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PEBBLE CLUSTERS AS A DIRECTIONAL STRUCTURE IN FLUVIAL GRAVELS: MODERN AND ANCIENT EXAMPLES

CONTENTS

Abstract

Pebble clusters abound in both the Recent alluvial gravels and the Late Paleozoic fluvial conglomerates of the Intrasudetic Basin. In fact, pebble clusters are small-scale pebble jams forming characteristically in front of obstacles. Some may also contain sand shadows behind them. Generally, any object protruding above the surface of accumulation may act as such an obstacle. As a rule, the structures parallel mean (paleo) flows. C-fabric measurements of flat clasts grouped to form pebble clusters revealed rather a high dispersion in dip directions attributable to perturbations of flow passing round the obstacles. Field evidence indicates that the best paleocurrent data may be obtained measuring the orientation of flat obstacles only. In alluvial environment pebble clusters (as well as imbrication in general) require turbulent, rapid or nearly so flows and may be considered to be indicative of such (paleo) hydraulic conditions. The presence of pebble clusters in debris-flow deposits is also briefly discussed.

INTRODUCTION

Pebble clusters — structures common to almost all fluvial gravels — have been defined by Dal Cin (1968, p. 233) as ,,wake-like piles of coarse particles" accumulated ,,in front of the obstacle which stopped them"[1]. The obstacle is usually a cobble or boulder. Pebble clusters have been found by Dal Cin to be good directional structures ,,because they are always parallel, or nearly so, to the direction of the current and because the wake is almost always upstream and the boulder downstream" (*op. cit.*, p. 233). The paper cited provides also good descriptions of the structures in questions as well as some empiric

[1] Earlier still Wobber (1964) has described similar features from the Lower Jurassic limestones of Glamorgan, South Wales. These were formed in a shallow sea owing to topographically-controlled longshore currents. Unfortunately, Wobber described them but did not give a name to them. Analogous structures (,,grouping in clusters") have been also reported from the Sularpsbäken brook by Johansson (1960, 1965). According to him these seem ,,to be an important factor in the splitting and skewness of the [pebble] fabric" (Johansson 1965, p. 12).

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relations between the shape and size of the clusters and analógous parameters of the boulders.

The application of these criteria for fossil fluvial gravels is, however, hampered by the fact that vertical cliffs only rarely cut the structures parallel to the paleoflow. Moreover, uncovering of the clusters in lithified deposits may be too time-consuming and expensive (see Dal Cin, *op. cit.*, p. 235—236). The same lithified gravels, on the other hand, commonly ensure conditions favouring fabric measurements. Fabric is, in fact, the main source of paleocurrent data in many if not all continental gravels. So, in the investigation described in this paper the aim has been to analyze in detail fabric of flat clasts shingled and grouped together to form pebble clusters. This has been performed on modern mid-channel bar gravels of the River Bóbr and some other natural streams of the Central Sudetes (pl. I, *1*, *2*). Another purpose of the study has been to demonstrate the applicability of such field-derived results to some fluvial conglomerates of the Intrasudetic Basin.

Although rarely considered to be self-contained structure, pebble clusters were, in reality, observed in many fluvial conglomerates ranging in age from the Archean till the Quaternary (see Pettijohn 1957; Potter and Pettijohn 1963; Pettijohn and Potter 1964; Johansson 1965; Reineck and Singh 1973). Perhaps amongst the best examples of pebble clusters in Archean conglomerates are the structures described and illustrated by Pettijohn (1930) from Little Vermilion Lake, Ontario.

FIELD AREA

The River Bóbr between Ciechanowice and Dębrznik was selected for study area because of the presence there of well developed gravel bars and frequent variations in discharge, which within the river banks is practically a natural phenomenon. A bar investigated in detail is located immediately below the confluence of the River Bóbr and the Lesk Creek, a right-side tributary of the Upper Bóbr (fig. 1; pl. I, *1*). The bar was studied systematically for six years ('70—'75). Although it has been found to be rather a permanent feature, yet each flood may result in some modifications in bar's topography or, at least, in the formation of new pebble clusters. These have been investigated in detail just after a late-spring flood in June '75.

Along its natural course, the River Bóbr is a bed-

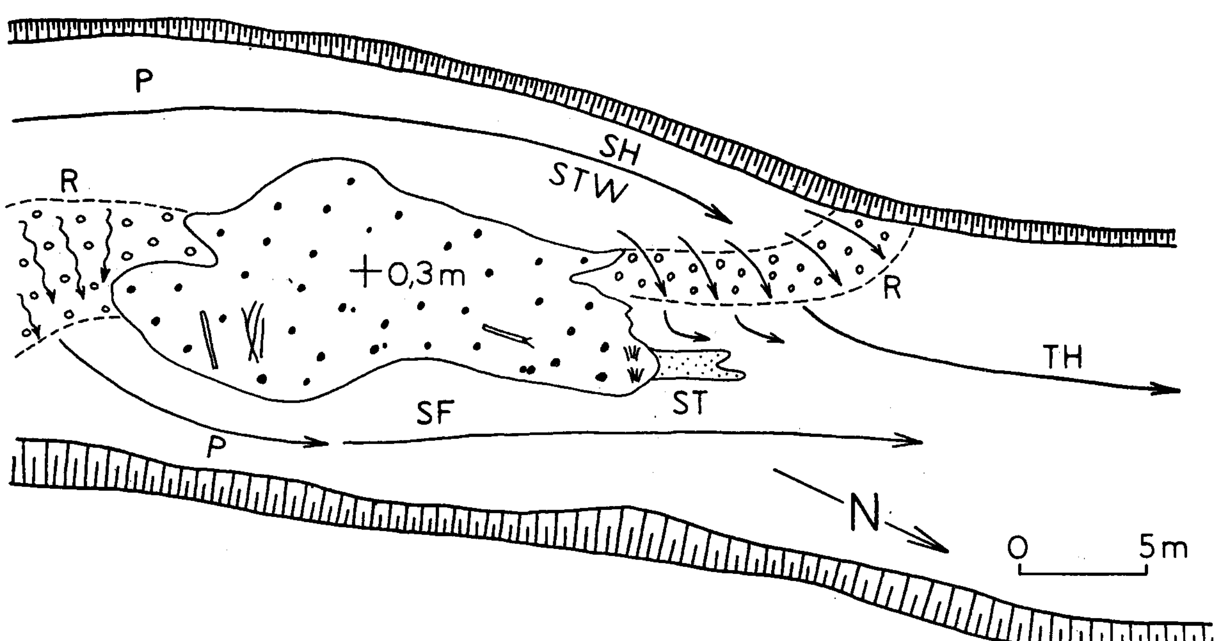


Fig. 1

Braid bar on the River Bóbr, 3050 m south-east of the old church in Marciszów: area of detailed study

Explanation to symbols: *P* — pool, *SH* — shoal, *STW* — standing waves, *R* — riffle, *TH* — thalweg, *ST* — sand tail, *SF* — secondary flow. Open circles — submerged cobble-boulder gravel, black dots — emerged bar top, unpatterned — deeper portions of channel (bottom not visible)

Łacha roztokowa na Bobrze, 3050 m na SE od starego kościoła w Marciszowie — obszar badań

