GUIDEBOOK

Bedded chalk marls in the Opole Trough: epicratonic deposits of the Late Cretaceous super-greenhouse episode

Guide to field trip B1 • 26 June 2015

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Bedded chalk marls in the Opole Trough: epicratonic deposits of the Late Cretaceous super-greenhouse episode

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Route (Fig. 1): From Kraków, we drive west by motorway A4 (direction of Wrocław). Leave motorway on the first slip road after crossing the Odra River (about 160 km from Kraków) towards the city of Opole (route 45). After nine kilometres turn left to the road leading to the active **Folwark Quarry (stop B1.1)**, which is our main destination. Visitors need a permission from Górażdże Heidelberg Cement Group office. Leaving the quarry we return to motorway via route 45 and turn toward Kraków again. After 7 km we leave the motor highway toward Gogolin and drive along route 409 toward Strzelce Opolskie. After next 12 km we turn right to Ligota Górna, then by next

Fig. 1. Route map of field trip B1.

Kędzierski, M. & Uchman, A., 2015. Bedded chalk marls in the Opole Trough: epicratonic deposits of the Late Cretaceous super-greenhouse episode. In: Haczewski, G. (ed.), *Guidebook for field trips accompanying 31st IAS Meeting of Sedimentology held in Kraków on 22nd–25th of June 2015*. Polish Geological Society, Kraków, pp. 145–158.
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4 km, we turn right to Wysoka and Góra Św. Anny. Driving up and down the hill along the Góra Św. Anny village we get to the Zdzieszowice-Leśnica crossroads and car park. The second (optional in the case of bad weather) stop of the field trip is located in an abandoned quarry in the **Góra Św. Anny Geopark (stop B1.2)** easily recognizable on the right side, a hundred metres north from the car park (Fig. 1).

Introduction to the trip

Geological background along the route

Driving west from Kraków we leave the Carpathian Foredeep Basin filled up with the Miocene fine-grained molasse sediments and we start to cross the Kraków-Silesian Monocline (Fig. 2) embracing the Permian through Upper Cretaceous sedimentary cover of the Variscan, partly folded, non-metamorphosed basement of the Brunovistulicum Domain. Locally, the cover is cut by Permian intrusions. The monocline is gently dipping to the west, hence, the route runs from the youngest, poorly exposed Upper Cretaceous marls and the underlying Middle/Upper Jurassic, mostly Oxfordian limestones, which are easily noticeable in the City of Kraków and its north vicinity as the white monadnocks or rock gates closing the narrow valleys deeply incised in the Ojców Plateau. The Oxfordian limestones are exposed also along the motorway, several kilometres west of Kraków. A large quarry at Zalas, visible on the left (southern) side of the motorway, 15 km from the entrance, reveals the Lower Callovian –Middle Oxfordian sandstone, marlstone to limestone sediments which cover Permian subvolcanic ryodacites (Matyja, 2006).

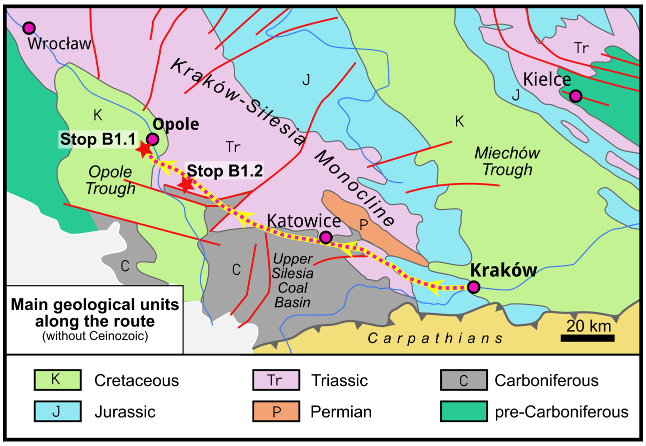

Fig. 2. The main geological units along the route.

Then, the route crosses an area built of the Triassic of the Germanic type, including a carbonate ramp of the Muschelkalk, which covers continental, variegated, fine-grained sandstones and clays with evaporates of the Buntsandstein. Further to the west, we enter an area of the Upper Permian continental playa-like basin facies intercalated with lavas and tuffs, which attain a considerable thickness in the Sławków Trough (50 km west from Kraków, vicinity of Jaworzno along our route). Passing by the Jaworzno power plant we enter the Upper Silesia Coal Basin, filled up with the Upper Carboniferous Paralic (Namurian A), Upper Silesia Sandstone (Namurian B–C), Mudstone (Westphalian A–B) and the Kraków Sandstone (Westphalian C–D) Series (Kotas, 1995). This is the largest industrial area in Poland, exploating one of the largest steam (hard) coal deposits in the world, rendering Poland as the largest coal producer in Europe, with resources estimated as high as 57 gigatons (to 2000 m of depth in beds over 0.6 m thick; Białecka, 2008). An exposure of the Upper Silesia Sandstone Series is visible on the right-side motorway escarpment between Katowice and Zabrze. Leaving the Upper Silesia Coal Basin in Gliwice we enter again the Kraków-Silesia Monocline at its Muschelkalk part. The Muschelkalk limestones are extensively explored in numerous quarries feeding the nearby cement industry. The Góra Św. Anny hill, the highest elevation along our route, reveals some Muschelkalk exposures, visible on the left side when crossing the hill pass. Then, going down from the pass, we enter the main venue of the trip – the Late Cretaceous filling of the Opole Trough, covering discordantly the Palaeozoic and Triassic basement.

The mid-Cretaceous world

The Cretaceous is known as a time of the Earth's climate and, at once, oceanic and atmospheric circulation, significantly different than nowadays (Hay, 2011). Moreover, it is also considered as a period of pronounced high global average temperature (both, on land and in the ocean), especially at high latitudes, of the lack of polar ice-caps and globally high sea-level, and it is thus called a 'greenhouse' period in the Earth history (Frakes, 1979; Gale, 2011). Furthermore, the middle of the Cretaceous period is even described as a 'super-greenhouse' making this time of particular interest for sedimentological and palaeoenvrionmental studies. For instance, the estimation of the Cenomanian–Turonian sea-surface temperature (SST) based on the $\delta^{18}O$ and Mg/Ca ratio of planktonic foraminifera revealed temperatures exceeding 35 °C in tropics (Huber *et al*., 2002; Wilson *et al*., 2002; Forster *et al*., 2007; Friedrich *et al*., 2012) and possibly reaching even 42 °C (Bice *et al*., 2006). Generally, the Turonian is considered a time of the highest global average temperature throughout the whole Cretaceous (Hay and Floegel, 2012). Such temperatures remained up to the Turonian-Coniacian transition. This extremely high SST was unarguably connected to elevated atmospheric pCO_2 (Barron and Washington, 1985) which should have attained at least 3500 ppm required in the models to achieve the assumed maximum SST (Bice *et al*., 2006). A submarine volcanic activity of the Ontong Java and Caribbean plateaus is regarded as the main source enhancing the mid-Cretaceous pCO_2 (Leckie *et al*., 2002; Jarvis *et al*., 2011).

