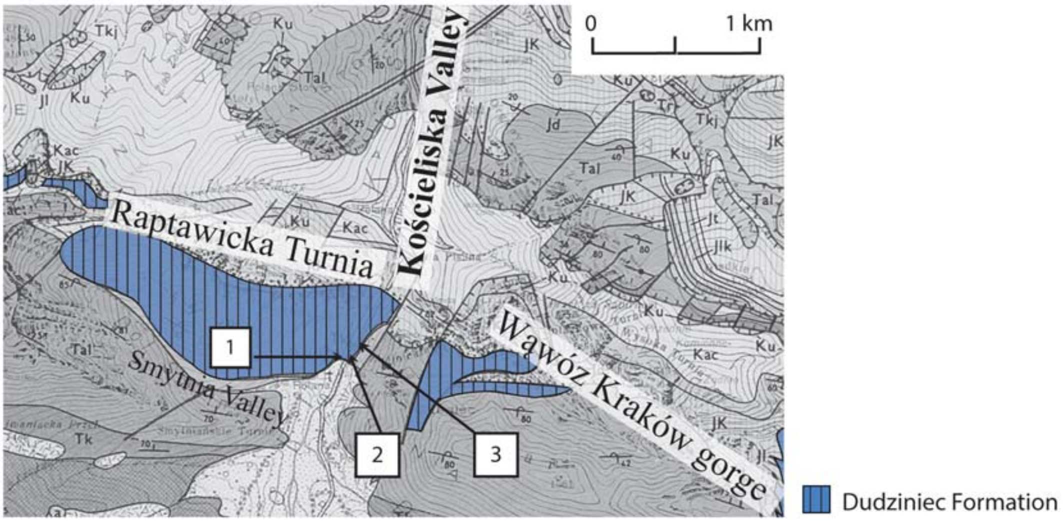
The orientation, shapes and sizes of the dykes of *Group I*, as well as their relation to the host-rocks, indicate the solely mechanical nature of their initiation and development processes. In contrast to that, in the case of the dykes of *Group II*, chemical erosion, possibly also in subaerial conditions, played an important role. Short vertical dykes were filled by rapid injection of loose material deposited on the sea bottom into fissures opening in a hard brittle substrate (mainly in the Bajocian) or were buried by migrating dunes of crinoidal sand (mainly in the Bathonian). The occurrence of fine unfossilliferous material (red micrite) in the more remote parts of the vast dyke systems of *Group II* is a result of sieving. Many systems of dykes show evidence of a multiphase history, during which the episodes of their infilling were separated by the development of ferruginous coats on the walls and by precipitation of calcite cements in the voids.

Dykes filled with sediments that penetrate the Dudziniec Formation have been described so far only from its topmost part, mainly from the Rzędy pod Ciemniakiem area in the parautochthonous folds (Bagiński 1985). In terms of their architecture they belong to the *Group I* described above; however, apart from being filled with crinoidal material and red micrite they contain also yellow sandy limestones resembling those of Lower Jurassic deposits. The nature of these sediments and the relation of the fissures to the top of the Dudziniec Formation remains, however, still dubious and requires further investigation.

Dykes filled with Lower Jurassic deposits and penetrating the Triassic have been described by Radwański (1959b) from the Smytnia Valley (a ramification of the Kościeliska Valley). The dykes accompany a cliff structure developed in the Norian substrate and penetrate down from an abrasion surface to a depth of 11 m. They are filled mainly with calcareous quartz-dolomite sandstones, identical to the overlying Lower Jurassic deposits, and with yellow dolomitic marls in more remote parts of the systems, often terminating in dissolution seams and stylolites.

MATERIAL AND METHODS

Due to the great variability of both shapes and relations to the bedding planes, all described structures



Text-fig. 4. Outcrop area of the Dudziniec Formation in the Kościeliska Valley (after Bac-Moszaszwili *et al.* 1979) and location of the studied sections with neptunian dykes

filled with internal sediments and calcite cements are further termed as dykes, irrespective of their orientation, and the interconnected networks of dykes are referred to as a system of dykes. Due to the interpreted marine origin of the infilling deposits (see below) the term "neptunian dykes" is used throughout the paper, and not the broader term "sedimentary dykes".

The studied systems of dykes and associated structures filled with sediments and hosted by the Dudziniec Formation outcrop in the Kościeliska Valley in the Western Tatra Mountains (Text-fig. 4). The Lower Jurassic deposits hosting the described structures occur on both sides of the Kościeliski Stream, between the Raptawicka Turnia crest and the Wąwóz Kraków gorge on the north, and the Smytnia Valley on the south. The natural exposures are generally small and scattered, and due to the location of the area in the Tatra National Park, no artificial excavations could be carried out. Therefore, particular structures can be observed only on limited surfaces, and their overall architecture on a bigger scale cannot be determined. The best developed and well exposed systems of dykes occur in the localities, in which sections 1, 2 and 3 of Jezierska *et al.* (2016) were described (Text-fig. 5), or close to them.

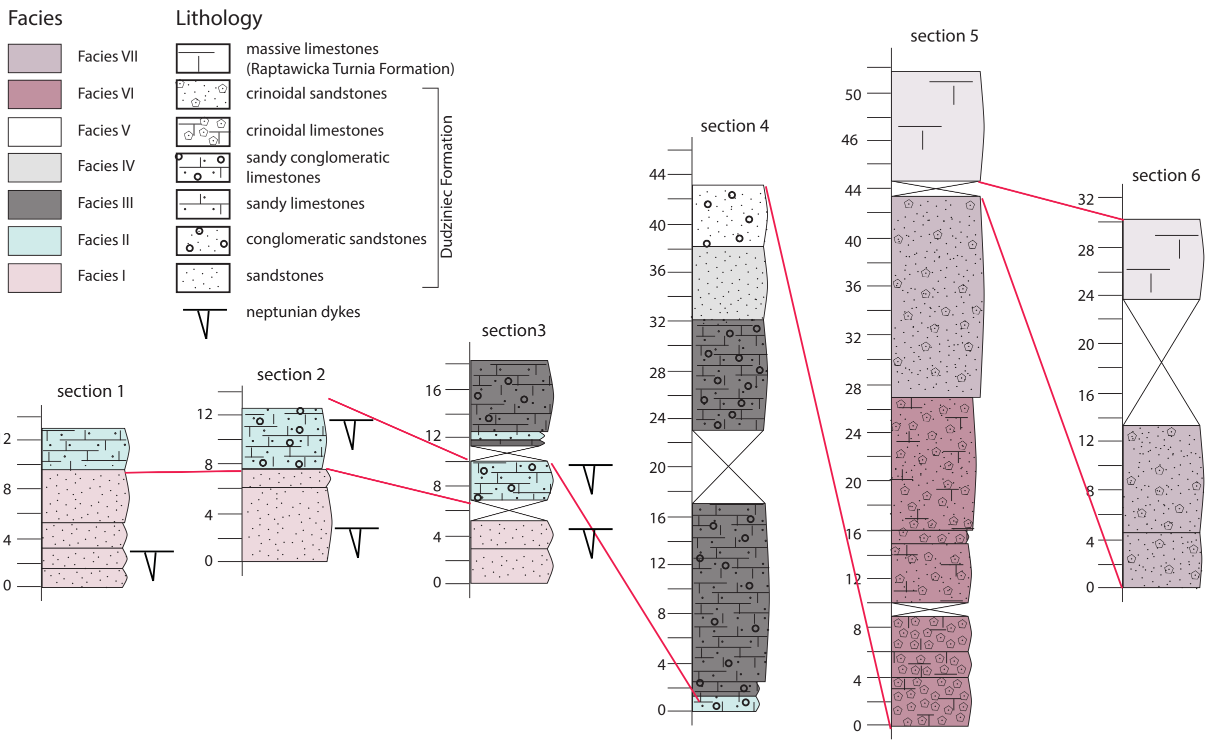
The general visible shapes of the systems of dykes, the character of their walls and the relation of the infilling sediments to the host-rocks have been studied. The position of the dykes within the sections of the Dudziniec Formation was analysed, and an eventual correlation of their existence with particular facies and/or other structures that point to the influence of synsedimentary tectonics on the development of the area was made. The description of the sections and their correlation, as well as the facies distinguished and the microfacies of the host rocks are adapted after Jezierska *et al.* (1916). Due to the mixed carbonate-clastic character of these deposits a combination of different classifications (Dunham 1962; Pettijohn *et al.* 1972; Zuffa 1980) had to be applied to describe particular microfacies.