Objaśnienia oznaczeń: *P* — przegłębienie korytowe, *SH* — spłycenie, *STW* — fale stacjonarne, *R* — bystrzyki, *TH* — nurt, *ST* — zaspa piaszczysta, *SF* — drugorzędny przepływ. Puste kółka — zanurzone żwiry (64—300 mm średnicy), czarne punkty — wynurzona część łachy, nieszrafowane — głębsze części koryt (niewidoczne)

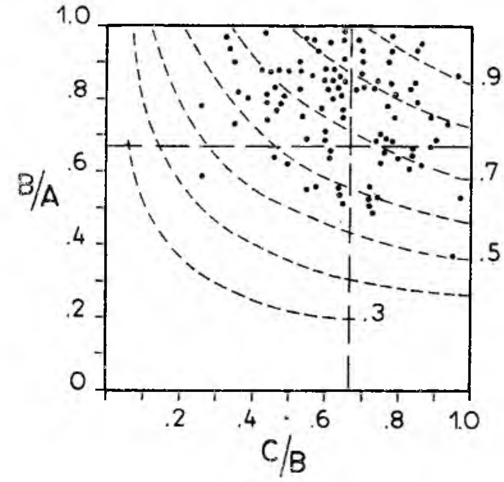


Fig. 2
Zingg diagram showing shape of rock fragments acting as obstacles. Flat pebbles predominate

Diagram Zingg'a ukazujący kształt fragmentów skalnych, które stanowiły przeszkody i spowodowały powstanie skupień otoczaków. Dominują otoczaki płaskie

-load, mountain, meandering stream with some intervening straight- and braided reaches. Peak discharge occurs in spring (after snow winters or owing to heavy spring rains) or in summer with secondary maxima in late autumn. Variations in discharge are rather large with bankful stages being up to 50 times a mean-stage discharge or more. The highest stage noted in the proximity of the bar was 1.5 m above the bar surface (summer '71). In flood the river carries mostly gravel (from pebbles to boulders). Finer materials including mud, sand, granules, and small pebbles (especially flat) are transported as a suspension load. Even during a mean--stage discharge the flow is supercritical above, below, and to the west of the bar. The flow is competent to transport granules and small pebbles (bedload) with little sand and mud acting as a suspension load. At the same time, tranquil flow along the eastern flank of the bar leaves behind rippled sand sheets. The top surface of the bar is relatively flat. The bar axis trends 345°. However, owing to some local irregularities in channel morphology, the mean high-stage flow over the bar is about 5°. At the surface, the bar is composed almost exclusively of gravel, which beneath the surface is infilled with granules, coarse sand, and occasionally also mud. The gravel coarsens upstream, the tendency being

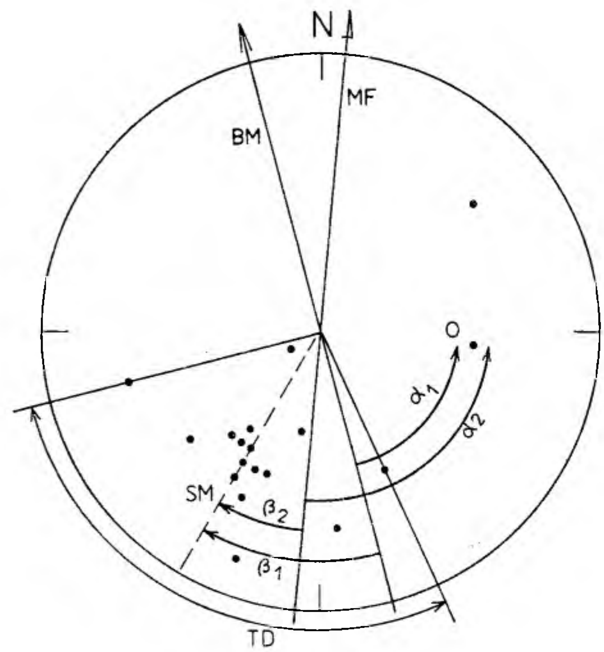


Fig. 3
Illustrating treatment of C-fabric field measurements. Total dispersion (*TD*) is defined as a sector containing all measurements, the most outstanding ones being ruled out, however.

α_1 is angular deviation of obstacle dip direction (0) from bar mean (BM). In this case $\alpha_1 = +70°$; α_2 – angular deviation of obstacle from mean flow (MF), here = +90°; β_1 – angular deviation of sector mean (SM) from bar mean (BM) = –45°, and β_2 – angular deviation of sector mean from mean flow (MF) = –25°

Sector mean is "eye-fitted" and generally independent of sector bisectrix. It runs through "eye-fitted" sector's centre of gravity

Diagram ilustrujący sposób opracowania terenowych pomiarów ułożenia klastów płaskich. Całkowity rozrzut (*TD*) określony jest jako sektor zawierający wszystkie pomiary z wyjątkiem najbardziej odchylonych.

α_1 – oznacza odchylenie kątowe azymutu zapadu osi C otoczaka stanowiącego przeszkodę (*0*) od średniego kierunku łachy (*MB*), w tym wypadku = +70°; α_2 – odchylenie kątowe przeszkody od średniego prądu (*MF*) = +90°; β_1 – odchylenie kątowe linii poprowadzonej przez ,,środek ciężkości" sektora (*SM*) od średniego kierunku łachy (*BM*) = –45°; β_2 – odchylenie kątowe wspomnianej linii od kierunku średniego prądu (*MF*) = –25°. Środek ciężkości sektora wyznaczony ,,na oko" i niezależny od symetralnej sektora

constant over the whole 6-year period. At the time of this investigation, maximum diameter of gravel (A axis) was 15 cm at the downstream end and 35 cm near the bar's summit. Another features noted from the bar top include transported trees, isolated lag boulders, occasional trunks, uprooted bushes, small sandy shadows, and, rarely, thin, clayey post--flood drapes that soon become destroyed owing to dessication.

FIELD TECHNIQUES AND PROCEDURES

In the course of field investigations pebble axes and orientation have been measured within 100 pebble clusters. These were selected through random pacing over the bar. Clusters examined were destroyed. A total of 579 rock fragments ranging in size from pebbles to boulders was examined. Also it was arbitrarily assumed that the smaller cluster should include at least three pebbles. An initial, down-current rock fragment supporting the whole structure is here termed „obstacle". As absolute values of size measurements are of less importance, the mean pebble size for each cluster was determined in the field and relative dimensions of the obstacles were noted.

Fabric analysis was limited to measurements of azimuths and dip angles of C-axes of flat pebbles (see Wobber 1964). This was justified by the fact that the structures investigated contained mostly flat clasts. The accuracy of all the measurements was 5°. The measurements resulted in 100 individual point diagrams. A further step was to determine individually for all the diagrams a number of parameters defined in figure 2. Angular deviations are „plus" if deflected counterclockwise from the bar mean or the mean flow and vice versa. To analyse the data in a somewhat more precise manner 12 collective contour diagrams („petrofabric diagrams") were made including a diagram of the orientation of flat obstacles and eleven diagrams of the orientation of all flat pebbles grouped into clusters using 50, 100, 150 measurements and so on.