The idea of the 'greenhouse' and 'icehouse' period in Earth's history was originally introduced by Fischer (1982), however, has been recently developed by Kidder and Worsley (2010, 2012) who recognized three basic modes for Earth's climate: icehouse, greenhouse and hothouse (= super-greenhouse). Moreover, the greenhouse can be further subdivided into cool- and warm-greenhouse.

The Albian through Coniacian climate is accepted as generally warm-greenhouse, however, three shifts into hothouse are pointed out at the Albian-Cenomanian, Cenomanian-Turonian and Turonian-Coniacian boundaries (Holz, 2015). The warm greenhouse is then characterized by global average temperature between 24 °C and 30 °C, no polar ice-caps and pCO_2 about 1200–4800 ppm. The oceans may become less oxygenated or anoxic under such conditions. In turn, the hothouse is assumed as a relatively short period of time (less than 3 my) which occurred during anomalously high atmospheric pCO_2 reaching up to 4800 ppm as a result of formation of the Large Igneous Provinces (LIPs). Vanishing of LIP usually ends hothouse due to rapid sequestration of CO_2 via enhanced weathering (Jarvis *et al*., 2011; Flögel *et al*., 2011).

However, some short-term coolings, when the surface waters were of about 2–4 °C cooler, are postulated for the mid-Cretaceous warm-greenhouse time (Forster *et al*., 2007; Jarvis *et al*., 2011). These periods were interpreted as cooling phases induced by formation of polar ice-caps which triggered glacio-eustatic changes of the sea-level in the Early Turonian and the late Early Coniacian (Uličny *et al*., 2009). The cooling phases are still problematic due to unknown mechanisms that may have caused them during warm-greenhouse or even hothouse in contrast to cool-greenhouse, where some 'cold-snaps' are more obvious, e.g., the Campanian-Maastrichtian Boundary Event (Holz, 2015).

Such warm-greenhouse or hothouse during the middle of Cretaceous may be inflated because none of the assumed odd heat stress for land plants caused by warm ocean temperatures has been reported so far (Hay and Floegel, 2012). Furthermore, Hasegawa *et al.* (2012) suggested also, that pCO_2 above the 1000 ppm triggered a drastic equatorial-ward shrinking of Hadley circulation to latitudes about 25–30° in the mid-Cretaceous. Accordingly, the hothouse would be characterized by a narrow zone of arid climate, similarly to the icehouse mode, but it would lack the polar ice-caps. Besides these internal mechanisms regulating the Earth's climate, there is a report of globally widespread enhanced helium (^3He) concentrations in the Turonian sediments, which are about 4-fold higher than in the Cenomanian or Coniacian, suggesting an extraterrestrial cause (a comet or an asteroid shower) of the cooling effect during the mid-Cretaceous warm-greenhouse time (Farley *et al*., 2012).

Moreover, the Cretaceous has had a specific oceanic condition which allowed accumulation of waste amount of organic-rich sediments during 'oceanic anoxic events – OAE' (Schlanger and Jenkyns, 1976; Arthur *et al*., 1990). Especially, the Cenomanian–Turonian boundary event (OAE-2) is considered a major disturbance of global carbon cycle in the last 100 Myr (Jarvis *et al*., 2011). Changes of the ocean's circulation were associated with formation of the Atlantic Ocean extending between the subarctic and subantarctic regions and its gateways connecting the northern with the southern parts, and the North Atlantic with the Pacific and the Tethys (e.g., Friedrich *et al*., 2012). During the mid-Cretaceous, the North Atlantic may be regarded as a nutrient trap with respect to the Pacific, in consequence of estuarine type of circulation. Intense upwellings along the North Atlantic coasts brought series of organic-rich sediments in response to the influx of intermediate or thermocline nutrient-rich and warm (>20 °C) Pacific seawater, connected with submarine igneous events (Trabucho-Alexandre *et al*., 2010; Friedrich *et al.*, 2012). Such accumulation of the organic-carbon-rich sediments also prevailed in the equatorial and mid-latitudinal Atlantic as well as in the neighbouring basins during the OAE-3 (Coniacian–Santonian). Meanwhile, the Tethys and North Atlantic sedimentation of that interval was dominated by occurrence of the oceanic red beds (see Wagreich, 2012).

Chalk and bedded-chalk facies

The chalk facies is unequivocally one of the most conspicuous facies of the Cretaceous, giving the period's name (see Hay, 2011). The chalk composition shows a predominant contribution of nannofossils, which seems to be a result of the Late Cretaceous seawater ionic specificity favourings precipitation of low Mg calcite (Stanley *et al.*, 2005). On the other hand, the chalk was deposited in the vast epicontinental basins that became flooded during the mid-Cretaceous high sea-level stage. This caused vanishing of the shelf-break front that separated the oceanic and shelf seawaters and allowed invasion of oceanic organisms such as calcareous nannoplankton into the epeiric seas (Hay, 2008). The bedded-chalk facies differs from the massive chalk in having distinctive bedding caused by varying siliciclastic contribution usually seen as marlstone-limestone alternation. Especially, the several cm thick clay-rich beds in the Turonian deposits are a noticeable feature of the chalk in northwestern Europe. According to Wray (1995), most of these beds are composed of detrital clays, and bentonites occur only exceptionally. This may indicate changes in terrigenous input resulting from sea-level fluctuations. As reported from the nearby Opole Trough Bohemian Cretaceous Basin, such short-term fluctuations involved sea-level falls of about 10–20 m during the Turonian through Lower Coniacian and they show frequency interval of 100 kyr, interpreted as glacio-eustatic changes (Uličny *et al.*, 2014).

The Opole Trough

The Opole Trough is an erosional remnant of the much more widespread Late Cretaceous cover filled up by epicontinental marls, marlstones, marly mudstones, marly limestones and limestones (Fig. 3). In general, this marly sedimentation in the Opole Trough coincides with the global maximum of the chalk accumulation and its products can be described as bedded-chalk marls (Walaszczyk, 1992). The total thickness of the Upper Cretaceous deposits in the Opole Trough is estimated at about 300 m, and most of them belong to the Upper Coniacian–?Santonian (Kotański and Radwański, 1977). They rest discordantly upon the Palaeozoic and Triassic basement, and are covered discordantly by Cenozoic, mainly Miocene and Quaternary deposits. The Opole Trough deposits dip gently to the west, therefore the oldest (Upper Cenomanian) layers are known from its eastern part (near Opole), whereas the youngest (Upper Coniacian–?Santonian) are known from the western part (Kotański and Radwański, 1977; Tarkowski, 1991; Walaszczyk, 1992). The main exposures are available in large quarries near Opole, important suppliers of cement industry.

