Stop 1 – Skrzydlna quarry – olistostrome-bearing succession of the Menilite Beds (Eocene-Oligocene) (Figs 13–26)

(*Marek Wendorff, Krzysztof Starzec, Aneta Siemińska*)

Skrzydlna is a village located about 50 km south-east of Kraków (Fig. 13). In the southern part of the village, near the local road between Skrzydlna and Kasina Mała, there is a quarry in which an almost 200-meter thick succession of the Menilite Beds (Oligocene) is exposed. The Menilite Beds is a unit widespread in the Carpathians (Fig. 14), rich in organic material, and composed mainly of dark brown shales, cherts and siliceous marls with sandstone interbeds. The total thickness of the complex varies from about 100 m in the southern part of their occurrence to maximum 550 m in the northern part (Kuśmierek, 1995). Greater thickness of this unit in some areas are mainly due to the intercalations of sandstone bodies, which sometimes may constitute half of the total thickness of the Menilite Beds. The relatively high content of organic matter, reaching 20% (e.g. Curtis *et al*., 2004), makes this unit the most important source rock of hydrocarbons in the entire Carpathian area. On the other hand, the interbedded thick sandstone complexes tend to be important reservoirs. The Polish Carpathians are one of the oldest oil provinces in the world, where the exploitation of crude oil dates back to the mid-nineteenth century.

The Skrzydlna quarry is located in an area with a complex structural structure. The Menilite Beds outcropping in the quarry together with the overlying Krosno Beds (beyond the quarry's perimeter) form a narrow zone of steeply dipping strata. The geological context of this zone is interpreted in various ways (e.g. Burtan, 1974; Polak, 1999; Cieszkowski *et al*., 2012; Jankowski & Margielewski, 2012). According to the authors of this chapter, this zone belongs to one of the Fore-Magura tectonic units, i.e. the Dukla or Grybów unit (Fig. 15). In the area of Skrzydlna, the Fore-Magura unit extends NW-SE and is located at the front of the Magura nappe, the margin of which here forms a tectonic bay. Further to the SE, this unit is continuing under the cover of the Magura Nappe, as evidenced by drilling data in the area of Słopnice. Still further to SE, the presence of this unit is marked by outcrops in several tectonic windows within the Magura Nappe (Fig. 2). The quarry at Skrzydlna is actively exploited, therefore some details of the unveiling change over time; this guide describes the situation observed in 2017–2019.

The structural development of the Fore-Magura Unit at Skrzydlna is related to the Lanckorona-Żegocina Zone, bordering the Fore-Magura Unit from the north. The origin of this zone has been variously interpreted (e.g. Skoczylas--Ciszewska, 1960; Książkiewicz, 1972; Burtan, 1978; Polak, 1999;

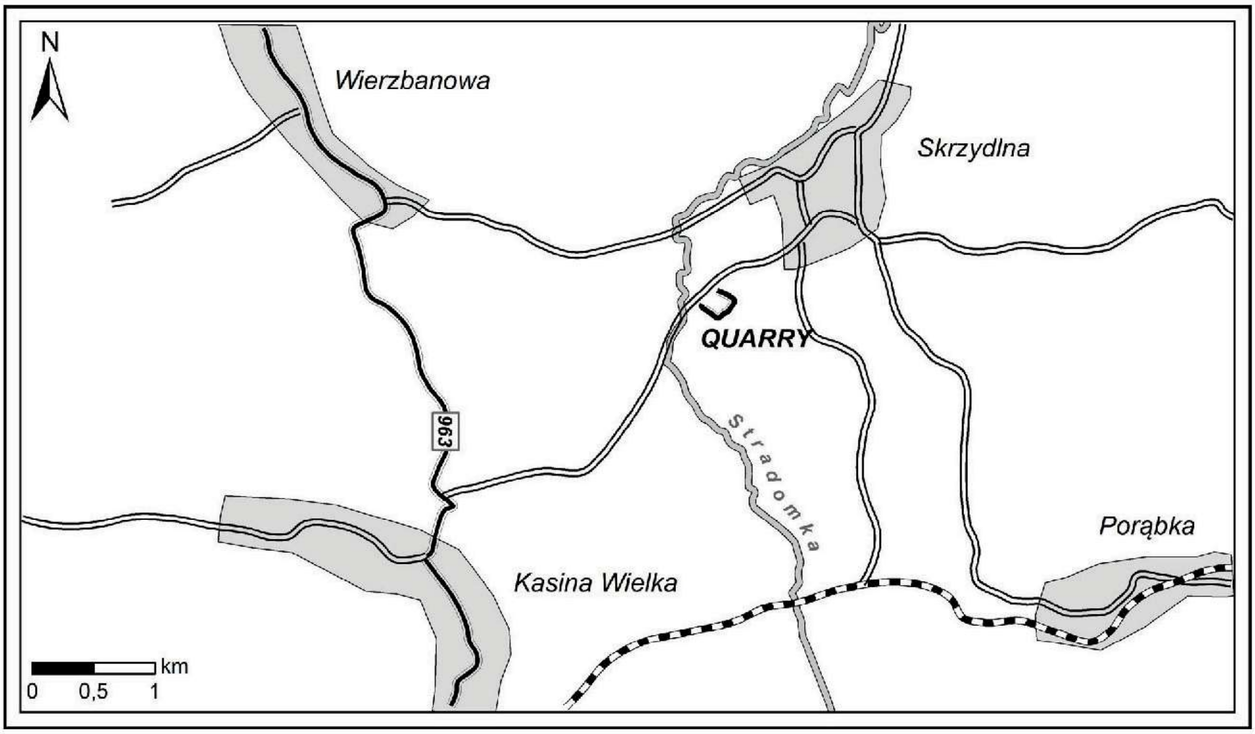

Fig. 13. Location of the Skrzydlna quarry

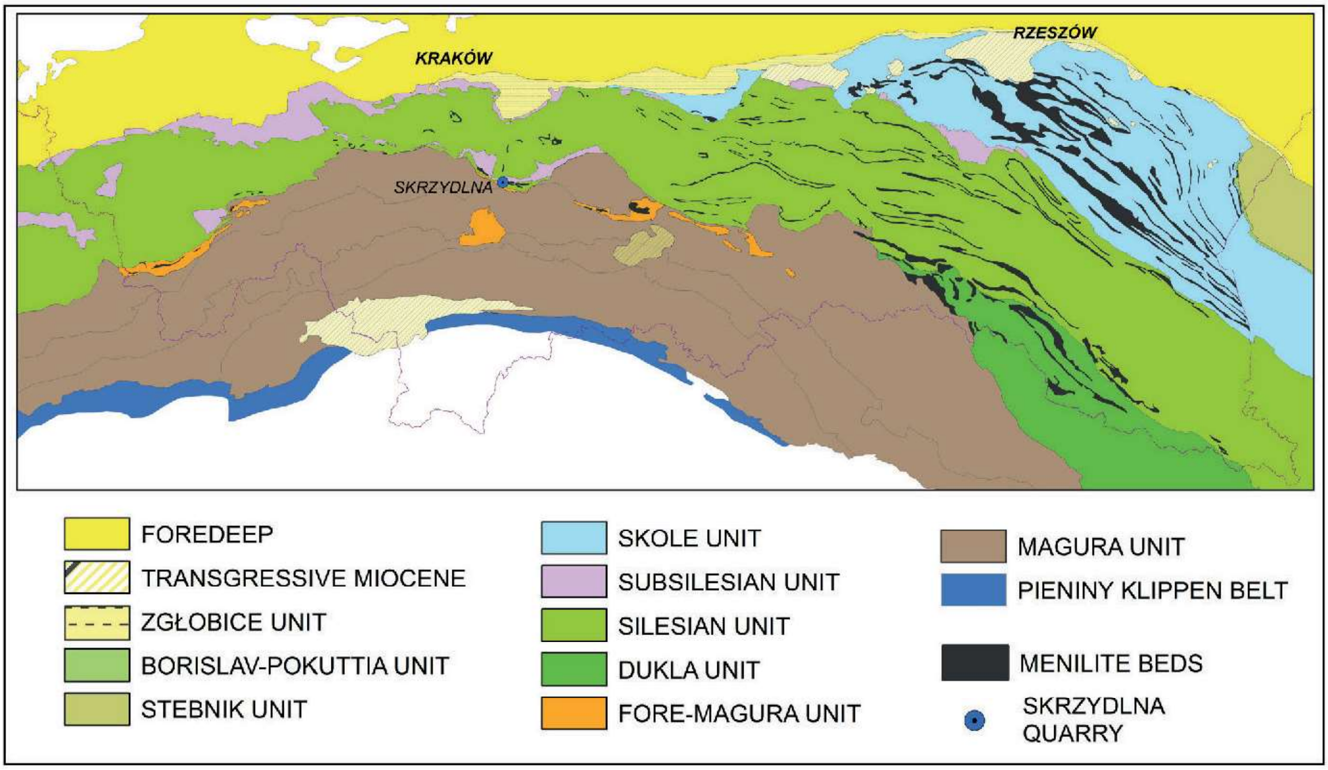

Fig. 14. Occurrence of the Menilite Beds within the Polish segment of the Carpathians

