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# SEDYMENTACJA I WSKAŹNIKI KIERUNKOWE TRANSPORTU W WARSTWACH KROŚNIEŃSKICH

(Tabl. XXIV — XXXIX i 15 fig.)

# *Directional structures and sedimentation of the Krosno beds (Carpathian flysch)*

(Pl. XXIV — XXXIX and 15 fig.)

## STRESZCZENIE

Pomiary kierunku transportu w warstwach krośnieńskich dokonane zostały na podstawie szeregu wskaźników na spągu (hieroglify), oraz wewnątrz ławic piaskowcowych.

Syndepozycyjne hieroglify nieorganiczne podzielić można na dwie zasadnicze grupy: 1) hieroglify powstałe bezpośrednio, w wyniku oddziaływania samego prądu, 2) hieroglify utworzone przez różne przedmioty wleczone po dnie przez prąd.

Grupa pierwsza obejmuje hieroglify prądowe w ścisłym słowa tego znaczeniu (tabl. XXV i XXVI), odlewy śladów opływania (Tabl. XXVII fig. 1), odlewy pręg falistych (tabl. XXVIII fig. 2) i zagadkowych „żłobków ściekowych" (tabl. XXVII fig. 2).

Do drugiej grupy należą odlewy śladów stykania się z dnem różnych przedmiotów niesionych przez prąd zawiesinowy, wleczonych lub toczonych po dnie. Są to rozmaite „hieroglify uderzeniowe" (tabl. XXV fig. 1, tabl. XXVI fig. 3), hieroglify wleczeniowe (tabl. XXXIII fig. 1, 2, tabl. XXXIV fig. 2), odciski śladów toczenia kręgów ryb itp. (tabl. XXX, tabl. XXIX fig. 2). W niektórych przypadkach można zidentyfikować przedmioty, które pozostawiły po sobie owe ślady. Okazały się nimi kawałki drewna, okruchy łupkowe, ziarna piasku, kości ryb itp.

Wszystkie wymienione ogólnie hieroglify są cennymi wskaźnikami kierunku prądu. Nie należy jednak utożsamiać hieroglifów prądowych z hieroglifami „uderzeniowymi", ponieważ prowadzi to nieuchronnie do błędnego odczytania kierunku transportu.

Do grupy wskaźników wewnątrz ławic piaskowcowych należy między innymi: dachówkowe ułożenie wydłużonych ziarn, warstwowanie

przekątne i smugi gruboziarnistego piasku osadzone za przeszkodami, które opływał prąd zawiesinowy.

W ławicach gruboziarnistych piaskowców obserwuje się często ułożenie dachówkowate takie, jakie występuje w żwirach rzecznych, to zn. osie wydłużonych ziarn zapadają w górę prądu. Odczytywanie kierunku na podstawie przekątnego uwarstwienia zostało oparte na nowej metodzie. Okazało się bowiem, że pochyłe laminy przekątnego warstwowania bywają często odciśnięte na spągowej powierzchni piaskowców w postaci znamiennych łukowych struktur (tabl. XXVIII fig. 1, rys. 11) zwróconych wypukłością w górę prądu.

Cennymi wskaźnikami prądu okazały się również skupienia bardziej gruboziarnistego materiału, które w formie płomienia lub smugi wyklinowującej się z prądem osadziły się za przedmiotami, które utkwiły czasowo lub na stałe w dnie. Wskaźniki te widoczne są na spągu ławic piaskowcowych wykazujących słaby stopień przesortowania materiału (fig. 13).

## Warunki sedymentacyjne

W warstwach krośnieńskich występują ławice osadzone przez prądy zawiesinowe i osuwiska podmorskie. Niektóre z ławic piaskowcowych powstały w wyniku ruchów masowych łączących w sobie cechy osuwiska i prądu zawiesinowego. Część spiaszczonych łupków jest również rezultatem osadzania przez prąd zawiesinowy.

Warstwy krośnieńskie, podobnie jak inne skały fliszu karpackiego, osadzały się poniżej podstawy falowania i pominąwszy może margle w stropie tych warstw, są osadem morza stosunkowo głębokiego.

Wyniki pomiarów kierunków transportu wskazują, że lądy, które dostarczały materiału do warstw krośnieńskich, znajdowały się wewnątrz geosynkliny karpackiej (zob. tabl. XXXVI — XXXIX, fig. 14 — 15). Pomiary tę, potwierdziły słuszność niektórych przypuszczeń odnośnie do umiejscowienia źródłowych kordylier uzyskanych na podstawie badań nad materiałami egzotycznymi we fliszu.