The Opole Trough attracts the attention of geologists since the early 19th century (Oeynhausen, 1822). Important works to be mentioned include those by Roemer (1870), Biernat (1960) and Kotański and Radwański (1977). Stratigraphy of the Opole Trough was the subject of Tarkowski's (1991), Walaszczyk's (1992) and Kędzierski's (2008) studies, which determined the age of deposits exposed in the Folwark quarry as the Middle Turonian–Middle Coniacian. Alexandrowicz

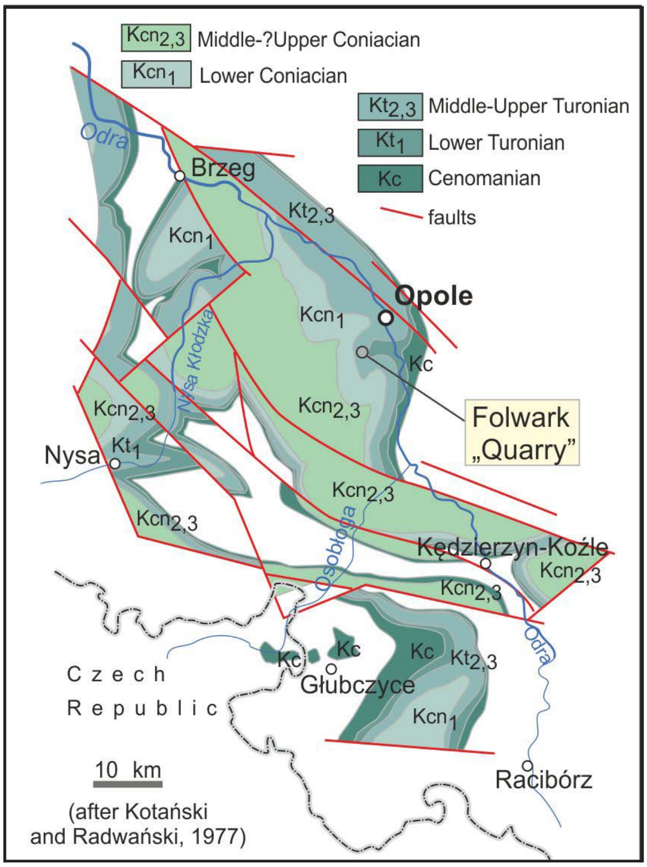

Fig. 3. The geological map of the Opole Trough Cretaceous deposits.

and Radwan (1973) subdivided the section of the Opole Trough on the grounds of the CaO content. According to this subdivision, the presented Folwark Quarry section embraces the Lower Clayey Marl, Lower Marl, Marly Limestone, Upper Marl and Upper Clayey Marl. All these lithologic units are easily recognizable in the field, since they differ in colour, related to the carbonate content which varies from 25% to 88% of $CaCO_3$ (Kędzierski, 2002). It is noteworthy that all of these units are sporadically intercalated with layers, up to 30 cm thick, of dark clayey marls and marly clays with considerably lower contents of carbonates (Fig. 4).

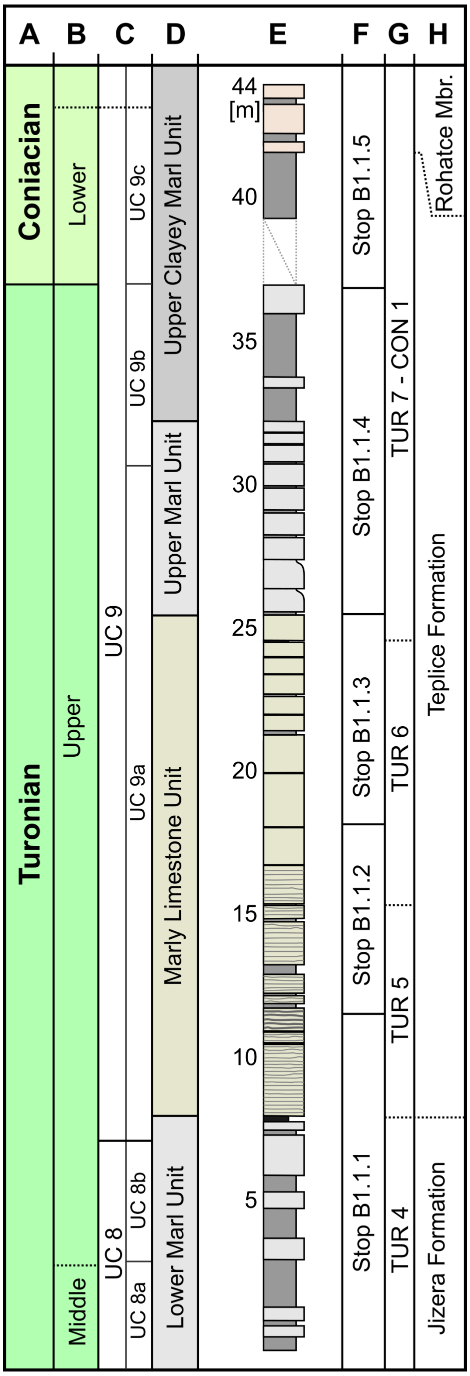

Fig. 4. Stratigraphy, lithology of the Folwark Quarry section compared with genetic sequences and litostratigraphical units of the Bohemian Cretaceous Basin. Meaning of the columns:
A – stages; B – substages; C – nannofossil biozones (Kędzierski, 2008); D – lithological units (Alexandrowicz and Radwan, 1973); E – composite Folwark Quarry section; F – part of the section visible at stops; G – genetic units sensu Uličny *et al.* (2009); H – formations of the Bohemian Czech Basin applied to the Opole Trough.

Other general palaeoecological and palaeoenvironmental studies were based on the following evidence: ichnofabrics (Kędzierski and Uchman, 2001), sharks (Niedźwiedzki and Kalina, 2004), echinoids (Olszewska-Nejbert, 2007) and sponges (Świerczewska-Gładysz, 2012). All of these studies were carried out on the best accessible Middle Turonian–Middle Coniacian sediments, since the other are only fragmentarily exposed or known from cores, now destroyed. Taking into account all data from these studies, one may obtain a general picture of the Middle Turonian throughout Middle Coniacian sea floor of the Opole Trough with a rather soft substrate and placed below the storm-wave base in a calm-water environment with a low to moderate rate of sedimentation. Sediments of the Middle Turonian *Inoceramus lamarcki* Zone represent the deepest environments (Kędzierski and Uchman, 2001; Niedźwiedzki and Kalina, 2004).

The Opole Trough lies in the transitional zone between the Tethyan and Boreal realms. Its nearest basins, which span the same time of sedimentation and show similar facies development, are the Bohemian Cretaceous and the Intra-Sudetic (Nysa Trough) basins. These basins were supplied by clastics mainly from the nearby Sudetic Islands (Western and Eastern) during the Cenomanian–Coniacian, therefore, the Opole Trough is regarded as a part of the so-called Circum-Sudetic Trap Basin (Walaszczyk, 1992; Fig. 5).