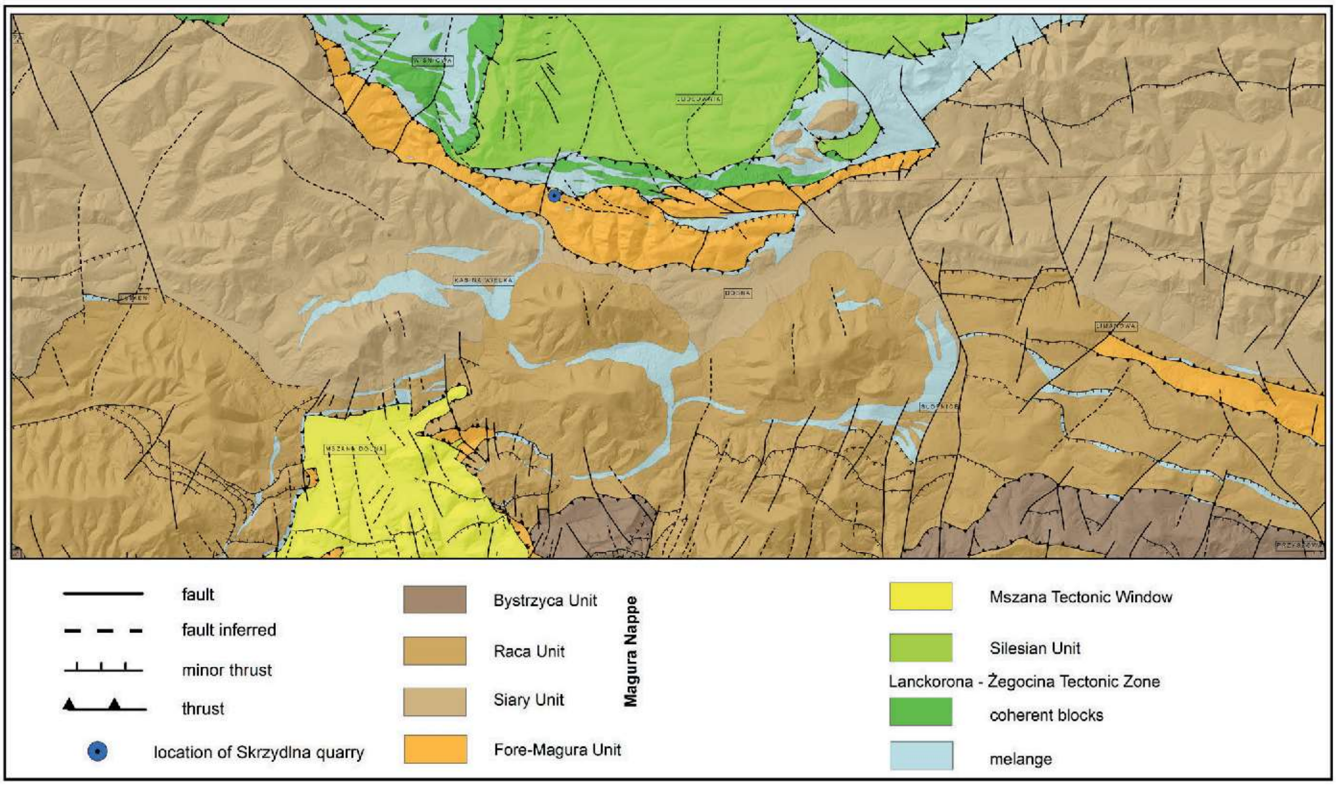

Fig. 15. Regional tectonic sketch with the location of the Skrzydlna quarry (based on Żytko *et al*., 1989, modified)

Jugowiec-Nazarkiewicz & Jankowski, 2001). Detailed mapping studies revealed that it is a zone of tectonic mélange (Fig. 16), composed of Early Cretaceous elements of provenance from the Silesian Tectonic Unit and formations considered typical of the Sub-Silesian series (mainly Węglowiec and Frydek marls, sandstones from Rajbrot, Szydłowiec and Czerwin). The cartographic image shows a series of blocks composed of continuous fragments of stratigraphic successions, which are most often embedded and isolated within a muddy-sandy matrix, rarely in direct contact with each other. According to Golonka *et al*. (2011) the melange in the Lanckorona-Żegocina zone was formed as a result of diapiric migration of less competent rocks along a fault zone. Jugowiec-Nazarkiewicz & Jankowski (2001) and Jankowski (2015) recognize that this is the result of a multi-stage deformation process involving thrusting, followed by strike-slip movements parallel to the strike of the fold structures, and at the final stage – the formation of normal faults. According to the authors of this part of the guide, following the Skrzydlna overthrust origin in the compressional phase of the formation of the Carpathian accretionary prism, this unit was subjected to the influence of strike-slip movements along the Lancorona-Żegocina zone. The effect of this movement is the arrangement of tectonic elements of the unit, i.e. the presence of fault zones containing tectonic melange and parallel to the strike of the Menilite and Krosno Beds, as well as a steep bedding observed in the quarry, forming a floral structure (Fig. 17). The quarry is actively mined, so some details of the outcrop change over time; this guide describes the situation observed in 2017–2019.

The succession exposed at Skrzydlna is a heterogeneous association of several facies complexes reflecting radical changes in tectonically-controlled sedimentation in the early Oligocene (Polak, 2000; Cieszkowski, 2006; Wendorff *et al*., 2015; Siemińska *et al*., 2020). The oldest part of the exposed succession is a complex of anoxic/dysoxic brown menilite shales, containing a thick layer of sandstone orange in colour and underlying whitish weathered marls and limestones (Fig. 18). Above rests a complex dominated by orange conglomerates (olistostrome succession), evolving upwards into a thinning/fining turbidite sequence (FU-'fining-upwards'; Fig. 19). The orientation of the quarry wall is approximately perpendicular to the strike of beds. These dip steeply and rest in the stratigraphically normal position on the left side of the exposure, gradually changing the orientation to the reversed position in the stratigraphically youngest part of the sequence on the right hand side of the exposure (Fig. 20). Today, following rapid progression of the mining work, the recently exposed face does not show this pattern and the steep bedding is more uniform instead.

