Research into mixed turbidite systems: Macro- and microscopic-scale observations — case study from the Szczawa Tectonic Window, the Fore-Magura zone of the Polish Outer Carpathians

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Abstract: Lower Oligocene turbiditic succession belonging to the Grybów Unit of the Fore-Magura Zone (the Polish Outer Carpathians) observed in Szczawa Tectonic Window contains mixed siliciclastic–carbonate turbidites, i.e. deposits composed of mixtures of siliciclastic grains, carbonate grains and mixture of silt, clay, carbonate mud and micrite. Co-occurrence of siliciclastic and carbonate components (called bed-scale compositional mixing) is the result of initial entrainment of these two heterogeneous fractions into sediment gravity flows, while bed-scale changes of carbonate content together with microscopic-scale, lamina by lamina segregation of components, indicate the process of hydraulic segregation of particles with different physical properties which were transported and deposited by turbidity currents. In addition to compositional mixing, strata mixing is observed in the studied succession. Strata mixing may have resulted from short-term climatic or relative sea level changes. Mixed turbidite systems, in comparison with shallow-marine mixed deposits, are poorly known and should be the subject of further comprehensive analysis.

Introduction

Mixed deposits are composed of mixtures of siliciclastic grains (extrabasinal fraction), carbonate grains (intrabasinal fraction, mainly bioclasts and intraclasts) and mixture of silt, clay, carbonate mud and micrite (Mount 1985; Chiarella et al. 2017).

Mixed siliciclastic-carbonate deposits can be recognized and described at different scales of observation, from stratigraphic units, through lithofacies complexes to individual beds (Chiarella et al. 2017). In the first two cases, mixing results from interbedding of siliciclastic and carbonate beds and/or bedsets and it is called strata mixing. In the latter one compositional mixing occurs when siliciclastic and carbonate particles are mixed and deposited contemporaneously in time and space to form millimetre- to meter-scale beds .

Ancient deep water mixed turbidites are poorly recognized, esp. in comparison with e.g. shallow water mixed deposits (e. g. Mount 1984; Longhitano 2011; Chiarella & Longhitano 2012; Flemming 2016). Hardly any papers raise this subject, some authors only describe petrology of mixed deposits and propose their first-order compositional classification (Zuffa 1980; Mount 1985), but there is still striking lack of papers attempting to provide genetic interpretation of composition, textures and structures observed in mixed turbidite systems. Numerous papers describe mixed shallow marine deposits where mixing of grain composition is due to supply of bioclastic components that constitute the main proportion of carbonate grains. Mount (1984) was the first who proposed conceptual models showing different types of mixing processes in shallow-water marine environments. However, these models are not applicable to deepwater depositional systems. Mixing of different scale in shallow-marine environments can greatly influence compositional mixing in deep-marine turbiditic facies because gravity driven flows transport large volumes of shallow-marine deposits into slope, continental break and basin floor domains. During downslope motion silicislastic and carbonate components undergo further processes of mixing, sorting and possible segregation within turbulent suspension. Different physical properties (specific density or morphometry) of the grains may result in different behaviour of particles of these two populations during transportation in suspension or near bed traction and, eventually, during sedimentation.

The present authors provide preliminary results of field and microscopic observations of mixed siliciclastic–carbonate turbidites from Szczawa Tectonic Window in order to: (1) present types of vertical changes in terms of compositional and stratal mixing and (2) suggest possible genesis of particular types of mixing.

Study area

Szczawa Tectonic Window is located in Western Outer Carpathians, 60 km south of Cracow, Poland. Along the course of Kamienica river, good quality outcrops reveal succession of deposits of Grybów Unit of Fore-Magura zone. The studied section is a 60 m thick fragment of a succession comprising lower Oligocene strata described as the Grybów Beds, and Cergowa Beds (Oszczypko-Clowes 2004) or Sub-Cergowa Beds (Uchman & Cieszkowski 2008). The succession is composed of turbiditic Bouma-type sequences (Tbcde, Tcde, Tce, Tde,…), which form very thin to very thick beds intercalated with marls (possibly deposited by turbidity currents), and thick and very thick massive sandstones described as Cergowa-type arenites.

Materials and methods

The studied succession was chosen for detailed centimetre-by-centimetre logging, photographic documentation and sampling. Microscopic observations including carbonates content estimations were performed on 24 thin sections; moreover, 20 samples obtained from different lithological types were prepared to measure carbonates content using Scheibler's method. Qualitative analysis included description of textures and sedimentary structures, and vertical changes in grains and cements composition between different depositional intervals and within various types of sedimentary structures. Moreover, authors made an attempt to differentiate between carbonate grains, pelitic carbonate matrix and syn- and post-depositional (diagenetic) cements.