Stop descriptions

B1.1 Folwark quarry

The Folwark quarry is located a few km south of Opole, between Folwark, Chrzowice and Chrząszczyce. (50°36′43″ N, 17°54′38″ E; Fig. 5)

The quarry is the largest one supplying the Górażdże cement factory via a conveyor belt. Middle Turonian through Middle Coniacian strata are exposed at the three excavation levels in the quarry. The part of the quarry section available to study between the lowermost and the

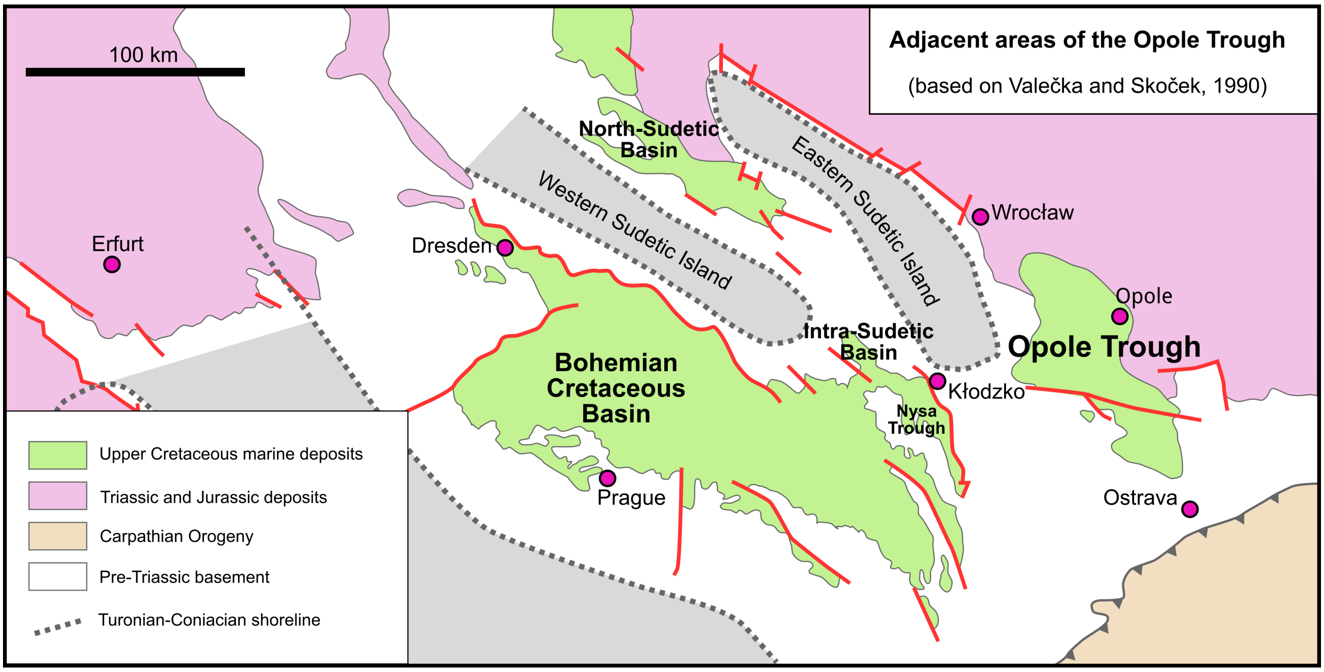

Fig. 5. Geological units adjacent to the Opole Trough.

middle levels represents the Lower Marl and the Marly Limestone units, embracing the Middle and Upper Turonian (Stops B1.1.1 and B1.1.2). The next higher part of the section, between the middle and uppermost levels, shows the Upper Turonian Marly Limestone and the Upper Marl units (Stop B1.1.3). The Upper Turonian through Middle Coniacian strata are exposed above the uppermost excavation level (Stops B1.1.4 and B1.1.5; Fig. 6).

The lithologic units best depict the general trends in carbonate contents, reaching the highest values in the Marly Limestone Unit, that can be partly described also as nodular limestones. The under- and overlying beds consist of sediments with lower carbonate contents, according to a scheme – the farther away from the nodular limestone, the lower is carbonate content, except for a siliceous marls package, a few meters thick, in the uppermost part of the quarry section (Stop B1.1.5; Fig. 7).

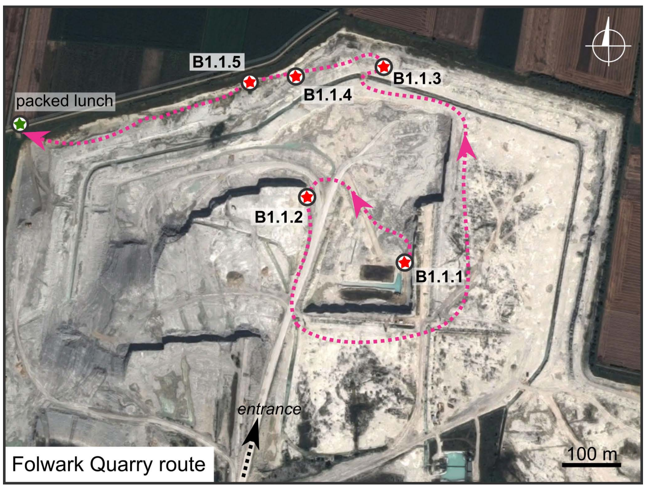

Fig. 6. Aerial view of the Folwark quarry and location of the stops and route (based on Google Maps).

This facies order is very similar to that known from the Bohemian Cretaceous Basin, where the Middle Turonian deposits with high carbonate content compose the Jizera Formation, which is under- and overlain by less carbonatic units: the Bílá Hora Formation and the Teplice Formation, respectively. Moreover, the package of siliceous marls can be compared to the Bohemian Rohatce Member (Teplice Fm.) (Čech *et al.*, 1980). Also, a general trend in long-term accommodation and supply rates, exponentially growing since the Early Turonian until Middle Coniacian, is similar to that observed in the Bohemian Cretaceous Basin (Uličny *et al.*, 2009). Generally, we suggest that the genetic sequences TUR 1–CON 1 sensu Uličny *et al.* (2009), distinguished in the Bohemian Cretaceous Basin, can be also recognized in the Opole Trough.

B1.1.1 The Lower Marl Unit, Middle Turonian, *inoceramid I. lamarcki* Zone

(50°36′43″N, 17°54′38″ E)

The lowest level in the quarry reveals thick-bedded, gray, massive marls altered with thick-bedded, a bit softer, dark gray clayey marls (Fig. 8).