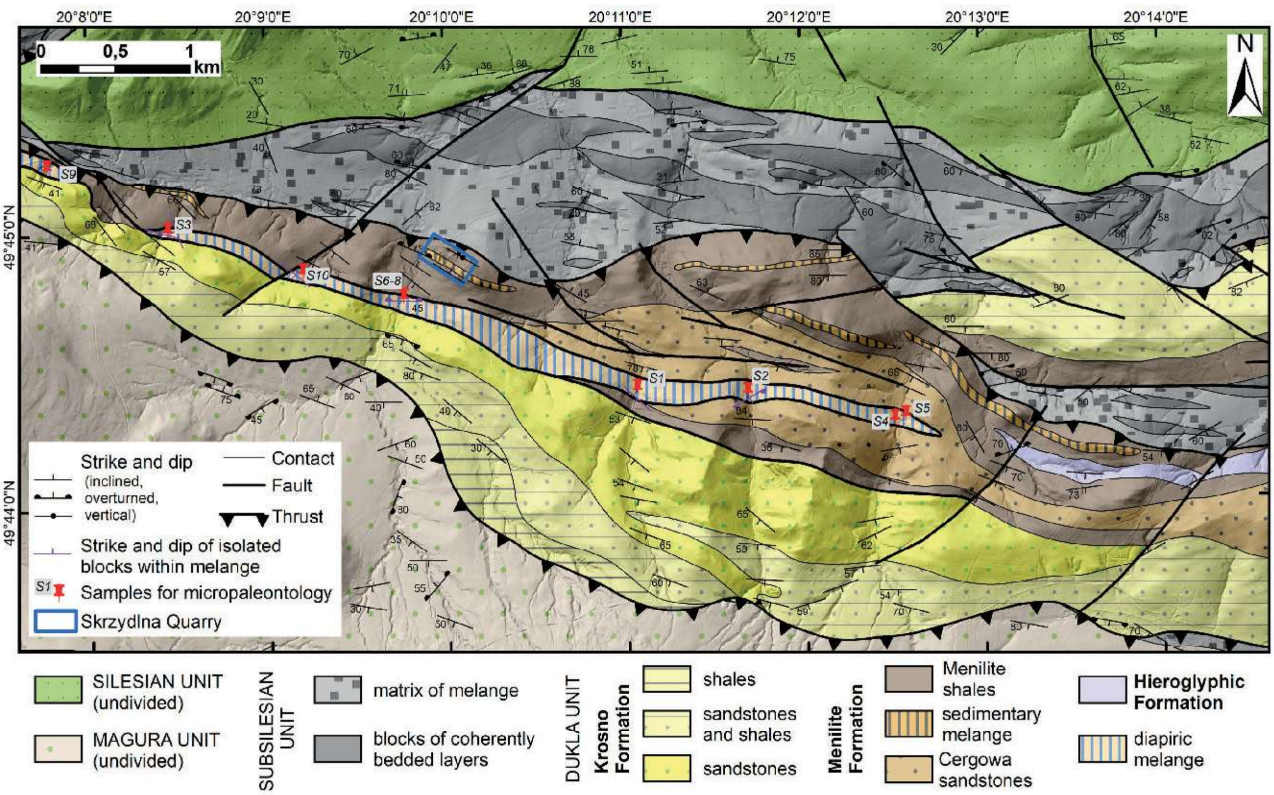

Fig. 16. Geological map of Skrzydlna region

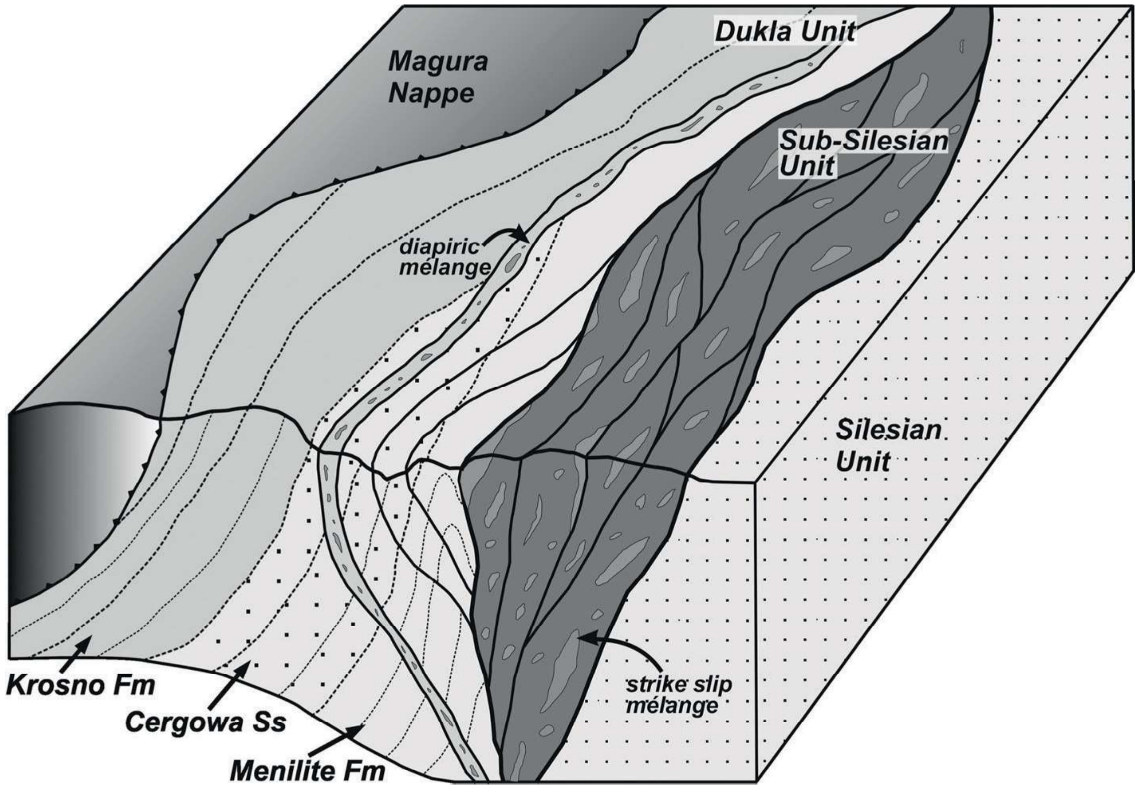

Fig. 17. Model of geological structure of Skrzydlna region

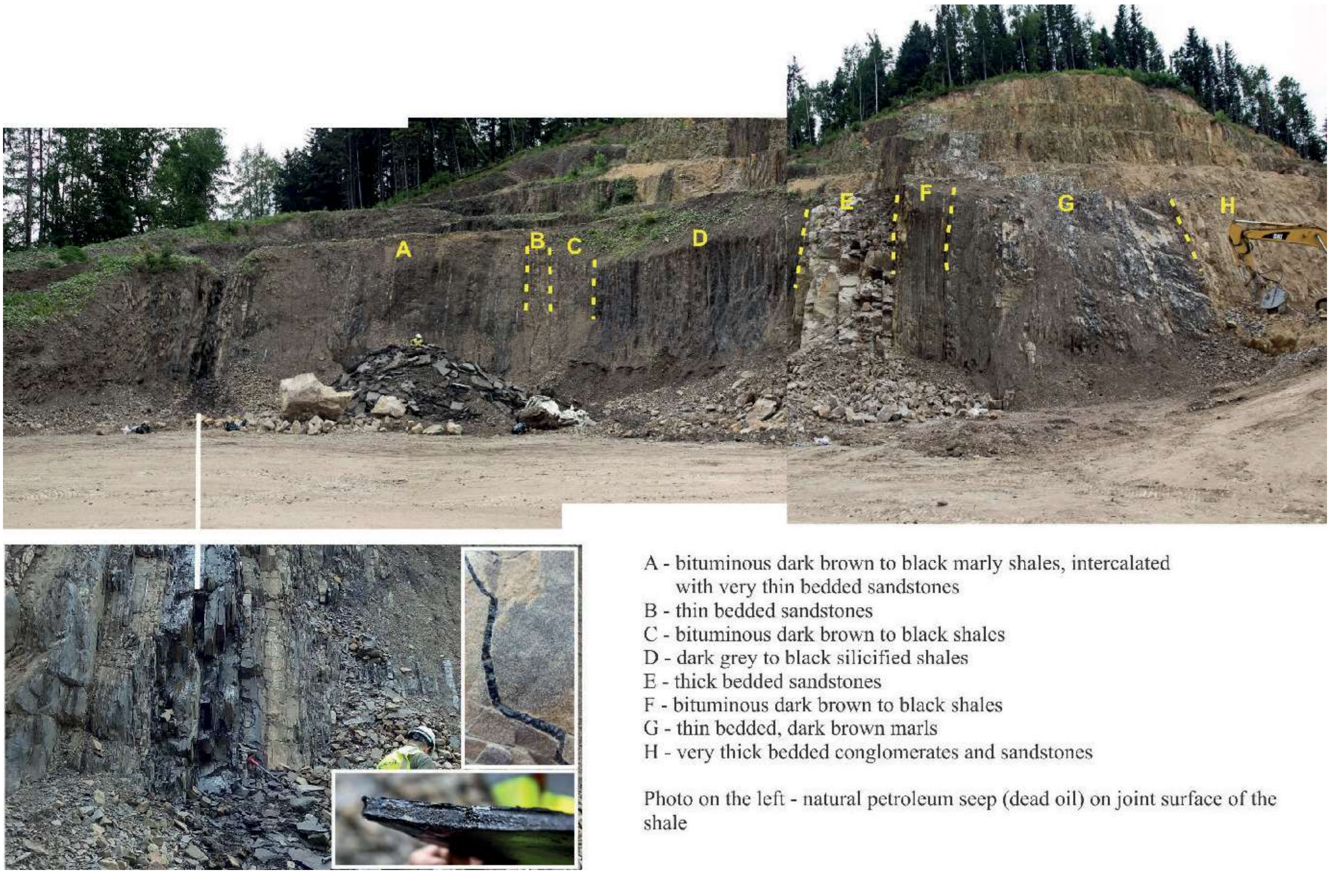

Fig. 18. General view of the NE part of the Skrzydlna quarry with lower part of the Menilite succession dominated by dark shales

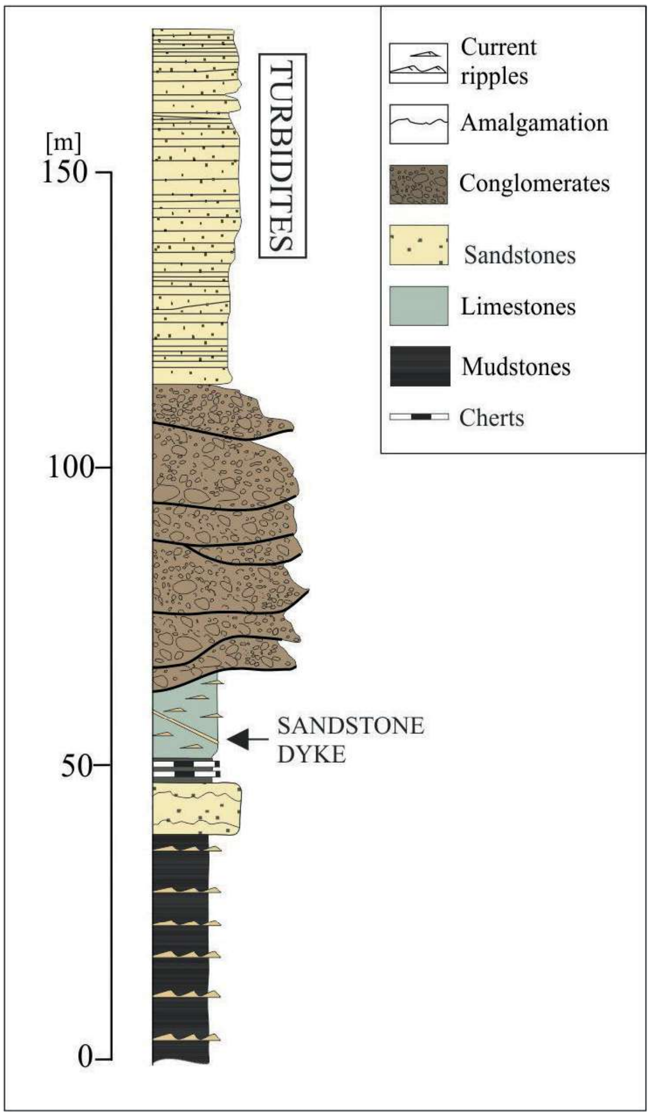

Fig. 19. Schematic section of the lithological succession at Skrzydlna quarry

Considering the succession age, the calcareous nannoplankton assemblages found in marl beds in the lower part of the exposed succession typified by shales analysed by K. Žecova, represent the NP 21 zone (Late Eocene). The youngest species, indicating the NP 22 zone (early Oligocene), were found in the limestone layer within the turbidites in the highest part of the open pit (Siemińska *et al.*, 2017).

The complex of menilite shales and siliceous shales located in the stratigraphically oldest part of the exposed succession (Fig. 6) contains rare, very thin interbeds of turbidite sandstones with current ripplemarks (Bouma Tcde; Tce) and cherts, and is intersected by several thin sandstone dykes. Above, there is a layer of fine- and medium-grained sandstone, 9 m thick, composed of massive, amalgamated intervals, devoid of mudstone interbeds, with a sharp erosive lower boundary. Following the next interval of the menilite shales with cherts, there is a 10-metre-long complex of thin layers of pelitic limestones and marls, locally silicified and containing isolated cross-laminated lenses of current ripplemarks of medium-grained quartz arenite.

The menilite shales complex represents a very low-energy deposition in a deep, calm, anoxic, tectonically inactive basin, interrupted by an episode of sandy material deposition from dense, rapidly decelerating gravity currents. On the other hand, sandstone dikes in menilite shales are interpreted here as the effects of liquefaction of unlithified sand layers caused by seismic events. We interpret the combination of these two phenomena as the earliest signals of uplift initiated in the source area (Fig. 21), accompanied by seismic shocks (Siemińska *et al.