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THE ORIGIN OF DISTURBED STRUCTURES IN TURBIDITES THE FLYSCH OF CENTRAL CARPATHIANS

(Figs. 1—10)

Abstract: In the present paper the most frequent cases of the so-called disturbed structures in turbidites of the central Carpathian Flysch are dealt with. Analysis of these beds shows that disturbed (deformational) structures have not been evoked by postdepositional gravitation movements (postdepositional gravity slumping of beds on slopes). These structures in turbidites are different from these arising in the slumps of shorter duration. By that time, the author accepts the opinion, that by the slumping of beds in the distal zones of the Flysch no typical turbidites may arise, and the disturbed structures enclosed in the former, have therefore different origin.

Introduction

The investigation of submarine gravitational slope failures in typical Flysch sediments is devoted greater attention, since there is a supposition that the submarine slopes along which transport and deposition of turbidity currents passed were so low that no gravitational slope failures were possible (Ph. H. Kuenen 1964, D. G. Moore 1961).

Important increase of gravitational processes takes place in areas proximal to the source zones. This topographical dependence was found by the study of sedimentary structures in subaquaeous gravity deposits of proximal zones that were considerably different from graded-bedded turbidites of distal zones.

Yet the occasional research of modern submarine slope failures, carried out on the seashore and delta front by K. Terzaghi (1957), and the study of flow of the deepwater sands over the steep sloping floor of submarine canyons (R. F. Dill 1964) leads to doubts the opinion on such mechanisms as slumps or slides, largescale mass movement of metastable sands and creep of sediments being able to cause the movement of turbidity currents.

Considering these facts, I dealt with such sedimentary structures (intraclasts) in the Flysch sandstones as:: crumpled fragments of clay layers, mudstones, chips, lumps and pebbles, that were formed by subaqueous gravity depositional processes, especially in sequences with cohesive claystone partings where they produced disturbed bedding (J. C. Crowell et al. 1966) or slurry beds (A. Wood, A. J. Smith 1959). It was right to emphasize wider range of plasticity of claystone sediments. The rise of mudstone lumps and crumpled fragments enclosed in sandstones is therefore usually ascribed to submarine slumping of combined Flysch sequences on the slope. Large blocks of consolidated claystone rocks of the composition similar to that of the surrouding beds irregularly distributed in sandstone matrix, indicate that original bed forms were completely disturbed.

From the methodical point of view it is important to give the dinamic picture of the development of these structures in different stages of transport and deposition followed on the base of primary current conditions. Another important task is to judge the active forces according to the shape and deformation of fragments.

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General Lithological Characteristics of the Flysch Sequence with Disturbed Structures

The majority of these structures were studied in the lower series of Central-Carpathian Flysch in the area of the Kežmarok and Spiš basins (in geographical sense). This area was always stratigraphically and sedimentologically interesting, since the lower series of the Flysch was ore-bearing. By means of detail prospection and drilling works (Z. Priechodská 1954), basal formation (Cretaceous?—Lutetian), claystone lithofacies (Lutetian — Lower Priabonian) with larger local accumulation of Mn-ores and with turbidite beds with the interval of lower parallel and current-ripple lamination, were distinguished there. Transition into typical Flysch sequence is gradual. Its Lower — Upper Priabonian age was determined by means of the globigerinal microfauna (O. Samuel 1965). In the Flysch, the upward increase of graded and structureless graywackes and subgraywackes may be observed. The Flysch with prevalence of sandstones in the Levočské hory Mts. was not included in this study.

