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O ODKSZTAŁCENIACH POPRZECZNYCH DO KIERUNKU UPŁYNNIEŃ W OSADACH

(4 fig.)

Transverse deformational patterns in unstable sediments

(4 Figs.)

STRESZCZENIE

W osadach o niestatecznym warstwowaniu gęstościowym struktury o wielobocznych zarysach powstają w przypadku jednoczesnego i równomiernego upłynnienia osadu, który bezpośrednio podściela warstwę o większej gęstości. Jeżeli proces upłynniania postępuje z wolna wzdłuż powierzchni stropowej warstwy o mniejszej gęstości, to na tej powierzchni powstają struktury o wydłużonych zarysach. Dłuższe osie tych struktur biegną na ogół prostopadle do kierunku rozchodzenia się deformacji. Jeżeli stosunek lepkości kinematycznej warstwy cięższej (k_1) do lżejszej (k_2) wyraża się zależnością $k_1 \gg k_2$, to wspomniany wyżej proces prowadzi do utworzenia się struktur przedstawionych na fig. 1, 2. W przypadku $k_1 \ll k_2$ powstają struktury uwidocznione na fig. 3.

Podobne w zarysach struktury uzyskano w doświadczeniach nad przepływem prądów zawiesinowych po dnie zbiornika wodnego z osadzonym uprzednio zespołem plastycznych warstewek (mieszanina gipsu i iłu), które podścielała warstwa upłynniającego się iłu. W przeciwieństwie do doświadczeń wykonanych uprzednio w podobnych warunkach (Dżułyński i Radomski, 1965) w omawianym przypadku plastyczne warstewki nie zostały uniesione prądem ani też wciągnięte w jego osad. Zostały natomiast rozerwane w równych odstępach i zwinięte w wałeczki ustawione poprzecznie do kierunku prądu. Zwinięcie nastąpiło w następstwie grzęźnięcia porozrywanych poprzecznie płatów w upłynniony ił. Ponieważ tarcie płynącej zawiesiny dało niewielką składową poziomą ruchu, wałeczki grzęzły skośnie, a to z kolei doprowadziło do utworzenia się struktury przedstawionej na fig. 4. Na uwagę zasługują tu wąskie wyciśnięcia iłu między wałeczkami skierowane wyraźnie pod prąd, a więc przeciwnie, niż ma to miejsce przy wyciskaniu wywołanym bezpośrednio przez tarcie płynącej zawiesiny (fig. 4).

Struktury uzyskane doświadczalnie mają swoje odpowiedniki wśród niektórych zaburzeń „syndepozycyjnych” w osadach złożonych w środowisku wodnym.

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Abstract. Transverse, elongate deformation patterns are described in unstable systems characterized by a reversed density gradient. The structures trend at right angle to the direction of propagation of the deformation. This may be due to the intermittent spread of a liquefaction front in the lower density layer, or to incipient horizontal shear inflicted by e. g. current drag.

1. In unconsolidated, water-saturated sediments with a reversed density gradient resulting from the superposition of high density layer on a layer of lower density, deformation is initiated when the viscosity of the lower density layer is reduced relative to that of the upper layer. This commonly results from spontaneous liquefaction (Terzaghi 1956). The manner, however, in which such liquefaction progresses relative to the interface between the layers, exerts a control on the deformational pattern. Liquefaction may be instantaneous and affect the whole system, so that the interface is deprived of support throughout its entire area at the same time. The resulting deformation in such a case, occurs over the whole area and takes the form of ascending or descending columns which, on attaining mutual contact, produce a polygonal pattern in horizontal section. The details of formation of such patterns in sediments and sedimentary rocks, have been discussed elsewhere (Artyushkov, 1965; Dżułyński, 1966; Dżułyński and Simpson, 1966). Deformations may, on the other hand, be instantaneous in only a part of the system and then progress slowly over the area initially unaffected.