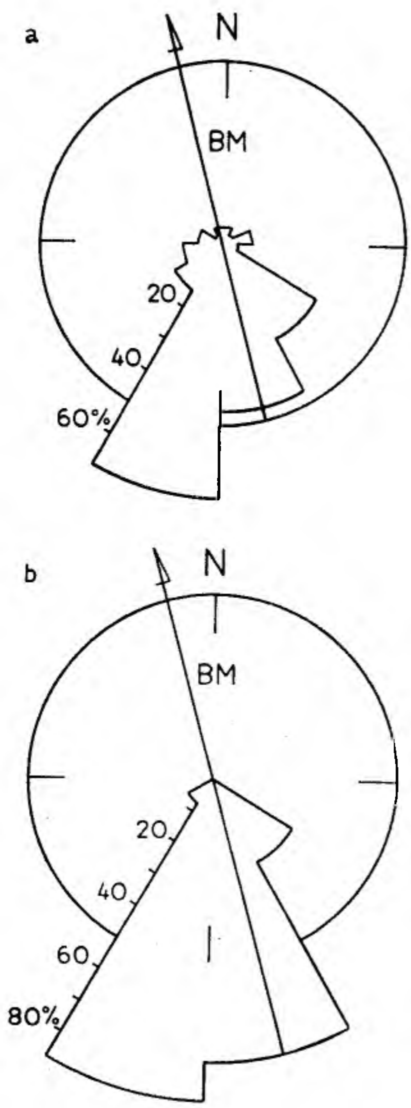


Fig. 4

a — showing angular deviation of obstacle dip directions (C-fabric) from bar mean (*BM*); *b* — angular deviation of sector means from bar mean

a — diagram ilustrujący odchylenie kątowe kierunku zapadu osi C płaskich przeszkód od średniego kierunku łachy (*BM*); *b* — odchylenie kątowe linii poprowadzonej przez ,,środek ciężkości" sektorów od średniego kierunku łachy

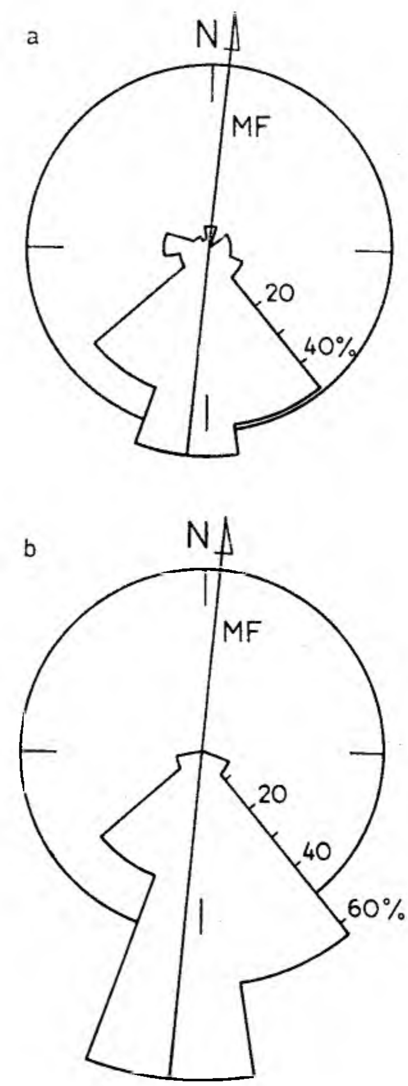


Fig. 5

a — showing angular deviation of obstacle dip directions (C-fabric) from mean flow (*MF*); *b* — angular deviation of sector means from mean flow

a — diagram ilustrujący odchylenie kątowe kierunku zapadu osi C płaskich przeszkód od średniego prądu (*MF*); *b* — odchylenie kątowe linii poprowadzonej przez ,,środek ciężkości" sektorów od średniego prądu

FIELD RESULTS

The main results of this field work may be briefly summarized as follows. The number of pebbles in the clusters examined ranged from 3 to 18 averaging 5.79. Only in 42 clusters of 100 investigated was the obstacle evidently coarser than the mean pebble; these obstacles were boulders and large cobbles. In 41 clusters the obstacle did not differ substantially in size from the mean pebble and in the last 17 clusters it was even strikingly smaller. This means that the largest clast may well occur within the structure, not only at its downcurrent end. The shape of pebbles acting as obstacles is given in figure 3. The deviation in dip direction from the bar mean of flat pebbles acting as obstacles ranged from +165° to −140° (fig. 4*a*). Similarly, figure 4b indicates the deviation of the sector means from the bar mean. This varied from +30° to −65°. The deviation in dip direction from the mean flow of flat obstacles was even greater ranging from +175° to −175° (fig. 5*a*). Finally, figure 5*b* gives the deviation of the sector means from the mean flow. This was found to vary from +55° to −50°.

Twenty-four selected point diagrams of 100 got in the field are illustrated in figure 6. It is evident from the diagrams that the dispersion in pebble dip direction varied from place to place. In many diagrams maxima (or sector means) cut the orienting current at an angle. It also seems that both the dispersion and the deviations changed randomly throughout the bar. C-fabric of flat obstacles is shown in figure 7. The chief maximum is deviated by the angle of −35° from the bar mean and −15° from the mean flow. The results of the eleven collective contour diagrams drawn to demonstrate the dispersion in dip directions of all flat clasts measured are as follows (see page 83; fig. 8):

Diagram No.	Number of measurements included	Angular deviation of chief maximum from mean flow
1	50	+35°
2	100	+30°
3	150	−30°
4	200	−25°
5	250	+15°
6	300	−30°
7	350	−20°
8	400	+15°
9	450	−10°
10	500	+5°
11	547	+5°

Finally, there is growing evidence that „fish-skin" imbrication typical of some channels and pebble-cluster imbrication in channels and on bars are both topography-controlled features (comp. e.g., Schlee 1957; Byrne 1963; A. K. Teisseyre 1975b). This is also the case with convex-up braid bars and gravelly point bars in general (pl. I, *3*, *4*). Only with flat subhorizontal surfaces is the effect of topography negligible.

DISCUSSION OF THE RESULTS

On the bar described above, similarly as on other bars along the River Bóbr, pebble clusters are composed mostly of flat strongly imbricated rock fragments ranging in size from pebbles to boulders. As pointed out by Dal Cin (1968) individual pebble clusters are essentially parallel to the orienting current. However, the biggest rock fragment they contain rests at the downcurrent end only in about 40 clusters of 100 investigated in detail. Consequently, caution is needed in applying the criterion, especially to paleocurrent studies of lithified fossil deposits. Field observations also seem to indicate that any object protruding from a pre-flood bar surface or simply resting on it may play an active role in the formation of pebble clusters. In fact, pebble clusters are also known formed in front of tree trunks buried in gravel.

It is also worthy of mention that pebble clusters can be by no means regarded to be coarse equivalents of sand shadows. Pebble clusters form invariably in front of the obstacle (Dal Cin 1968). And, in so being, they may be considered to be small-scale counterparts of boulder trains, boulder jams and similar depositional features known from coarse gravels of mountain valleys and some alluvial fans. Sand shadows (Dżułyński and Ślączka 1958; Dżułyński 1963), on the other hand, accumulate characteristically behind (= downcurrent) the obstacle. In fact, some pebble clusters reveal sand shadows or gravel shadows developed to the lee of the obstacle.