*, 2018; Jankowski & Wysocka, 2019). A massive sandstone interval is interpreted as the result of deposition out of high-density turbidite within a distribution channel, eroded and extending into the open menilite basin. The nature of this interval may suggest a series of long-lasting hyperpycnal flows. Features of the overlying limestone complex suggest hemipelagic deposition periodically interrupted by traction currents reworking a limited amount of sandy material, as indicated by isolated starved current ripplemarks. This unit also injected with sandstone dikes that represent three generations. We suggest that two intersecting thin veins and one 30 cm thick injection together with a massive layer of 9 m thick sandstone are the earliest signs of the approaching uplift responsible for the origin of the overlying coarse clastic complex.

The overlying olistostrome sequence consists of amalgamated layers deposited by debris flows, in which a rich sandy matrix with extra-basinal pebbles supports single blocks (olistoliths) over 0.5 meters long. The olistostrome basal surface is uneven, erosionally incised within the quarry by min. 10 m into the underlying carbonate complex (Fig. 22), and contains casts of drag marks of large objects extending NW-SE (Fig. 23). The intrabasinal rock fragments are plastically deformed elements of broken sandstone layers and clasts of black menilite shales. In 2017, among the extrabasinal olistoliths, in the middle of the complex's thickness, there was a block of Jurassic limestone measuring 10 m × 2.5 m. Two layers of black shales mark breaks in the sedimentation of the high-energy facies. The conglomerate layers are accompanied by irregularly appearing layers of massive ('structureless') sandstones geometry of which is determined by uneven contact with the conglomerate. Most often, the overlying conglomerate rests on the sandstone erosionally, while the bottom of the overlying sandstone layer adapts to the irregular surface of the underlying conglomerate (Fig. 24). Correlation between sections outcropping in the quarry benches suggests a kind of rough, indistinct organisation of facies: the coarser-grained conglomerate bodies filling lower parts of erosional channels, followed by and passing laterally to finer conglomerates and some pebbly sandstones. The facies distinguished in this complex are illustrated and summarized in Figure 25. In the upper part of the olistostrome sequence, the texture of the sandy matrix of conglomerates irregularly becomes finer and the structure better ordered.