The lithology and internal sedimentary structures of the sediments infilling the voids have been studied in detail. The relation of internal sediments to the cements occurring in the voids was also analyzed. Thirty thin sections were made from samples of characteristic sediments, cements or sedimentary structures.

RESULTS

Distribution of the neptunian dykes and stratigraphy of the host rocks

The dykes occur in profiles 1 to 3, exposed in which are the lower parts of the Dudziniec Formation outcropping in the Kościeliska Valley (Text-figs 4 and 5). They are hosted by pinkish-grey/pinkish-white hybridic limestones of Facies I (Text-fig. 6A), microfacially represented by sparry-hybridic arenites (Text-fig. 6B; for a detailed facies and microfacies description of the studied sections see Jezierska *et al.* 2016), and by pinkish-purple sandy-conglomeratic limestones of Facies II (Text-fig. 6C), microfacially



Text-fig. 5. Sections of the Dudziniec Formation in the Kościeliska Valley (after Jezierska *et al.* 2016), with the position of the studied neptunian dykes

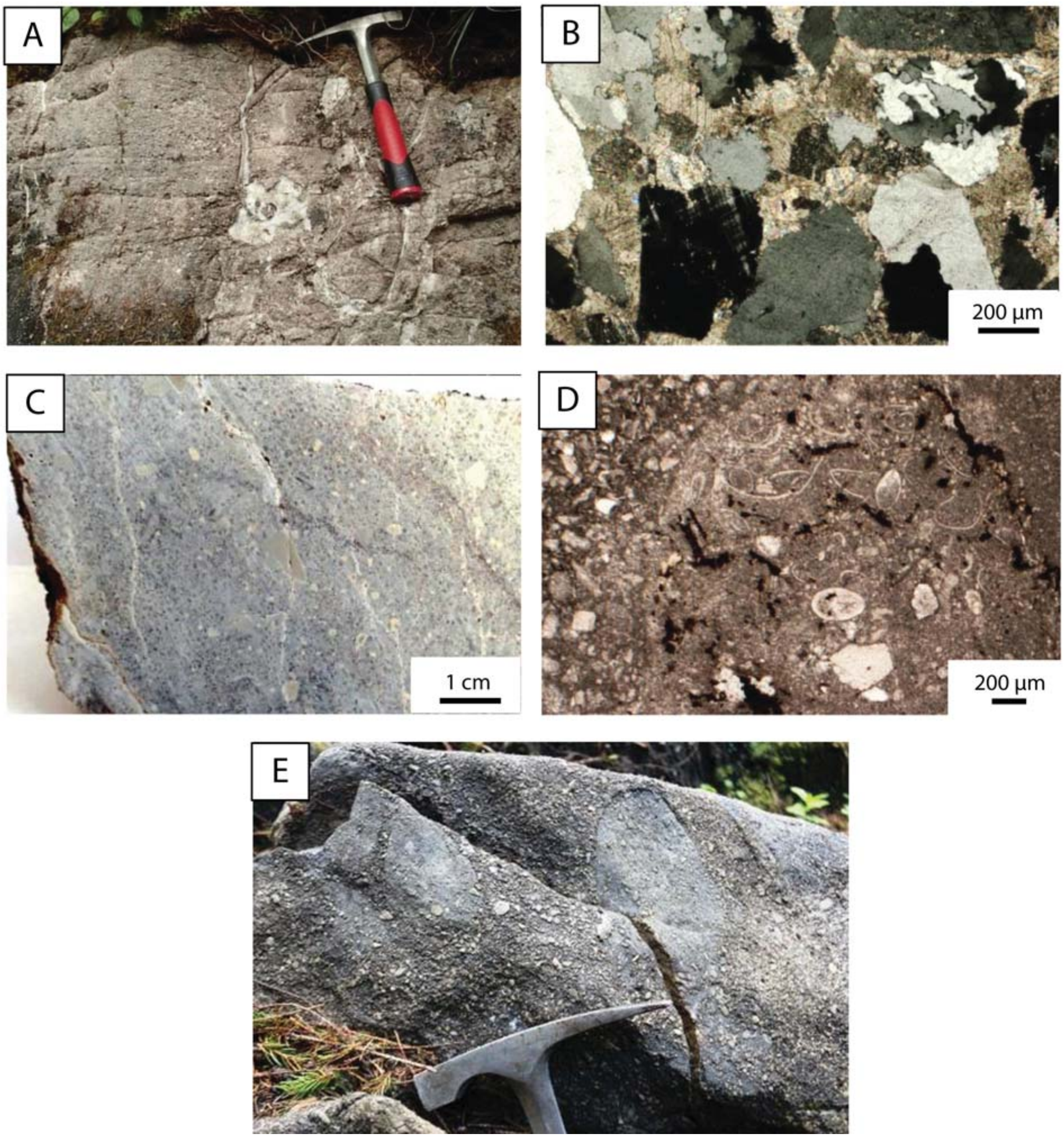
represented by silicidoloclastic-bioclastic wackestones (Text-fig. 6D). As far as the exposures permit one to study their distribution in detail, the dykes are evenly distributed within these two facies and do not follow any particular horizons. The summarised thickness of the two facies in the studied sections is around 12 m. No dykes have been found higher in the sections, and no internal unconformity or discontinuity surface within the Dudziniec Formation, from which the dykes would penetrate downwards, has been identified.