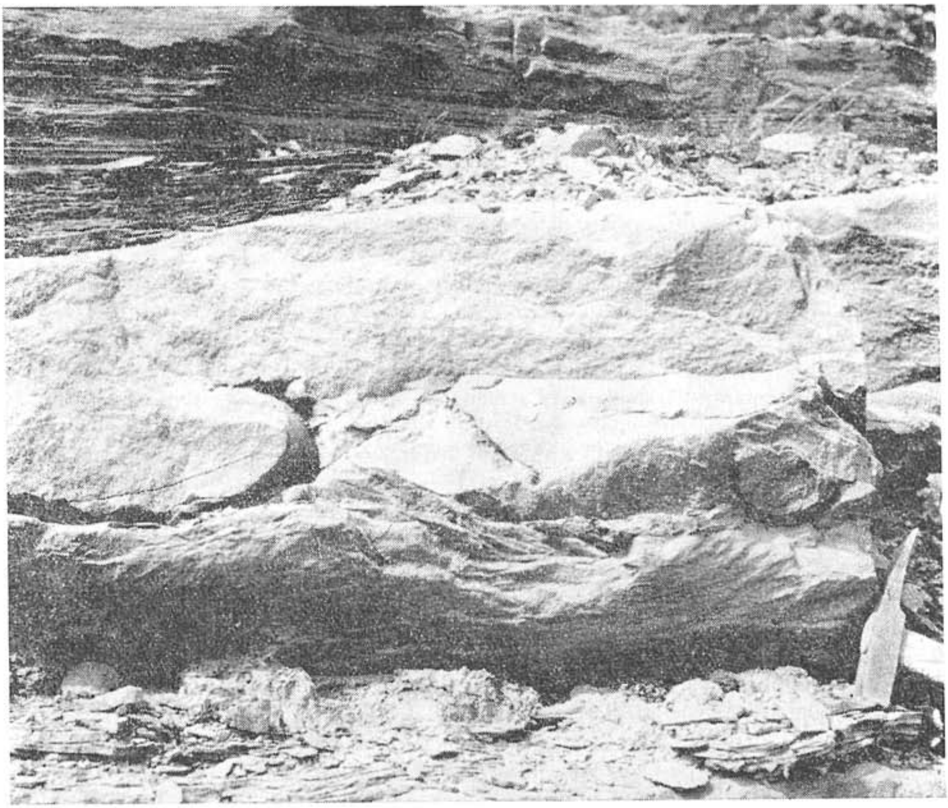

Fig. 1. Disturbed bedding. In sudden deposition of the load and at the impact on the bottom, the current got slower. This change of velocity caused the formation of traction structures, i. e. of sharp-superimposed set of parallel lamination. The figure shows a detail of rolled claystone sheets followed along the whole bottom part of the bed in the continuous horizon. The locality Levočský potok.

The position of the lower series of the Flysch in relation to the source zone was studied by means of paleocurrent analysis by R. Marschalko and A. Radomski (1960). These and following investigations (R. Marschalko 1968) showed that deposition of Flysch took place at the beginning and in the course of the main filling of the basin in the distance of 35—50 km from the sources in NE and SE. In the Flysch there were no lens shapes of coarse clastics of the pebble mudstone type — these are rather characteristic of marginal facies. In current direction from E to NW, SWW, the decrease of bed thickness from max. 3 m to 40—60 cm and prevalence of calcareous claystones may be observed. In this direction deepening of the basin with the respective modification of slopes may be observed.

Main Types of Disturbed Structures in Sandstones

Case 1. More or less continuous crumpled sheets and fragments of claystone layers near the base or inside sandstones with traction structures (planparallel laminae) in the top

Inside the sandstanes there are crumpled sheets of claystone layers in continuous position enclosed near the base and higher up (fig. 1). The entire, partly rolled layers with accompanying silt laminae are usually surrounded by coarses sand grains.

Not only the crumpled fragments and sheets, but also graded beds resting upon the former, or the accompanying graded matrix indicate that the original claystone beds were gradually disturbed by the crumpling from below, and partly or completely displaced forward from the place of their original occurrence. Although these structures indicate the possible slump origin in non-turbulent flow, a set of coarse parallel lamination in the top of the sandstones (fig. 1) points out to the forming under the condition of the main deposition of the turbidity current. The current pattern of the forming of such bed is approximately as follows: As soon as the sedimen-laden turbidity current becomes insufficient to maintain grains in suspension, qick deposition takes place, and decreased current velocity represents conditions for the forming of traction structures. Sudden transition from the higher to the lower current velocity produced a superimposed set of coarse gradation laminae in the top (fig. 1). Freezing of high concentration of grains in the current and sudden deposition and impact of sediment load caused considerable disturbation and interruption of the weak-cohesive claystone layer. Owing to the „inert" movement of flow in very short time and distance, dragging of the fragments and their disturbance take place. Thus the forming of disturbed structures is not connected with the slumping of beds on the slope. J. C. Crowell et al. (1966) were right when emphasizing the term disturbed structures to be more suitable than slump structures.

The importance of a sudden failure and disturbance influenced by the arrival and impact of the heavy sand-laden current was proved experimentally by S. Dżulynski, A. Radomski (1966), bringing thus a new view of frequent types of deformational slump-like structures. The main characteristics differing these structures from slumps are the following:

1. Disturbed fragments and sheets — concentrated in evidently continuous position most frequently near the base of the bed — are usually accompanied and mixed with coarse-grained graded matrix.

2. The strata with these fragments must include the traction structures showing turbulent flow conditions and excluding plastic mass flow and spontaneous liquefaction, the so-called subsidence flow (K. Terzaghi 1957) that cause destruction of traction structures.

