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# DOŚWIADCZENIA NAD PRZEŁAMEM PIERZASTYM W OSADACH

(Tabl. XXXIII, XXXIV i 4 fig.)

*Experiments on feather fracture in sediments*

*(Pl. XXXIII, XXXIV and 4 Figs.)*

## STRESZCZENIE

Na powierzchniach niektórych spękań w skałach występują często drobne, listewkowate nierówności ułożone w pierzaste wzory (tabl. XXXIII, fig. 1, 2, tabl. XXXIV, fig. 1). Struktury owe, opisane po raz pierwszy przez W o o d w o r t h a (1897) pod nazwą „feather fracture", znane są głównie z powierzchni spękań ciosowych. Stąd wywodzą się używane w polskim piśmiennictwie naukowym określenia: „cios pierzasty" (K s i ą ż k i e w i c z, 1966) lub „relief pierzasty na spękaniach ciosowych" (B o r e t t i - O n y s z k i e w i c z, 1967).

Struktury pierzaste pojawiają się jednak równie często na powierzchniach nieregularnych spękań lub obrywów w nie utwardzonych jeszcze osadach czwartorzędowych i współczesnych, a także na ściankach szczelin z wysychania (fig. 2 i 3). Struktury te są pewnym rodzajem przełamu zadzierzystego, który określać będziemy nazwą przełamu pierzastego.

Bardzo podobne przełamy pierzaste znane są z powierzchni rozerwań w metalach poddawanych rozciąganiu, jak również w niektórych, „kruchych" tworzywach niemetalicznych, jak np. w szkle lub w oziębionej do niskich temperatur parafinie.

Prawidłowe rozwiązanie pochodzenia przełamu pierzastego podał już W o o d w o r t h (1897), przyjmując, iż przełam ten powstaje w wyniku rozrywania tensjonalnego bez przesunięć wzdłuż płaszczyzny pęknięcia. Wyżej wymieniony autor ustalił również zależność, jaka istnieje między kierunkiem rozprzestrzeniania się szczelin a ułożeniem struktur pierzastych. Wykazał on, iż owe pierzaste struktury rozchodzą się wachlarzowo z punktu lub z osi w kierunku rozprzestrzeniania się szczeliny. Ostatnio wysunięto jednak pogląd odmienny, według którego pierzaste listewki na powierzchniach spękań mogłyby również zbiegać się w kierunku rozprzestrzeniania się szczelin (H i l l, 1965, 1966), a więc odwrotnie, niż to przyjmowali W o o d w o r t h i jego następcy.

W związku z zaistniałymi wątpliwościami w odniesieniu do znaczenia kierunkowego przełamu pierzastego, autorowie przeprowadzili szereg prostych doświadczeń, posługując się jako tworzywem modelowym, drobnoziarnistym, zailonym i wilgotnym piaskiem, a więc tym rodzajem osadu, w którym we współczesnych i czwartorzędowych utworach najczęściej pojawia się przełam pierzasty. Wyniki doświadczeń zostały w sposób uproszczony przedstawione na fig. 4. Okazało się, iż układ struktur pierzastych jednoznacznie wskazuje na kierunek rozprzestrzeniania się szczelin tensjonalnych, i to we wszystkich przypadkach zgodnie z prawidłowością wykrytą przez Woodwortha.

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Abstract; The results of experiments on the fracture of moist sands and silts are given. The surfaces of the fractures discussed display feather fracture similar to that observed on joint surfaces of rocks. The „feathers" diverge from regions of stress concentration, that is from the areas or points of origin of fractures, and extend in the direction of fracture propagation. The feather fracture results from tensile forces acting upon a rock which is in the state of transition from ductile to brittle behaviour.

Feather fracture (Woodworth, 1897, „plumose markings" of Parker, 1942) is a common splitting figure on joint surfaces. It consists of minute hackly ridges of very low relief, diverging from a point or indistinct axis on the faces of joint blocks (Pl. XXXIV, Fig. 1, Textfig. 1). The feather pattern on two opposing joint walls is complementary and interlocking, since the „feathers" are the splitting figures themselves (Woodworth, 1897; Parker, 1942; Hodgson 1961, 1961a).