The internal stratigraphy of the Dudziniec Formation is still poorly understood. Local correlation of the sections in the Kościeliska Valley, based on geometrical relations, facies and microfacies, has been proposed by Staśkiewicz (2015) and by Jezierska *et al.* (2016). The conglomeratic limestones of Facies II in sections 2 and 3 contain fairly abundant, but mostly poorly preserved brachiopod and bivalve faunas. The occurrence of *Spiriferina* [*Spiriferina walcotti* Sowerby, 1822 or *Dispiriferina davidsoni* (Eudes-Deslongschamps, 1865)] in Facies II in section 2 indicates its Sinemurian to Early Pliensbachian age (Siblik 1965; Rousselle 1977). Most probably, Facies I and II correspond to Unit 1 (complex 1) of Horwitz and Rabowski (1922), who determined its age as Sinemurian. They are overlain by Facies III, developed as dark-grey sandy-conglomeratic limestones (silicidoloclastic-bioclastic packstones) in section 3, which correspond well to the “grey to dark grey and black limestones” of the Smytnia Member of Lefeld *et al.* (1985) of late Sinemurian to early Pliensbachian age.

General shapes, dimensions and relation to the host-rocks

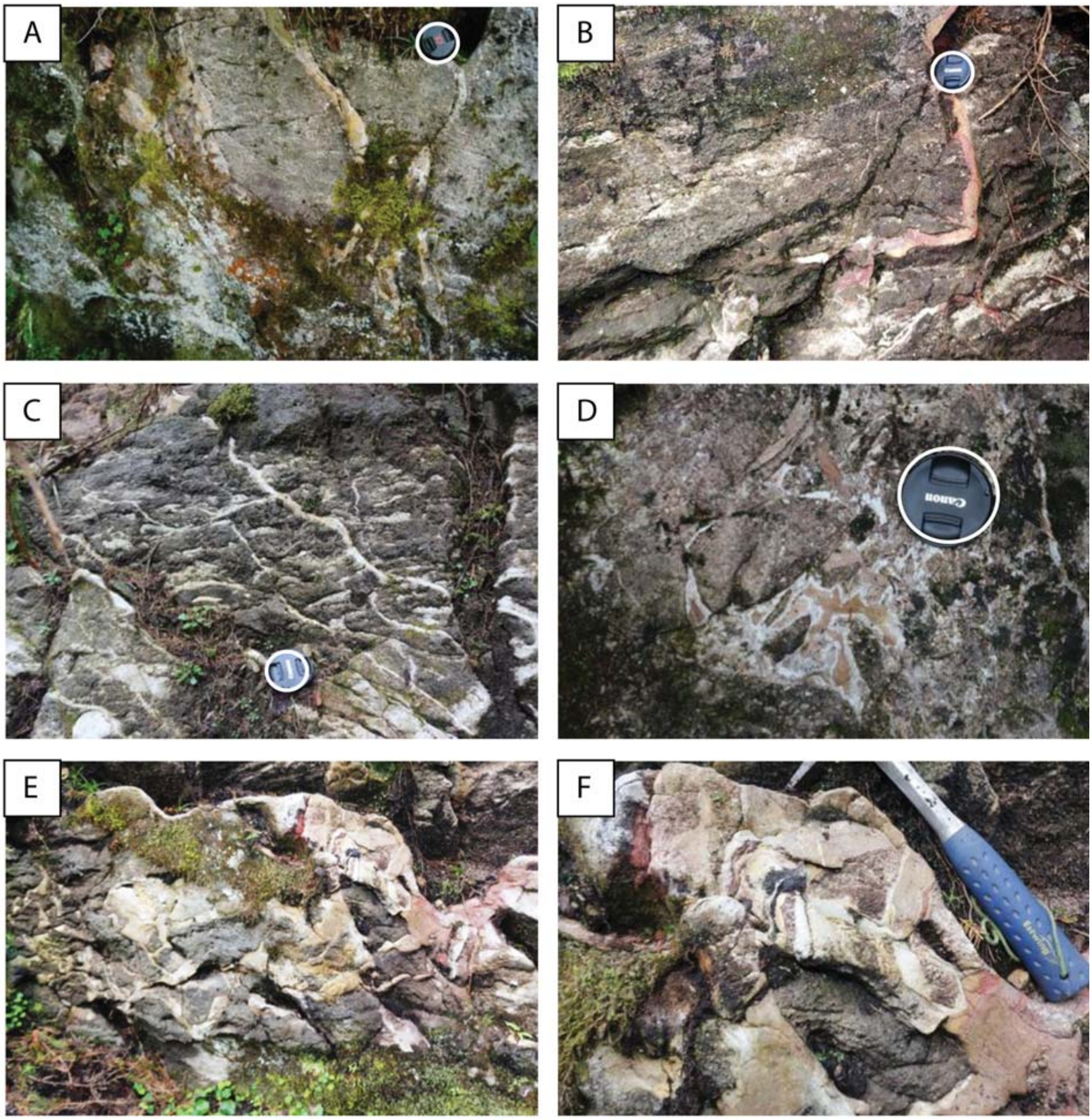
The rocks hosting the neptunian dykes are usually indistinctly bedded (Text-fig. 6A). In Facies I the beds are typically 30–100 cm thick, in Facies II – 10–30 cm thick. The dykes run irregularly in all directions in relation to the bedding – along the bedding planes or parallel to them, but they also cut them perpendicularly and obliquely (Text-fig. 7A–C). In contrast to the Triassic hosting the Middle Jurassic dykes in the foldic and parautochthonous units, the bedding planes in the Dudziniec Formation are poorly developed, and usually cannot be traced for long distances laterally, and therefore they are only rarely followed by the dykes.

The described dykes show a whole array of irregular shapes (Text-fig. 7). The width is variable,



Text-fig. 6. Facies and microfacies of the Dudziniec Formation hosting the described neptunian dykes. A, B – Facies I, section 1; hybridic limestones (A), sparry-hybridic arenites (B); C, D – Facies II, section 2; sandy-conglomeratic limestones (C), silicidoloclastic-bioclastic wackestones (D); E – intraformational breccia composed of semi-lithified clasts, section 4

usually between few and a dozen or so centimetres, and commonly differs within a single structure (Text-fig. 7A). Only rarely do the dykes follow any particular orientation or relation to the bedding planes on distances longer that a metre. The ramifications are usually short and irregular. In several places the host-rock is so densely cut by a network of cross-cutting dykes filled with various sediments and cements that it has an appearance of an internal breccia (Text-fig. 7E, F). The nests of such internal breccias have irregular shapes, with no distinct elongations, and their dimensions, as seen in cross-cuts on the exposed surfaces, do not exceed few square metres, usually less than a square metre.