Field evidence also indicates that flat pebbles grouped into pebble clusters may dip in various directions irrespective of being arranged in rows paralleling the mean orienting current. In general,

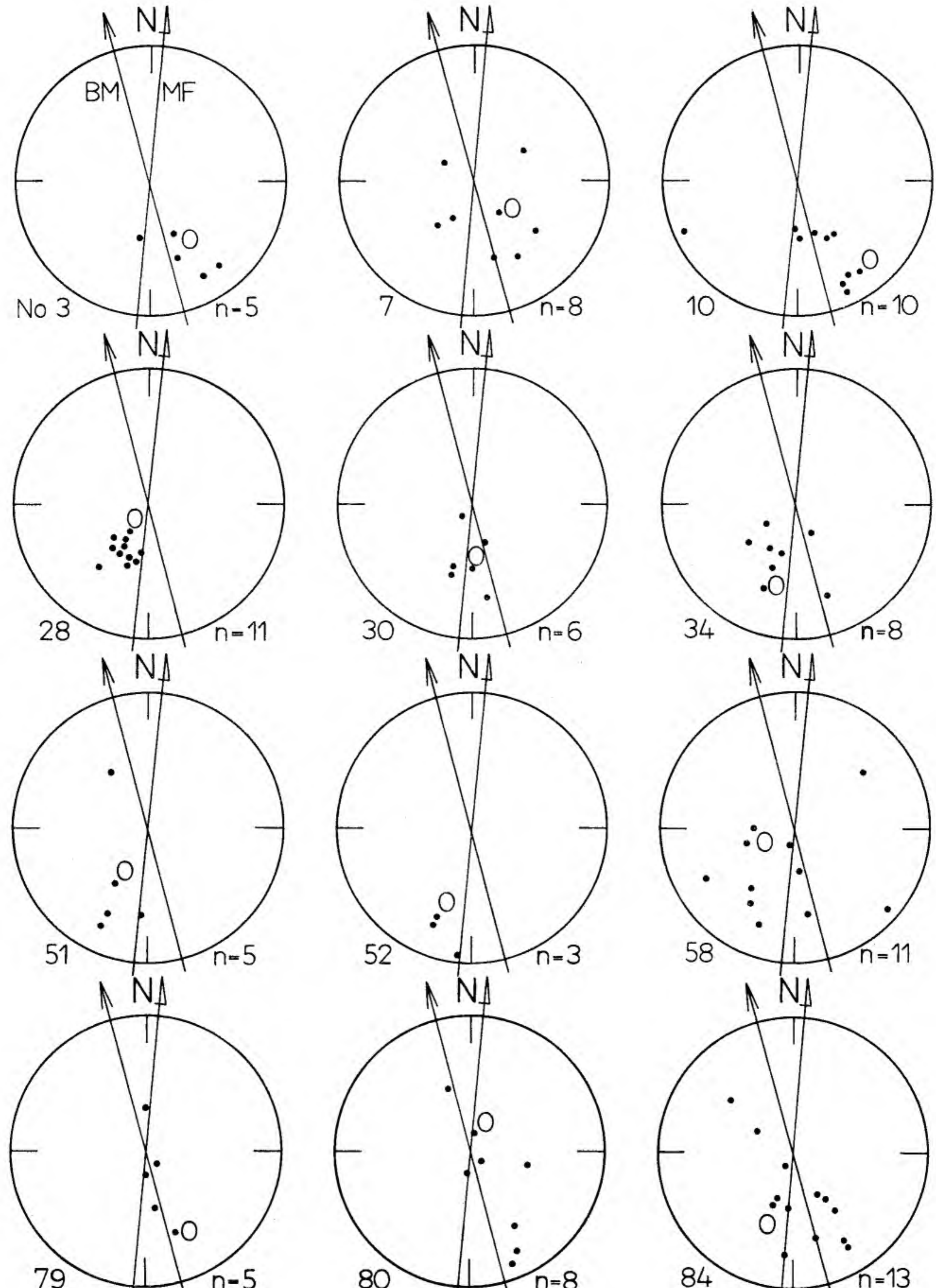
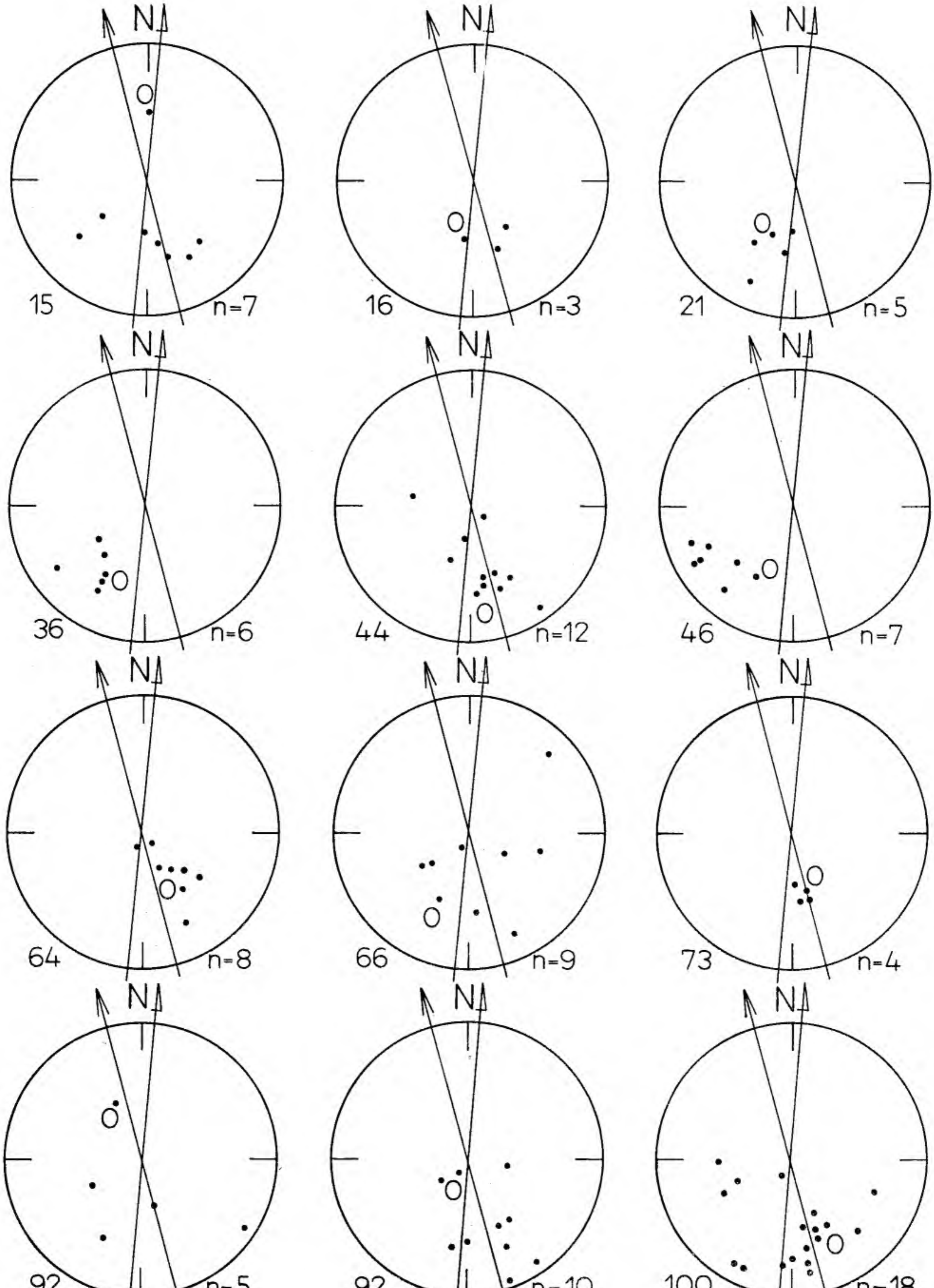