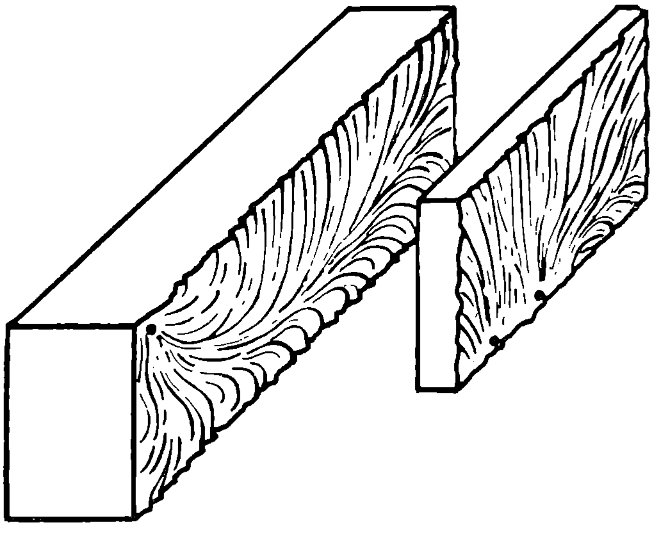

Fig. 1. Różne układy struktur pierzastych na sąsiednich i równoległych powierzchniach ciosowych. Kropkami oznaczono miejsca rozchodzenia się szczelin. Rysunek według okazu z fot. 1 Pl. XXXIV

Fig. 1. Two parallel and neighbouring joint surfaces showing different feather patterns. Dots mark the points from which the fractures started

The feather fracture in sedimentary rocks is not limited to the surfaces of true joints which occur in parallel sets. It appears on various parting surfaces which are irregular and curved. Furthermore, the feather fracture occurs on the faces of contraction joints in volcanic rocks (Woodworth, 1897), on the surfaces of disjunctive cracks developed in semi-consolidated Recent and Pleistocene silts (Pl. XXXIII, Figs. 1, 2), and on the surfaces of desiccation (Pl. XXXIII, Fig. 2 Textfig. 2 and 3) and infiltration cracks [1].

[1] i.e. cracks formed by liquid infiltration into dry powdered medium (see Cegła et. al., 1967).

Although the origin of feather fracture in rocks is not yet clearly understood, it is widely agreed that the presence of „feathers" is indicative of lateral separation of joint blocks normal to the surface of fracture (Woodworth, 1897; Muehlberger, 1961; Roberts, 1961 a, b; Hodgson, 1961 a, b; Hill, 1965). Indeed, feather fracture is never associated with slickensides tectoglyphs [2] or rock-polish (Woodworth, 1897).