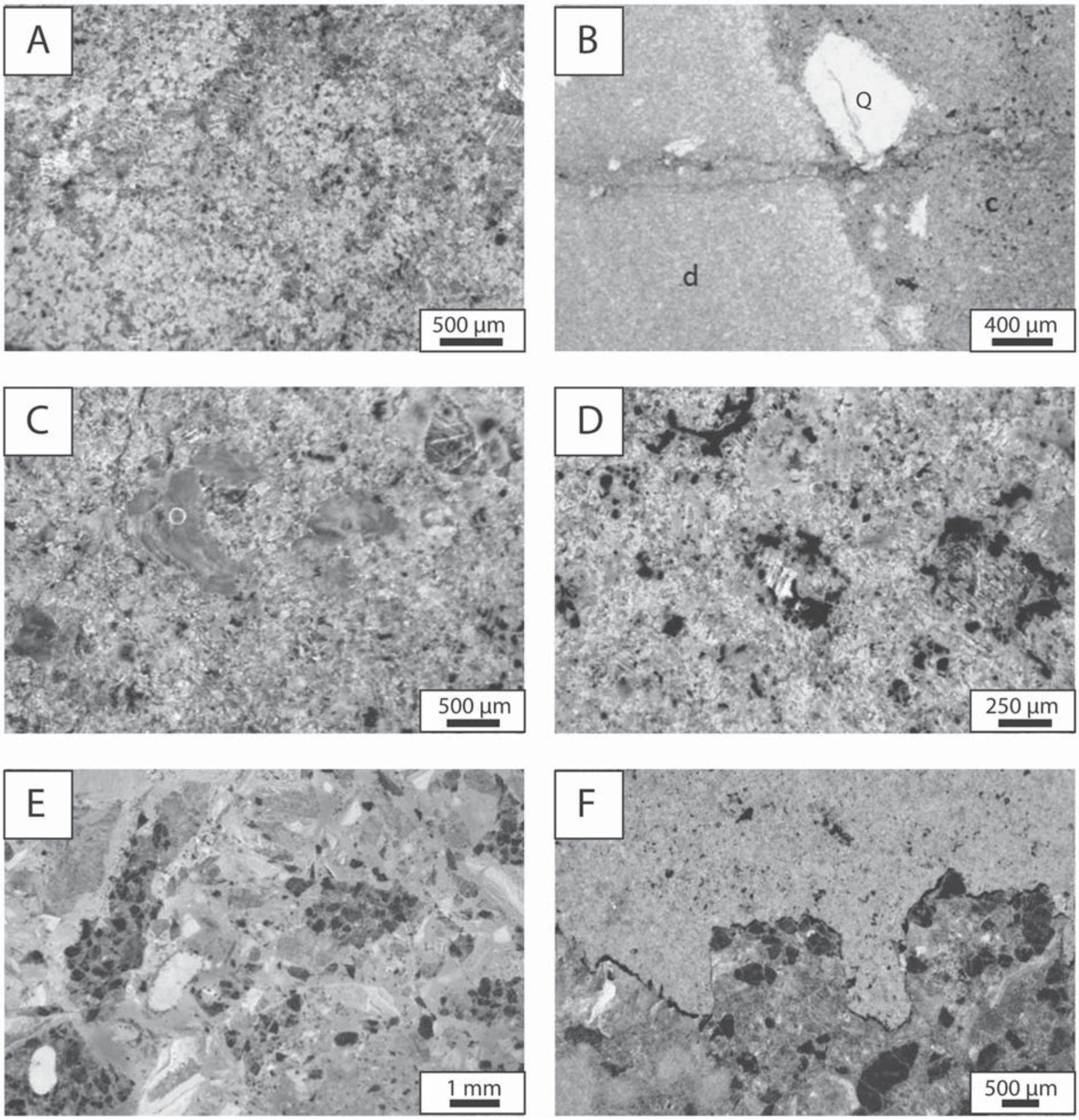


Text-fig. 7. Neptunian dykes penetrating the Dudziniec Formation. A – system of mainly vertical dykes filled with orange sandstones accompanied by calcite cements; section 2; B – dyke filled with red pelitic material; section 3; C – network of dykes running in various directions in relation to the bedding; section 3; D – irregularly shaped dykes filled with red pelitic material and calcite cements; section 1; E, F – internal breccias; section 3

Infillings

The neptunian dykes penetrating the Dudziniec Formation are filled with various types of deposits and cements.

Most commonly the dykes are filled with variously coloured pelitic limestones – usually red to orange, but less commonly also white, grey, pink and violet calcilutites of Microfacies A (Text-fig. 8A). The micritic and microsparry material is usually arranged in laminae subtly differing in fraction and colour. The colour differences are most probably related to the varied content of dispersed ferruginous compounds. The lamination generally runs parallel to the walls of the dykes (which in variously oriented structures corresponds to horizontal, vertical and



Text-fig. 8. Microfacies of the infillings of the neptunian dykes. A – calcilutites (Microfacies A); section 3; B – small corroded quartz grain (Q) embedded in variously coloured calcilutites (c, d) of Microfacies A (from Staśkiewicz 2015); section 2; C, D – fine calcarenites of Microfacies B with strongly corroded fragments of possible crinoid origin; section 2; E – ferruginous hybridic arenites of Microfacies C; section 1; F – stylolitic contact between calcilutites (Microfacies A) infilling the dyke and the host rock; section 3

oblique lamination as related to the host-rocks' bedding). Only in the nests with internal breccia in some places does it show a more complex character, with cross beddings and internal erosional surfaces. In some cases, the pelitic material is separated from the host rocks by a zone of calcite cements (Text-fig. 7D). Sporadically, mainly in the laminae neighbouring the walls, the calcilutites, which are generally devoid of any coarser material, contain small (up to 0.6 mm in diameter) corroded quartz grains (Text-fig. 8B).

Fine calcarenites (Microfacies B), are the second sediment commonly present in the dykes (Text-fig. 8C, D). Macroscopically they are usually indiscernible from the pelitic limestones described above;

however in this case the material is composed of carbonate grains with dimensions typically ranging between 0.1 and 0.5 mm, occasionally larger. Some of the grains can be identified as strongly corroded crinoid ossicles. The calcarenites are usually orange to red in colour (due to staining by dispersed ferruginous compounds). In a similar fashion to the calcilutites, they occur in all types of structures (vertical, horizontal, etc.), form laminae and occasionally are accompanied by layers of calcite cements.

The third distinct type of sediments filling the dykes are red, ferruginous calcareous sandstones, microfacially represented by ferruginous hybridic arenites – Microfacies C (Text-fig. 8E). The arenites are composed of quartz grains (up to 50% of the rock volume), accompanied by alkaline feldspars (5%) and by dolomicritic and dolomicrosparitic grains (up to 10%), in a sparry or pseudosparry matrix. Rare corroded crinoidal elements and shell fragments are also present. The grain elements are poorly sorted, with dimensions ranging typically between 0.5 and 2 mm (individual quartz grains reaching up to 8 mm).

In many cases different types of infillings co-occur in particular systems of interconnected dykes, although individual structures filled by only one particular type of internal deposit can also be found. Generally, microfacies A and B (calcilutites and calcarenites) occur together in broader dykes (or broader parts of dykes), where they form laminae, commonly accompanied by calcite cements. Narrower and more distant ramifications are usually filled by calcilutites and/or calcite cements. Sandstone infillings occur in separate systems, but can also be found accompanying other types of internal deposits, mainly in the nests of internal breccias.

Character of walls

The character of the walls of dykes largely depends on the type of the infilling deposits, as well as on their architecture. In the case of dykes filled with fine calcareous material (microfacies A and B), in which there is a distinct contrast between the internal sediment and the host-rocks, the contact is sharp, although usually irregular and overprinted by stylolitisation (Text-fig. 8F). Individual quartz grains, most probably derived from the host-rocks, occur in places embedded in the micritic material infilling the dykes, mostly in vertical structures. In some cases the walls are covered by calcite cements.