W zachodniej części geosynkliny karpackiej zaznaczył się silnie wpływ kordyliery śląskiej, który ku wschodowi sięgał do rejonu sanockiego. W południowo-wschodniej części depresji centralnej gruboziarniste piaskowce były donoszone prądami zawiesinowymi z południowego wschodu i południa. Źródłem tych osadów był przypuszczalnie masyw marmaroski i hipotetyczny „wał dukielski". Drobnoziarniste skorupowe piaskowce przeławicające wspomniane wyżej gruboziarniste ławice wykazują często przeciwny kierunek transportu i jak wynika z pomiarów, materiał ich był donoszony z zachodu lub południowego zachodu.

Innym źródłem osadów krośnieńskich był wyraźnie zaznaczający się w sedymentacji warstw krośnieńskich ląd sanocki (kordyliera sanocka), który wznosił się nad poziom morza w eocenie i oligocenie między obecnym rejonem inoceramowym (płaszczowina skolska), a centralną depresją (płaszczowina śląska). Wpływ sanockiej kordyliery zaznacza się głównie w północnym inoceramowym rejonie, w mniejszym natomiast stopniu w obrębie depresji centralnej.

Tak zwana „facja marglista" w obrębie dolnych warstw krośnieńskich w obszarze na południe i południowy wschód od Krosna pokrywa się z rejonem, do którego dochodziły prądy zawiesinowe i osuwiska z różnych kierunków i źródeł, to znaczy z centralną częścią basenu sedymentacyjnego. Przypuszczalnie prądy te utraciły po drodze znaczną część niesionego materiału klastycznego i to było powodem mniej intensywnej sedymentacji piaskowcowej.

Podczas sedymentacji wyższego ogniwa warstw krośnieńskich warunki ulegają zmianie. Wpływ masywu marmaroskiego i wału dukielskiego stopniowo ustaje, a na południowo-wschodnich obszarach warstw krośnieńskich w granicach państwa zarysowuje się wyraźna przewaga kierunków transportu z północnego zachodu.

Zmiany w kierunkach dopływu materiału i w charakterze osadów są odbiciem zmian w ukształtowaniu basenu krośnieńskiego. Zachodnia część tego zbiornika zaczyna się podnosić w ciągu trwania sedymentacji krośnieńskiej, przy równoczesnym zanurzaniu się kordylier na obszarze całej geosynkliny. Punkt zwrotny w ewolucji geosynkliny karpackiej (w zewnętrznej strefie fliszowej) nastąpił w momencie zniknięcia kordylier pod powierzchnią wód. Ten krytyczny moment odzwierciedla się w sedymentacji warstw krośnieńskich pojawieniem się ostatnich dużych osuwisk i prądów zawiesinowych, których osady występują w warstwach środkowo-krośnieńskich.

Po zanurzeniu się kordylier rozpoczyna się nowy etap sedymentacji w geosynklinie. Margle, które odpowiadają temu nowemu okresowi choć integralnie związane są z warstwami krośnieńskimi, nie mają już charakteru fliszowego osadu. Podczas sedymentacji tych utworów ruchy orogeniczne trwały nadal i uwieńczone zostały paroksymalnym sfałdowaniem i wyciśnięciem zawartości dawnych basenów sedymentacyjnych.

Z problemem sedymentacji warst krośnieńskich wiąże się zagadnienie wielkości skrócenia oraz ruchów poziomych w geosynklinie. Istnienie wewnętrznych kordylier pociąga za sobą konieczność przyjęcia dużego zwężenia stref geosynklinalnych.

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Abstract. Distribution of the turbidity currents in the Krosno beds implies the existence of at least three major sources. They were situated within the Carpathian geosynclinal belt. The Krosno sandstones resulted from the activity of turbidity currents and watery slides. In several sections, interstratification of coarse and fine-grained sandstones with opposite directions of supply occur. Various types of sole markings are discussed from the point of their applicability as current indicators. The descriptions of some hitherto undescribed markings are given in detail, i. e. casts of spinal joints of fish rolled over the bottom, brush casts, prod casts, vibrations marks, spiral groove casts etc. Some intrastratal directional structures are also discussed.