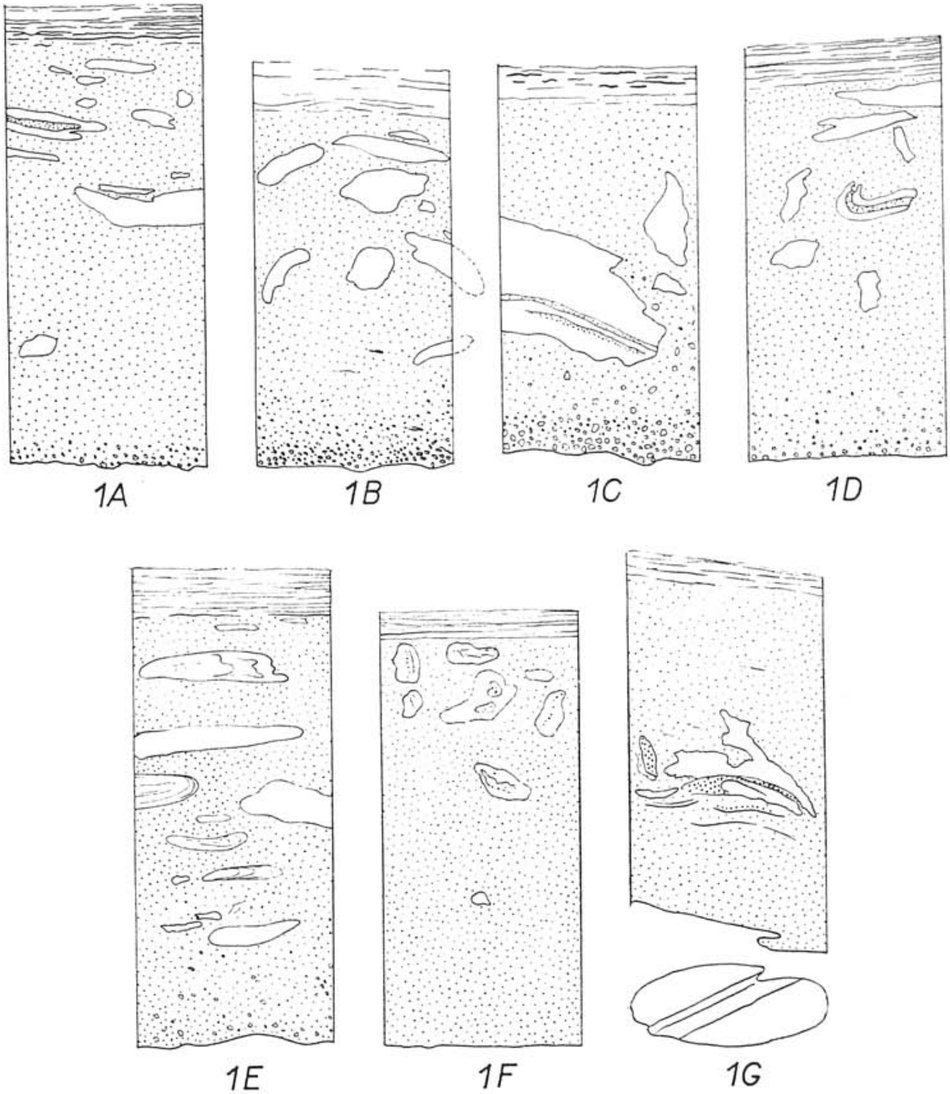

Fig. 2. Various types of chips, crumpled fragments, intraclasts and pebbles of clay in graded and structureless sandstones of the lower division. All beds had lower parallel lamination with more or less continuous transition into overlying claystones. The beds were surrounded always by calcareous claystones. A — Unrounded elongated fragments of claystones, parallel with the bed surface. Borehole B-83, 132,50 m. B — Irregularly distributed rounded fragments and pebbles generally represent normal manner of occurrence. Borehole H 1-3, 288,70 m. C — Large, anguler clay fragment directly in coarse fraction. Borehole N-46, 87,70 m. D — Chips and crumpled fragments of claystone. Borehole B-51, 96,10 m. E — Parallel-arranged crumpled fragments of clays with deformed internal structures. Borehole B-46, 136,45 m. F — Irregularly distributed clay fragments with internal silt laminae in the upper part of bed. Borehole B-58, 73,90 m. G — Fragment with diffusive margins. On the base of bed — drag marks. Borehole B-51, 79,70 m.