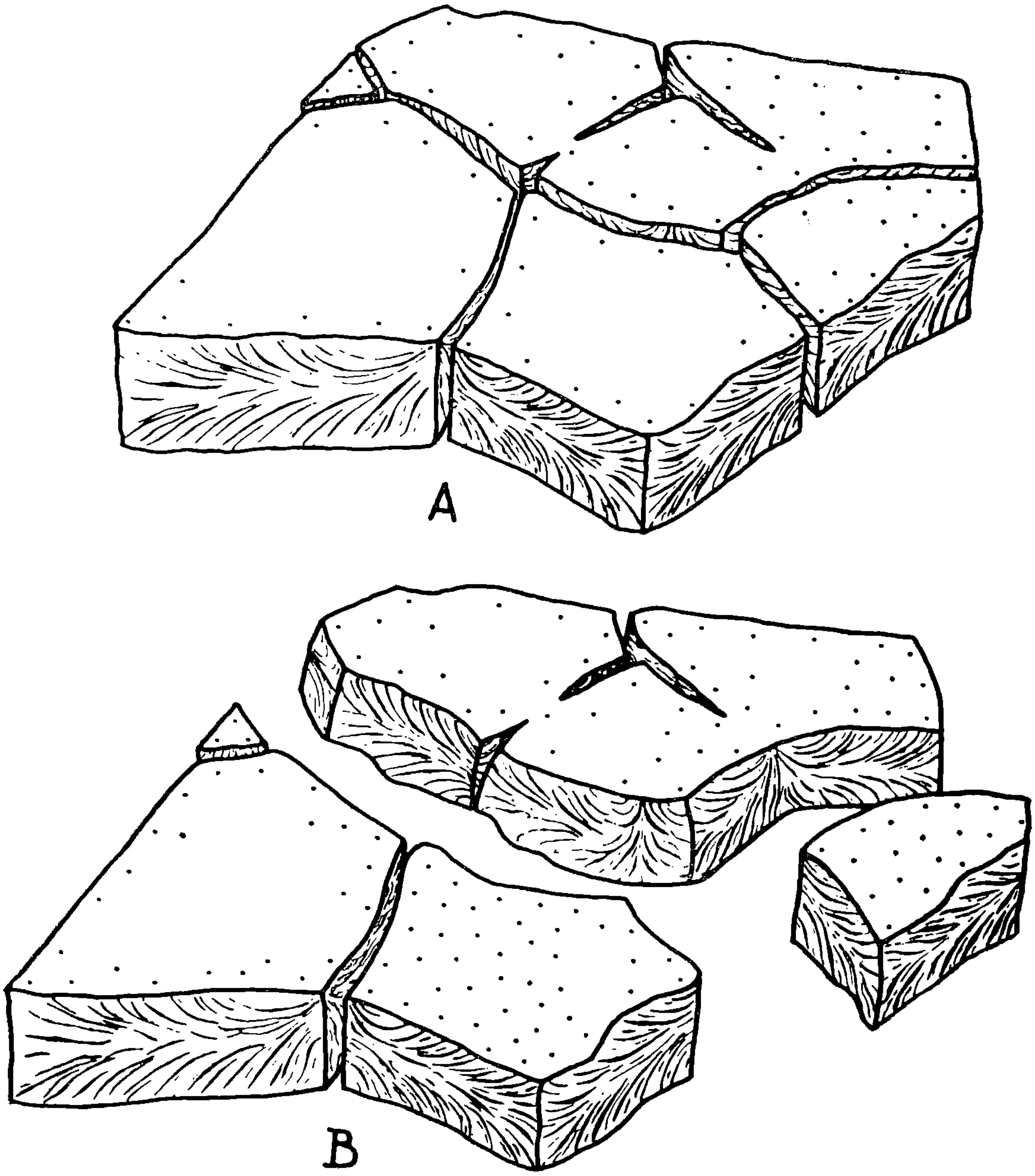


Fig. 2. Przełam pierzasty na ściankach wielobocznych szczelin z wysychania
Fig. 2. Feather fracture on the surfaces of polygonal drying cracks

Feather fracture appears to be closely allied to the so called „shatter cones" (see for example Dietz, 1961, Pl. I; and Woodland, 1964, Fig. 25), and to a number of discoidal fractures with „percussion rays"

[2] Care should be taken not to confuse feather fracture with morphologically similar tectoglyphs indicated as „tectonic chevrons" (Dżułyński and Kotlarczyk, 1965).

(Woodworth, 1897, Pl. 5, Fig. 3, Ragatt, 1954, Fig. 1) or to „hackle marks" of Solomon and Hill (1962). It has been also observed that some „brittle" materials in tension, such as glass or cooled paraffin, develop a similar kind of fracture (Woodworth, 1897; Sheldon, 1912).

Important for the explanation of feather fracture in rocks is the analogy with the „herringbone fracture" displayed by fatigue and static

