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O WZORACH PRZESTRZENNYCH ZABURZEŃ KONWOLUTNYCH W OSADACH O WARSTWACH STATYSTYCZNIE JEDNORODNYCH I NIEJEDNORODNYCH

(Tabl. XXXVII—XXXVIII i 4 fig.)

Patterns of density controlled convolutions involving statistically homogeneous and heterogeneous layers

(Pl. XXXVII—XXXVIII and 4 Figs.)

STRESZCZENIE

Zaburzenia konwolutne powstają najczęściej w następstwie pionowych ruchów w osadach laminowanych o niestatecznym warstwowaniu gęstościowym. Zaburzenia tego rodzaju mogą układać się w regularne wzory konwekcyjne, jeśli spełnione będą ku temu określone warunki. Jednym z nich jest dwudzielność ławicy konwolutnej (skorupowej), to znaczy występowanie w niej dwu członów, z których dolny ma mniejszą gęstość. W ławicach o jednolitym składzie litologicznym taka dwudzielność może zaistnieć w przypadku różnic w upakowaniu ziarn. Innym warunkiem, niezbędnym do pojawienia się regularnych wzorów konwekcyjnych w odkształceniach konwolutnych, jest statystyczna jednorodność członów pod względem strukturalnym. Warunek ten wymaga, by wymiar członów biorących udział w odkształceniu był dostatecznie wielki w porównaniu z istniejącymi w nich nieciągłościami strukturalnymi. Te ostatnie powinny również być dostatecznie blisko siebie rozmieszczone, tak aby w skali danego członu tworzyły zbiór gęsty.

Konwolucje o regularnym uporządkowaniu przestrzennym przedstawione na przykładach dwudzielnych ławic z fig. 1—4, tabl. XXXVII—XXXVIII mogły się dopiero wówczas utworzyć, gdy miąższość ich górnych członów wzrosła, i to do tego stopnia, iż człony te stały się statystycznie jednorodne. Tam gdzie górnym członem była warstwa zbudowana ze zmarszczek piaszczystych, warunek jednorodności, a zarazem warunek powstania samorzutnych i regularnych odkształceń konwolutnych został spełniony dopiero wówczas, gdy rozmiary zmarszczek zmalały w porównaniu z miąższością warstwy riplemarkowej. Pokrywa się to z wnioskiem wypływającym z dość dużych średnic pogrązów o kształcie komór konwekcyjnych (fig. 1; tabl. XXXVII fig. 1), o których skądinąd wiadomo, iż są proporcjonalne do miąższości warstw (członów) objętych ruchami gęstościowymi.

W osadach o niestatecznym uwarstwieniu gęstościowym, w których pojawia się szereg układów dwudzielnych, lub nieciągłości, względnie

nierówności, w obrębie poszczególnych członów są w porównaniu z miąższością tych ostatnich znaczne, nie dochodzi do utworzenia się samorzutnych i regularnych odkształceń konwekcyjnych. Nieciągłości takie wpływają bowiem w sposób istotny na przebieg zaburzeń konwolutnych i rozstrzygają zarówno o kształcie, jak i miejscu tworzenia się pogrązów oraz wciśnięć lżejszego osadu. W takich przypadkach może się wprawdzie pojawić regularność w układzie zaburzeń konwolutnych, ale będzie ona jedynie odzwierciedleniem pewnych prawidłowości w kształcie lub w rozmieszczeniu nieciągłości. Tak bywa, między innymi, w przypadku konwolucji powstałych w wyniku grzęźnięcia odosobnionych zmarszczek piaszczystych lub grzęźnięcia cienkiej warstwy riplemarkowej w laminowane podłoże o mniejszej gęstości, (nierówności w stropie cienkiej warstwy riplemarkowej są duże w porównaniu z jej miąższością). Jest to jednak regularność nie samorzutna, ale wymuszona i zdeterminowana, ponieważ pogrązy wystąpią pod grzebietami zmarszczek, a wyciśnięcia pomiędzy nimi.

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A b s t r a c t. Convolute structures may show patterns identical with those produced by instability in density stratification in fluids, provided that the layers involved in deformation are structurally homogeneous in a statistical sense. Non-penetrative discontinuities on the other hand may, if present, control the deformation and determine the pattern of convolute structures.