The sediments are totally bioturbated with predominance of *Thalassinoides* isp. and *Planolites* isp. (*Thalassinoides* ichnofabric; Kędzierski and Uchman, 2001). *Chon-*

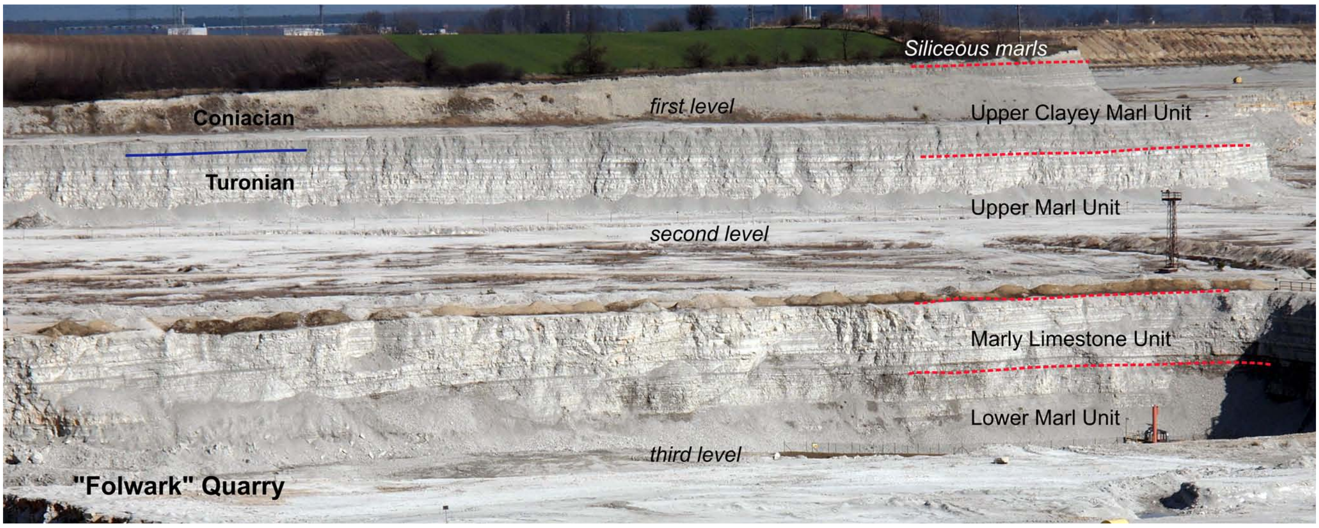

Fig. 7. General view of the Folwark quarry with stratigraphy and lithological units marked.

drites isp. is abundant in the lowest part. *Trichichnus* isp. is common and *Zavitokichnus* isp. is very rare (Fig. 9). Among body fossils, inoceramids and pyritized sponges are common. Some large inoceramid shells (possibly *I. cuvieri*) are commonly covered by worm incrustations.

The lowermost part of the section available here, used to be better exposed in the nearby Odra Quarry, where the *Chondrites* ichnofabric was recognized (Kędzierski and Uchman, 2001). This ichnofabric may indicate less oxygenated pore waters in the sediment, in coincidence with the deepest phase of the basin development, as recognized on the basis of shark teeth (Niedźwiedzki and Kalina, 2004).

Going up the section available at this stop, ~10 metres above the excavation level (13 m in Fig. 8) , there are prominent dark clay intercalations which visible the best from a distance. Below one of these intercalations, *Chondrites* and *Thalassinoides* are well visible thanks to their black filling. These intercalations gradually pass into the surrounding sediments and we did not find any evidence of the accompanying them bottom erosion. However, one of downfallen blocks shows that the clayey layer is underlain by eroded clasts. This can be interpreted as an omission surface marking the maximum of regression followed by lowstand system tract (LST) deposits with enhanced input of terrigenous material visible as the clayey intercalation (Fig. 10). We assume that the other prominent clay-rich intercalations visible in the quarry, also record sea-level falls and LST. These can be interpreted as boundaries of genetic sequences. Therefore, the Lower Marl Unit may correspond to the TUR 4 genetic sequence sensu Uličny *et al.* (2009) (Fig. 4).

B1.1.2 The Marly Limestone Unit, Upper Turonian, inoceramid *I. costellatus* + *M. incertus* zones

(50°36′48″ N, 17°54′30″ E)

The Marly Limestone Unit is exposed in the upper part of the section visible from the lowermost part of the excavation, and along the road going to the middle part of the quarry. A characteristic feature of this marly limestones is their nodular character that makes them appear as thick-bedded strata stripped irregularly with thin layers of clays (Fig. 8). Due to their highest carbonate content in the whole section of the Opole Trough, they can be easily distinguished as the brightest sediments. The nodular limestones are totally bioturbated with predominance of *Thalassinoides* isp., *Planolites* isp. and subordinately *Chondrites* isp. Noteworthy, *Thalassinoides* reaches its maximum size here (Fig. 9). Apart from frequent inoceramids and sponges, the marly limestones bear also the common echinod *Micraster* ex. gr. *leskei* (see Olszewska-Nejbert, 2007).

On the basis of studies of ichnofabric (Kędzierski and Uchman, 2001) and shark teeth (Niedźwiedzki and Kalina, 2004), the depositional environment of this unit is interpreted as shallower than that of the underlying Lower Marl Unit. The Marly Limestone Unit coincides with the Late Turonian cooling phase that triggered a sea-level fall and changes in weathering and water fertility (Voigt and Wiese, 2000; Wiese and Voigt, 2002). Accordingly, this unit corresponds to TUR 5 through TUR 6 genetic sequence sensu Uličny *et al.* (2009; Fig. 4).

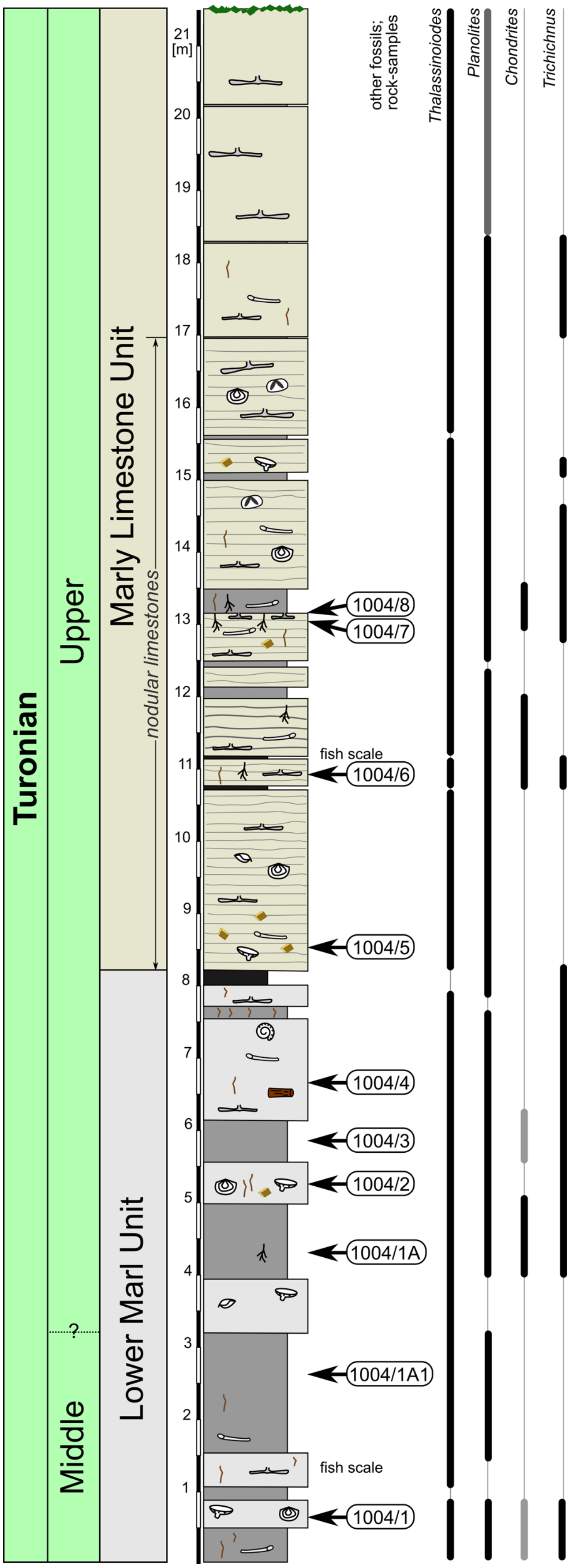

Fig. 8. The lower part of the Folwark Quarry section.