## INTRODUCTION

The accumulation of the flysch sediments in the western part of the Carpathian geosyncline came to its end during the Oligocene. The marine clays and sands of Tortonian age rest unconformably upon the folded and denuded flysch rocks.

The uppermost flysch sediments in the Carpathians are called Krosno beds, named so by T. Tietze (1889) from the small town of Krosno in the Central Carpathians. It is widely agreed that the bulk of the Krosno beds is of Oligocene age. Nevertheless the stratigraphical position of the lowest and uppermost horizons of the strata discussed must not be considered as definitely determined. According to F. Bieda (1947) and H. Świdziński (1950) the lowest portion of the Krosno beds belongs still to the uppermost Eocene. It seems also probable that in the Eastern Carpathians the sedimentation of the Krosno beds continued up to the Middle Miocene (Maslakova 1955).

The deposition of the Krosno beds was synchronous with the late stages of the Alpine orogeny. The strata described here give the clearest evidence as to the movements preceding the final folding and thrusting within subsiding zone of geosynclinal belts.

## PREVIOUS SEDIMENTOLOGICAL STUDIES

Although various sedimentary structures displayed by the Krosno beds have been known for many years, very little has been written about them.

M. Książkiewicz (1956, 1958) published the first maps showing the direction of turbidity currents in the Carpathian flysch. The Krosno beds were also included and the fan-like arrangement of currents spreading away from the source situated south of the present margin of the Magura nappe, clearly demonstrated.

Z. Obuchowicz (1957) gives a summary of recent sedimentological studies carried out within a limited area south of Besko. An important fact which emerges from this study is a regional difference in the direction of supply between the lower and upper parts of the Krosno beds. Conditions of deposition of the Krosno beds are also discussed by Obuchowicz and the conclusion is that the strata here decribed have been laid down both in deep and shallow waters on the slope and top of the shelf.

The first detailed description of submarine slumps in the Krosno beds has been given by O. Ganss (1941, 1942). The above named author called attention to the fact that the sedimentation of the Krosno beds was accompanied by differential uplift of some parts of the original sea floor.

Some observations are also to be found in numerous regional reports, especially in those of J. and St. Wdowiarz, but space does not allow an adequate review here. All necessary references are given in the text.

This paper owes its origin to the sedimentological investigations and measurements of current directions carried out by the present writers during the field season 1957. The directions of turbidity currents from the outcrops situated in the western part of the Carpathians have been kindly supplied by Prof. M. Książkiewicz.

## ACKNOWLEDGMENTS

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## STRATIGRAPHY AND LITHOLOGY OF THE KROSNO BEDS

A brief outline of the stratigraphy and lithology Krosno beds will be given. For more complete informations the reader is referred to the papers by Z. Opolski (1933) and Z. Obuchowicz (1957)[1].

The Krosno beds are of widespread occurrence and with the exception of the Magura Nappe they appear in all tectonic units in the Polish Carpathians. They are marine throughout and were laid down in rather deep water.

The Krosno beds occupy the larger part of the Central Depression (see maps attached). Here the fullest succesion is found and the strata discussed occur in their typical development. They comprise fine and medium-grained sandstones of gray and light-gray colours, marly shales and silts. The shales are usually also light coloured but intercalations of black shales are not infrequent in the lowest and upper parts of the Krosno beds.

Taken as a whole the Krosno beds show no strong contrasts in their lithological character. Similar rock types appear again and again at different levels and places. Such a behaviour implies the repeated return

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[1] The Krosno beds have been mapped and worked up by numerous geologists. The papers and maps of J. St. Wdowiarz, L. Horwitz and H. Świdziński concerning the eastern part of the Carpathians and those of J. **Burtan**, K. Ciszewska and M. Książkiewicz concerning the western part are of special interest. The preparation of the presents paper would have been impossible without their extensive studies.

of similar depositional conditions and the unexpected uniformity of the supplied material [1].

In the absence of sufficient paleontological data the stratigraphy of the Krosno beds is based upon lithological differences, although it is known that particular rock types merge one into another, being only facies of original sea floor deposits.

There are only few widespread and easily distinguished rocks units to apply as key beds in making correlations. Unquestionable stratigraphical criteria have not yet been found in spite of numerous investigations approaching the problem from various points of view. At the present time the best methods available, seems, to be tracing and comparing of rock groups from place to place as it was suggested by Z. Opolski (1933). This method of correlation has been adopted by several geologists mapping the Krosno beds.