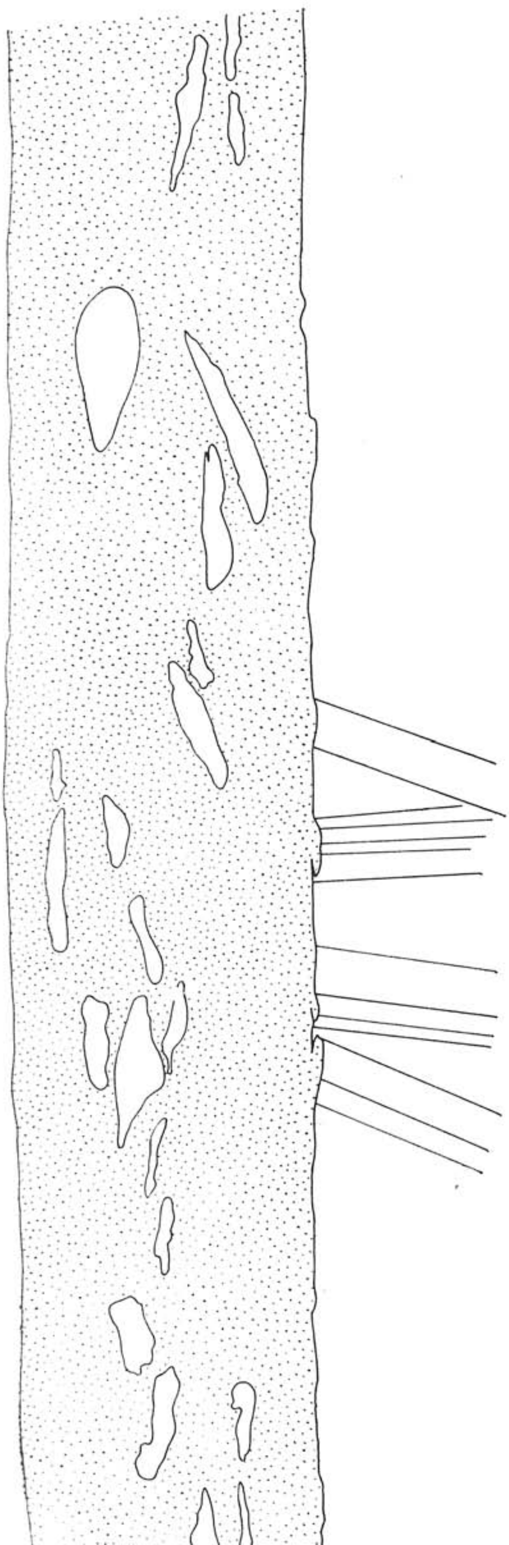

Fig. 3. Bed of structureless sandstone without traction structures in the top. Fragments of various shapes, irregularly oriented, are not in contact. Distinct drag marks crossing in the angle of 25°.

Case 2. Mudstone lumps, fragments and pebbles in graded and structureless lower division with or without traction structures in the top.

Mudstone fragments and pebbles are frequent phenomena in the series of the Flysch sandstones in the Kežmarok and Spiš depressions. In natural exposures, these structures were studied in connection with substratal lineations (sole markings) and traction structures in the top of beds. Excellent inner details of these fragments were found in drill cores. In this paper only a part of various occurrences and forms are presented.

Fragments and pebbles were present mostly in the upper part of the lower graded division (Fig. 2). In structureless beds along the whole thickness (Fig. 3). The increasing amount of fragments was observed with the decreaes of coarse fraction. In one bed there were often flat, elongated, discoid and irregular forms with sharp edges; interesting were crumpled fragments and pebbles with deformed structure of siltstone laminae (Fig. 2 D. E. F., Fig. 4, 5, 6) or with completely diffusive edges. (Fig. 2 G).

The size of fragments rarely exceeded the thickness of claystone parting and moved within 2—15—25 cm. No accumulation and arrangement of fragments in the base of graded beds nor their sorting according to their size were observed. The fragments were not in contact with one another, neither pebbles and flat fragments did form imbricated structures and pavements. That is why they were not selectively rolled over the substratum as e. g. stream pebbles in certain conditions of flow, but they were carried, propped and floated in the flow of fine grains. They were not found in the division of lower parallel lamination of these beds. Their turning over the smooth substratum of flat laminae would be, though, possible, but the current velocity was insufficient. Consequently, the velocity of flow with fragments reached quite high values. This is fully demonstrated by linear sole markings produced by these currents. Permanently parallel and especially crossing drag marks, formed downward quick current with the character of a traction carpet in the sense of S. Dżułynski, J. E. Sanders (1962), were found there. Graded nature of the carpet is evident in many cases, and in agreement with R. G. Walker (1965) we may admit the traction carpet to represent an effective mechanism for the separation of coarse grains from the turbidity current. E. F. McBride (1962) and J. H. Spott's (1964) investigations of the grain orientation in turbidites showed the paths of grains following forces linear with the flow of current, and grains oriented parallel with the flow, in spite of the rapid deposition. Thus it might seem that flat fragments and pebbles carried