Fig. 6

Point diagrams illustrating C-fabric of flat pebbles in 24 selected pebble clusters from the mid-channel bar shown, in figure 1

Downcurrent is to the north. Figures in the lower left-hand corners refer to clusters' serial numbers. Attention: upper hemisphere projections used in all the diagrams! *BM* – bar mean, *MF* – mean flow, *O* – obstacle



Diagramy punktowe ułożenia otoczaków płaskich w 24 wybranych skupieniach otoczaków z łachy centralnej pokazanej na figurze 1

Kierunek z prądem — ku północy. Numery w dolnych, lewych narożach diagramów oznaczają kolejne numery badanych skupień. Górna półkula. *BM* — średni kierunek łachy, *MF* — średni prąd, *O* — przeszkoda

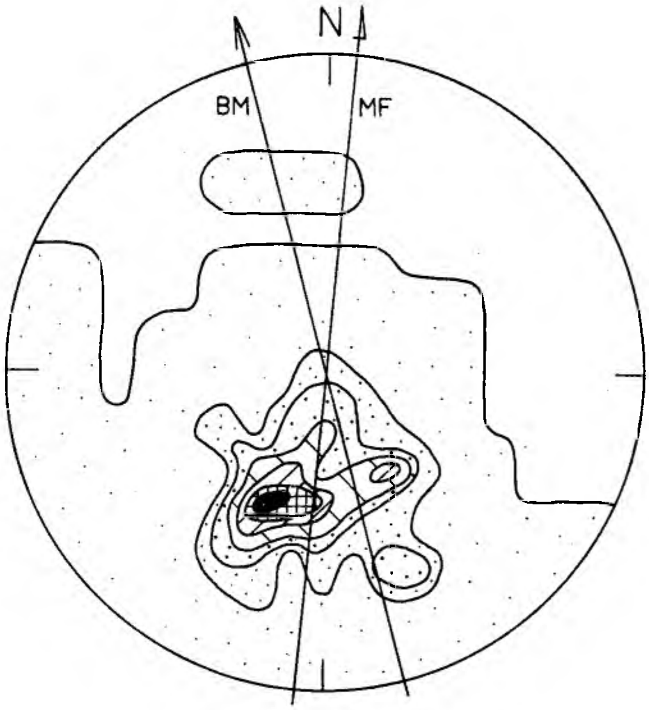


Fig. 7

Contour diagram showing orientation (C-fabric) of flat obstacles (95 readings). Upper hemisphere

Concentrations lines: 0—2—4—6—8—10—12— (13) per cent. See also figure 6

Diagram konturowy orientacji osi C otoczaków płaskich stanowiących przeszkody (95 pomiarów). Górna półkula

Linie koncentracji: 0—2—4—6—8—10—12— (13)%. Patrz także figura 6

the bigger the pebble cluster the larger the dispersion in dip directions of flat clasts. The fact may be easily accounted for in terms of flow perturbation round the obstacle (pl. II, *1—4*; see e.g., Richardson 1968; Karcz 1968). In reality, the most stable position of flat clasts in many pebble clusters seen along the course of the River Bóbr was to dip obliquely

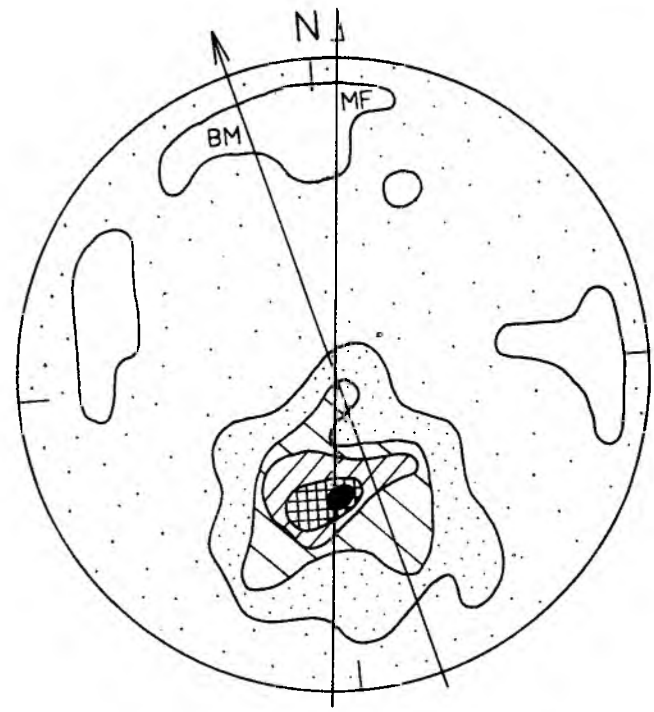


Fig. 8

Collective contour diagram of 547 C-fabric measurements of flat clasts grouped in clusters from the mid-channel bar, River Bóbr. Upper hemisphere.

Concentration lines: 0—2—4—6—8—9—(9.1) per cent. See also figures 6 and 7

Zbiorczy diagram konturowy 547 pomiarów ułożenia otoczaków płaskich ze skupień otoczaków badanych na łasze centralnej na Bobrze. Górna półkula

Linie koncentracji: 0—2—4—6—8—9—(9,1)%.

upcurrent (fig. 6 and 9). It may be concluded, therefore, that single C-fabric measurements of flat clasts arranged in pebble clusters may result in quite false (paleo)current directions, particularly in lithified fossil deposits. For instance, in the case of the bar