The walls of the dykes filled with calcareous sandstones (Microfacies C) are very ragged and irregular. Common are elements of the host-rocks embedded in the dykes, both as individual grains, and as larger rock fragments. The walls are often corroded, and the finer internal sediment penetrates between the larger clasts of the host-rock, which, taking into account the small contrast between the two lithologies, results in the gradual character of the transition between the surrounding rock and the dyke's infilling. Calcite cements covering the walls are very rare.

In places in which the rocks are densely cut by variously oriented dykes, the occurrence of large, sharp-edged fragments of the host-rock in a *para in situ* position, give the structures an appearance of an internal breccia.

DISCUSSION

In the Central Western Carpathians, the Lower and Middle Jurassic sequences record the great influence of synsedimentary tectonic activity on the area's development. As a result of the opening of the Vahic Ocean, the Carpathian region became separated from the stable continent of Palaeoeurope (Plašienka *et al.* 1997; Csontos and Vörös 2004). Vast carbonate platforms that developed in the Triassic were subjected to disintegration due to a prevailing extensional regime (Plašienka 1995, 2012; Michalík 2007). These processes were commonly accompanied by the development of neptunian dykes hosted by the Triassic and Jurassic rocks and filled with Jurassic sediments. In the CWC, apart from the Tatra Mts., the Jurassic neptunian dykes are known mainly from the Pieniny Klippen Belt (Zydorowicz 1991; Mišik 1994; Aubrecht and Kozur 1995; Mišik *et al.* 1995; Aubrecht and Túnyi 2001; Sidorczuk 2005; Wierzbowski *et al.* 2005; Schlögl *et al*. 2009). Lower Jurassic neptunian dykes and associated breccias are recorded also from other areas of the Alpine system, such as: Male Karpaty (Michalík *et al.* 1994), Julian Alps (Črne *et al.* 2007), southern Alps (Winterer *et al.* 1991) and Spain (Winterer and Sarti 1994).

Syndepositional tectonic instability influenced the sedimentary development during the Early and Middle Jurassic in both the High-Tatric and the Sub-Tatric domains (Jach 2002, 2005; Łuczyński 2002). In the High-Tatric area it governed the facies development, their distribution, as well as the completeness of the stratigraphic record (Wieczorek 2000; Jezierska and Łuczyński 2016). The occurrence of neptunian dykes is commonly one of the important symptoms of such activity. Yet, almost no neptunian dykes have been described so far from the thick Lower Jurassic Dudziniec Formation exposed in the autochthonous unit, the sedimentary record of which indicates great influence of syndepositional tectonic activity on the facies development. The deposition of mixed sandy-carbonate facies was controlled mainly by tectonic activity and by the distance from alimentation areas, with the sandy facies representing periods of block faulting and instability, and the crinoidal facies corresponding to the episodes of deposition in relatively stable conditions (K. Wójcik 1979, 1981; Staśkiewicz 2015; Jezierska *et al.* 2016).

So far from the High-Tatric succession have been recorded mainly neptunian dykes penetrating the Triassic and filled by the Middle Jurassic deposits (Łuczyński 2001a) best developed in the allochthonous Czerwone Wierchy and Giewont units. Dykes filled with the Dudziniec Formation were described by Radwański (1959b) from the Smytnia valley, whereas dykes hosted by the same formation (its topmost part) were mentioned by Bagiński (1985) from the parautochthonous folds of the Rzędy pod Ciemniakiem area. In the present paper dykes are discussed that penetrate the lower parts of the formation in the autochthonous series. Their occurrence corresponds well to the general picture of facies development of the area in the Early Jurassic.

Origin of the infilling sediments and character of deposition within the voids

The studied systems of neptunian dykes are infilled by two distinct types of deposits (fine carbonates of Microfacies A and B, and coarse-grained sandstones of Microfacies C), and although sometimes they co-occur in the same interconnected networks, the two varieties of internal sediments must have been derived from different sources and deposited in a different manner.

The calcilutites and fine calcarenites of Microfacies A and B have no counterparts in the sedimentary column of the Dudziniec Formation, which could facilitate as their source rocks. The occurrence of very fine, often ferruginous pelitic material devoid of microfossils in vast systems of neptunian dykes is often attributed to the so-called "sieve effect" (Wiedenmayer 1964; Winterer *et al.* 1991) with very fine particles percolating down into the interconnected networks. Such an interpretation was proposed for the vast systems of dykes filled with red pelite and hosted by the Triassic of the High-Tatric series (Łuczyński 2001a). In that case, the red crinoidal limestones of the Bathonian Krupianka Formation were interpreted to be the source of the infilling material. However, in that case the systems of dykes clearly penetrate downwards from an unconformity surface located at the base of the formation, and the length of narrow fissures, often cutting the substrate to depths exceeding 100 m, made such an interpretation plausible. In the studied case, with no dykes found higher in the sections of the Dudziniec Formation, it seems very unlikely that the fine carbonate material could have been derived from carbonate sediments of the Middle Jurassic.

The fine calcarenites (Microfacies B) contain fine and strongly corroded carbonate grains identified as crinoid ossicles, and the calcilutites (Microfacies A) very fine corroded quartz grains (Text-fig. 8B). It is very difficult to envisage the source of this material. Potentially it could be derived from the walls of the fissures, as both crinoidal and sandy facies are present in the sedimentary column that is cut by the dykes. However, their dimensions and size segregation, as well as the corrosion of their surfaces, indicate that they have undergone substantial transport, and were subjected to weathering. This suggest that they come from an external source.

Radwański (1959b) describing the dykes filled with Lower Jurassic material and penetrating the Norian in the Smytnia Valley pointed out that they are infilled by calcareous quartz-dolomite sandstones, identical to the overlying Liassic, but also, particularly in the more remote parts of the voids, by yellow dolomitic marls, the source of which is difficult to determine. He attributed their occurrence partly to sieving, but also suggested that the material was partly dissolved and reprecipitated in the dykes. In that case exposed parts of Norian limestones were dissolved. A similar process can explain the occurrence of calcilutites and fine calcarenites of Microfacies A and B in the dykes described herein.

In the Early Jurassic, during the deposition of the Dudziniec Formation, the Czerwone Wierchy and Giewont units were uplifted and exposed to subaerial weathering (Łuczyński 2002). In those areas, the Middle Jurassic rests directly on Triassic (Anisian) limestones. Subjected to erosion were mainly the Triassic limestones and dolomites of the foldic units, however, due to block faulting, probably some parts of the autochthonous unit, in which sedimentation of sandy-crinoidal facies took place, also became temporarily uplifted and eroded. In the parautochthonous series in the Rzędy pod Ciemniakiem area, the Dudziniec Formation is limited to a thickness of a few up to a dozen or so metres, or is even missing in some sections (Łuczyński 2002; Jezierski 2014). It cannot be also excluded that, due to differentiation of the sea bottom caused by syndepositional tectonic activity, small isolated carbonate platforms developed within the autochthonous domain, which acted as alimentation areas.