1. INTRODUCTION

The present paper is concerned with one aspect only of density controlled convolutions, namely, their patterns in three dimensions. Broader questions concerning the varieties, environments and details of formation of convolute lamination, fall outside the scope of the present article. The reader is referred to the voluminous literature listed in publications by E i n s e l e (1963) and D a v i e s (1965).

Field evidence has shown that where convolutions involve a system of two structurally homogeneous members (which may consist of a number of layers), their pattern is identical with that of density controlled deformations in unstable plastic or liquid media. Before proceeding with this question it is desirable to define some terms already used in structural analysis of tectonites.

According to P a t t e r s o n and W e i s s (1961, p. 854) a body is considered as „statistically homogeneous on a certain scale when the average of the internal configuration in any volume element is the same for all volume elements with dimensions not smaller than the scale of consideration". Thus a rock, or a sediment, which is heterogeneous on a small scale may be homogeneous on a large scale with respect to certain properties. Structural homogeneity in a statistical sense demands that the discontinuities which may occur in a given body should be „penetrative", i. e. small on the scale of the body and „repeated at distances so small" that they can be „considered to pervade it ...uniformly ...at every point" (T u r n e r and W e i s s, 1963, p. 21). Discontinuities which are non-uniformly distributed or are large on the scale of the member are non-penetrative and members in which they occur may be regarded as heterogeneous. Viewed from the point of structural homogeneity, the patterns of convolutions may be determined by the presence of non-penetrative discontinuities while, spontaneous convective patterns will occur only where the structural discontinuities are penetrative in the sense of Turner and Weiss (1963).

A. REGULAR CONVECTIVE PATTERNS

2. CONVOLUTIONS PRODUCED IN THE ABSENCE OF UNIDIRECTIONAL HORIZONTAL SHEAR

2.1. The first case to be discussed is that shown in Fig. 1 and Pl. XXXVII, Fig. 1. In this, the deformations affect a bed of fine grained sandstone which consists of two members; the lower one with parallel lamination, and the upper, composed of a multitude of crumpled ripples. The pattern of deformation is that which arises from vertical down-sinking of a plastic or fluid layer of high density into a soft sub-stratum of lower density, provided the ratio $k_1/k_2 \ll 1$ (where k_1 and k_2 are kinematic viscosities of the upper and lower members respectively). Patterns of this kind have been repeatedly described from experiments on instability in density stratification in fluids (Benard, 1801; Hudino, 1933) and sediments (Artyushkov, 1965; Dżułyński, 1966), in the absence of horizontal shear.