2. Such a case was investigated in an experiment in which a soft layer of plaster of paris turbidite was deposited upon a thixotropic clay

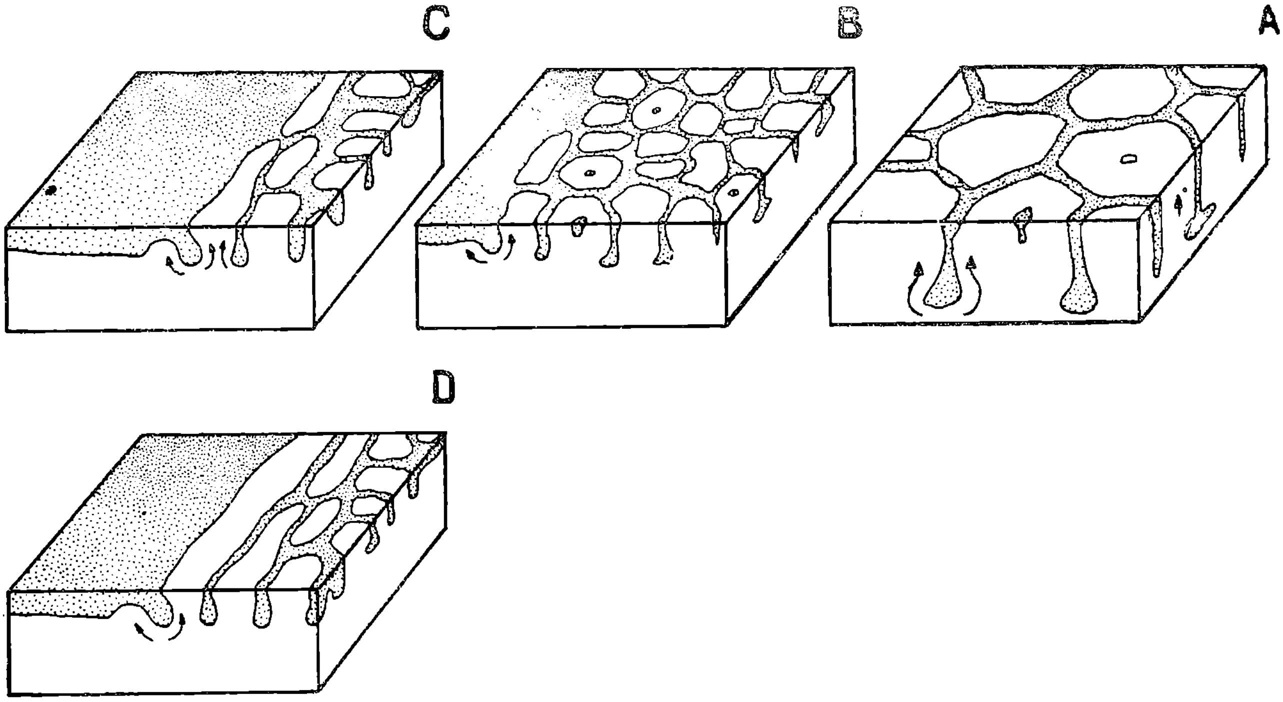

Fig. 1. Tworzenie się poprzecznych zaburzeń przy powolnym przesuwaniu się strefy upłynnienia od obszaru zaburzonego strukturami o zarysie wielobocznym $k_1 \gg k_2$

Fig. 1. Schematic presentation of deformational patterns showing dependence upon the propagation of liquefaction in unstable system with $k_1 \gg k_2$. Based on experiments. A — polygonal pattern formed on instantaneous liquefaction. B — margin of polygonally disturbed area. Dotted area to the left not yet affected by deformation. The decrease in the size of polygons between A and B reflects the decreasing thickness of the high density layer. C-D — lateral propagation of deformation with change in pattern to transverse structures

to produce an unstable system. The thickness of the turbidite layer increased slightly towards the proximal end of the tank. The system was then subjected to a localized, minimal shock at the proximal end by gently tapping the injection shute. This disturbance was followed by instantaneous deformation over the greater part of the turbidite layer, and rising clay columns were seen to form a polygonal pattern on the top surface of the system. The plaster of paris was reduced to narrow walls separating the polyhedral clay columns indicating that its kinematic viscosity k_1 was greater than that of the clay layer, k_2.