The products of weathering were washed by surface waters, probably mainly after heavy rains, into the sedimentary basin of the autochthonous unit, partly as small suspended particles and partly dissolved, finally reaching the fissures open on the sea bottom. Reprecipitation of dissolved ions resulted in development of microsparry infillings. Larger particles washed into the fissures are represented by corroded crinoidal elements and small quartz grains, probably derived mainly from the uplifted parts of the parautochthonous areas. Final determination of the nature of these deposits requires further detailed petrological and geochemical studies.

Both facially and microfacially the ferruginous calcareous sandstones (ferruginous hybridic arenites of Microfacies C) infilling the dykes resemble the sandstone facies components of the Dudziniec Formation outcropping in the Kościeliska Valley. This suggests that this type of dyke is intraformational, and that the source of their infillings should be sought within the Lower Jurassic sequences. The closest resemblance is to the pinkish-grey/pinkish-white hybridic sandstones of Facies I, outcropping in sections 1 to 3 (see Jezierska *et al.* 2016). However, in sections 2 and 3 the dykes with these deposits are hosted by the overlying Facies II (Text-fig. 6), which indicates that the material must have been derived from a different, younger source. Potentially the sandy material could also come from calcareous lithic sandstones of Facies IV, siliceous conglomeratic sublithic-subarkose sandstones of Facies V, or even hybridic crinoidal sandstones of Facies VII. However, no dykes have been found hosted by rocks higher in the sections than Facies II, which makes this hypothesis doubtful. Therefore, most probably the ferruginous calcareous sandstones that infill the dykes are derived from facies that are absent in the sections exposed in the Kościeliska Valley in direct vicinity of the described structures. At least part of the material could come also directly from the walls of the dykes.

Age of the dykes, initiation and development of voids

The history of dykes filled with sediments, such as neptunian dykes, is often separated into three stages: initiation, development and infilling (Smart *et al.* 1987). Particular stages can be short and occur directly one after another, or even simultaneously, or can be separated by a considerable amount of time. In any case, the age of a neptunian dyke is determined by the age of the infilling deposits.

If the above presented conclusions concerning the nature and the source of the deposits filling the described structures are correct, the dykes are intraformational, and their whole development history marks a distinct and probably a relatively short episode following the deposition of Facies II. The lack of dykes penetrating the deposits of Facies III and younger suggests that this episode terminated before their deposition. This indicates that the age of the dykes is most probably Sinemurian to early Pliensbachian. However, it cannot be entirely excluded that the systems cut also the younger deposits of Facies III or even IV, but their higher parts – master dykes (see Mallarino 2002), are not exposed and simply have not been found. This may be suggested by the lithological resemblance of the ferruginous calcareous sandstones infilling the dykes and the calcareous lithic sandstones of Facies IV in the sections. In this case, the sediments of Facies IV would be the source rock of the sandstone infillings, and the age of the dykes would be accordingly younger. A younger – late Pliensbachian age of the dykes would be in accordance with the syndepositional tectonic activity in the Sub-Tatric Križna Unit, marked by the appearance of crinoidal facies (Jach 2002).

Fracturing of the host rocks indicates that they must have been relatively quickly sufficiently lithified (Masse *et al.* 1998). Rapid lithification is characteristic rather for e.g., microbial carbonates or beach rocks and not for grainstone facies (de Wet *et al.* 1999). Most probably, early lithification of at least some parts of the Dudziniec Formation sequence was possible due to temporary subaerial exposure of the sediments and the influence of meteoric waters during early diagenesis (compare Dravis 1996). The coarse-grained facies (e.g., Facies II in section 4) contain internal erosional surfaces and intraformational breccias composed of semi-lithified clasts (Text-fig. 7E; Staśkiewicz 2015; Jezierska *et al.* 2016) and thus probably the sequence abounds in hidden, unrecognisable associated sedimentary gaps. It is characteristic that the dykes are found in the eastern area of exposure of the Dudziniec Formation (Kościeliska Valley), in shallow-most facies, and are not found in the west (Chochołowska Valley) representing the deeper parts of the basin. On the other hand, the ragged surfaces of the walls of the dykes, particularly those filled with sandstones, indicate that the host-rocks were not fully lithified.

The development of the discussed structures took place in multiple stages. The irregularity of the voids and fissures hosting the internal sediments, and the occurrence of internal breccia nests, indicate that their initiation and development processes cannot be attributed to a single fracturing event. The same can be stated about the infilling processes, as is indicated by the complex architecture of the infilling deposits, with laminations, internal erosional surfaces and the occurrence of layers of calcite cements (compare e.g., Blendinger 1986). During the periods in which the systems of interconnected voids and fissures became sealed and were not permeable for deposits, calcite cements precipitated in the remaining spaces.

The time relation between the infilling of the dykes by fine carbonate sediments of Microfacies A and B and by the sandstones of Microfacies C is unclear, as no univocal cross-cutting relations are visible. The two types of deposits co-occur in some of the structures, which suggests that the processes of their deposition, in both cases taking place in several stages, generally represent the same episode of formation of neptunian dykes.

CONCLUSIONS

The studies of neptunian dykes penetrating the Lower Jurassic Dudziniec Formation exposed in the Kościeliska Valley in the High-Tatric succession of the Tatra Mountains allow us to present the following general conclusions:

1) The sedimentary development of the Lower Jurassic sandy-carbonate facies in the autochthonous unit, as was previously postulated, was strongly influenced by synsedimentary tectonic activity, such as block-faulting. The described dykes are yet another symptom of these processes.

2) The distribution of Jurassic neptunian dykes in the High-Tatric succession is limited neither to the foldic and parautochthonous units nor to the Triassic as the host rocks. The relatively rare occurrence of dykes in the Dudziniec Formation of the autochthonous unit is probably caused by different mechanical properties of the poorly bedded coarse-grained sandy crinoidal rocks as compared to the well-bedded Triassic limestones and dolomites.

3) The described dykes are most probably of Sinemurian to Pliensbachian age.

4) The development of the fissures took place in multiple stages and the infilling deposits came from multiple sources. The same fractures opened several times.

5) The sandy varieties of the infillings came directly from the host rocks or from loose sediments present on the sea bottom at the time of fracturing. The fine carbonate internal deposits most probably came from uplifted and corroded carbonate massifs (possibly from the allochthonous High-Tatric units). Products of weathering, both in dissolved form and as small particles, were washed into the sedimentary basin of the autochthonous unit, and redeposited within the dykes.

6) The early ideas of the late Professor Andrzej Radwański, to whom this issue is dedicated, particularly those concerning the origin of fine carbonate material filling the dykes, are still inspiring and can explain the sedimentary phenomena described here very well.

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REFERENCES

Andrusov, D., Bystricky, J. and Fusan, O. 1973. Outline of the structure of the Western Carpathians, 1–44. Guide-book for the geological excursion, X Congress of the Carpathian-Balkan Geological Association. Bratislava.

Aubrecht, R. and Kozur, H. 1995. *Pokornyopsis* (Ostracoda) from submarine fissure fillings and cavities in the Late Jurassic of Czorsztyn Unit and the possible origin of the recent anchialine fauna. *Neues Jahrbuch für Geologie und Paläontologie*, *Abhandlungen*, **196**, 1–17.