B1.1.3 The Marly Limestone and Upper Marl units, Upper Turonian, *M. incertus* inoceramid Zone

(50°36′44″ N, 17°54′28″ E)

The Upper Marl Unit is available at the base of the second exploitation level. It is similar to the Lower Marl Unit and shows alternation of softer and darker marls with brighter and harder marls, medium to thick- bedded in both types. A distinct dark, clay-rich intercalation, several cm thick, present ca. 4 m above the exploitation level (Fig. 11), may represent the maximum of regression at the base of the layer and the following LST clayey deposits. It can be interpreted as the boundary between the TUR 6 and TUR 7 genetic sequences sensu Uličny *et al.* (2009) (Fig. 4).

The sediments of this unit are strongly bioturbated, and the ichnofossil assemblage is similar to the previous units with the predominance of *Thalassinoides* and *Planolites*, and, subordinately *Chondrites* (*Thalassinoides* ichnofabric in Kędzierski and Uchman, 2001; Fig. 12). Body fauna is common, with inoceramids and sponges (partly pyritized).

B1.1.4 The Upper Clayey Marl Unit, Upper Turonian – Lower Coniacian, inoceramid *C. waltersdorfensis*+*C. brongniarti*+*C. deformis* zones

(50°36′54″ N, 17°54′37″ E)

The next Upper Clayey Marl Unit is available from the uppermost exploitation level and it is represented mainly by thick bedded soft, dark clayey marls gradually passing into brighter marls, also soft (Fig. 11). The *Thalassinoides* ichnofabric (Kędzierski and Uchman, 2001) and ichnofossil assemblage does not differ from the underlying unit, and body fossils alike (Fig. 12). However, predominance in thickness of clayey marls over marly clays and marls record increasing input of terrigeneous material in this unit. This coincides with the same trend recognized in the Bohemian Cretaceous Basin (Uličny *et al.*, 2009), and is the result of the uplift of the East Sudetic Island in its Śnieżnik Massif part (~70 km south-west from the City of Opole; Kędzierski, 2002). This part of the Folwark Quarry section can be compared to the TUR 7 and CON 1 genetic sequences sensu Uličny *et al.* (2009).

B1.1.5 The Upper Clayey Marls Unit with intercalations of the siliceous marls, Lower Coniacian – Middle Coniacian, inoceramid *C. crassus+I. kleini* zones

(50°36′54″ N, 17°54′24″ E)

The uppermost part of the section available in the Folwark quarry is represented by hard, bright, thick- to medium-bedded (0.3 to 1 m thick) siliceous marls intercalated with thin (several cm) layers of dark clayey marls. These siliceous marls differ from the underlying sediments in the *Chondrites* ichnofabric (Kędzierski and Uchman, 2001). This may indicate deposition on a sea-floor depleted in oxygen (dysoxic) as a result of a sea-level rise. Therefore, this part of the section represents deeper sedimentary environment than the underlying units, but similar to that suggested for the Lower Clayey Marl Unit (see Stop B1.1.1). The supposed Early Coniacian relative sea-level rise was triggered by tectonic rearrangement of the East Sudetic Island and it is connected to the high rate of subsidence in the adjacent areas such as the Bohemian Cretaceous Basin and the Opole Trough (see Uličny *et al.*, 2009).

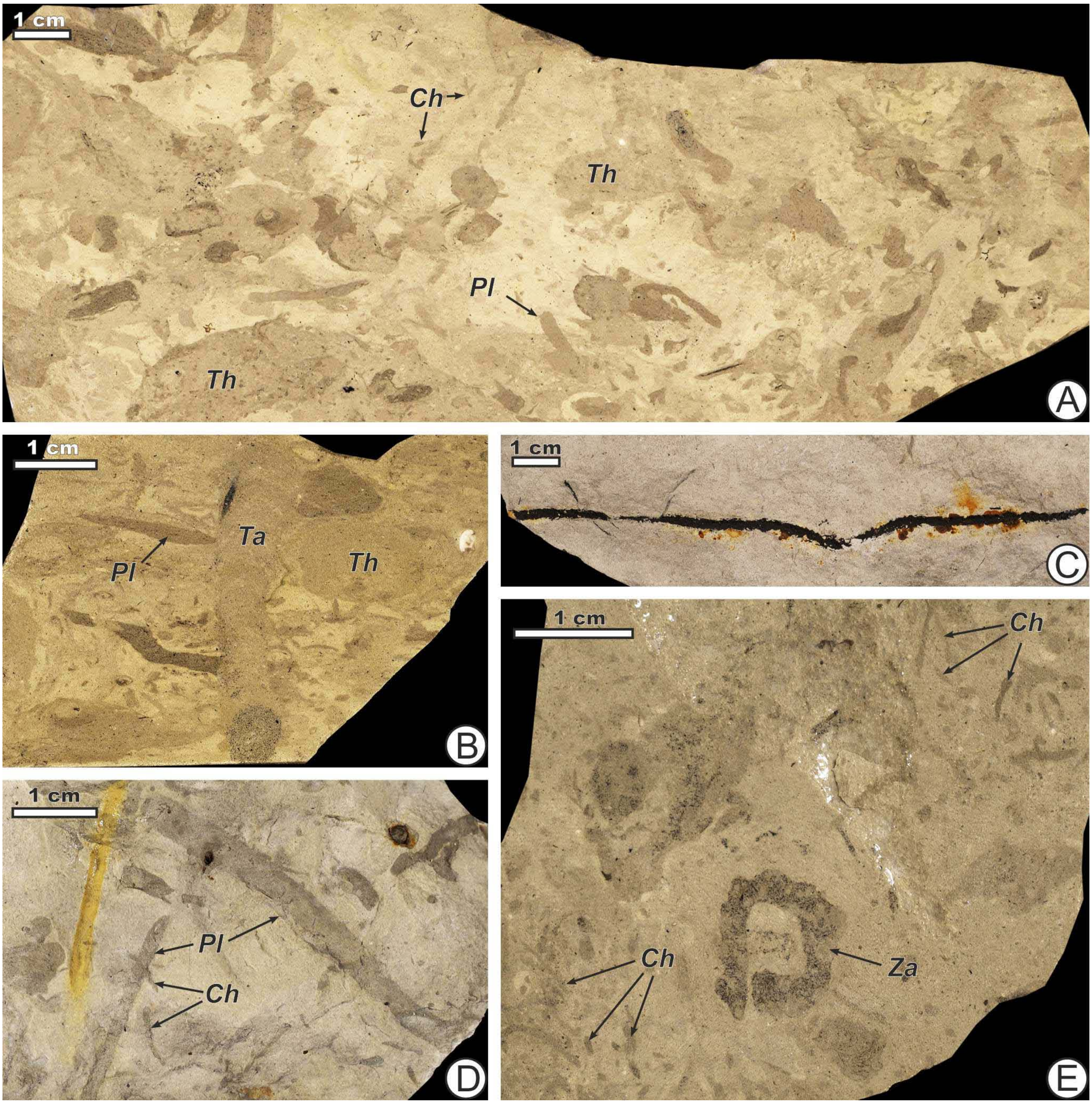

Fig. 9. Ichnofabrics and trace fossils in horizontal sections (wet surfaces, contrast improved by means of a software). Lower part of the quarry. Trace fossils: *Chondrites* (*Ch*), *Thalassinoides* (*Th*), *Planolites* (*Pl*), *Zavitokichnus* (*Za*). **A.** Sample 1004/7A1. **B.** Sample 1004/1A. **C.** *Trichichnus*, sample 1004/2. **D.** Sample 7. **E.** Sample 1004/1.