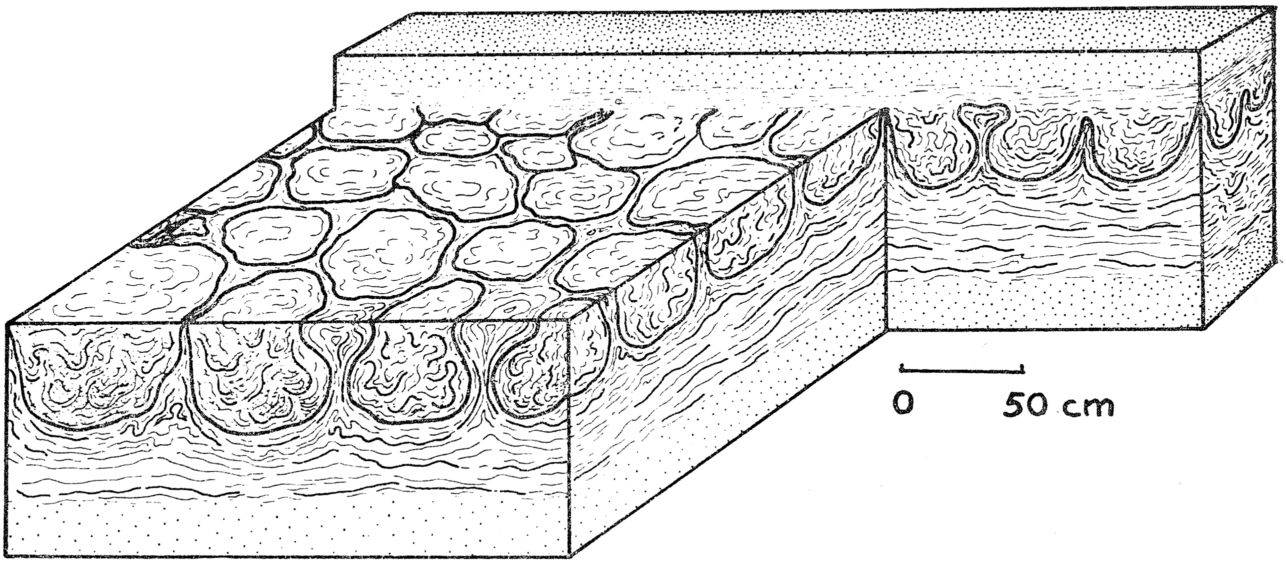

Fig. 1. Wzór przestrzenny struktur konwolutnych w dwudzielnej ławicy utworzony przy całkowitym braku przemieszczenia między członami. $k_1 \ll k_2$ (k_1 — lepkość kinematyczna górnego członu z riplemarkami, k_2 — lepkość kinematyczna dolnego, równolegle laminowanego członu)

Fig. 1. Pattern of convolution produced in a two-member system in the absence of horizontal shear. $k_1 \ll k_2$. Top member rippled. Three dimensional picture of the structures shown in Pl. XXXVII fig. 1

Development of a pattern of more or less, polyhedral structures is however, possible only under conditions of structural and statistical homogeneity of the layers involved in the deformation. In the system under consideration both members conform to these conditions. The ripples and the laminations are small and evenly distributed throughout the members in which they occur i. e. they are penetrative discontinuities on the scale of the members. They are also penetrative on the scale of the deformations.

The size of polyhedral structures is known to be proportional to the thickness of the members involved in density controlled deformation. It can be seen therefore, that the convolute deformations shown in fig. 1 could not have started until the greater part of the member had been deposited.

Although the members display no apparent difference in lithology or texture, it is suggested that the reverse density gradient was due initially to a difference in packing.

The material which has been squeezed up from below to form polygonal ridges displays in some instances, mushroom-shaped terminations at the junction between three neighbouring pendent lobes. Elsewhere, these terminations show a marked lateral spreading over the top surface of the rippled member, showing a vaguely defined, polygonal pattern where they come into mutual contact. The absence of truncated laminae in these structures implies that they developed within a sediment envelope since, it is unlikely that coherence could have been maintained at the sediment-water interface. Their development over the top-most ripple surface is an indication that deformation continued after the last ripples were deposited.

2.2. Configurations identical with those described in 2.1. are known to occur where both members are laminated (at least within the range of deformation). In such cases, the interface between the members is not clearly defined, furthermore, the cause of the initial reverse density gradient is even less evident than in the type discussed above, although it is probably due to similar reasons.

3. DEFORMATION IN THE PRESENCE OF HORIZONTAL SHEAR

3.1. The convolutions shown in Figs. 1, 2, and Pl. XXXVII, Fig. 2. involve a system which also consists of two members with the rippled one on top. As in the case discussed in 2.1, both the ripples and the laminations are penetrative features and the members may be considered as structurally homogeneous. The pattern of the interface is, however, different in that it consists of parallel, relatively narrow ridges, which trend in the direction of current flow as inferred from associated directional structures. Such a pattern is indicative of horizontal shear between the two members, and is analogous to the pattern produced by a flow of heavy suspension on a soft substratum (compare Dżułyński and Simpson, 1966). The pattern shown in fig. 1 and 2 cannot, however, be explained simply in terms of a suspension flow, since deformation must have started only after the first ripple layer at least, was formed, otherwise, the condition of structural homogeneity displayed by the member, could not have been achieved (see p. 403, 405).

Two possibilities may be invoked to explain the pattern; 1 — The ridges were already present as incipient current forms before the arrival of the ripples, and then grew up by differential compaction as the ripple layer increased in thickness.

2 — There was a horizontal shear along the interface between the two members.