Aubrecht, R. and Túnyi, I. 2001. Original orientation of neptunian dykes in the Pieniny Klippen Belt (Western Carpathians): the first results. *Contributions to Geophysics and Geodesy*, **31**, 557−578.

Bac-Moszaszwili, M., Burchart, J., Iwanow, A., Jaroszewski, W., Kotański, Z., Lefeld, J., Mastella, L., Ozimkowski, W., Roniewicz, P., Skupiński, A. and Westwalewicz-Mogilska, E. 1979. Geological map of the Polish Tatra Mts. at the scale of 1:30 000. Wydawnictwa Geolologiczne; Warszawa. [In Polish]

Bagiński, S. 1985. High-Tatric Jurassic in the Rzędy pod Ciemniakiem area, Tatra Mountains. Unpublished Msc Thesis, Jagiellonian University, Cracow. [In Polish]

Blendinger, W. 1986. Isolated stationary carbonate platforms: the Middle Triassic (Ladinian) of the Marmolada area, Dolomites, Italy. *Sedimentology*, **33**, 159–184.

Črne, A., Šmuc, A. and Skaberne, D. 2007. Jurassic neptunian dikes at Mt Mangart (Julian Alps, NW Slovenia). *Facies*, **53**, 249−265.

Csontos, L. and Vörös, A. 2004. Mesozoic plate tectonic reconstruction of the Carpathians region. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, **210**, 1–56.

de Wet, C., Dickson, J., Wood, R., Gaswirth, S. and Frey, H. 1999. A new type of shelf margin deposit: rigid microbial sheets and unconsolidated grainstones riddled with meter scale cavities. *Sedimentary Geology*, **128**, 13–21.

Dravis, J. 1996. Rapidity of freshwater calcite cementation – implications for carbonate diagenesis and sequence stratigraphy. *Sedimentary Geology*, **107**, 1–10.

Dunham, R. 1962. Classification of carbonate rocks according to depositional texture. *AAPG Memoir*, **1**, 108–121.

Eudes-Deslongschamps, E. 1865. Recherches sur l'organisation du manteau chez les Brachiopodes articulés et principalement sur les spicules calcaires contenus dans son interieur. *Mémoires de la Société Linnénne de Normandie*, **14**, 1–36.

Horwitz, L. and Rabowski, F. 1922. Sur le Lias et le Dogger hauttatriques de la Tatra. *Posiedzenia Naukowe Państwowego Instytutu Geologicznego*, **3**, 15–18. [In Polish with French summary]

Jach, R. 2002. Lower Jurassic spiculite series from the Križna Unit in the Western Tatra Mts, Western Carpathians, Poland. *Annales Societatis Geologorum Poloniae*, **72**, 131–144.

Jach, R. 2005. Storm-dominated deposition of the Lower Jurassic crinoidal limestones in the Križna unit, Western Tatra Mountains, Poland. *Facies*, **50**, 561–572.

Jenkyns, H. 1971. The genesis of condensed sequences in the Tethyan Jurassic. *Lethaia*, **4**, 327–352.

Jezierska, A. and Łuczyński, P. 2016. Jurassic unconformities in the High-Tatric succession, Tatra Mountains, Poland. *Geological Quarterly*, **60**, 273–290.

Jezierska, A., Łuczyński, P. and Staśkiewicz, A. 2016. Carbonate-clastic sediments of the Dudziniec Formation (Lower Jurassic) in the Kościeliska Valley (High-Tatric series, Tatra Mountains, Poland): role of syndepositional tectonic activity during the Early and Middle Jurassic. *Geological Quarterly*, **60**, 869–880.

Jezierski, P. 2014. Character of the unconformity between the Triassic and the Jurassic in the autochthonous unit of the Tatra Mountains. Unpublished Msc Thesis, University of Warsaw. [In Polish]

Jones, B. 1992. Void-filling deposits in karst terrains of isolated oceanic islands: a case study from Tertiary carbonates of the Cayman Islands. *Sedimentology*, **39**, 857–876.

Jurewicz, E. 2005. Geodynamic evolution of the Tatra Mts. and the Pieniny Klippen Belt (Western Carpathians): problem and comments. *Acta Geologica Polonica*, **55**, 295–338.

Jurewicz, E. 2012. Nappe-thrusting processes in the Tatra Mts. *Przegląd Geologiczny*, **60**, 432–451. [In Polish with English summary]

Kotański, Z. 1959. Stratigraphic sections of the High-Tatric Series in the Polish Tatra Mts. *Biuletyn Instytutu Geologicznego*, **139**, 7–160. [In Polish]

Kotański, Z. 1979. The position of the Tatra Mts in the Western Carpathians. *Przegląd Geologiczny*, **27**, 359–369. [In Polish]

Lefeld, J., Gaździcki, J., Iwanow, A., Krajewski, K. and Wójcik, K. 1985. Jurassic and Cretaceous lithostratigraphic units of the Tatra Mountains. *Studia Geologica Polonica*, **84**, 1–93.

Lehner, B. 1991. Neptunian dykes along a drowned carbonate platform margin: an indication of recurrent extensional tectonic activity? *Terra Nova*, **3**, 593–602.

Łuczyński, P. 2001a. Development history of Middle Jurassic neptunian dykes in the High-Tatric series, Tatra Mountains, Poland. *Acta Geologica Polonica*, **51**, 237–252.

Łuczyński, P. 2001b. Pressure-solution and chemical compaction of condensed Middle Jurassic deposits, High-Tatric series, Tatra Mountains. *Geologica Carpathica*, **52**, 91–102.

Łuczyński, P. 2002. Depositional evolution of the Middle Jurassic carbonate sediments in the High Tatric succession, Tatra Mountains, Western Carpathians, Poland. *Acta Geologica Polonica*, **52**, 265–378.

Mallarino, G. 2002. Piana Degli Albanesi, Monte Kumeta and the "Saccense Domain": pelagic resedimented, and high-energy skeletal post-drowning facies from western Sicily. Appendix – neptunian dykes at Monte Kumeta. In: M. Santantonio (Ed.), 6th International Symposium on the Jurassic System. Palermo, Italy, 12−22 September 2002. General Field Trip Guidebook, pp. 205–209. Palermo.

Masse, J-P., Borgomano, J. and Al Maskiry, S. 1998. A platform transition for lower Aptian carbonates (Shuaiba Formation) of the northeastern Jebel Akhdar (Sultanate of Oman). *Sedimentary Geology*, **119**, 297–309.

Matyszkiewicz, J., Krajewski, M., Kochman, A., Kozłowski, A. and Duliński, M. 2016. Oxfordian neptunian dykes with brachiopods from the southern part of the Kraków-Częstochowa Upland (southern Poland) and their links to hydrothermal vents. *Facies*, **62**, 12.

Michalík, J. 2007. Sedimentary rock record and microfacies indicators of the latest Triassic to mid-Cretaceous tensional development of the Zliechov Basin (Central Western Carpathians*)*. *Geologica Carpathica*, **58**, 443–453.