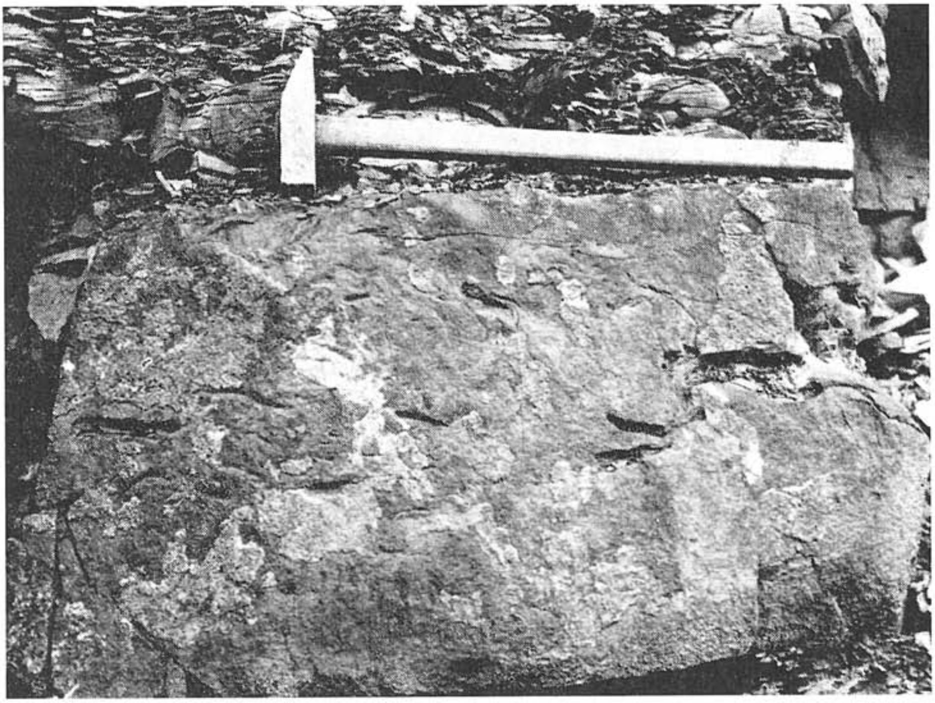

Fig. 4. Graded bed in calcareous claystones. Deformational fragments of claystones (intraclasts) distributed approximately horizontally in the central part of the bed. The fragments left cavities and the internal structure cannot be followed. On the base of the bed there are drag marks. In the top no lamination occurs.

by this flow should have the position parallel with the long axis in the current direction. This was, however, not observed in any of several cross-sections parallel with the flow of the current (Fig. 7).

Two explanations of this phenomenon may be offered:

1. The carried flat fragments without contact with the forming hydroplastic substratum of the traction carpet are lifted — due to high turbulency — and again abruptly thrown under various angles into the substratum, regularity of orientation decreasing with the increasing velocity of turbulency. Owing to this, the extremely flat fragments quickly loose their stability and change their orientation. The more irregular fragments, the poorer orientation. If turbulence decreases with the fading slope to such an extent that the fragments — in spite of their weight — fall down to the base of the flow, they are finally driven forward with gradually growing traction carpet.

2. Another explanation possible, especially suitable for sharp-edged fragments and lumps is that were carried in the flow of grains without turbulency — en mass. Dispersive stress at grain collision maintained grains in dispersion, and the flow of grains with mudstone fragments continued in non-turbulent flow, inertly, therefore it was called inertia flow of sand grain by J. E. Sanders (1965). Mudstone fragments were not turned in turbulent suspension above the