The first possibility is difficult to reconcile with the close correspondence between the wave length of the deformation and the thickness of the upper member since, it appears, from experiments on „striped soils" (D ż u ł y ń s k i, 1963., B u t r y m et al., 1964.), that with large values of viscosity, the wave-length of convective shear ridges increases relatively to the scale of the unstable system. Moreover, such ridges are formed in the presence of a very small horizontal translation between the members involved in the deformation. It is suggested therefore that the convolution pattern depicted in Fig. 2 and 3 resulted from down-

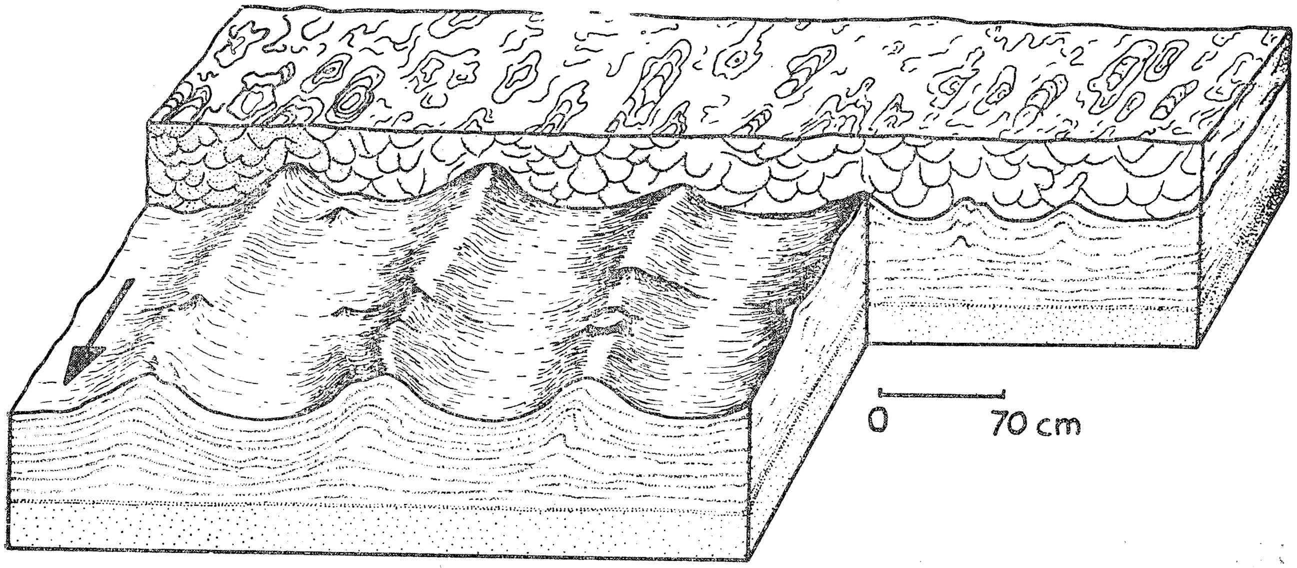

Fig. 2. Wzór przestrzenny struktur konwolutnych w dwudzielnej ławicy przy niewielkim przesunięciu poziomym między członami. $k_1 \approx k_2$. Górny człon złożony ze zmarszczek piaszczystych, dolny — laminowany równolegle. Porównaj z fig. 2 Tabl. XXXVII

Fig. 2. Pattern on convolutions produced in the presence of horizontal shear. $k_1 \approx k_2$. Top member rippled. Compare with Pl. XXXVII fig. 2