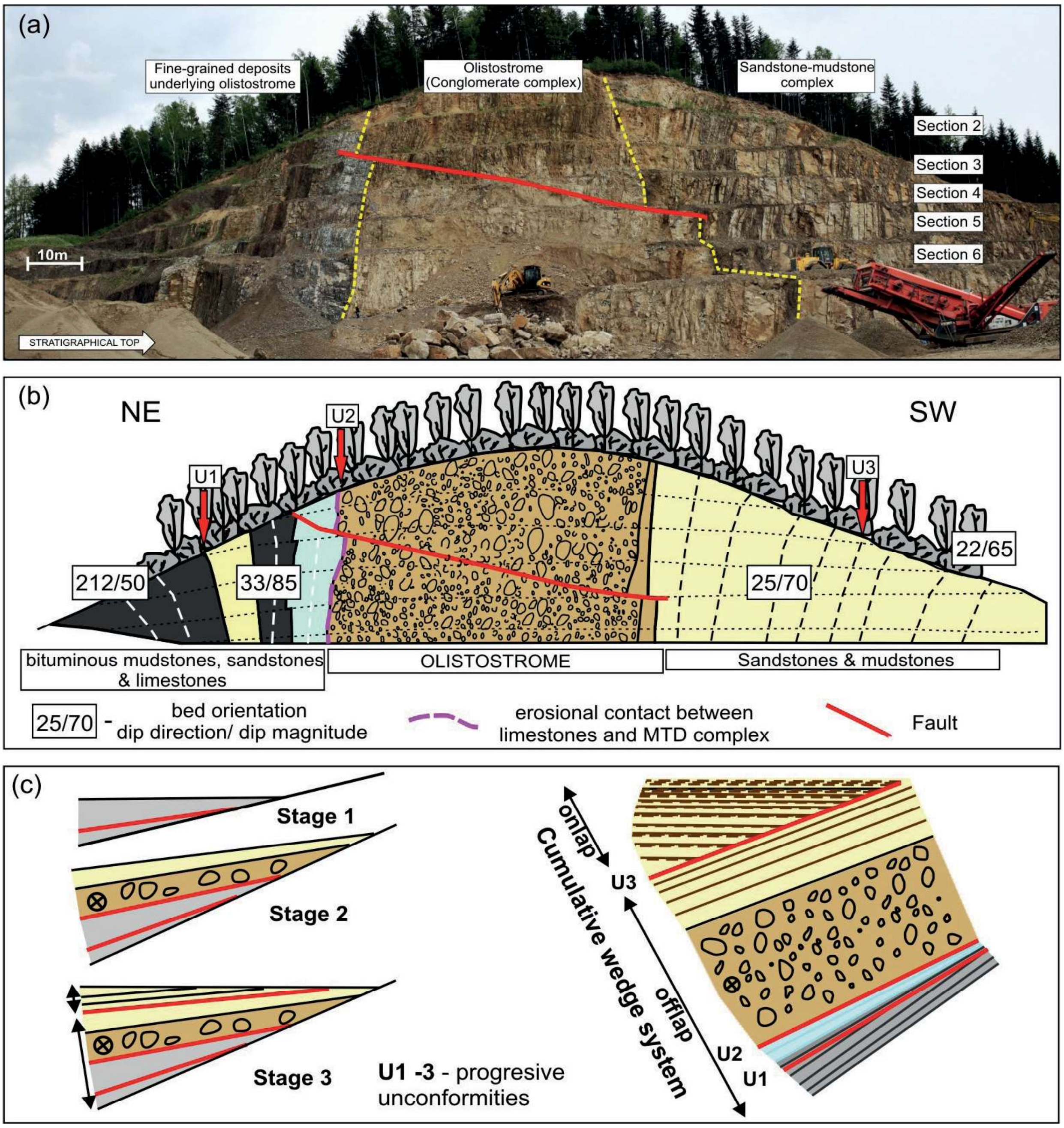

Fig. 20. General view (a) of the main lithological complexes exposed in the Skrzydlna quarry face and the sketch of the main lithological intervals in the quarry face (b). Dotted lines denote mining benches 2–6 labelled as Sections 2–6 in photograph (a); U1–U3 indicate unconformable contacts. Note gradual changes of bed attitude. Progressive unconformities related to synsedimentary rotation of the succession; geometry and stratigraphic relations based upon thirty bed attitude readings (modified from Siemińska *et al*., 2020) (c)

The transition from the olistostrome succession to the overlying turbidite complex is marked by several hybrid strata, each consisting of turbidite sandstone followed by linked debrite (i.e muddy sandstone rich in mudstone clasts). Some of the other layers have the characteristics of continuous/long-term gravity flows: hyperpycnally-fed turbidites. The overlying sequence, deposited mainly by short-lived classic surge-type turbidites, consists of three fining-upwards cycles (F-U). Two of them begin with very thick, amalgamated layers of massive sandstone deposited by high-density turbidity currents that fill channels cut 2.5 m into the underlying strata. Bouma sequences appear above, representing 'normal' density to dilute turbidites, with Ta-e rhythms fining and thinning to Tce in the uppermost thin-bedded sandstone and shale assemblages. Turbidite sandstones are quartz arenites with frequent admixture of carbonized plant remains. Overall, this 60 m thick turbidite succession forms an upward thinning megasequence composed of smaller upward fining/thinning cycles.

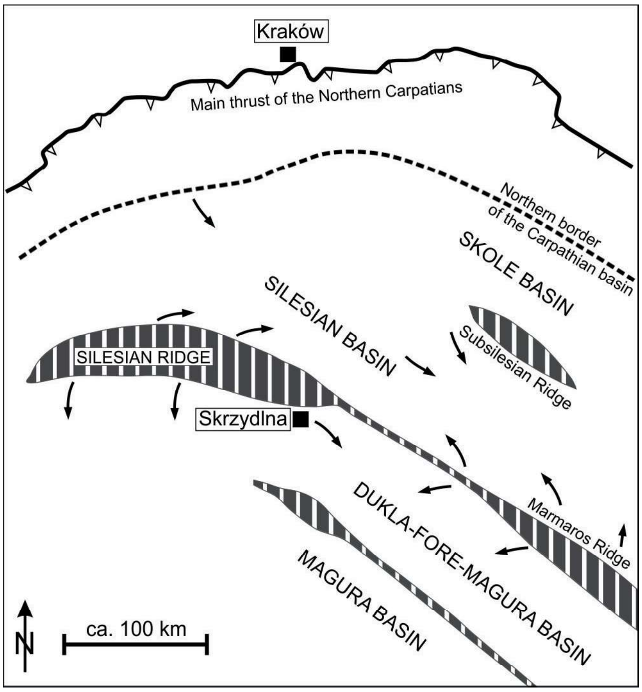

Fig. 21. Palinspastic sketch map showing arrangement of sedimentary basins, source areas (ridges) and main palaeotransport directions during sedimentation of the Menilite Formation (modified from Winkler & Ślączka, 1992)