Michalík, J., Rehakova, D. and Sotak, J. 1994. Environments and setting of the Jurassic Lower Cretaceous succession in the Tatric area, Male Karpaty Mts. *Geologica Carpathica*, **45**, 45–56.

Mišík, M. 1994. The Czorsztyn Submarine Ridge (Jurassic − Lower Cretaceous, Pieniny Klippen Belt): an example of a pelagic swell. *Mitteilungen der Österreichischen Geologischen Gesellschaft*, **86**, 133–140.

Mišik, M., Sykora, M., Siblik, M. and Aubrecht, R. 1995. Sedimentology and brachiopods of the Lower Jurassic Luty Potok limestone (Slovakia, West-Carpathian Klippen belt). *Geologica Carpathica*, **46**, 41–51.

Pettijohn, F., Potter, P. and Siever, R. 1972. Sand and Sandstones, 1–618. Springer; New York.

Plašienka, D. 1995. Passive and active margin of the northern Tatricum (Western Carpathians, Slovakia). *Geologische Rundschau*, **84**, 748–760.

Plašienka, D. 2012. Jurassic syn-rift and Cretaceous syn-orogenic, coarse-grained deposits related to opening and closure of the Vahic (South Penninic) Ocean in the Western Carpathians – an overview. *Geological Quarterly*, **56**, 601–628.

Plašienka, D., Grecula, P., Putiš, M., Kováč, M. and Hovorka, D. 1997. Evolution and structure of the Western Carpathians: an overview. *Mineralia Slovaca – Monograph*, 67–72.

Rabowski, F. 1954. Researches in the Kominy Tylkowe region in the Tatra Mountains performed in 1938. *Biuletyn Instytutu Geologicznego*, **86**, 29–35. [In Polish]

Rabowski, F. 1959. High-Tatric series in western Tatra. *Prace Instytutu Geologicznego*, **27**, 1–173. [In Polish]

Radwański, A. 1959a. Researches on petrography of the High-Tatric Lias. *Przegląd Geologiczny*, **7**, 359–362. [In Polish]

Radwański, A. 1959b. Littoral structures (cliff, clastic dikes and veins, and borings of Potamilla in the High-Tatric Lias. *Acta Geologica Polonica*, **9**, 31–280. [In Polish with English summary]

Radwański, A. 1968. Petrographical and sedimentological studies of the High-Tatric Rhaetic in the Tatra Mountains. *Studia Geologica Polonica*, **25**, 1–146. [In Polish with English summary]

Rousselle, L. 1977. Spiriférines du Lias moyen et supérieur au Maroc (Rides Prérifaines; Moyen Atlas) et en Espagne (Chaine Celtibérique orientale). *Notes du Service geologique du Maroc*, **38**, 153–175.

Schlögl, J., Mangold, C., Tomašových, A. and Golej, M. 2009. Early and Middle Callovian ammonites from the Pieniny Klippen Belt (Western Carpathians) in hiatal successions: unique biostratigraphic evidence from sediment-filled fissure deposits. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **252**, 55–79.

Siblik, M. 1965. Some new Liassic brachiopods. *Geologický Sborník Slovenskej Akadémie Vied*, **16**, 1–264.

Sidorczuk, M. 2005. Middle Jurassic Ammonitico Rosso deposits in the northwestern part of the Pieniny Klippen Belt in Poland and their palaeogeographic importance; A case study from Stankowa Skała and "Wapiennik" quarry in Szaflary. *Annales Societatis Geologorum Poloniae*, **75**, 273–285.

Siemiradzki, J. 1923. Liassic and Jurassic Fauna from the Tatra Mountains and Podhale. *Archiwum Towarzystwa Naukowego we Lwowie*, **3**, 1–3. [In Polish]

Smart, P.L., Palmer, R.J., Whitaker, F. and Wright, V.P. 1987. Neptunian dykes and fissure fills: an overview and account of some modern examples. In: N.P. James and P.W. Choquette (Eds), Paleokarst, 149–163. Springer Verlag; New York.

Sowerby, J. 1822. The mineral conchology of Great Britain, 1–383. B. Meredith; London.

Staśkiewicz, A. 2015. Lower Jurassic (Dudziniec Formation) in the Kościeliska Valley (Tatra Mts.). Unpublished Msc Thesis, University of Warsaw. [In Polish]

Uchman, A. 2014. Introduction – sedimentary rocks of the Tatra Mountains. In: R. Jach, T. Rychliński and A. Uchman (Eds), Sedimentary Rocks of the Tatra Mountains, 12−28. Wydawnictwa Tatrzańskiego Parku Narodowego; Zakopane.

Wendt, J. 1971. Genese und Fauna submariner sedimentärer Spaltefüllungen im mediterranen Jura. *Palaeontographica Abhandlungen A*, **136**, 122–192.

Wendt, J. 2017. A unique fossil record from neptunian sills: the world's most extreme example of stratigraphic condensation (Jurassic, western Sicily). *Acta Geologica Polonica*, **67**, 163–199.

Wieczorek, J. 2000. Condensed horizons as turning events in passive margin evolution: The Tatra Mts. examples. *Zentralblatt für Geologie und Paläontologie*, Teil I, Jahrgang 2000, 1/2, 199–209.

Wiedenmayer, F. 1964. Obere Trias bis mittlerer Lias zwischen Saltrio und Tremona (Lombardische Alpen). Die Wechselbeziehungen zwischen Stratigraphie, Sedimentologie und syngenetischer Tektonik. *Eclogae Geologicae Helvetiae*, **56**, 529–640.

Wierzbowski, A., Schlögl, J., Aubrecht, R. and Krobicki, M. 2005. Rediscovery of the classic locality of Callovian in Babiarzowa Klippe (Pieniny Klippen Belt, Poland). *Tomy Jurajskie*, **3**, 11–14.

Winterer, E., Metzler, C. and Sarti, M. 1991. Neptunian dykes and associated breccias (Southern Alps, Italy and Switzerland): role of gravity sliding in open and closed systems. *Sedimentology*, **38**, 381–404.

Winterer, E. and Sarti, M. 1994. Neptunian dykes and associated features in southern Spain: mechanics of formation and tectonic implications. *Sedimentology*, **41**, 1109–1132.

Wójcik, K. 1979. Sedimentation and facies development of the High-Tatric Liassic in the Chochołowska Valley. Unpublished Msc Thesis, University of Warsaw. [In Polish]

Wójcik, K. 1981. Facies development of the vicinity of the Chochołowska Valley. *Przegląd Geologiczny*, **39**, 405–410. [In Polish with English summary]

Wójcik, Z. 1959. High-Tatric series of the southern slopes of Bobrowiec. *Acta Geologica Polonica*, **9**, 165–201. [In Polish]

Zuffa, G. 1980. Hybrid arenites: Their composition and classification. *Journal of Sedimentary Petrology*, **50**, 21–29.

Zydorowicz, T. 1991. Diagenesis of the Upper Jurassic pelagic deposits of the Pieniny Klippen Belt in Poland. Unpublished PhD Thesis, Polish Geological Institute. Warszawa [In Polish]

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