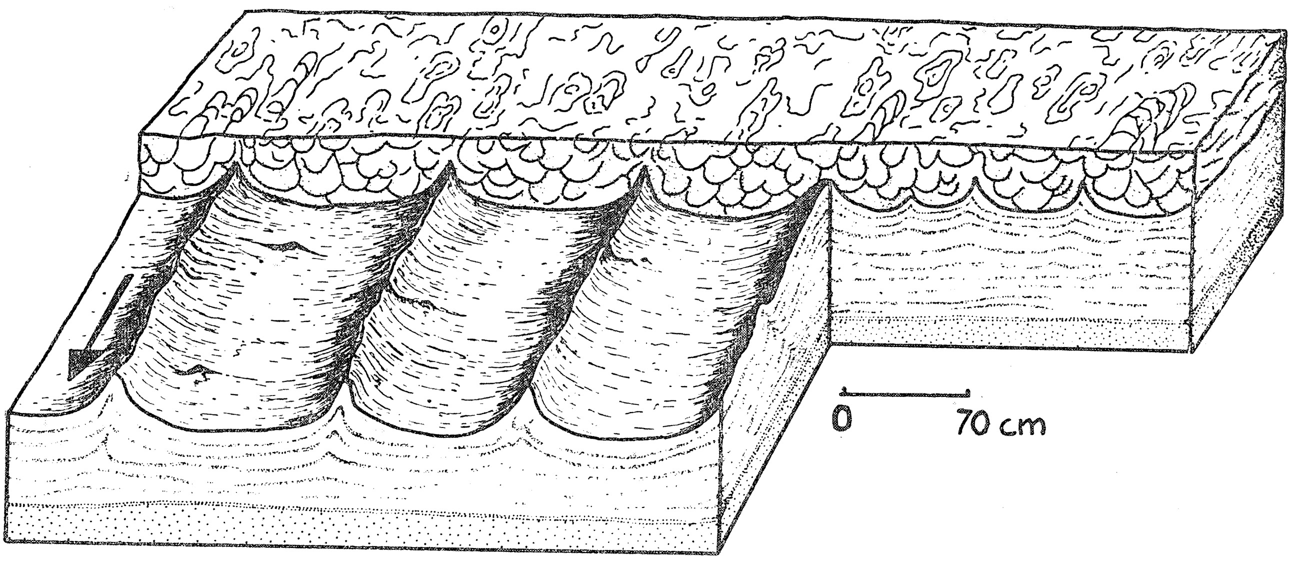

Fig. 3. Wzór przestrzenny konwolucji w dwudzielnej ławicy utworzony przy niewielkim przesunięciu między członami. $k_1 \ll k_2$. Porównaj z fig. 3 Tabl. XXXVIII

Fig. 3. Pattern of convolutions produced in the presence of horizontal shear. $k_1 \ll k_2$. Compare with Pl. XXXVIII, Fig. 3

-sinking of the rippled layer combined with a slight horizontal displacement. The displacement was most probably caused by the shearing effect of current-drag, and facilitated by partial liquefaction of the sediment underlying the rippled layer.

3.2. The convolute deformation shown in fig. 4 resulted from the same process as that discussed above. In this instance however, both members show parallel lamination.