The distal part of the turbidite was at first, unaffected, so that an irregular boundary surface was formed between this area and that already deformed. Disturbances were then observed, spreading very slowly and intermittently towards the distal end (Fig. 1 and 2), breaking

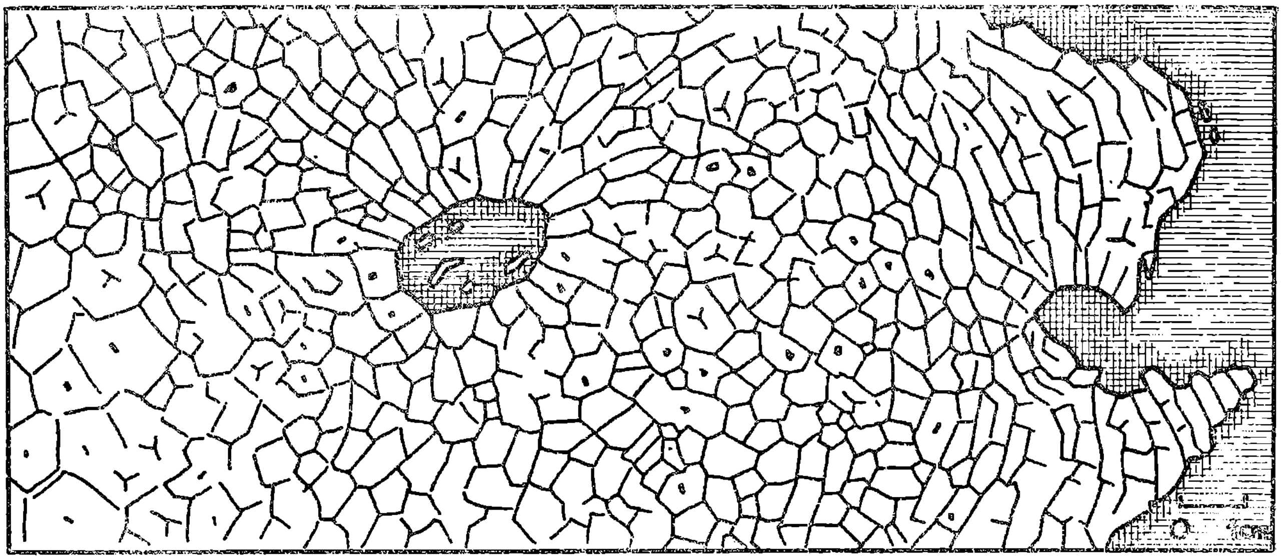

Fig. 2. Widok z góry układu zaburzeń przedstawionych na fig. 1

Fig. 2. Plan view of the deformation shown in Fig. 1. Left side — polygon covered area affected by instantaneous liquefaction of the low density layer. Right side — transverse pattern trending parallel to the margin of the intact layer of higher density (hatched area)

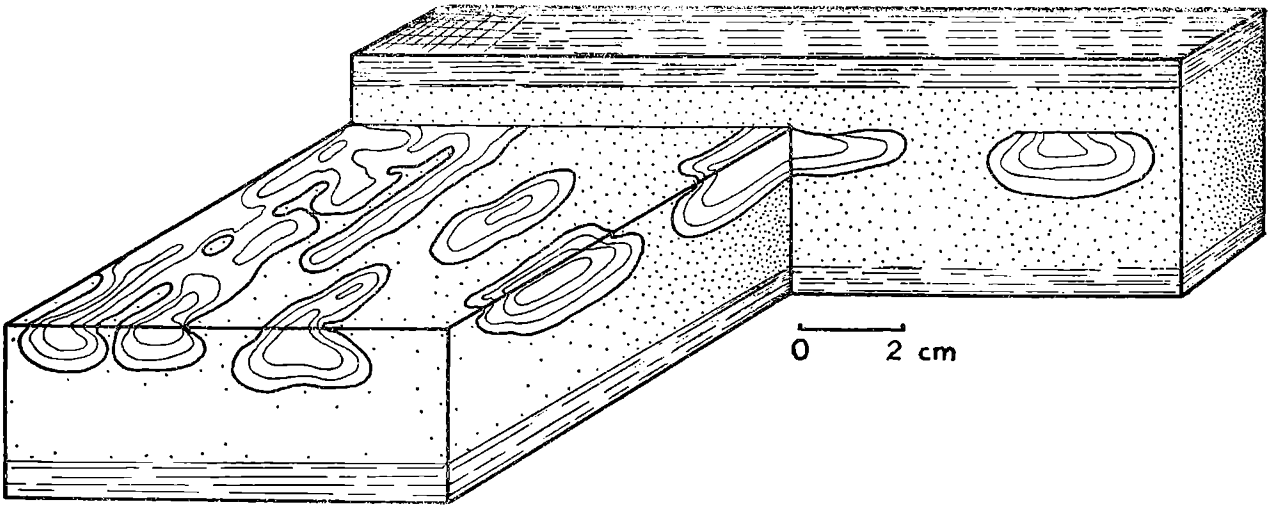

Fig. 3. Wydłużone struktury utworzone w warstewkach o większej gęstości i pogrzęźnięte w upłynnionym osadzie $k_1 \ll k_2$. Na podstawie doświadczeń