It has been pointed out by Z. Obuchowicz (1957) that a detailed study of sole markings might greately contribute to the explanation of stratigraphical problems in the Krosno beds. The above author succeeded in finding a tectonic repetition in the section of the Krosno beds in Besko, hitherto regarded as uninterrupted sequence. He arrived at this conclusion by comparing directions of current markings in the lower and upper members of the Krosno beds.

The Krosno beds have been divided into three members, i.e. Lower, Middle and Upper members. In some areas there are, however, only two members, sufficiently distinct to justify their separation.

Lower Krosno beds are composed largely of thick-bedded sandstones with poorly developed shaly intercalations. They pass downwards into the Menilite beds [2].

Middle Krosno beds are built up largely by thin and medium bedded sandstones separated by marly and silty shales. The proportion of sandstones to shales is smaller than in the lower part of the strata discussed. The sandstones display a profusion of convolute bedding which is thought to be a characteristic feature of this horizon.

Inclusions of thick-bedded sandstones are not infrequent in the eastern part of the Central Depression, thick-bedded glauconite sandstones appear. They have been recognized as a good guiding horizon traceable for a distance of many tens of kilometres (J. Burtan, St. Wdowiarz, W. Sikora, K. Żytko). Last time (1958) K. Żytko seams this sandstone is contemporaneous to the „Jasło shales". The glauconite sandstones belong throughout to the Middle Krosno beds [3].

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[1] Data concerning the petrology of the Krosno beds are to be found in the papers of St. Jaskólski (1931), A. Oberc (1947. The summary of recent petrological studies on the Krosno beds carried out by several petrologists are given by Z. Obuchowicz (1957).

[2] The stratigraphical link between the Krosno and Menilite beds (Upper Eocene) is called Passage beds. These latter comprise sandstones of the Krosno beds type and black shales resembling the Menilite shales from below. A part of the Menilite beds seems to be equivalent to the Krosno beds.

[3] Over wide areas they are separated from the thick-bedded sandstones of the Lower Krosno beds by a series of thin and medium-bedded sandstones, but in some places they seem to rest directly upon the thick-bedded sandstones.

The layers of light coloured marls called „Jasło shales" are thought to be another important key bed (see H. Świdziński 1947 and St. Jucha 1957).

It is of interest to note that in the Skole unit, northeast of Sanok layers of diatomites have been recently discovered by J. Kotlarczyk (1957, 1958). They are thought to be also a guide horizon.

Upper Krosno beds comprise marly shales interbedded with few and thin layers of fine-grained sandstones only. In the closing stages of accumulation of the Krosno beds diatomite layers were being laid down in the area of the Skole unit (J. Kotlarczyk, 1958).

Although the proportion of shales to sandstones as measured vertically increases upwards, there are areas where large shaly deposits occur in the lower part of the Krosno beds. The paleogeographic importance of this will be discussed later.

In the present state of knowledge it is difficult to give a precise estimate concerning the thickness of the Krosno beds in each section. In the Central Depression where the strata discussed show their typical development the thickness of the Krosno beds has been estimated by H. Świdziński at 3 210 m. in the Besko profile.

To the west the thickness of the Krosno beds decreases. Although in many places tectonic squeezing must also be responsible for reduction of the Krosno beds [1], there is good reason to believe that in the Western Carpathians their original thickness was much smaller than that in the Central Depression. The same accounts for the poorly developed Krosno beds within the Dukla Folds.

The Krosno beds afford a comparatively safe ground for reconstruction of current directions. They reveal far less tectonic deformations than many other units in the Carpathians with the exception of the Podhale flysch.

In the eastern part of the Polish Carpathians the Krosno beds fill elongate synclines and cover the limbs of long and narrow asymmetric anticlines. These latter run parallel to the main trend of the Carpathians without conspicuous changes in strike. The axes of these folds plunge gently either to the east or to the west. Therefore the error in measurements of current indices due to the pitch of folds are slight and may be ignored.

To avoid errors, current reading from all intensely deformed strata has been discarded. It is impossible, however to trace current marks on the same bed over large areas. The results of measurements plotted on the maps correspond to comparatively small units inside a given members. Fortunately current indicators, although varying from one layer to another, do not differ generally in sections of important thickness. This means that the same direction of supply, whether from one source or not, persisted in a given region over a sufficiently long period to make comparison of distant sections possible without drastic errors even if a detailed stratigraphy has not yet been adequately established.