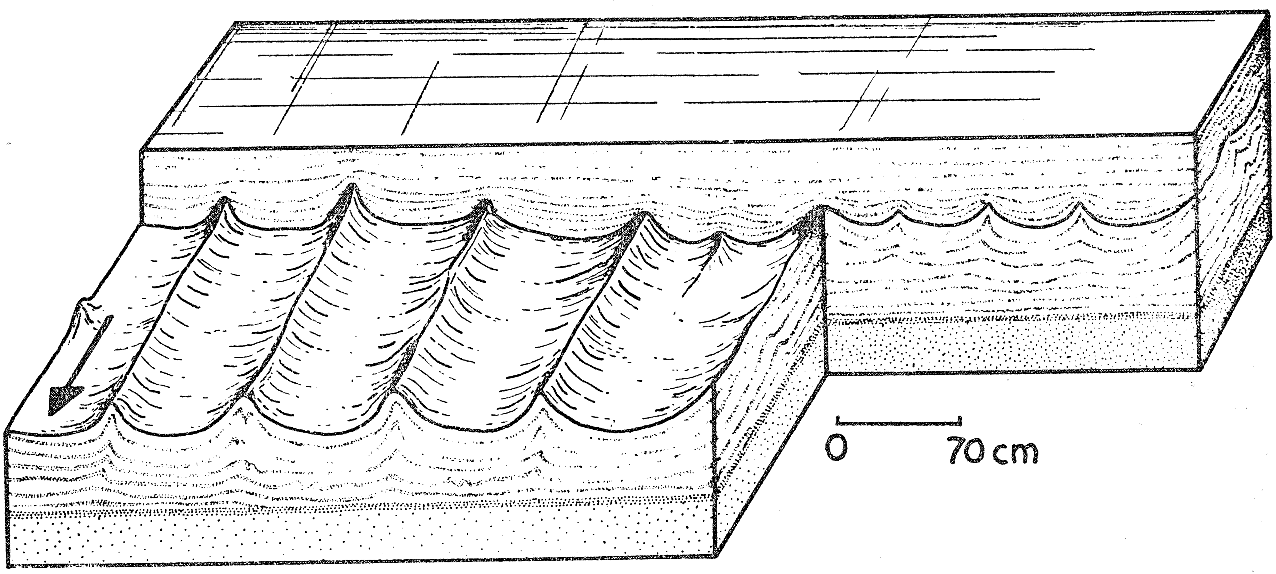

Fig. 4. Wzór przestrzenny konwolucji w warunkach jak na fig. 3. Obydwa człony równolegle laminowane. $k_1 \ll k_2$

Fig. 4. Pattern of convolutions produced in the presence of horizontal shear. Both members laminated. $k_1 \ll k_2$

3.3. Conical structures which occur intermittently on the crests of the ridges, represent diapiric intrusions formed after the shearing effect along the interface had disappeared. This is shown by the fact that the cones stand vertically. In some instances however, the apices are deflected in a down-current direction, indicating that their rate of growth was sufficient to reach a level where current-drag was still effective. The development of the diapires probably expresses the establishment of incipient „convective cells" within the troughs on the cessation of shear. The distribution of the cells would however, be controlled by the ridges, which represent non-penetrative features with regard to the system. Since the rise of existing elevations on the surface of low density material in an unstable system is a well-established fact, this would determine the preferred position of the cones on the ridge crests. It is realised that the latter also, may continue to grow upwards. The cones, once produced, create ideal conditions for „differential loading" and thus provide the easiest route for low density sediment to assume a higher and more stable position.

Conical structures, from the Krosno beds, have hitherto been interpreted as due to the sucking action of eddies on a hydroplastic substratum (Dżułyński and Smith, 1963.). In the light of present experimental data, this interpretation seems rather improbable and necessary of revision.

B. PATTERNS CONTROLLED BY NON-PENETRATIVE DISCONTINUITIES IN THE MEMBERS INVOLVED IN DEFORMATION

4.1. The patterns of convolutions discussed above, conformed more or less to convective patterns in homogeneous layers with a reversed density gradient. The regularity of such patterns is broken when one, or both, of the members shows non-penetrative discontinuities. The presence of such features may control the vertical readjustment movements within the system to the extent that the pattern of deformation is entirely dependent upon their shape and distribution.

An example of convolutions which are dependent on non-penetrative discontinuities, is provided by ripple load convolutions which result from down-sinking of ripples into a soft substratum (Einsele, 1963; Dżułyński and Ślączka, 1964; Davies, 1965). The ripples, whether isolated (incomplete) or in the form of a thin rippled layer, exert a differential pressure on the substratum with a maximum beneath the crests. With the onset of liquefaction, the lower density material of the substratum moves upwards into the low pressure areas between the crests of the ripples. The ripple structure therefore, inhibits the development of regular convective cells. It should be noted however, that if the non-penetrative features are regularly distributed, the pattern of deformation may display an „inherited" regularity.

In contrast to homogeneous systems where the distribution of domes and down-sinking lobes is undetermined, the initial distribution of non--penetrative elements controls the position of diapiric injections and down sinking of high density material (see p. 403). Non-penetrative features may be erosional or depositional structures, or due to variation in texture. They may also result from different degrees of liquefaction.

It will be obvious from the above discussion that even in simple two--member systems, a complex transitional series may exist between regular convective patterns and those determined by non-penetrative features. Convolute beds frequently represent multi-member systems in which the sequence of deformation may be even more complex. In such systems, deformation may occur at several levels within a sediment pile which is itself then involved in deformation on a larger scale. The low rank (earlier) structures may respond either as penetrative or non-penetrative features during the formation of high rank (later) structures. Multi--member systems may also develop when deformation progresses more or less concomitantly with deposition.