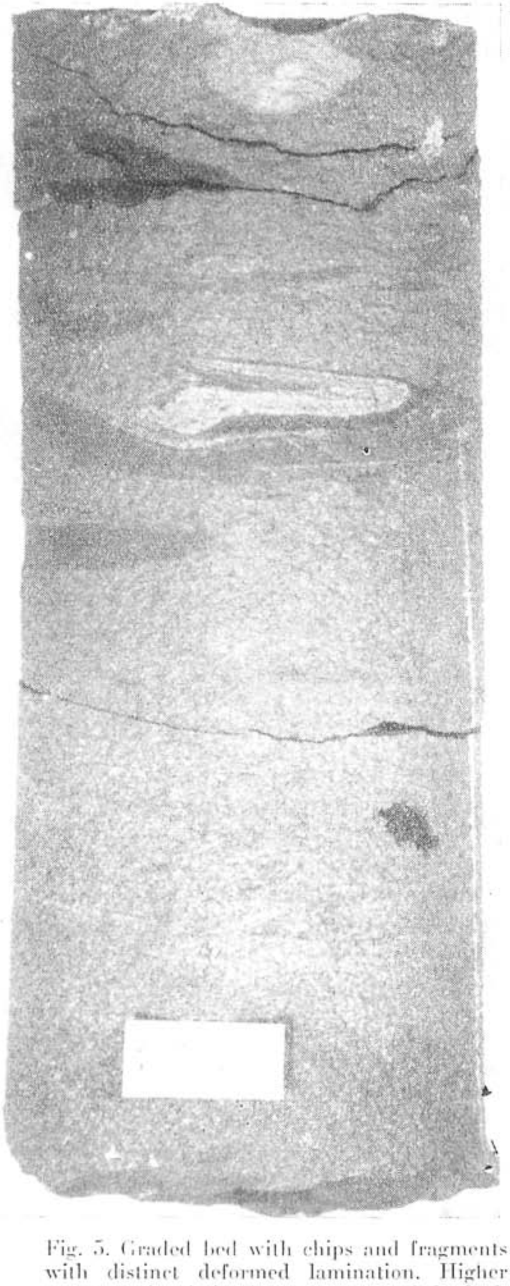

Fig. 5. Graded bed with chips and fragments with distinct deformed lamination. Higher concentration is in the upper part of the bed, and partly also in laminae not presented on the photograph. The light lenticle represents the pebble of muddy limestone. Borehole J-22, 132,50 m.

Fig. 6. An unusual shape of the crumpled claystone fragment is „flowing" in a graded bed with distinct traction structures (parallel laminae) in its top. On the latter there is again a bed with initial grading. Lokality Brezovica.

hydroplastic substartum of the carpet as in the preceding case, but were carried directly in the substratum of the grain flow. At high velocity linear drag marks were produced by the flow. Owing to the absence of driving by turbulent suspension, no traction structures in the top of beds were formed by the grain flow. The grains in an inertia flow follow linear paths, since the grain collision evokes a mass effect (R. A. B a g n o l d 1956). Paths of flat elongated fragments should follow the forces linear with the flow and be oriented parallel to the latter. If this condition is not given, and the fragments are more or less irregularly distributed in graded beds with flute casts or drag marks on the base and with traction structures in the top, then rather the first explanation should be accepted.

The last mentioned current features cannot be found in submarine postdepositional slumps where chaotic mixing of comparatively cohesive sand clay layers are accompanied by rotation or by the forming of slump folds.

On suitable slope, however, the plastic mass flow gets quicker, gravitation force overtakes internal friction, and gradual rearrangement of solids and fragments is quite probable. Due to the internal stress there appears parallel position of fragments, differences between the arrangement of solids in a mature slide or in an inertia flow of sand grain will not be great, and differences between slide marks produced by gravity slumping and drag marks produced by flow of grain, may be unimportant, as well. The study of slumps occurring directly in sequences shows that suitable slopes offering the above conditions did not exist.

Consequently, the conclusion may be drawn, that mudstone fragments and pebbles included in graded sandstones were transported in turbidity currents and in inertia flows of sand grains in large distance. They may be well distinguished from slides owing to numerous features, of which current structures, scour marks, drag marks, current lamination and arrangement of fragments are the features of greatest importance.

Case 3. Slumps with Current Traction Structures Missing.

The presence of crumpled fragments of clay with „slump-like" structure in turbidites evokes the question whether or not the turbidity currents may rise due to the slumping of several alternating turbidites separated by claystone partings. The structures of slumps may be well distinguished, since the beds lose their continuity, they are rolled and accumulated from a larger area to smaller one. It was already found (R. Marschalko 1963) that slump folds of turbidites in claystones did not pass into slump avalanches. Continuity of these beds may be followed, although some switch and amalgamation of the sand beds due to the interruption of clay parting may be expected (fig. 9, 10). These and other cases indicate that cohesion offered sufficient degree of stability of sandstones, the shear stress never exceeded the yield limit, and the plastic mass flow was not changed into viscous fluid flow and turbidity current (R. H. Dott 1963).