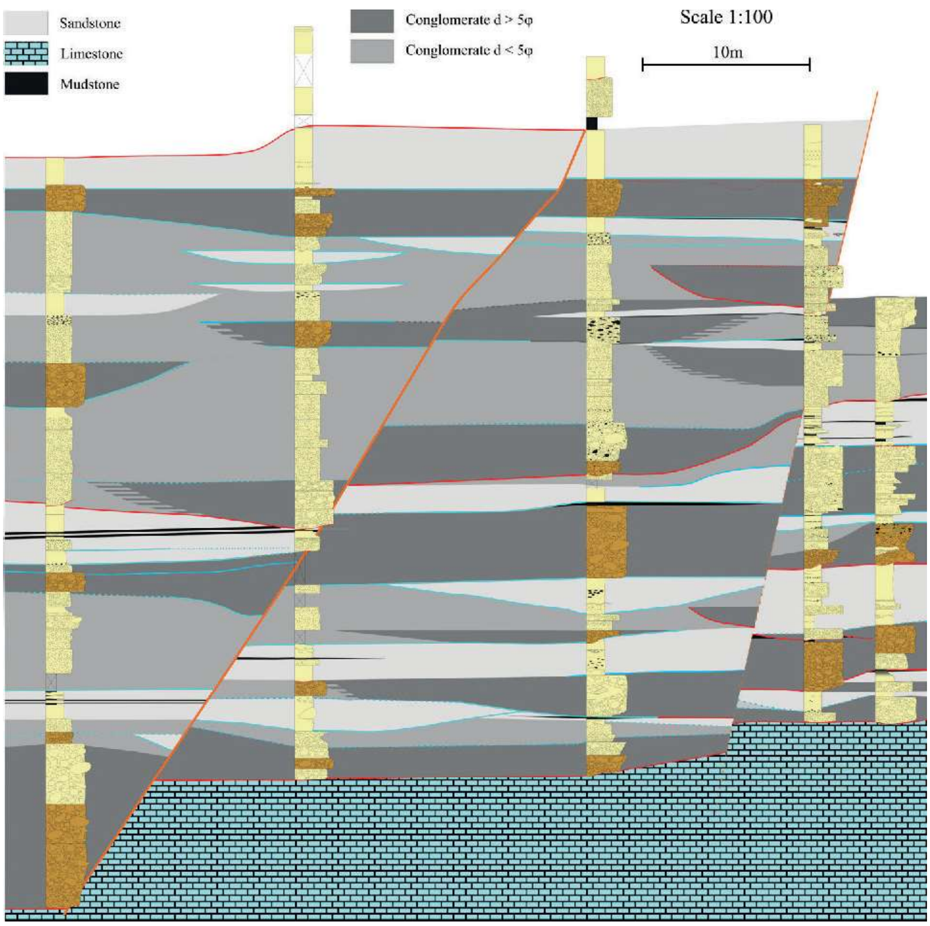

Fig. 22. Correlation of detailed sedimentological logs of Skrzydlna quarry outcrop within five exploitation levels as documented in years 2017–2018. Two main stages of olistostrome deposition are indicated by broad erosional surfaces marked red (modified from Siemińska *et al*., 2018, 2020 and interpretation by Wendorff *et al*., 2015)

Extreme facies contrasts between the fine-grained, anoxic basin sediments underlying the olistostrome and the suddenly appearing olistostrome complex deposited by gravity mass flows delivering very coarse-grained unsorted materials and oxidized water to the basin, suggest rapid uplift and very intense erosion of the source area (Wendorff *et al*., 2015; Siemińska *et al*., 2018). The abundance of dark shale intraclasts indicates the involvement of the slope and/or basin bottom paved with dark menilite-type sediments, the proximal part of which has been transformed into a slope bordering an uplifted block – the source of detrital material. Vertical changes in the conglomerate lithology of the olistostrome complex are a reflection of three main phases of deposition (Fig. 10). The beginning of each phase is marked by an erosive surface on the scale of the entire exposure (Fig. 6). The broad lithological diversity, age distribution and shapes of extraclasts in the olistostrome imply a complex structure of the source area, which included Mesozoic rocks. This suggests that the topography of the source zone was very diverse and changed over time. Very well rounded boulders, some equant and prolate, suggest long-term rolling of large blocks on the abrasion platform. The huge angular block of Jurassic limestone reflects collapse of a cliff face and the subsequent block sliding. Slumped fragments of sandstone layers with much better sorted than the conglomerate matrix imply landslides and slides of slabs – gravity-induced dismemberment of sandstone layers initially deposited in the proximal/upper slope zone. All these features suggest that the olistostrome succession originated as a result of mass transport of debris flows (MTD) locally transformed into high density turbidity currents, landslides, sliding of blocks and slabs of dismembered beds. This stage was succeeded by various turbulent sediment flows, from high to low density turbidites in the later phase of deposition (Siemińska *et al*., 2020). The occurrences of dunes at the turbidite deposition stage indicates periods of long-lasting flows redepositing sands by traction, most probably at the mouths of the distributary channels.

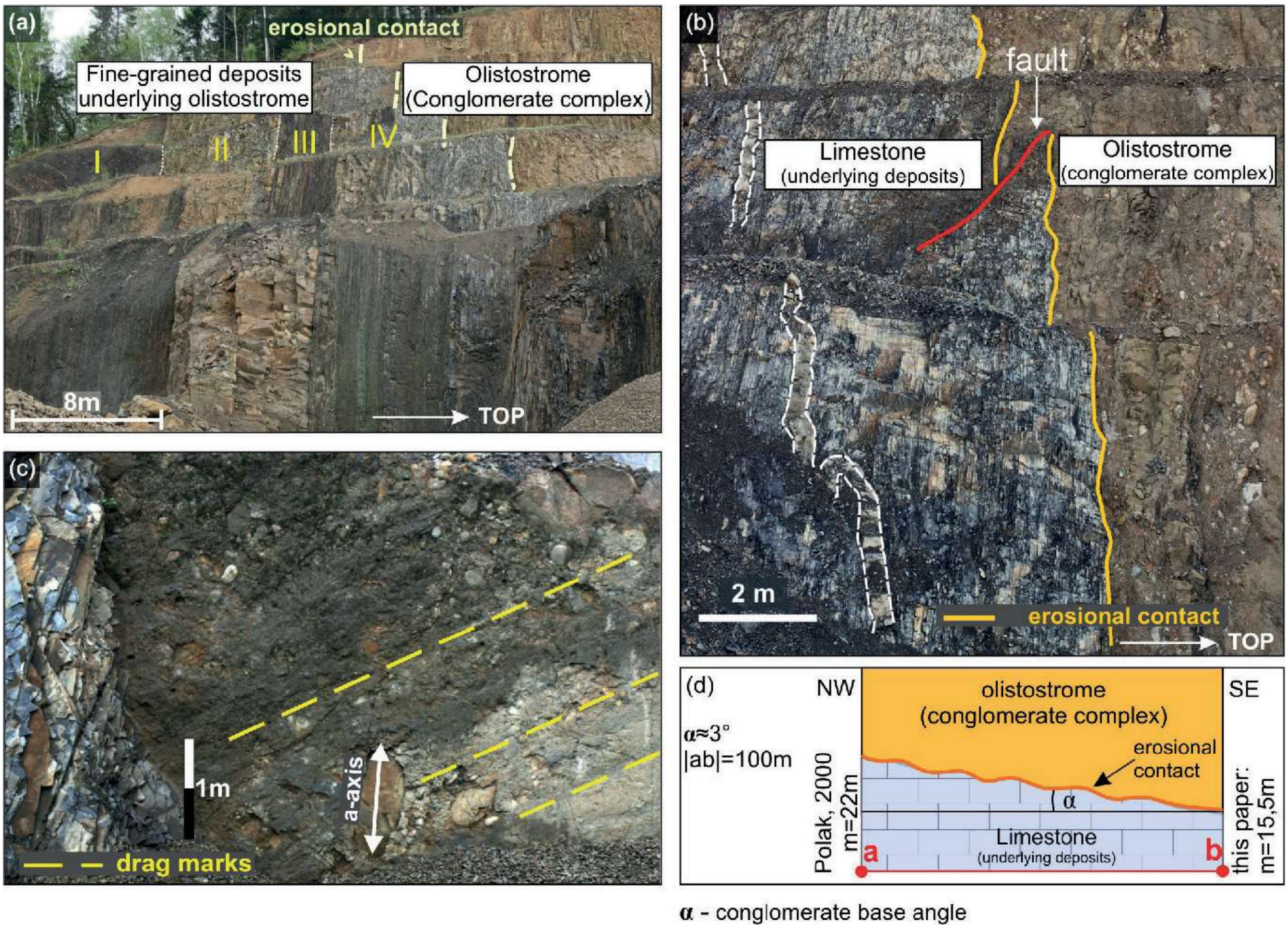

Fig. 23. General view (a) of deposits underlying olistostrome: I – calcareous and siliceous shales, II – amalgamated sandstone, III – siliceous shales, IV – limestone. Close-up view of erosional contact between limestone complex, containing sandstone dyke shown with dashed outline, and overlying olistostrome (b). Grooves at the basal erosional surface of olistostrome complex (c). Orientation of long axis of the elongated clast suggests rolling during the last stage of transport. Difference in limestone thickness measured by Polak (2000) and the present authors (in 2016) in section sub-parallel to the palaeocurrents reflects inclination of the erosional base of the olistostrome relative to the underlying limestone bedding (d).