CONCLUSION

It would appear that the concept of statistical and structural homogeneity as applied to sedimentary deformations may serve to clarify the question of patterns as observed in some types of convolutions. Regular convection patterns of convolute structures are possible only under conditions of structural homogeneity of the members involved in the deformation. Otherwise the patterns are controlled by non-penetrative features. It is realised that the term, convolutions, covers a variety of structures which may form under different conditions and represent genetically different structural types. A large group of convolutions belong however, to deformational structures resulting from instability in newly laid, water saturated sediments. The types discussed in this paper fall within this group. They are furthermore, closely related to some „patterned" load deformations occurring on the bottom surfaces of current deposited sediments and to a number of structures commonly classed as „involutions".

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OBJAŚNIENIA TABLIC
EXPLANATION OF PLATES

Tablica — Plate XXXVII

Fig. 1. Górna powierzchnia ławicy z konwolucjami. Warstwy Inoceramowe, Koninka. Porównaj z ilustracją fig. 1 w tekście

Fig. 1. Top surface of convoluted bed. Inoceramian beds, Upper Cretaceous. Koninka — Polish Carpathians. Compare with text fig. 1

Fig. 2. Przekrój prostopadły przez dwuczłonową ławicę z konwolucjami. Warstwy Krośnieńskie, Mymoń. Porównaj z ilustracją fig. 2 w tekście

Fig. 2. Vertical section through convolutions. Krosno Beds, Oligocene. Mymoń — Polish Carpathians. Compare with text fig. 2