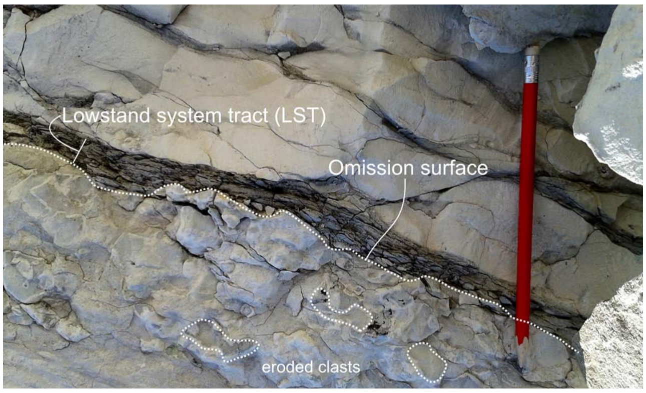

Fig. 10. Genetic sequence boundary – an example from Lower Marl Unit.

The siliceous marls are also characterized by the occurrence of exceptionally large *Trichichnus* isp. (Fig. 12). The recent studies (Kędzierski *et al.*, 2015) show that this trace fossil can be interpreted as a pyritized remnant of a bacterial mat produced by sulphide-reducing large bacteria related to *Thioploca* spp. Moreover, since the *Thioploca* is operating across the redox boundary in sediments, *Trichichnus* is thus considered as a fossilized wire enabling electron transfer between the reduced and oxide zones (Kędzierski *et al.*, 2015). Applying the ecology of modern Thioploca and similar bacteria to the Lower–Middle Coniacian siliceous marls of the Opole Trough, we suggest that the occurrence of large *Trichichnus* reflects powerful bioelectrical processes developed in dysoxic sediments across the redox boundary. This implies that siliceous marls are a facies which recorded specific conditions in the water column (radiolaria bloom?) and on the sea-floor, related somehow to the increasing rate of terrigenous supply.

Moreover, the siliceous marls are similar to the so-called 'clinking marls', known from the Nysa Trough (Intra-Sudetic Basin), in their high content of silica. Micropalaeontological studies have shown that the high silica content reflects enhanced contribution of radiolaria in the microfauna assemblages (Kozdra, 1993). Altogether, the enrichment in radiolaria and stratigraphic position allow us to describe these siliceous marls as an equivalent of the Rohatce Member (Teplice Fm.) in the Bohemian Cretaceous Basin (Čech *et al.*, 1980).

B1.2 Góra Św. Anny Geopark

(50°27′10″ N, 17°09′56″ E)

This optional stop presents a part of the St. Anna Hill (Góra Św. Anny) Geopark, a former quarry of nepheli-

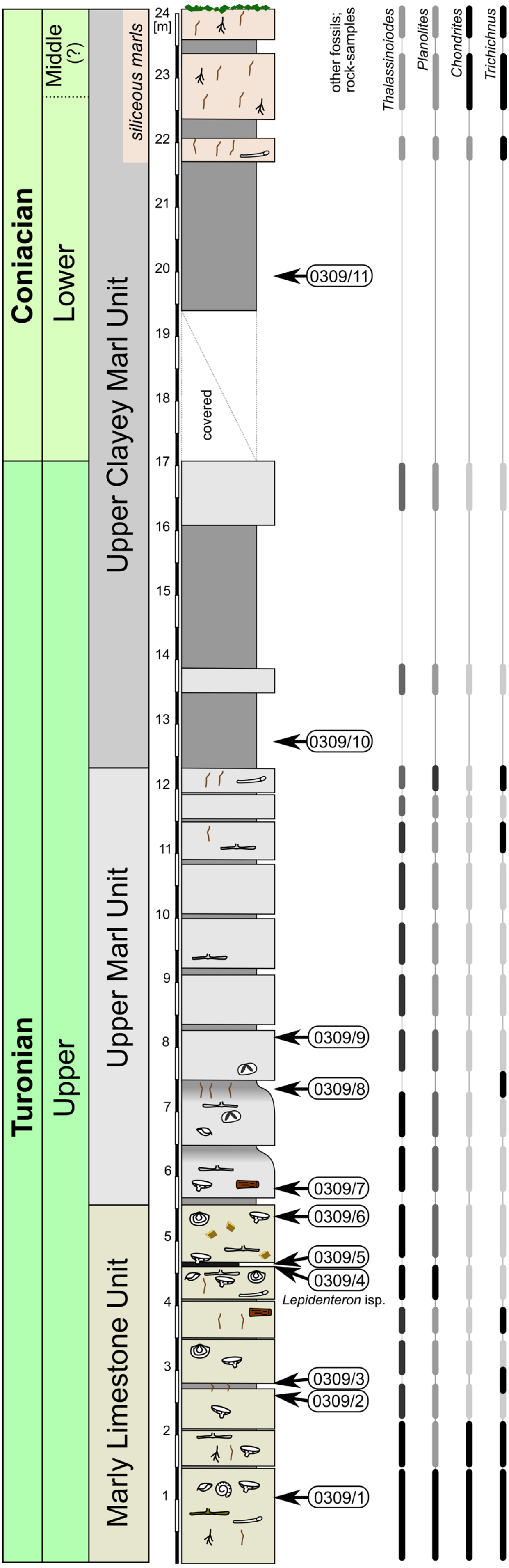

Fig. 11. The upper part of the Folwark Quarry section.

nite in an eroded Late Oligocene volcanic caldera (Fig. 14). The caldera has a sedimentary cover which contains Triassic (Muschelkalk) and Upper Cretaceous, recognized in xenoliths. The latter are represented by Cenomanian coarse-grained sandstones and Upper Turonian marly limestones (Niedźwiedzki, 1994).

