The Cergowa Sandstone at Stasiana and Iwla: An example of turbidity hyperpycnal flow deposits in the Outer Carpathians (Dukla region)

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Abstract: Up to 350 m thick succession of the Cergowa Sandstone (Lower Oligocene) forms lenticular depositional body within the Menilite Formation of the Dukla and Silesian tectonic units. In an axial part of the studied lithosome, in Stasiana and Iwla sections, the Cergowa Sandstone is developed as the succession of deepwater deposits stacked in aggradational pattern. Detailed sedimentological study enabled to document several types of sedimentary structures with their vertical oscillations, and other characteristic sedimentary features. 'Non-Bouma-type' sequences, which are typical of studied sections, indicate that studied part of the succession of the Cergowa Sandstone was deposited from sustained long-lived turbidity currents. Many sedimentary features testify that these currents were fed by hyperpycnal flows initiated by river discharges. These are as follow: (1) predominance of sand-prone beds with scarcity of mudstone intercalations; (2) high proportion of tractional structures in thick-bedded sandstones; (3) occurrences of beds called 'flood hydrographs'; (4) lack of larger erosional features in thick and very thick sandstone beds; (5) presence of partly rounded, aligned mudstone clasts in quasi-massive and massive sandstones; (6) occurrences of lofting rhythmites — a distinctive facies of hyperpycnites. Moreover, the presence of abundant plant debris derived from land and large volume of well-sorted mainly fine-grained sand point to possible supply from shelf-edge deltas fed with considerable amounts of clastic input from the exposed shelf. This was related to relative sea level fall during Oligocene Icehouse and tectonic activity of the Dukla Subbasin.

Introduction

Hyperpycnal flow is a type of gravity flow which can occur both in lacustrine and marine settings. By its nature, hyperpycnal flows are strictly connected with direct river inflow into standing waters, especially during flood events. To create hyperpycnal discharge, river waters carrying suspended sediments must be denser than waters of the basin in order to sink and continue down the slope as sediment gravity flow. In the case of fresh-water lakes, even small amount of sediment in suspension is enough to cause the plunging of the river waters and consequently, to form hyperpycnal underflow (Mulder et al. 2003). On the contrary, marine environment requires much denser river suspensions to cause plunging of river waters.

Long-lived hyperpycnal flows differ substantially from classical turbidity currents: in terms of initiation, behaviour and related deposits. Surge type flows are related to the collapse of unstable materials in slope areas (Normark & Piper 1991). Initial submarine gravity mass movements, like slides or slumps, transform into bipartite turbulent flows which accelerate during downslope motion and then quickly lose their energy. They deposit individualised or stacked beds composed of Bouma-type sequences. On the contrary, long-lived hyperpycnal flows originate on the land as direct fluvial discharge into ambient marine waters. They are slow-moving, but can travel for long distances and over long periods of time, as long as the river discharge continues (Zavala et al. 2011). Fluctuating flows produce composite beds: 'non-Bouma-type' sequences. Another difference is that hyperpycnal flow contain initially fresh interstitial water.

The Cergowa Sandstone is a lithostratigraphic subdivision of the Cergowa Beds (the Menilite Formation) of the Dukla and Silesian tectonic units, Early Oligocene in age. It comprises elongated, lenticular depositional body dominated by sandstone facies and stretching from NW to SE. An axial complex of sandstone beds, reaching up to 350 m in thickness, is laterally and vertically passing into heterolithic facies and marls. In Stasiana, Iwla or Lipowica the Cergowa Sandstone forms a complex of deposits stacked in aggradational pattern, which reflects syndepositional tectonic activity in the Dukla Subbasin and intensified subsidence coeval with efficient sediment supply to deepwater depositional system (Pszonka 2015).