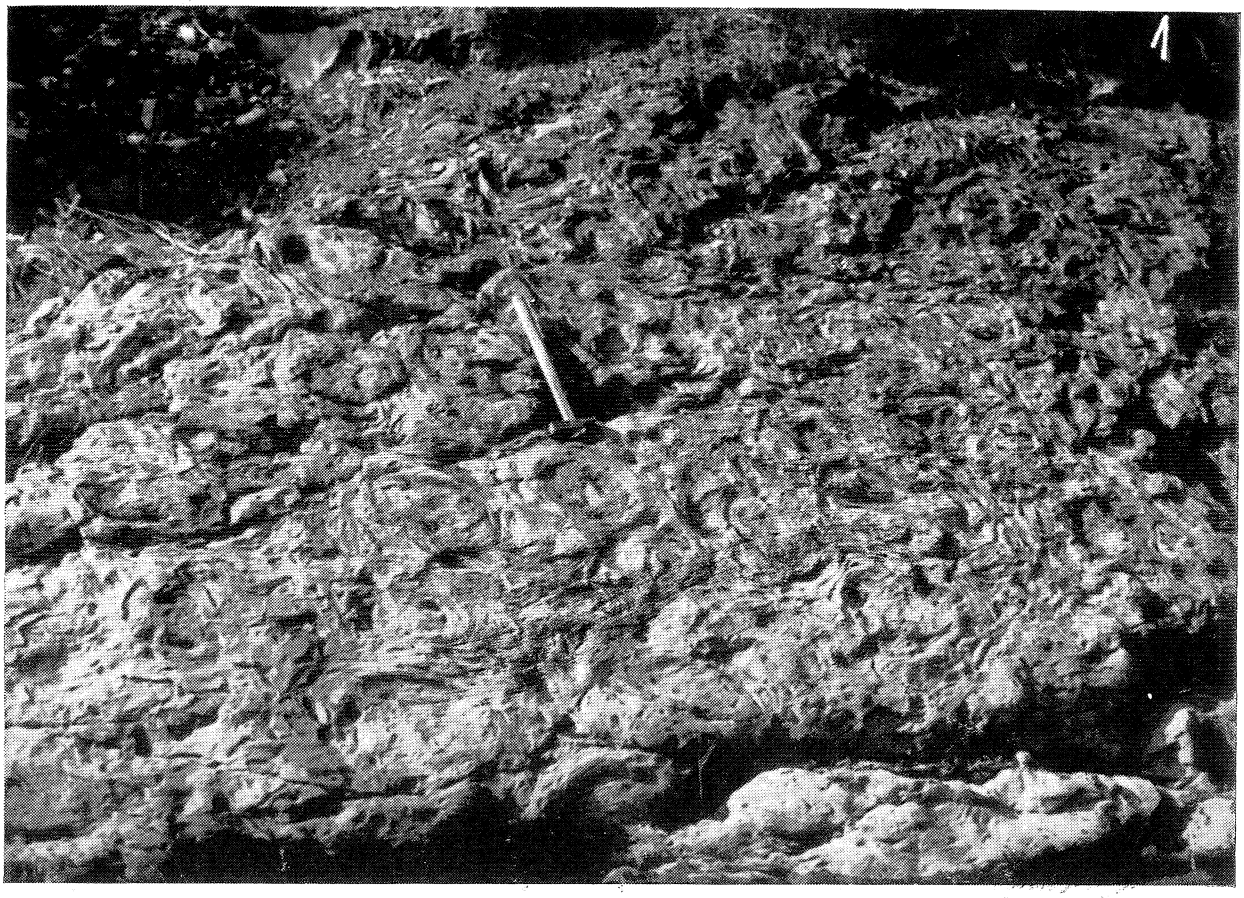
Tablica — Plate XXXVIII

Fig. 1. Fragment „łęku" zaburzeń konwolutnych wyjęty z miejsca zaznaczonego literą X na fig. 2 tablica XXXVII

Fig. 1. „Synclinal" fragment of convoluted rippled layer showing deformed ripples. Specimen taken from place indicated by X on Fig. 2 Pl. XXXVII

Fig. 2. Grzbiety i struktury stożkowe na stropowej powierzchni członu podścielającego „warstwę" z riplemarkami. Warstwy Krośnieńskie, Mymoń

Fig 2. Ridges and cones on the interface between rippled and laminated member. Krosno Beds, Mymoń — Polish Carpathians



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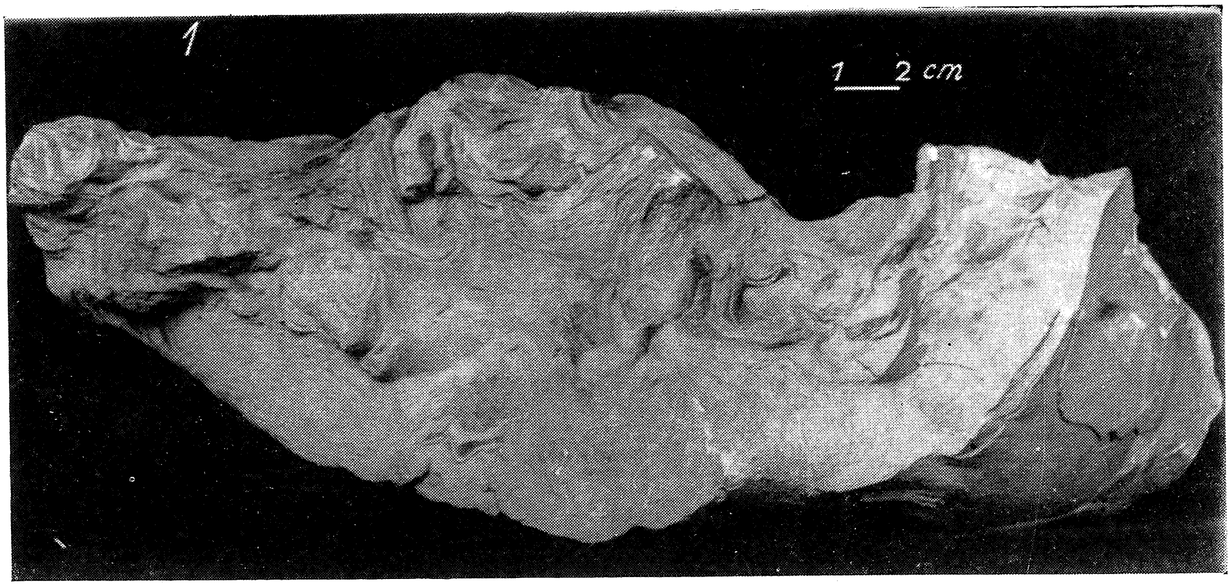

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