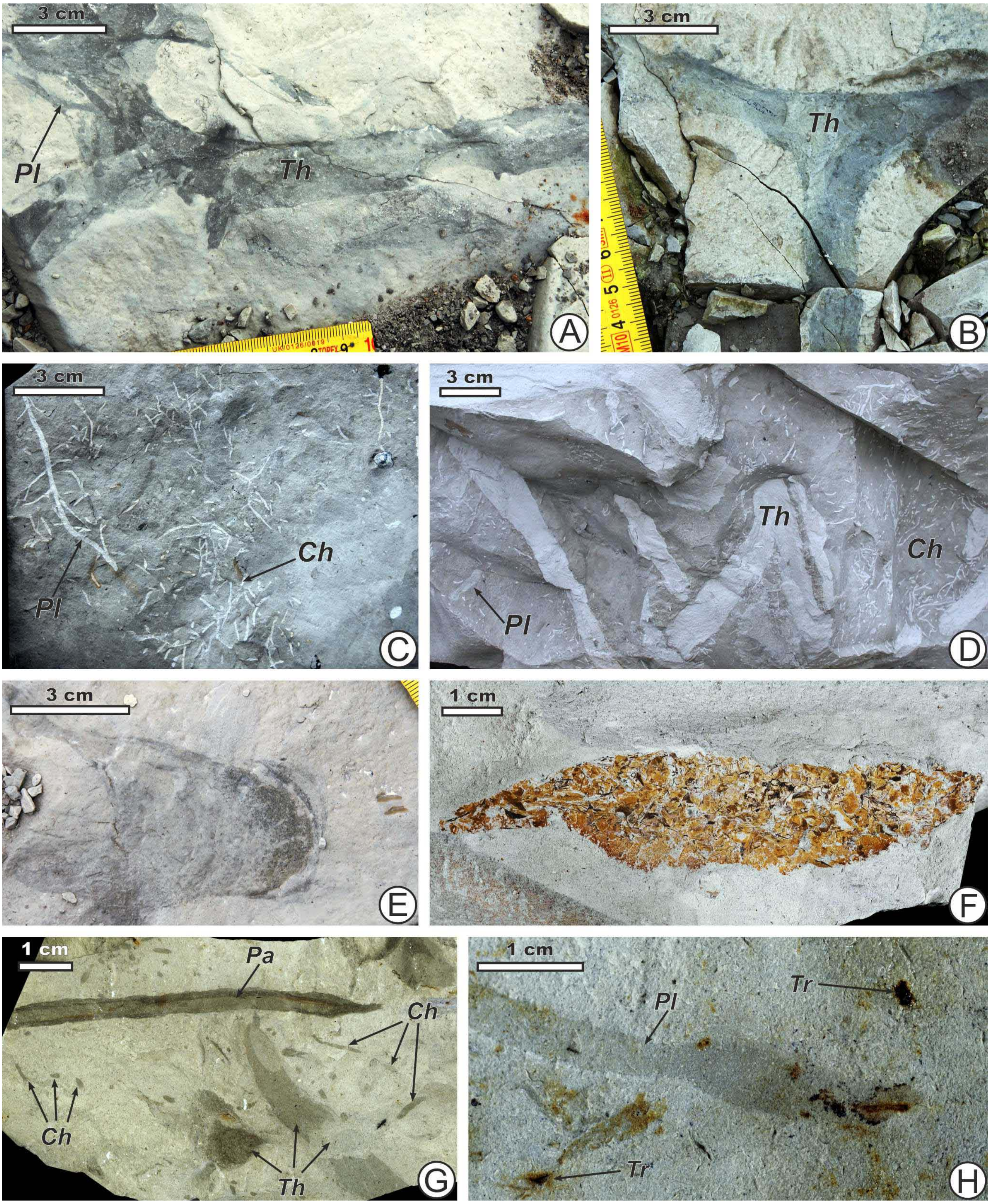

Fig. 12. Ichnofabrics and trace fossils in horizontal sections (wet surfaces, contrast improved by means of a software). Upper part of the quarry. Trace fossils: *Chondrites* (*Ch*), *Thalassinoides* (*Th*), *Planolites* (*Pl*), *Palaeophycus* (*Pa*), *Trichichnus* (*Tr*). **A–E** – field photographs. **A–B.** *Thalassinoides* suevicus and other trace fossils filled with darker sediments on the floor of the upper level. **C–D.** Trace fossils filled with lighter sediments. **E.** *Rhizocorallium* isp. **F.** *Lepidenteron lewesiensis*, sample 0309/4. **G.** Sample 0309/8. **H.** Sample 0309/10.

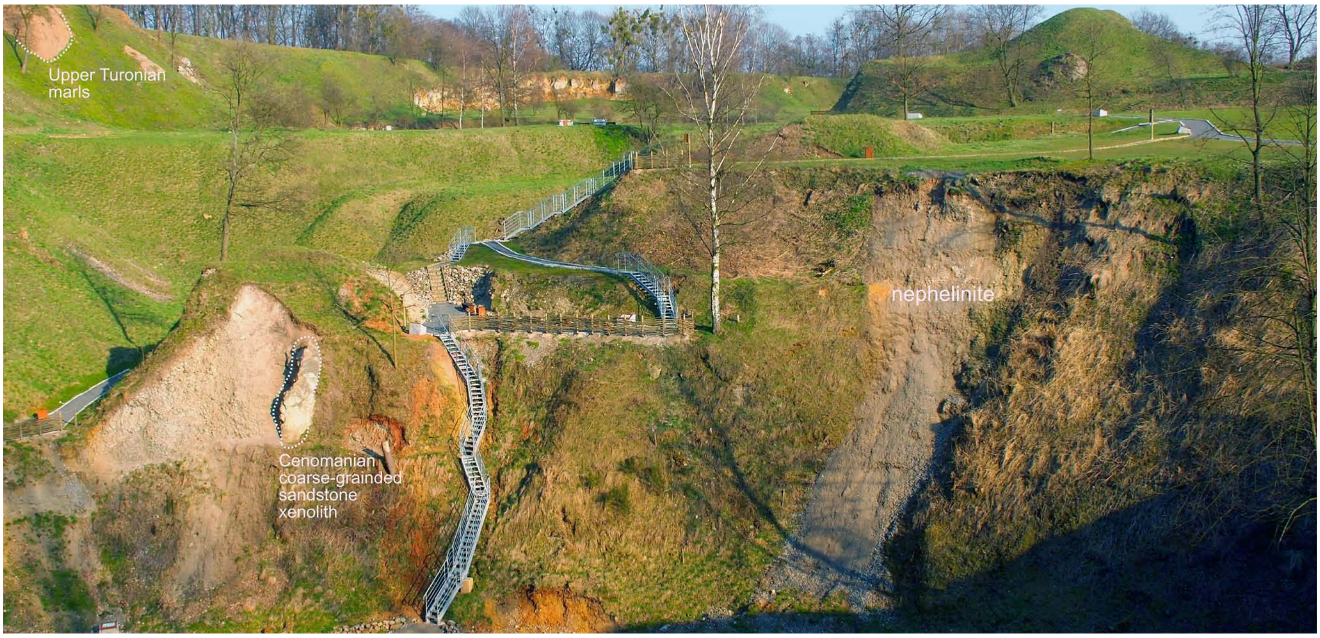

Fig. 13. General view of the abandoned nephelinite quarry in the Góra Św. Anny geopark.

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