There are cases, however, when high speed turbidity currents run before the slower slumps, and the structures of the latter are formed and deposited over the former

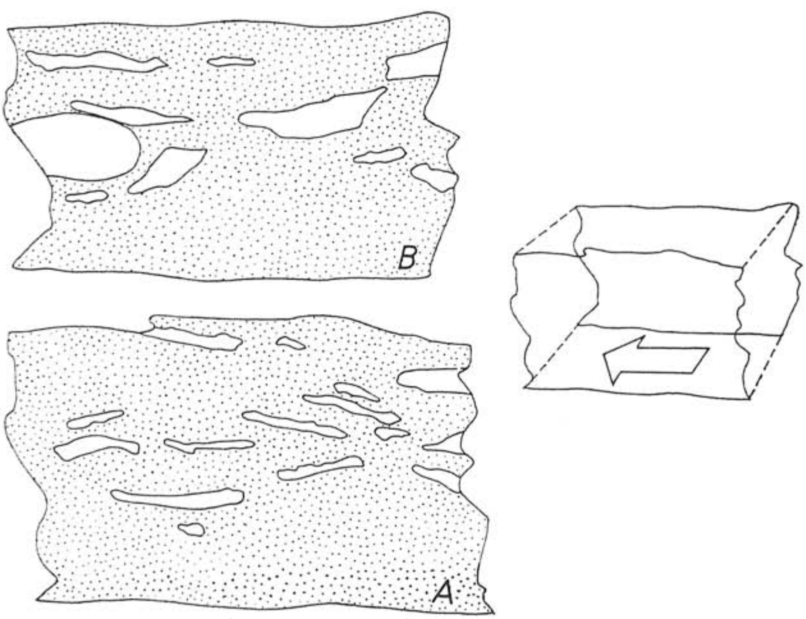

Fig. 7. Bed of structureless sandstone with flat angular fragments and pebbles. Sections parallel with current direction are presented in axonometric projection. Direction flow arrowhead found according to tool marks. Loc. Iliašovce, quarry.

(Fig. 9, 10). We may suppose then, that distances between the moving slumps and turbidity currents are the same, and the origin of both cannot be sought in loco. It seems that crumpled fragments and chips of claystones accumulated and inclosed in turbidite sands did not rise by the slumping of the proper turbidity beds on gentle slopes. Their origin may be axplained:

1. by gravity movements of sliding mass over the steeply inclined slopes composed of claystones. The sliding masses eroded various consolidated claystones in substratum and dragged them down into movement.

If such a slump passed the critical inclination of slope, and movement of longer duration, then it acquired the nature of an inertia grain flow and behaviour of a turbidity current. In such case the sorting of grains is good and chips, fragments of clays get elongated and get rounded shape.

2. By the impact of heavy sediment laden turbidity current or slide on combined sequences of sandstones and impermeable beds of clays. Owing to this the excess water from the pores of sands cannot escape, and prevents any volume change. In the

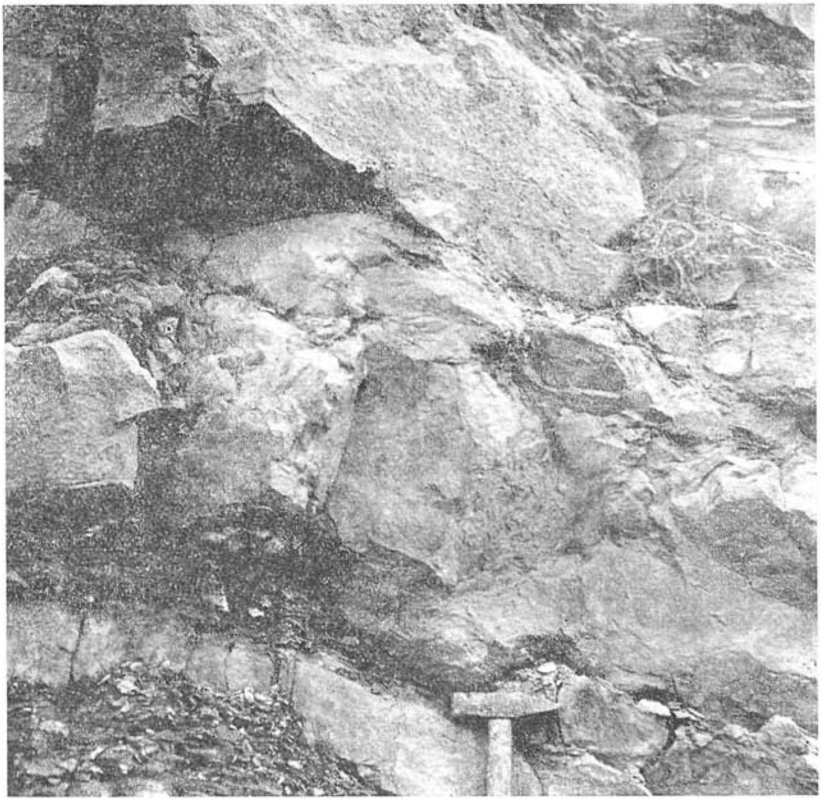

Fig. 8. Sedimentary slump took place in consolidated beds. Sand beds, separated by clay partings preserved their partial identity, although claystones were completely compressed. Clay partings, and especially sandstones have great range of cohesion, therefore the plastic mas flow does not pass into viscous turbidity current. The locality Holohumnica.