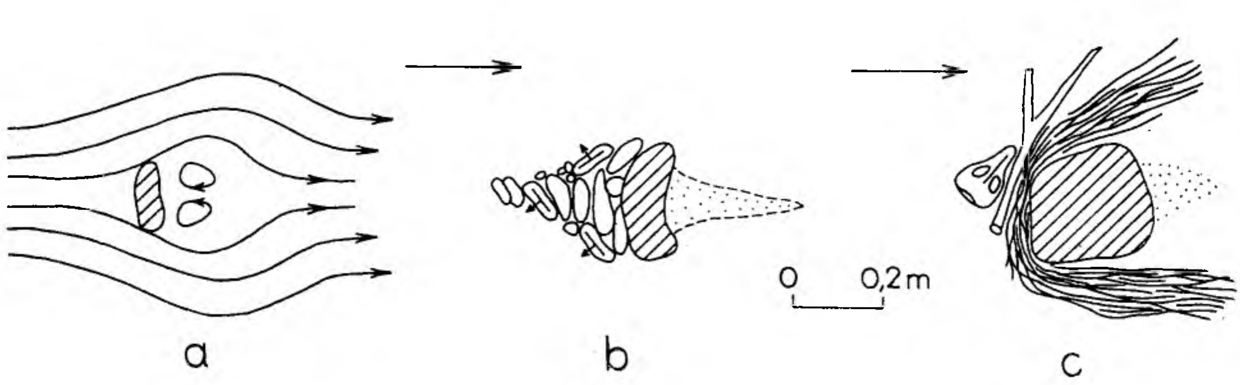


Fig. 9

a — fluid flow round oval, resistance body. Modified from Troskolański (1969, p. 476); *b* — pebble cluster in front of obstacle and sand shadow behind it. Note that the most stable position for many outer flat pebbles is dip obliquely upcurrent; *c* — small plant jam. Note fox cranium; *b* and *c* taken from channel of the River Bóbr between Lubawka and Błażkowa

a — opływ cieczy dookoła ciała oporowego obłego (według Troskolańskiego 1969, str. 476); *b* — skupienie otoczaków przed przeszkodą i zaspa piaszczysta za nią. Najbardziej stabilna pozycja zewnętrznych otoczaków płaskich wymaga ustawienia się skośnego pod prąd; *c* — mały zator roślinny. Widoczna czaszka lisa; *b* i *c* pochodzą z koryta Bobru między Lubawką a Błażkową in question, even 300 randomly selected C-fabric measurements may give diagrams with maxima deviated from the real (known) flow by the angle of ±30°. On the other hand, fairly good (paleo) current data may be get if fabric measurements are limited to flat obstacles only (fig. 7).

PEBBLE CLUSTERS IN LITHIFIED FLUVIAL DEPOSITS

Although seldom described in detail and even much more rarily considered a self-contained directional structure, pebble clusters are in fact amongst the most common features of ancient alluvial gravels. The present writer's investigations into the Dinantian conglomerates of the Intrasudetic Basin have demonstrated that pebble clusters they commonly contain do not differ substantially from their Recent counterparts (pl. III, *1*, *2*). These resemble one another not only in an overall morphological sense (i.e., the size, number of pebbles put together, and the position of the largest clast) but also from the pebble-fabric viewpoint. An example of fossil pebble clusters is given in figure 10a. The paleoflow indicated by the chief maximum in the contour diagram (fig. 10*b*) is deviated from a mean local paleocurrent by the angle of some 20°.

It seems appropriate to discuss now the (paleo) environmental significance of pebble clusters. It has been found that in the Dinantian conglomerates mentioned pebble clusters are characteristic primarily of relatively tightly-packed and rather poorly stratified gravels. These bear features thought to be indicative of deposition on ancient braid bars. The features may be briefly listed as follows: (1) tight packing, (2) contact imbrication (Laming 1966) of flat clasts commonly grouped in clusters, (3) poor bedding or internal homogeneity, (4) thickness not uncommonly limited to fraction of a metre, (5) flat, irregular, or slightly concave-up lower bed surfaces and convex-up upper surfaces (if only preserved), (6) shape elliptical or elongated in plan, (7) gradual lateral transitions into channel-fill deposits, (8) evidence of unidirectional transport, (9) scattered large objects within gravel (transported tree trunks, lag blocks and boulders), and (10) presence of sedimentary structures indicative of supercritical flow as, for instance, standing waves (see A. K. Teisseyre 1975a, b). Field experience teaches us also that the „obstacle fabric'' gives the best results if applied to genetically homogeneous layers of gravel (in the case of multiple beds) or simple beds (irrespective of their thickness).

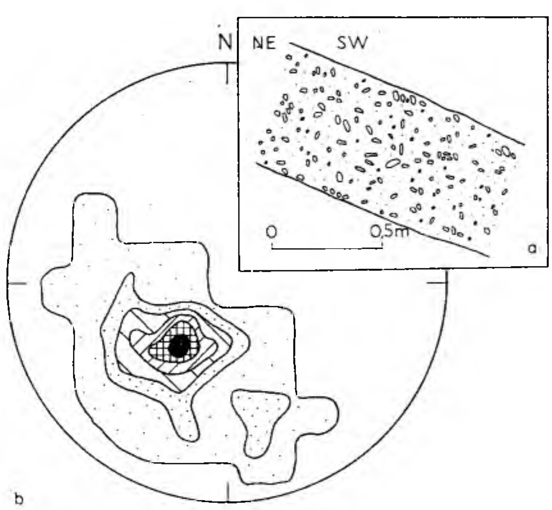


Fig. 10

a — pebble clusters in the Upper Visean fluvial conglomerate. Paleocurrent from right to left. Szczawno Formation, outcrop on Zadzierna Mt., north of Bukówka; *b* — showing C-fabric of flat pebbles that acted as obstacles in the conglomerate shown in figure *a*. Upper hemisphere, measurements tilt-corrected, 50 readings. Concentration lines: 0—2—4—6—8—10—(11) per cent

a — skupienia otoczaków w górnowizeńskim zlepieńcu pochodzenia rzecznego. Paleoprąd z prawej na lewą. Formacja ze Szczawna, odsłonięcie na Zadziernej, na północ od Bukówki; *b* — diagram ukazujący orientację otoczaków płaskich, które stanowiły przeszkody w zlepieńcu pokazanym na figurze *a*. Górna półkula, 50 pomiarów, wychylenie tektoniczne skorygowane. Linie koncentracji: 0—2—4—6—8—10—(11)%

Another problem to be briefly discussed is a (paleo) hydraulic meaning of pebble clusters. Dal Cin (1968) suggests that the formation of the structures in question requires rather a selective transport than mass transport. The conclusion, however, is not confirmed by the present writer's investigations into the Carboniferous and Permian debris-flow deposits of the Sudetes. The controversy is perhaps more apparent than real being related to some terminological inaccuracies. In the Intrasudetic Basin, similarly as elsewhere, debris-flow deposits commonly contain rock fragments grouped together into typical pebble clusters (pl. III, *3*, *4*). There is evidence, therefore, that the formation of pebble clusters requires the same hydrodynamic conditions as imbrication in general: both originate characteristically under conditions of turbulent, rapid or nearly so flows and can be regarded to be indicative of such (paleo)hydraulic conditions. If so, they may well be expected to occur in debris-flow deposits for many of them do (and did) originate from viscous but still turbulent flows (Blackwelder 1928; Sharp and Nobles 1953; Lustig 1965, Johansson 1965; Scott and Gravlee 1968; Lindsay 1968; Helley 1969; Visher 1971).

SUMMARY

Field investigations by the present writer lead to the following conclusions.

1. Pebble clusters are amongst the most common structures of both the modern gravels of the River Bóbr and the continental Paleozoic conglomerates of the Intrasudetic Basin.

2. An „average" modern pebble cluster in the area investigated comprises about 6 clasts, mostly flat. As a rule, these are in contact with one another leaning against an initial rock fragment or obstacle. Pebble clusters form characteristically in front of such obstacles and some may contain sand shadows behind them. Generally, the structures parallel the flows that created them. However, the biggest clast they contain may well be found within a cluster, not only at its downcurrent end. This also means that any pebble protruding above the surface of accumulation may serve as an obstacle giving rise to the formation of pebble clusters.