Field observations

Detailed sedimentological study enabled to document several types of sedimentary structures and facies in the Stasiana and Iwla sections. The most common sedimentary structures in sandstones are: massive *m*, quasi-massive *(m)*, stratification/spaced lamination including low-angle stratification *s*, and cross-ripple lamination *c*. Plane-parallel or wavy lamination in sandstones and siltstones *l*, occurrences of debrites *D* and massive mudstones/marlstones *M* are rare. Moreover, several intercalation of hard marly limestones *L*, up to 3 m thick, are present. 'Non-Bouma-type' sequences, e.g. *m-(m)-m-(m)*, *m-s-m-s* or *s-c-s-c* are commonly observed within single sandstone beds and bedsets. Single intervals of such sequences are separated by non-erosional discontinuity surfaces, amalgamation surfaces or transitional boundaries. Sequences of this type constitute thick- and very thick beds. Some beds composed of several 'non-Bouma-type' sequences can reach up to 8 m. Bedsets composed of many such stacked beds and devoid of mudstone intercalations can attain thickness of several tens of meters, as was documented in Iwla. The characteristic feature of the Cergowa Sandstone sections studied is the scarcity of sole structures (if present, they are mostly load casts and grooves) and larger erosional features, i.e. chutes or channels. Two types of vertical oscillations of sedimentary structures were recognized: (1) first-order oscillations of small-scale (alternations of sedimentary structures within single beds), (2) second-order large-scale oscillations distinguished on the basis of changes of *m*+*(m)*/*s*+*c* ratio. In the latter case, they are at the scale of over a dozen to several tens of meters.

The occurrence of mudstone clasts and coalified plant detritus is the another characteristic feature of studied profiles. The first occurs as (1) dispersed lithic grains that occur together with other framework grains (up to very coarse-grained sand), (2) larger (>1 cm across) and partly rounded clasts aligned to diffuse discontinuity surfaces in quasi-massive and massive sandstones (*(m)* and *m*), (3) small clay chips and angular, tabular clasts, up to 10 cm in length aligned to stratification/lamination surfaces observed in *s* and *c* intervals; some several-centimeters-thick cross-laminated intervals abound in clay chips. Coalified plant detritus is common in siltstones and sandy siltstones, but was also observed in laminated sandstones. It is present (1) as laminae in laminated siltstones and sandstones or (2) as dispersed material in structureless siltstones. The largest plant fragments are several centimeters in length. Several thin coal intercalations, up to 1 cm thick, were recorded.

Evidence for hyperpycnal flows

Sedimentary record of the Cergowa Sandstone implies the way this complex originated. 'Non-Bouma-type' sequences are here interpreted as deposits of sustained, long lived high- and normal-density turbidity currents. This type of gravity flows can produce thick and very thick composite beds under condition of quasi-steady turbulent flow and incremental aggradation of sand (Kneller & Branney 1995). Fluctuations in velocity and sediment concentration within a flow result in characteristic oscillations of sedimentary structures (Zavala et al. 2011). Therefore, it can be assumed that the discussed flows were driven by long-lived hyperpycnal discharges initiated by river effluents (Zavala et al. 2011).