Results

Lithology

Turbiditic Bouma-type sequences constitute about 75 % of studied succession. They form beds 5–265 cm thick, stacked in complexes of high-frequency (bed thickness 5–55 cm) and low-frequency (bed thickness 25–265 cm) lithofacies variations. Bouma-type sequences are devoid of Ta subdivision. The lowermost parts of beds are developed as parallel-laminated sandstones (Tb), ripple cross-laminated sandstones and coarse siltstones (Tc) and parallel-laminated siltstones (Td). Sandstones and siltstones are grey, dark-grey or grey-ashen, calcareous. Tbcd, Tcd, Td sequences/intervals can attain 30 cm in thickness. They pass into silt-mud laminations, up to 6 cm thick (Te1 lamination, Piper 1978), or directly into dark-grey, grey or black massive calcareous mudstones, or into grey/light grey massive marls (Te). Thickness of Te subdivisions vary from some centimetres to more than 150 cm (up to 225 cm), but typically does not exceed 100 cm, and commonly constitute more than 60 % of whole thickness of the single turbidite bed.

Within complexes of high-frequency lithofacies changes, there occur depositional rhythms composed of very thin and thin beds of marls alternating with very thin mudstone intercalations, up to 8 beds in one rhythm, which together form packets up to 50 cm thick. Some of marly beds show signs of lamination which may indicate their deposition from very dilute, residual turbidity currents.

The succession contains solitary extremely thick beds: sandstone–calcareous mudstone/marlstone couplets, up to 5.5 m thick. Sandstones which form lower parts of these beds are thick and very thick, medium to fine-grained, massive, with basal several-centimetre thick interval enriched in coarse and very coarse sand-sized grains and mudstone intraclasts dispersed in upper parts, in some cases in form of whole fragments of dark mudstones beds — rafts reaching 100 cm across. Uppermost parts of sandstones exhibit signs of soft-sediment deformation (pore-waters escape) and laminated structures (e.g., dune-like forms or wavy laminations), followed through grain-size break by normally-graded calcareous mudstones enriched in muscovite and grading into massive marlstones.

Compositional mixing and strata mixing

Almost the entire succession contains carbonates as: (1) skeletal grains (lithoclasts and bioclasts) and matrix/cements or (2) almost only matrix/cements with minor fraction of carbonate grains. The first case corresponds to classical definition of compositional mixing, i.e. mixing of siliciclastic and carbonate skeletal grains with co-occurrence of clay minerals and pelitic carbonate matrix and cements, and it is applicable to sandstones and siltstones. The second case generally refers only to mudstones and marlstones.

Sandstones and siltstones developed as Tb/Tc/Td divisions of Bouma sequence contain relatively high proportion of carbonates, varying from 15 % to more than 50 % of rock total weight. Rarely, carbonates occur only as pore-filling cements with no carbonate grains in "pure" siliciclastic arenites. Much more common are sandstones and siltstones which contain both pore-filling carbonate matrix or cements, and carbonate grains. The proportion of the latter ones in total grain population changes from less than 1–2 % of bulk volume of framework grains (only single particles are present) to more than 30 % in some laminated siltstones and sandstones. Carbonate grains occur mostly as abraded lithoclasts of micrite/sparry texture, and bioclasts – foraminifera tests and other microplanctonic skeletal remains. Microscopic observations of laminated intervals reveals two regularities: (1) segregation of components in ripple cross-laminations within single cross lamina: lower lamina enriched in heavy minerals (pyrite/hematite, zircon), middle lamina consisting mostly of siliciclastic grains with medium grain coarser than in lower one, and upper lamina enriched in carbonate grains (both bioclasts and intraclasts, occasionally almost only bioclasts); lamina with heavy minerals is sometimes absent; (2) alternating of silt laminae enriched in carbonates and laminae depleted of carbonates; the first are rich in siliciclastic grains, the latter — noticeably enriched in clay minerals and muscovite. What is important, carbonate content correlates with number and size of siliciclastic grains.

Massive sandstones which constitute the lower part of extremely thick beds, are usually lacking significant amount of carbonate grains in total grain number, at least these contain no carbonate grains, matrix and cements. These sandstones are (1) quartz arenites with subordinate feldspar grains and rock fragments of metamorphic rocks, mudstones, sandstones and carbonates, or (2) quartz/sublithic wackes with mudstone and sandstone lithoclasts, and carbonate or carbonate-clayey cements/matrix. In some beds, the first graded vertically into the latter ones.