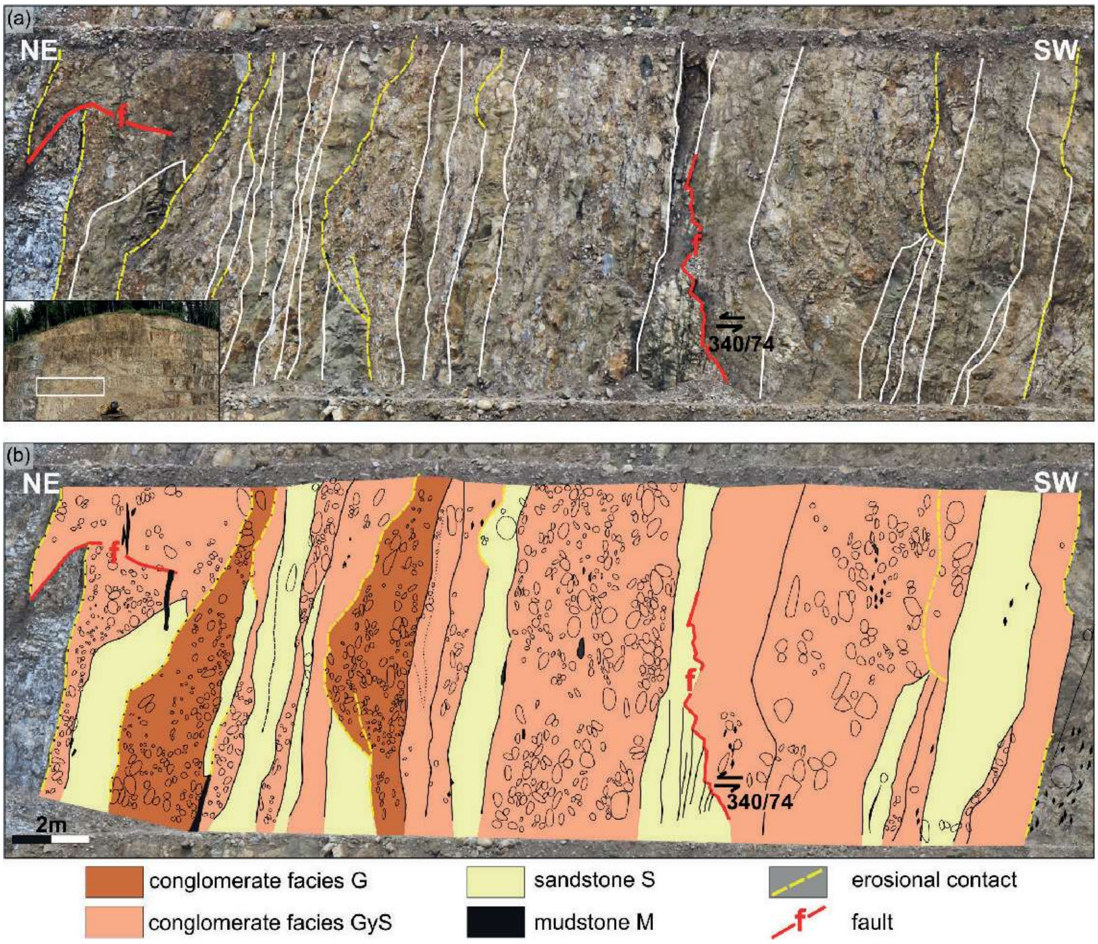

Fig. 24. The main characteristics of the conglomerate complex are very high variations of bed thickness and sedimentary features, even within beds. These are shown in the photograph (a) and emphasised in drawing (b) by subdivision into facies. Note that lateral and vertical changes occur even at a distance of some tens of centimetres. Inset in (a) indicates position of the photograph in the quarry face

From the point of view of basin infilling processes, the sudden appearance of the olistostrome in a low-energy, oxygen-poor menilite basin, the features of the olistostrome basal surface, and the presence of the menilite shales intraclasts suggest that this thick clastic complex deposited by debris flows fills a channel eroded in the slope of the uplifted source zone (Fig. 26). The trend of changes in the bedding dip direction observed in 2017–2019, in the absence of clear traces of slip and shear on the bedding surfaces, suggests syntectonic deposition on the substratum of a rotated block (Fig. 20), similar to the stratigraphic relationship and the formation of progressive unconformities documented for the first time in the Pyrenees (Riba, 1976). Lateral and vertical facies changes in the olistostrome complex reflect significant hydrodynamic variations within and between successive flows. The first-order F-U sequence composed of second-order F-U sequences within the overlying turbidite succession implies the formation of a retrograding submarine fan (Fig. 26; Wendorff *et al*., 2015). Age-wise, the olistostrome and fan succession were deposited during the climate-controlled (cooling) global sea level fall in the Eocene and Oligocene. Therefore, its genesis can be associated with a magnification of influence of the tectonic uplift of the source zone by the simultaneous marine regression, i.e. amplification of uplift of the alimentation area. In addition, the observed nannoplankton assemblages may reflect eustatic sea level fluctuations and temporarily low environmental salinity, which could be related to tectonic movements, climate change and the gradual isolation of the Paratethys in the late Eocene and Oligocene (Švábenická *et al*., 2007; Siemińska *et al*., 2017; Pszonka *et al*., 2023).

Authors' editorial note:

The material presented in this description of the Skrzydlna quarry succession is partly based upon the following publications: Siemińska et al. (2017, 2018, 2020); Wendorff et al. (2015), and also includes unpublished results of the first author. This is edited and modified English version of the Guide to Skrzydlna previously prepared in Polish for the 88th Meeting of the Polish Geological Society in May 2023.