There are many other indicators that suggest deposition of the Cergowa Sandstone from turbidity hyperpycnal flows. This interpretation is supported by previous work (discussed below) of Plink-Björklund & Steel (2004), Zavala et al. (2011, 2012), Pszonka (2015), Wendorff et al. (2016). Some indicators are related to paleogeography and environmental conditions of the Dukla Subbasin during deposition of the described complex. These are as follows: (1) Deposition of the Cergowa Sandstone coincides in time with relative sea level fall (during Oligocene Icehouse) and forced regression that could have resulted in forming of shelf-edge deltas fed with considerable amounts of clastic input from the exposed shelf platforms. Direct connection of fluvial deltaic system with the basin slope enabled redeposition of large amounts of well-sorted mainly fine-grained sand into deepwater system by hyperpycnal flows sourced from progressive erosion of deltaic deposits; (2) Nannofossil assemblages from the Cergowa Beds, which indicate low salinity of marine waters and even brackish coastal environment. This amplify the density contrast between river effluent and ambient marine waters sufficiently to trigger the hyperpycnal underflow; (3) Predominance of sand-prone beds with scarcity of mudstone intercalations as the effect of separation of coarse and fine populations within the flow due to buoyancy effect on the latter one and deposition of the 'fines' in more distal settings; (4) High proportion of tractional structures in thick-bedded sandstones, testifying to recurrences of long-lasting tractional flows; (5) Occurrences of beds called 'flood hydrographs'. Sedimentary record of these beds is explained by the behavior of river in flood; (6) The lack of larger erosional features in thick and very thick sandstone beds. Hyperpycnal flows are relatively slow and generally not able to erode their substratum in contrary to short-living turbidity currents triggered by slope instability; (7) Presence of partly rounded, aligned mudstone clasts in quasi-massive and massive sandstones. Their position and roundness reflect bedload transport along depositional boundaries that migrated upward during gradual aggradation of sand from long-lived flow; (8) Occurrence of siltstones with abundant coalified plant detritus and muscovite, which are interpreted as lofting rhythmites — a distinctive facies of hyperpycnites, accumulated from lofting plume, which is a typical feature of hyperpycnal flows. Moreover, the presence of abundant coalified plant material and coal laminae strongly suggest the connection of marine depositional environments with fluvial-deltaic system of sediment supply.

Conclusions

The studied part of the succession of the Cergowa Sandstone was deposited from sustained long-lived turbidity currents. Many sedimentary features indicate that these currents were fed by hyperpycnal flows initiated by river effluents. Moreover, the presence of abundant plant debris derived from land and large volume of well-sorted mainly fine-grained sand point to possible supply from shelf-edge deltas fed with considerable amounts of clastic input from the exposed shelf. This was related to relative sea level fall during Oligocene Icehouse and tectonic activity of the Dukla Subbasin.

References

Kneller B.J. & Branney M.J. 1995: Sustained high-density turbidity currents and the deposition of thick massive sands. *Sedimentology* 42, 607–616.

Mulder T., Syvitsky J. P. M., Migeon S., Faugères J.-C. & Savoye B. 2003: Marine hyperpycnal flows: initiation, behavior and related deposits. *Marine and Petroleum Geol.* 20, 861–882.

Normark W.R. & Piper D.J.W. 1991: Initiation process and flow-evolution of turbidity currents: implications for the depositional record. *SEPM Special Publication* 46, 207–230.

Plink-Björklund P. & Steel R. J. 2004: Initiation of turbidity currents: outcrop evidence for Eocene hyperpycnal flow turbidites. *Sedimentary Geology* 165, 29–52.

Pszonka J. 2015: Studium sedymentologiczne warstw cergowskich w jednostce dukielskiej i przeddukielskiej Karpat fliszowych. *Instytut Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk. Studia, rozprawy, monografie*, 196 (in Polish).

Wendorff M., Pszonka J. & Zielińska M. 2016: Cechy turbidytów i uwęglonej materii organicznej jako wskaźniki warunków zasilania basenu warstw cergowskich w Lipowicy, jedn. dukielska Karpat Zewnętrznych. In: Olszewska-Nejbert D., Filipek A., Bąbel M. & Wysocka A. (Eds.): VI Polska Konferencja Sedymentologiczna POKOS 6 „Granice Sedymentologii", 28.06.2016–01.07.2016, Chęciny-Rzepka. *Uniwersytet Warszawski*, 137–138 (in Polish).

Zavala C., Arcuri M., Meglo Di M., Gamero Diaz H. & Contreras C. 2011: A Genetic Facies Tract for the Analysis of Sustained Hyperpycnal Flow Deposits. In: Slatt R.M. & Zavala C. (Eds.): Sediment transfer from shelf to deep water — Revisiting the delivery system. *AAPG Studies in Geology* 61, 31–51.

Zavala C., Arcuri M. & Blanco Valiente L. 2012: the importance of plant remains as diagnostic criteria for the recognition of ancient hyperpycnites. *Revue de Paléobiologie, vol. spéc.* 11, 457–469.