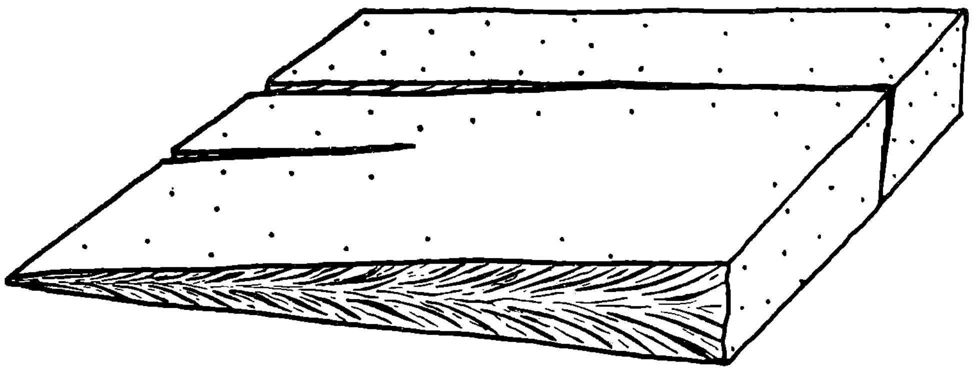

Fig. 3. Przełam pierzasty na równoległych szczelinach z wysychania. Kierunek rozprzestrzeniania się szczeliny od lewej ku prawej

Fig. 3. Consistent orientation of feathers on the surfaces of parallel drying cracks. Fracture started at the left side

tension ruptures in metals (see Bridgman, 1912 Fig. 8; Nadai, 1950 Fig. 15—11). The significance of this analogy lies in the implication of similarity of causes and some common sets of physical factors for both, the „herringbone fracture" in metals and the feather fracture in rocks (Roberts, 1961; Boretti-Onyszkiewicz, 1967).

The herringbone fracture in metals results from relatively rapid separation, perpendicular to the fracture surface. The mechanism involved in the formation of this type of fracture is not yet completely understood. There is, however, little doubt that the „arrows" in the herringbone pattern in metals (which correspond to the „barbs" of feathers in the feather fracture in rocks) point in the direction from which the tensional cracks originated (Nadai, 1950).

A divergence of opinions has been recently expressed concerning the question of directional significance of similar features exhibited by the feather fracture in rocks. Most authors following Woodworth (1897) proceed from the assumption that the feathers diverge in the direction of splitting, and that they are „concave to the point of origin of the fracture" (Woodworth, 1897 p. 166). However, Hill (1965, 1966) suggested another possibility, namely that some feather fractures might have propagate concave edge forward, i.e. the feather barbs may converge in the direction of fracture propagation. Another controversial question is, whether the feather fracture is necessarily indicative of „rapid separation of medium which proceeded with a high rate of propagation" as assumed by Roberts (1961, p. 489). According to Roberts, slow fracturing inhibits the formation of feather patterns. This assumption, however, is incompatible with occurences of feather fracture on the faces of drying cracks (Textfig. 2 and 3) and other divisional surfaces in soft, semi-consolidated sediments.

The present series of experimental investigations was begun with a view to testing this premise and was conducted on materials so chosen as to have similar mechanical properties to natural silts showing feather fracture.

The tests were performed on silts and fine silty sands of uniform grain-size which were settled from dense watery suspensions in cardboard boxes. The removal of excess water through the permeable cardboard walls gave a suitable model material containing just enough interstitial water to ensure dilatant behaviour. After the removal of the cardboard walls, the settled sand bodies retained the shape of orthogonal slabs. These were subjected to tensile stresses up to the point of failure.

The results of the tests are as follows:

1) With slight bending of the slab, open fractures started to from at a number of points along the crest of the deformed slab. These incipient cracks became the regions from which the diverging feathers were observed to propagate downwards, concomittantly with a slow propagation of cracks in this direction (Textfig. 4 A).

2) If bending was accompanied by unidirectional progressive splitting, as illustrated on Fig. 4B, the feathers which started to radiate from the incipient crack, deviated laterally in the direction of progressing fracture (Textfig. 4 B, Pl. XXXIV, Fig. 4).

3) If unidirectional splitting exclusively was applied, and in such a way that the incipient fracture developed first on one side of the slab only, and then progressed laterally towards the other side (Textfig. 4C, Pl. XXXIV, Fig. 3), a feather fracture resulted with the axis trending roughly parallel to the top and bottom surfaces of the slab (Pl. XXXIV, Fig. 3).

4) If tensional stress was applied so as to produce two incipient cracks on the opposite sides of the slab (Fig. 4 D), and then these cracks started to propagate towards each other, the „reversed feather fracture" of Woodworth was formed.

Thus it is apparent that the feather fracture provides a reliable criterion for determining the direction of fracture propagation. The feathers diverge always in the direction of fracture propagation, in agreement with the view set forth by W o o d w o r t h (1897).