Fig. 3. Elongated structures of laminated sediment embedded in structureless substratum. $k_1 \ll k_2$. Based on experiments

the plaster of paris layer into elongated bodies parallel to the boundary between the deformed and intact areas, and transverse to the direction of propagation. As a result of its higher kinematic viscosity, the plaster of paris formed narrow bands, restricted between broader clay intrusions.

3. In similar experiments with a more viscous clay ($k_1 \ll k_2$) (at least at the beginning of deformation), the configuration is reversed in that the clay now forms the narrow bands. The slow lateral spreading of the deformation breaks up the plaster of paris layer (or sets of plaster of paris laminae differing in colour) in the form of highly elongated, canoe-shaped bodies. These may be only partly separated by the clay ridges, forming patterns similar to that shown in Fig. 3. As the viscosity of the clay decreased with progressing deformation, the bodies sank down so that their margins were warped upwards in the manner shown by Kuenen's experiments (Kuenen, 1958) on the „pseudo-nodules" of Macar (1948). On reaching a more resistant base-level the structures showed a tendency to flatten by lateral spreading.

Since the configuration of the boundary surface may change during the process of deformation, those structures formed in the final stage of the process need not necessarily parallel those formed at an earlier stage.

4. In other experiments a morphologically similar pattern was obtained as follows [1]; Dilute suspensions of plaster of paris were successively released to form a sequence of horizontal turbidite laminae upon a soft clay substratum. A denser suspension was then introduced onto the still soft, laminated sequence. The resulting structures are shown in Fig. 4. The elongate structures exhibit a roughly rhomboidal shape in vertical cross-section and display typical pseudo-nodular features with almost complete closure of the warped laminae. The longer axis of the rhomboids dips consistently in the down-current direction so that the diapiric clay ridges separating the pseudo-nodular structures are deflected in the up-current direction. The deformational structures depicted in Fig. 4 differ from those produced by Dżułyński and Radomski

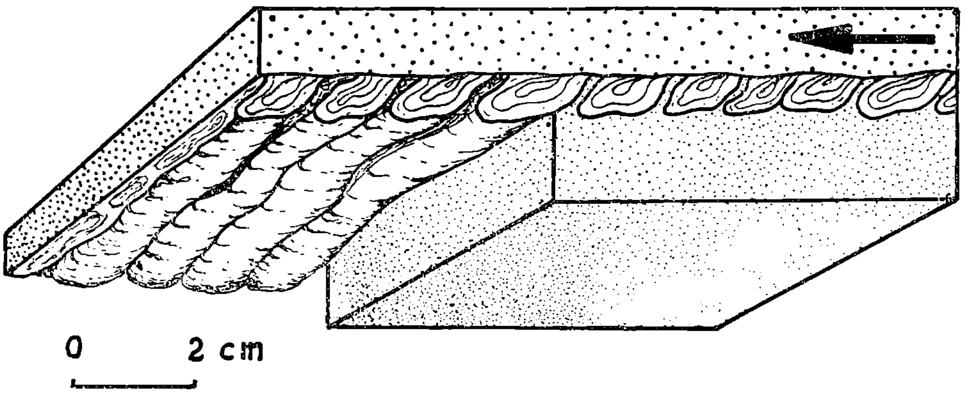

Fig. 4. Odkształcenia w pierwotnie poziomo ułożonych warstewkach podścielonych upłynniającym się iłem. Zaburzenia wywołane przejściem zawiesiny, która osadziła ławicę pokrywającą strefę zaburzeń

Fig. 4. Transverse patterns of structures obtained experimentally in the presence of horizontal shear exerted by a moving suspension. Suspension deposit open stippling. Densely stippled layer below the deformation structures represents liquefied clay layer. Note „flame structures" deflected in the up-current direction

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[1] Experiments conducted jointly with Dr. A. Radomski.