3. C-fabric measurements of flat clasts grouped into modern clusters indicate a great dispersion in dip directions irrespective of supporting evidence as to unidirectional transport. A more detailed study has revealed that the dispersion is at minimum if measurements are limited to flat obstacles only. Generally, several tens of such readings may give (paleo)current directions that are deviated from real paleoflows by the angle of $\pm 5-15°$. However, if all flat clasts are taken into account even 300 measurements may fail to give a similar accuracy.

4. The dispersion in dip directions seems to be attributable to perturbations of flow passing round the obstacles. This may well account for the field-observed fact that the most stable position for many flat clasts grouped into clusters is to dip obliquely upcurrent. In other words, C-fabric of flat clasts at least is generally not determined by the downcurrent elongation of the whole structure. It should be kept in mind, however, that the conclusions refer primarily to flat-topped bars. In the case of convex-up depositional surfaces complications are to be expected as pebble fabric may be topographically-controlled, to some degree at least.

5. In the case of lithified alluvial gravels, the least time-consuming (and perhaps the most authentic) paleocurrent data may be obtained measuring the orientation of flat obstacles. What geologists should do in investigating fossil deposits is made measurements within genetically homogeneous layers of gravel the shape and origin of which is at least roughly known. Thus „point" fabric measurements in places selected by haphazard ought to be stopped in favour of „within-form" fabric studies.

6. Investigations into both modern and ancient alluvial gravels appear to indicate that pebble clusters may be found in both channel- and bar deposits. Also they may be observed in overbank gravels.

7. The (paleo)hydraulic meaning of pebble clusters is the same as imbrication in general: they require turbulent, rapid or nearly so flows and may be considered to be indicative of such (paleo)-hydraulic conditions. Moreover, pebble clusters may well be found within debris-flow deposits provided they were laid down by turbulent flows.

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Andrzej Karol TEISSEYRE*

SKUPIENIA OTOCZAKÓW JAKO STRUKTURA KIERUNKOWA WE WSPÓŁCZESNYCH I KOPALNYCH ŻWIRACH RZECZNYCH

STRESZCZENIE

Skupienia otoczaków (pebble clusters: Dal Cin 1968) należą do najpospolitszych struktur współczesnych żwirów Bobru (fig. 1, 9; pl. I) i lądowych zlepieńców młodszego paleozoiku niecki śródsudeckiej (fig. 10; pl. III). Skupienia te zawierają przeciętnie po 6 otoczaków, przeważnie płaskich (fig. 2). Zwykle otoczaki stykają się ze sobą, opierając się jednocześnie na jakiejś przeszkodzie. Skupienia otoczaków tworzą się zawsze przed przeszkodą i mogą być uzupełnione przez małe zaspy tylne za przeszkodą (fig. 9). Ogólnie biorąc, wydłużenie tych struktur jest równoległe do kierunku prądu. Największe klasty mogą jednak występować wewnątrz skupień, a nie tylko przy ich końcu skierowanym z prądem. W zasadzie każda przeszkoda stercząca ponad powierzchnię żwiru może dać początek opisywanym tu strukturom.

Pomiary ułożenia klastów płaskich, wchodzących w skład współczesnych skupień otoczaków, wykazują dużą dyspersję kierunków zapadu tych otoczaków, i to niezależnie od oczywistych dowodów jednokierunkowego transportu (fig. 3—6). Bardziej wnikliwa analiza wykazała, że dyspersja ta jest najmniejsza, gdy pomiary wykonuje się tylko na płaskich przeszkodach. W takim przypadku wystarczy, ogólnie biorąc, wykonanie kilkudziesięciu pomiarów, by uzyskać kierunki transportu różniące się od rzeczywistych o około $\pm 5-15°$ (fig. 7). Jeśli bierze się pod uwagę nachylenie wszystkich klastów płaskich, występujących na jakiejś powierzchni lub w jakiejś warstwie, konieczne może być wykonanie 300—500 pomiarów, by otrzymać zbliżoną dokładność uzyskanego (paleo) prądu (fig. 8). Omawiana dyspersja kierunków zapadu otoczaków płaskich wydaje się być wynikiem perturbacji zachodzących w przepływie omijającym przeszkodę.

Obserwacje terenowe wykazały, że najbardziej stabilne ułożenie wielu otoczaków płaskich wchodzących w skład skupień polega na ustawianiu się tych klastów skośnie pod prąd (pl. I—II; fig. 9). Ponadto okazuje się, że ułożenie takie jest w zasadzie niezależne od zgodnego z prądem wydłużenia samych struktur (fig. 6). Należy jednak pamiętać, że wnioski powyższe dotyczą przede wszystkim płaskich łach roztokowych. Na łachach wypukłych, łachach meandrowych oraz w korytach ułożenie otoczaków płaskich jest w znacznym stopniu kontrolowane przez ukształtowanie powierzchni (pl. II). Skupienia otoczaków są typowe zarówno dla żwirów łach, jak i koryt rzecznych.

W przypadku żwirów kopalnych najszybszą metodą ustalania paleoprądów wydaje się być technika mierzenia ułożenia klastów płaskich, które stanowiły przeszkody (fig. 10). Ogólną zasadą przy badaniu takich utworów powinno być wykonywanie pomiarów w warstwach żwiru jednorodnych pod względem genetycznym. Jest także nader pożądane, by kształt i pochodzenie tych warstw były znane, przynajmniej orientacyjnie.

Hydrauliczne znaczenie skupień otoczaków jest takie samo jak imbrykacji w ogólności — wymagają one turbulentnego, przeważnie nadkrytycznego przepływu i mogą być uważane za wskaźnikowe dla takich właśnie warunków. Skupienia otoczaków mogą też równie dobrze występować w osadach gruzowo-błotnych pod warunkiem, że osadziły się ze spływów turbulentnych (pl. III).

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PLATE I

PLANSZA I

1. Braid bar on the River Bóbr (see fig. 1 for location). Note numerous pebble clusters and standing waves in the channel. Current from left to right. After flood in July '71

Łacha roztokowa na Bobrze (lokalizacja jak na fig. 1). Widać liczne skupienia zimbrykowanych otoczaków i fale stacjonarne w korycie. Prąd z lewej na prawą. Po powodzi w lipcu 1971

2. Transverse braid bar on Polski Potok Brook, south of Bogaczowice. Current from upper left to lower right. After flood in June '65

Poprzeczna łacha roztokowa w korycie Polskiego Potoku na południe od Bogaczowic. Prąd z lewej na prawą. Po powodzi w czerwcu 1965

3. Imbricated cobbles (bar head gravel) on point bar of the River Bóbr just above Błażkowa. Current from right to left

Gruby, zimbrykowany żwir górnej części łachy meandrowej, rzeka Bóbr powyżej Błażkowej. Prąd z prawej na lewą

4. The same point bar. Note shallow chute channel with cobbles and boulders grouped in clusters. Dip directions of platy fragments are topographically-controlled. View is upcurrent