Rapid separation is apparently not a necessary condition for the formation of feather fractures. These splitting figures may form with slowly propagating cracks, depending on the mechanical properties of the material fractured. Dry slabs, when acted upon by tensile stresses, broke down without discernible feather fracture. In such cases the separation progressed rapidly and the incipient fractures were instantaneously transmitted from a great number of points. It appears that the delayed propagation of fractures favours, while the rapid progression and instantaneous formation of a multitude of incipient cracks inhibits the formation of feather fracture. It should be borne in mind, however, that the speed at which the cracks move is determined by the mechanical properties of the material (H a r d y, 1959).

In the experiments discussed, the fractured materials were in elastoplastic state, and showed the mechanical properties which were transitional from ductile to brittle behaviour. This is presumably another factor favouring the formation of feather fracture. Soft, water-saturated sediments may show the transitional behaviour under atmospheric pressure. More indurated rocks would respond in the same manner under confining pressure.

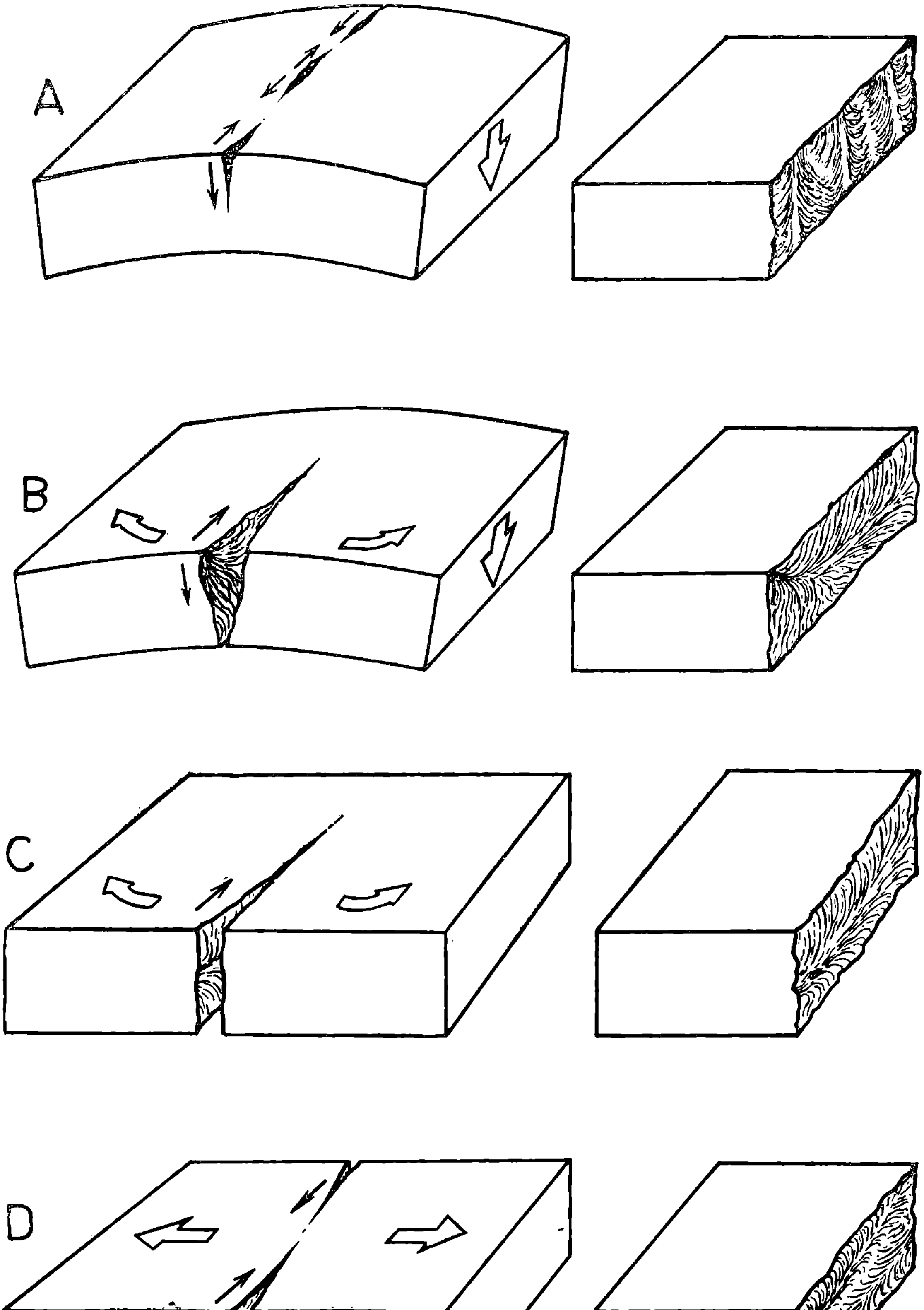


Fig. 4. Układ struktur pierzastych w zależności od sposobu odkształcania. Objaśnienia w tekście

Fig. 4. Different orientation of feathers depending on the manner in which the tensional force is applied. Explanation in text

Feather fracture commonly begins on external surfaces of the slabs under test. However, the axes of feathers starting from points on the top or bottom surfaces of slabs tend to deviate from their incipient vertical course, and trend parallel to these surfaces. This behaviour, conspicuous in thin slabs, accounts for the predominance of parallel orientation of feather axes with respect to bedding surfaces, as observed on natural joint planes.

It is to be noted that fractures may be initiated either on top or bottom surfaces of slabs in the absence of bending, and result from simple lateral tension. This is a characteristic property of tensile fracture in the so-called „brittle" materials subjected to tensile stresses (Bridgman, 1952). As indicated by Hill (1965) small „imperfections" on bedding surfaces of rocks may prove to be important in the initiation of fractures.