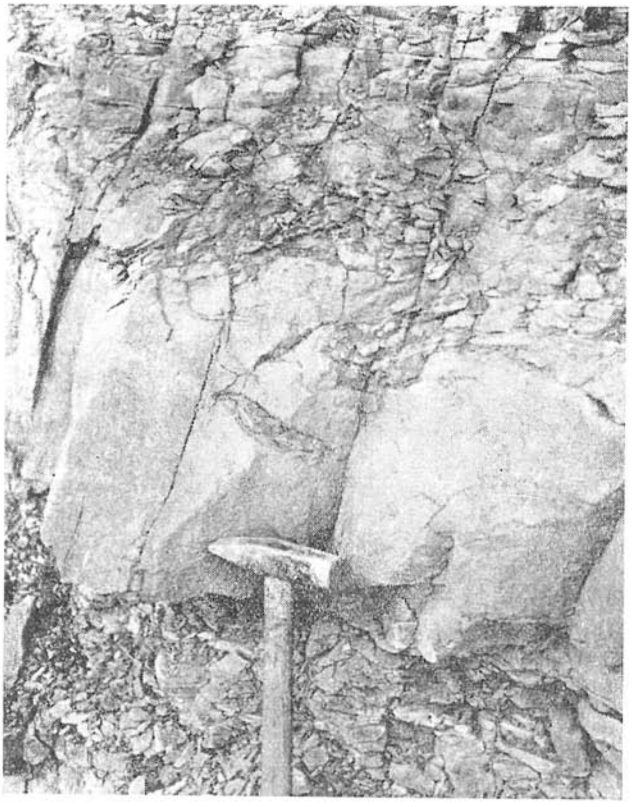

Fig. 9. In the top of the turbidite with deformed fragments of clay and silt there is a slump bed. Due to gradual transition, forming of these beds is out of question and it is quite probable that the turbidity current took place before the slump. Crossing of drag marks on the base of the bed eliminates the possibility of the rise of beds by slow creep of sand. The locality Kežmarok, cut of Poprad.

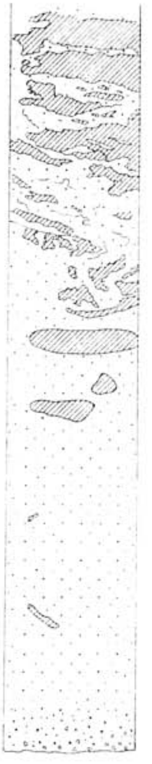

Fig. 10. Graded sandstone with slump structures on the top. Gradual transition from graded turbidite into slump is noteworthy. Borehole B-85, 150,90 m.

whole body the pressure of pore water is mobilized by compress. The shear stress causes spontaneous liquefaction of sand mass. This evokes reduction of shear resistence and sliding. The mass flow may thus change into inertia flow and turbidity current on suitable slope.

Conclusion

1. The study of disturbed structures in turbidites is of great importance for the knowledge of subaqueous gravity mass flow processes. By the analysis of the dinamic picture of disturbed structures and by means of current substratal lineations and current traction structures dependent upon hydrodynamic conditions of flow, it was possible to show that the inertia flow of sand grains and turbidity current are the terminal constituents of differentiation in subaqueous gravity depositional processes.

2. Disturbed structures in turbidites are distinctly differing from those originating in

slumps of short duration of cohesive mass over moderate slopes of the distal zone. The presence of slumps following the turbidity current (and not vice versa) being gradually deposited over the latter, indicates that they do not originate in some near place, but overtake quite long distances, and that turbidity currents were not preceded by slides on moderate slopes. The slumping of beds in distal zones of Flysch cannot cause the rise of typical turbidites and the claystone crumpled fragments have different origin.

3. If conditions of the slope were insufficient, the impact of sediment-laden turbidity current on the substratum caused only the failure and disturbed bedding, that may be well distinguished from the postdepositional slumping owing to numerous characteristic features. It is very probable that on suitable slopes this mechanism is decisive for the rise of these structures. By further movement the crumpled fragments and chips of clays are included into the flow.

4. Although the paleoslope — over which the transport and deposition of turbidites of the lower series of the Central-Carpathian Flysch passed, was low, the distance from proximal zone was not so great. In case of lateral filling of the basin this area, the slopes in proximal zones must have been steep.

The preservation of disturbed structures was possible in case of non-existing bottom currents with the supposition of a closed and deeper trough.

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