Ta sama łacha meandrowa. Widoczne jest płytkie koryto przelewowe, w którym grube żwiry tworzą skupienia. Kierunki zapadu klastów płaskich są kontrolowane przez ukształtowanie powierzchni koryta. Widok pod prąd

2

4

1

3

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Skupienia otoczaków jako struktura kierunkowa we współczesnych i kopalnych żwirach rzecznych

PLATE II
PLANSZA II

1. Boulder cluster on submerged braid bar immediately below Lubawka. Current from upper left to lower right

Skupienie bloków na powierzchni zanurzonej łachy roztokowej na Bobrze poniżej Lubawki. Prąd z lewej na prawą

2. Large cluster on braid bar of the River Bóbr above Błażkowa. Note dispersion in dip directions of flat clasts. Current from upper right to lower left

Duże skupienie żwirów na łasze roztokowej na Bobrze powyżej Błażkowej. Widoczna dyspersja kierunków zapadu otoczaków płaskich. Prąd z prawej na lewą

3. Large clusters on point bar of the River Bóbr below Lubawka. Note that flat pebbles between boulders (centre) suggest flow direction that is 90° apart. View is upcurrent

Duże skupienie żwirów na łasze meandrowej na Bobrze poniżej Lubawki. Małe otoczaki płaskie widoczne między blokami sugerują przepływ odchylony o 90° od średniego prądu skierowanego ku obserwatorowi

4. Pebble clusters in sand-floored channel on braid bar of the River Bóbr, Marciszów. Current from top to bottom

Skupienia zimbrykowanych otoczaków w wyścielonym piaskiem korycie na łasze roztokowej na Bobrze, Marciszów. Prąd ku obserwatorowi

2

4

1

3

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PLATE III

PLANSZA III

1. Large clusters in cobble-boulder conglomerate, Bogaczowice Formation (Lower Visean?), outcrop in Bogaczowice. Paleocurrent from left to right

Skupienia otoczaków w średnioziarnistym zlepieńcu z blokami, formacja z Bogaczowic (wizen dolny?), odsłonięcie w Bogaczowicach. Paleoprąd z lewej na prawą

2. Large clusters in more sandy cobble-boulder conglomerate, Sady Górne Formation (Lower Visean?), outcrop in Sady Górne. Paleoflow from right to left

Duże skupienia otoczaków w bardziej piaszczystym zlepieńcu średnioziarnistym z blokami, formacja z Sadów Górnych, dolny wizen (?), odsłonięcie w Sadach Górnych. Paleoprąd z prawej na lewą

3. Pebble clusters in debris-flow deposit, Lubomin Formation (Middle Visean?), outcrop in Miszkowice. Southerly paleoflow was from left to right

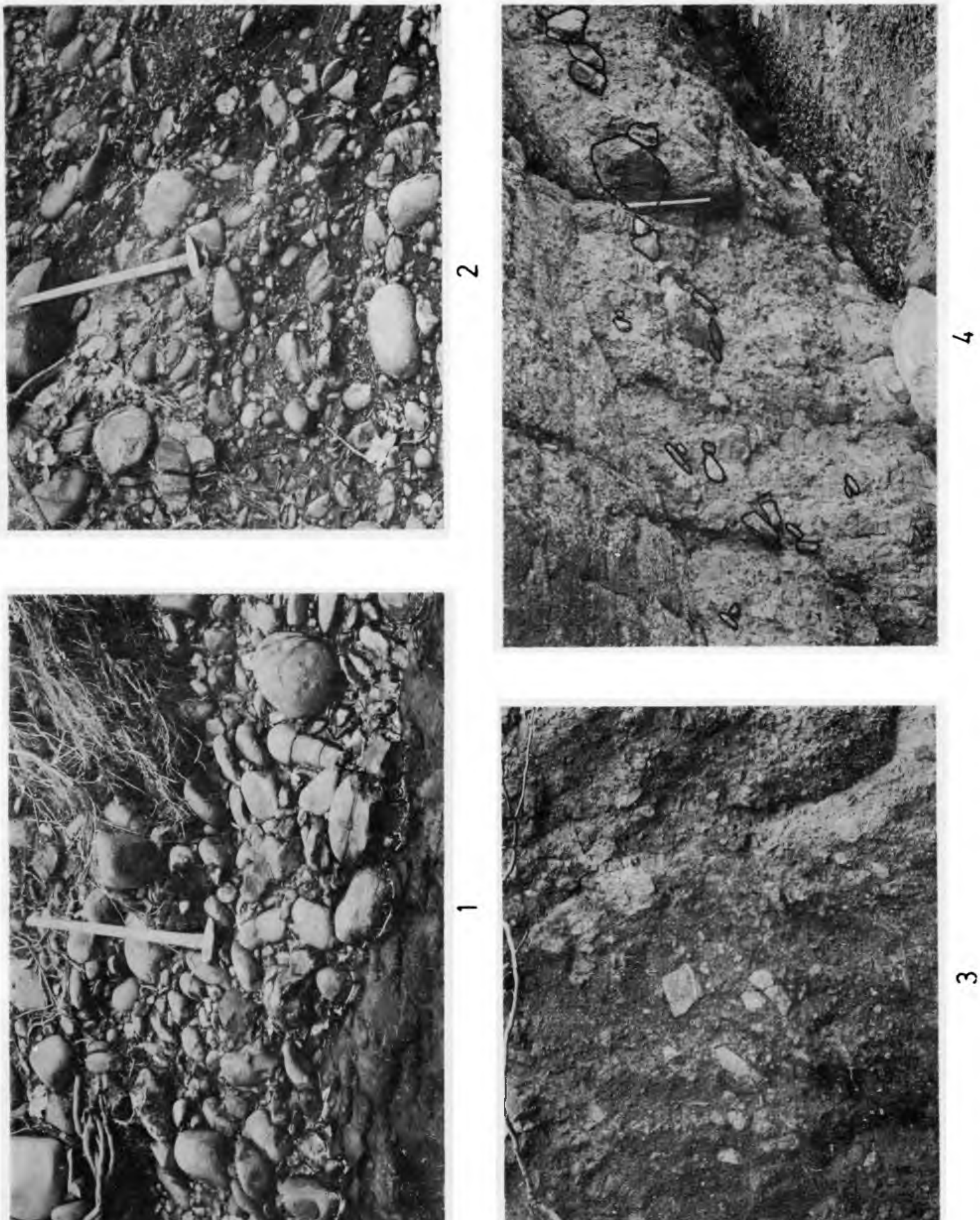
Skupienia klastów płaskich w osadzie gruzowo-błotnym, formacja z Lubomina (wizen środkowy?), odsłonięcie w Miszkowicach. Paleoprąd z lewej na prawą (ku południowi)

4. Bed of debris-flow deposit, location as above. Note numerous pebble clusters (some of which are rimmed). Hammer for scale is 57 cm long

Ławica osadu gruzowo-błotnego, odsłonięcie jak wyżej. Widać liczne skupienia klastów, niektóre retuszowane. Młotek ma 57 cm długości

All photos taken by the author

Wszystkie zdjęcia autora



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Skupienia otoczaków jako struktura kierunkowa we współczesnych i kopalnych żwirach rzecznych