In the studied succession, there are different patterns of change of carbonates content in vertical profiles of individual beds. In the case of turbidite beds composed of Bouma-type sequence, carbonates content: (1) increases towards bed top — Tbcd, Tcd, Tc, Td intervals usually contain relatively high proportion of carbonates (20–35 % of total weight) and grades into marlstones which contain more than 40 % of carbonates; (2) is highest in laminated intervals (some ripple cross-laminated intervals contain more than 50 % of carbonates in rock total weight) and decreases upward — carbonates are replaced in part by clay minerals. In one extremely thick, bipartite bed, within massive sandstone, carbonate content increases from zero (lower two meters) to about 25 %, then decreases slightly in Te interval (to 20 % of rock total weight) just above sandstone and eventually increases when grading into marlstone. The highest content of carbonates is recorded from depositional rhythms composed of thin-bedded marlstones, where it ranges from 40 % to 60 % of rock total weight.

In the studied section, only characteristic depositional rhythms composed of thin-bedded marlstones (carbonate beds), which interbed turbidite beds (mixed ones) fit the definition of strata mixing used by Chiarella et al. (2017). Moreover, it is the example of coexistence of compositional and strata mixing.

Discussion

The structures and textures of laminated intervals, especially segregation of components, were formed due to hydraulic separation of fractions of different physical properties. Hydraulic sorting is most effective in some cross laminae: heavy siliciclastic grains are separated from lighter and coarser bioclasts. Similarly, quartz-carbonate rich and clay-muscovite rich couplets of laminae originated via hydraulic separation of coarse and heavy particles from light and buoyant components. Moreover, a part of pelitic carbonate matrix observed in quartz-carbonates rich laminae may have originated from physical abrasion of carbonate grains, especially those derived from unconsolidated/poorly consolidated carbonate muds.

Changes of carbonate content in vertical profiles of beds may be owing to segregation of carbonate grains and pelitic carbonate matrix within sediment gravity flows and result in deposition of massive, thick sandstones with upper part enriched in carbonates. Decrease of carbonate content in some pelitic intervals just above silt- and sand-sized intervals is associated with increase in content of clay minerals and muscovite deposited from dilute turbidity currents.

Mixing of marlstone rhythms with turbidite beds, classified as strata mixing of bed-scale, can be interpreted, according to Chiarella et al. (2017), as the result of: (1) short-term sea level changes and deposition of marlstone rhythms during relative sea level rise; (2) short-term climate changes from arid (marlstones) to humid (turbidite beds) conditions or (3) tectonic control on the sediment supply from the continent. Moreover, the occurrences of extremely thick sandstone-marlstone beds may indicate catastrophic events, e.g. floods or large-volume submarine slumps triggered by seismic shocks or tsunamis.

Perspectives

The extensive research into mixed turbidite systems is still missing, both in terms of depositional processes, grain and chemical composition and source areas for different constituents, and their interplay in depositional environment. Similar to mixed turbidites from Szczawa Tectonic Window, compositional and strata mixing is expected from other turbiditic successions with high carbonate content. Therefore, there is a vast field to further analysis.

When mixed turbidite systems are considered, a few specific research problems arise: (1) what is the source area of siliciclastic and carbonate grains and how are they mixed in marine environments; (2) how hydrodynamic processes control the distribution and organization of silicislastic and carbonate components within turbidity currents and other sediment gravity flows; (3) how analysis of microfossils (mostly foraminifera assemblages) could enable us to interpret depositional environments from which these were redeposited; (4) how porosity and permeability vary throughout mixed turbidite beds and how these properties are affected by depositional and diagenetic processes. In addition, we need to differentiate between carbonate extraclasts and intraclasts in order to get information about the source area (provenance) and to distinguish pelitic carbonate matrix and carbonate cements of different origins.

Conclusions

On the basis of preliminary research into mixed turbidite succession from the Szczawa Tectonic Window we can conclude that:

- compositional mixing is the major type of mixing observed in the studied succession and manifests itself as the co-occurrence of siliciclastic and carbonate detrital components;
- compositional mixing results from initial entrainment of siliciclastic and carbonate detritus in shallow-marine and slope areas;
- vertical changes of carbonate content at bed-scale and microscopic-scale (lamina by lamina) reflect the process of hydraulic sorting of grains of different physical properties transported and deposited by turbidity currents;
- occurrences of marly packets which interbed the stacked turbidite beds, as well as presence of extremely thick beds (sandstone-marlstone couplets) may point to short-term climatic or relative sea level changes, and result in strata mixing.

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