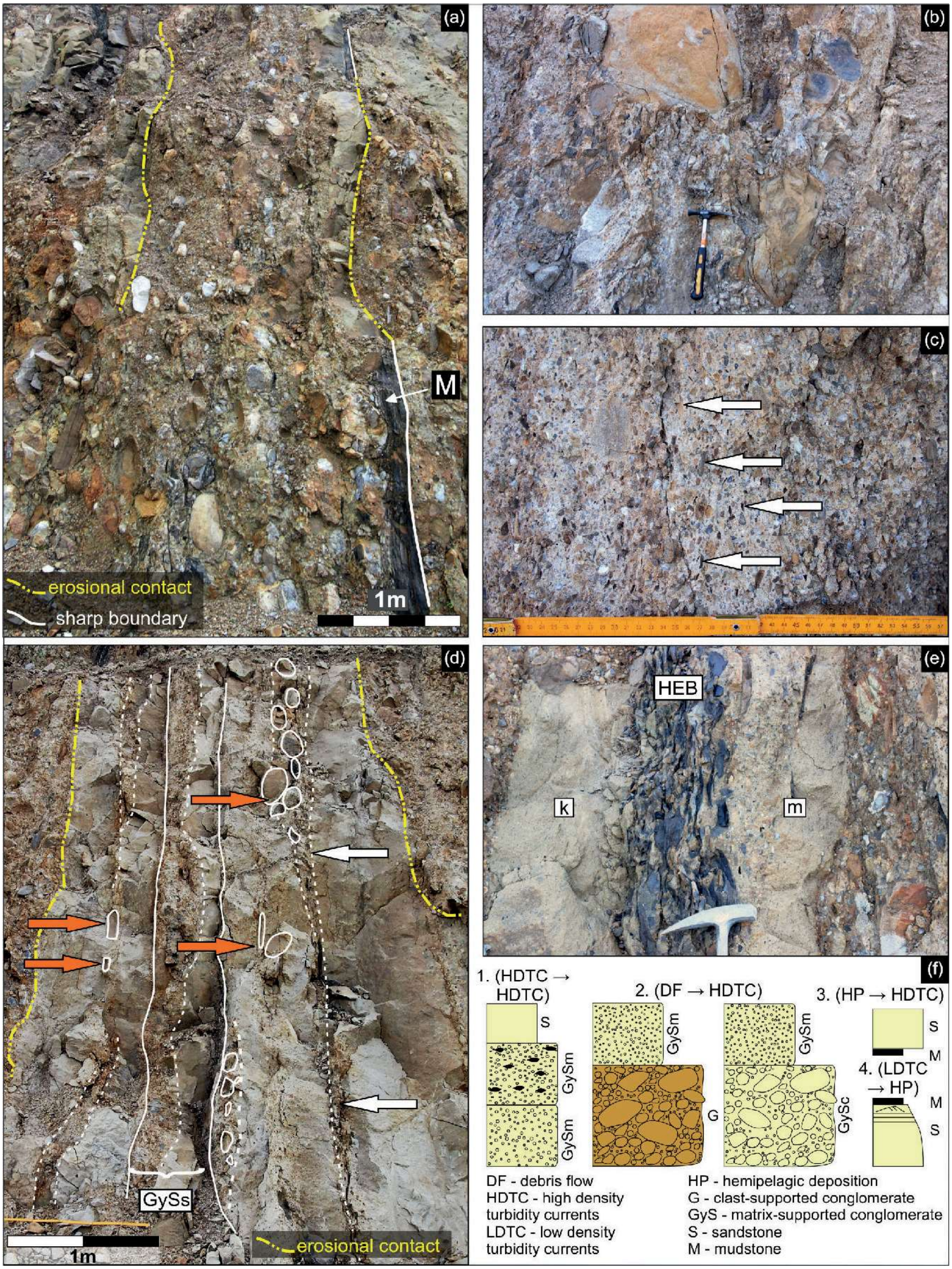

Fig. 25. Examples of olistostrome lithofacies exposed in Skrzydlna quarry. Conglomerates: very coarse-grained with blocks/olistoliths (a), with clasts of black menilite mudstone (b), and medium-grained with clasts oriented parallel (c). Sandstones (d) with conglomerate pockets, and hybrid beds with clasts of black mudstone (e). Subfacies of conglomerates and their predominant transitions (f)

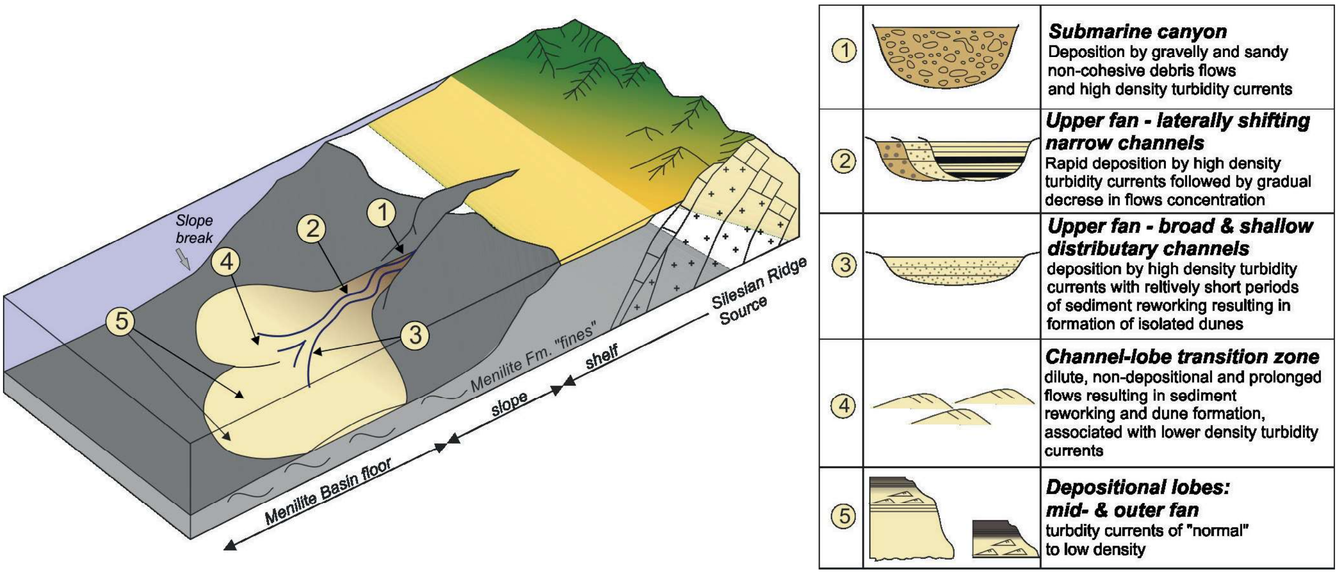

Fig. 26. Model of evolution of the Skrzydlna olistostrome to turbidite megasequence, interpreted in terms of Walther's Law of Facies as grading from proximal submarine canyon fill to distal small turbidite fan. Note five associations of facies, their palaeotopographic expression, and selected sedimentary features, deposition zones and the main controlling processes (1–5). Interpretation by Siemińska *et al*. (2018, 2020) and Wendorff *et al*. (2015)

Stop 2 – Skalski stream near Jaworki village (Late Cretaceous deposits with exotics) (Figs 27, 28)

(*Michał Krobicki, Barbara Olszewska*)

The Upper Cretaceous and Paleogene exotic-bearing gravelstones of the PKB are linked with flysch/flyschoidal sequences of the Sromowce Formation and the Jarmuta Formation, respectively (Birkenmajer, 1977, 1979, 1986). These exotic rocks are useful for reconstructing the basement and sedimentary cover of source areas (Birkenmajer, 1988). The present outcrop is located in the Skalski stream (below the lower station of ski lift – Birkenmajer, 1977, 1979, 1988; Birkenmajer & Lefeld, 1969; Radwański, 1978; Birkenmajer & Wieser, 1990; Birkenmajer *et al*., 1990). Lower Cretaceous Urgonian-type exotic rocks often occur within such gravelstones (Bukowiny Gravelstone Member – Birkenmajer & Lefeld, 1969) which represents a submarine slump, in the middle of the Sromowce Formation of the Niedzica Succession (Birkenmajer, 1977, 1979; Birkenmajer & Jednorowska, 1987b) (Fig. 28).

The Urgonian (named after the village Orgon, east of Tarascon, France) is a characteristic shallow-water carbonate facies that accumulated along the Tethys northern shelf from the Barremian to the Late Albian. The facies encloses hard, light-coloured limestones with foraminifers and pachyodonts, marls with *Orbitolina* (foraminifers) and transitional sediments – detrital or siliceous limestones (Foury, 1968). Characteristic fossils of the facies are bivalves (rudists), corals, hydrozoans, bryozoans, small and large foraminifera and algae. The origin of the Urgonian facies is connected with the Barremian rearrangement of the world ocean (Renard, 1986). The Barremian regression uncovered large parts of the shelves on which abundant shallow-water communities proliferated until the mid-Aptian transgression caused, locally, their emersion and destruction (Scott, 1995). In the Inner Carpathians, the Urgonian facies is represented in the Hightatric units of the Tatra Mts (Lefeld, 1974, 1988; Masse & Uchman, 1997) and the Manín Unit of the Váh valley (Andrusov, 1953; Mišík, 1990). In the PKB, the Urgonian-like facies occurs in the Haligovce Nappe (Birkenmajer, 1959; Haligovce Limestone Formation – Birkenmajer, 1977) and as exotic pebbles in the Upper Cretaceous Sromowce Formation and the Upper Cretaceous–Paleocene Jarmuta Formation (Birkenmajer & Lefeld, 1969; Birkenmajer, 1970, 1977, 1979, 1986; Birkenmajer & Wieser, 1990). In the Outer Carpathians, the Urgonian-type limestones occur exclusively as exotic pebbles in younger deposits (Birkenmajer, 1970, 1973, 1977; Birkenmajer & Lefeld, 1969; Oszczypko, 1975; Burtan *et al*., 1984). Micropalaeontological investigations of these limestones were so far limited to determination of orbitolinids, without full documentation of other foraminifers typical for the Urgonian facies (except for remarks by Mišík, 1990; Krobicki & Olszewska, 2004). Foraminiferal assemblages of the Early Cretaceous Urgonian-type limestones contain many stratigraphically significant species of