The appearance of feather fracture is a reliable, though not exclusive [1], criterion of rupture by tension in a plane which perpendicular to the direction of tension. It is, however, indicative of neither the external conditions under which the fracturing is accomplished nor the type of the forces which preceed the final rupture (see Roberts, 1961). This is already evident from the fact that feather fracture is equally common on the surfaces of drying cracks as on the fracture surfaces in specimens tested in pure bending or static tension.

Feather fracture shows, however, the manner in which the fractures were initiated and propagated, and therefore may furnish a valuable clue to the early deformational history of rocks.

It should finally be noted that measurements of the orientation of feather fracture on joint faces offers a possibility to explain the origin of some of the joint systems for which no satisfactory mechanical explanation has been advanced.

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## OBJAŚNIENIA TABLIC
## EXPLANATION OF PLATES

### Tablica — Plate XXXIII

Fig. 1—2. Przełam pierzasty na ścianach obrywów powstałych w czwartorzędowych utworach mułowych w następstwie podcięcia przez rzekę. Dolina Wisłoki na pn. od Dębicy. Fot. L. Starkel

Figs. 1—2. Feather fracture in Pleistocene muds. Disjunctive fissures in river undercuts. Phot. L. Starkel

Fig. 3. Przełam pierzasty uzyskany doświadczalnie. Zarysy struktur pierzastych zaokrąglone w wyniku wtórnego upłynnienia

Fig. 3. Experimentally produced feather fracture. Feather structures slightly blurred due to partial liquefaction

Tablica — Plate XXXIV

Fig. 1. Przełam pierzasty na powierzchniach spękań ciosowych we fliszu. Warstwy podmagurskie. Zawoja. Ze zbiorów prof. M. Książkiewicza

Fig. 1. Feather fracture on joint of flysch sandstones. Sub-Magura beds (Eocene). Courtesy of prof. M. Książkiewicz

Fig. 2. Przełam pierzasty na ściankach doświadczalnych szczelin wysychania

Fig. 2. Feather fracture on the surfaces of experimental drying cracks

Fig. 3—4. Przełam pierzasty uzyskany doświadczalnie. Objaśnienia w tekście

Figs. 3—4. Feather fracture produced experimentally. Explanations in text

Addendum. After this paper was sent to the Editor, the present authors came across an important publication by A. Corte and A. Higashi on „Experimental Research on Desiccation Cracks in Soil" published in Cold Regions & Engineering Laboratory Research Report 66, December 1964. In this publication feather fracture on desiccation cracks is described as „interfacial fracture markings".


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