(1966) in experiments on similar models, not only in their pattern but also in their position relative to the flow which triggered off the deformation .In the case investigated by the above authors the laminae were deformed by the flow and, due to buoyancy effect, lifted into and incorporated in the heavy suspension. In the case under discussion the flowing suspension merely exerted a slight horizontal shear, warping the set of laminae and thus initiating a transverse pattern relative to the flow direction. At the same instant, the clay substratum underwent liquefaction and the transverse structures sank to form pseudo-nodular bodies. However, as a result of the slight horizontal translation of the laminated sequence inherent in the formation of the initial warping, the trajectory of the sinking bodies was deflected in the down-current direction.

5. Very similar patterns to those discussed above have been produced in experiments designed to investigate the instability of layered fumes with temperature generated reversed density gradients, in the presence of a very low velocity shear (Graham, 1934). Graham did not attempt to interpret the pattern but it would appear that a parallel may be tentatively drawn with the structures discussed in section (4). Chandra (1938) interpreted an analogous pattern as a boundary effect, on the basis that its developement was limited to the walls of the chambers in which the experiments were conducted. It is probable that this suggestion holds true for the structures described in sections (2) and (3), where the boundary effect is exerted by the liquefaction front. It is suggested that a progressing liquefaction front may also play a part in the formation of transverse structures in systems where there is a component of horizontal shear. Here it would be generated concomitantly with the flow of the heavy suspension and enhance the transverse elongation already induced by shearing.

6. The structures described above are, seemingly, uncommon in natural sedimentary sequences. It is suggested, however, that the lack of field evidence may be largely a reflection of the scarcity of three--dimensional descriptions of deformation structures. The type described in section 2., may presumably occur in association with density controlled, patterned grounds, however, field evidence is lacking. Structures corresponding to those in section (3), have been found in flysch siltstones. They have also been noted in some „crumpled limestones” from the Wellenkalk (Bogacz et al., 1968). Structures which may be compared with those discussed in section (4), are known from the bottom surfaces of some composite sandstone beds in flysch. The basal part of such beds consists of fine grained, laminated sandstone which is strongly welded across a surface of discontinuity, marked by a change to the coarser sandstone which makes up the rest of the bed. The deformations are limited to the laminated part and display elongate structures, trending more or less transverse to the direction of current flow, associated with roughly polygonal, circular, and irregular deformation structures. A similar association has been observed among the experimental „replicas”. This is probably due to the fact that the current shear may not affect the field uniformly, so that structures formed simply by down-sinking may occur simultaneously.

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WYKAZ LITERATURY
REFERENCES

Artyushkov E. V. (1965), Convective deformations developed in feebly lithified sedimentary rocks (in Russian). *Izviest. Akad. Nauk USSR, ser. geol.*, no. 12, p. 79—101.

Bogacz K., Dżułyński S., Gradziński R., Kostecka A. (1968), Origin of crumpled limestone in the Middle Triassic of Poland. *Rocz. Pol. Tow. Geol. (Ann. Soc. Geol. Pol.)*, 38, Kraków, in press.

Chandra K. (1938), Instability of fluids heated from below. *Proc., Roy. Soc., ser. A*, 164, p. 231—242, London.

Dżułyński S. (1966), Sedimentary structures resulting from convection-like pattern of motion. *Rocz. Pol. Tow. Geol. (Ann. Soc. Geol. Pol.)*, 36, p. 3—21, Kraków.

Dżułyński S., Radomski A. (1966), Experiments on bedding disturbances produced by the impact of heavy suspensions upon horizontal sedimentary layers. *Bull. Acad. Pol. Sc., Sér. sc. géol. et géogr.*, 14, no. 4, p. 227—230.

Dżułyński S., Simpson F. (1966), Experiments on interfacial current markings. *Estratto da Geologica Romana*. 5. p. 197—214.

Graham A. (1934), Shear pattern in an unstable layer of air. *Phil. Trans., Roy. Soc.*, London, A, 232, p. 265—296.

Kuenen Ph. H. (1958), Experiments in Geology, *Trans. Geol. Soc.*, Glasgow, 23, pp. 1—28.

Macar P. (1948), Les pseudonodules du Famenien et leur origine. *Ann. Soc. Geol. de Belg.*, 72, p. B, pp. 47—74.

Stewar A. D. (1963), On certain slump structures in the Torridonian Sandstones of Applecross. *Geol. Mag.* 100, p. 205—218.

Terzaghi K. (1956), Varietties of submarine slope failures. *Proc. Tex. Conf. Soil. Mech. Found. Eng.*, 8, 52, 41 p.