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[1] According to M. Książkiewicz (1930, 1936), and J. Burtan (1937) the Krosno beds in the Western Carpathians are stripped off from their base.

Judging from the present island arcs we may assume that the geosynclinal troughs were arcuate. If no farther changes in the shape of these troughs have occurred the present orientation of current indicators would give approximately the true direction of supply. If not, a correction should be made. As a matter of fact it seems probable that the original curvature of the troughs underwent some changes, both during the accumulation of flysch and afterwards, but the amount of change is not known. Therefore the paleogeographic reconstructions shown on the maps attached are based upon the present shape of the Carpathian arc as if no changes intervened.

## SEDIMENTARY STRUCTURES AND TYPES OF BEDDING DISPLAYED BY THE KROSNO BEDS

A brief review of various structures exhibited by the Krosno beds will be given. Several types discussed are depicted in fig. 1 — 9.

### NON-GRADED, THICK-BEDDED SANDSTONES

As it was noted already they are of widespread occurrence in the lower and in the middle part of the Krosno beds. The sandstones here described appear often, one upon another, separated by very thin and insignificant intercalations of silts or marly shales. Some are well sorted with obscure stratification, other display a poor degree of sorting with small pebbles and slabs of shale disseminated in the matrix (fig. 1).

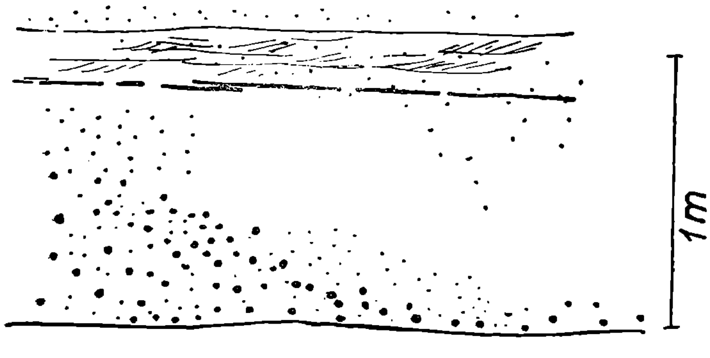

Fig. 1. Piaskowiec o nieuporządkowanej strukturze. Besko
Fig. 1. Non-graded coarse sandstone. Besko

The coarse material may occur in the shape of obscure layers within the sandstone bed (fig 2 and 4). Clay matter becomes usually more abundant towards the top surface and cross-bedding of the current-ripple type, convolute bedding of lamination may appear. The soles of the sandstone discussed display groovings, flute casts, bounce casts etc. but there are also numerous examples of smoth lower surfaces.

A large part of these sandstones seems to be produced by dense turbidity currents. The deposits of such currents are frequently devoid of grading (Ph. H. Kuenen 1951). In some cases watery slides were responsible for their deposition. Prof. Ph. H. Kuenen proposes the term „fluxo-turbidites" for this type of beds [1]. As a matter of fact there are transitional types between the sandstones above mentioned to „slurry mud-flows" and slides.

Fig. 2. Ławica złożona. Besko
Fig. 2. Composite bed. Besko

In several sections accumulation of sands was due to the supply at such short intervals and at changing rates so that shaly intercalations could not develop or were washed away by the next current (see fig. 3) [2]. Hence „composite beds" of sandstones resulted, ranging in thickness up to 10 or more metres.

Composite beds consist of two or several components which might be named „sub-layers". It is not to be implied that the mechanism of deposition was the same in different sub-layers. Laminated or cross-bedded members of the section shown on fig. 3 were obviously deposited by currents differing in their properties from those which had laid down poorly graded „massive" sub-layers.

It is worth noting that in the sandstones here discussed the elongate grains show up-current inclination, i.e. they dip in the direction whence the current came. In rare occasions only down-current inclination has been found. This opposite imbrication was due to the „lateral sedimentation" (see van Straaten 1951) on the slopes of poorly marked foreset laminae.

Due consideration should be given to the composite beds which consist of different sub-layers closely fitting together along the uneven, eroded surface of the preceding member. Good examples of such composite beds are illustrated in fig. 2, 4, 5, Pl. XXIV, fig. 1.

The upper part of the composite beds shown by fig. 4 consists of the sandstone with an admixture of coarse material of pebbles. The lower sub-layers are composed of more fine-grained sandstones. Numerous

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[1] A discussion concerning „fluxo-turbidites" will be given in a joint paper „Turbidites in flysch of Polish Carpathians" by M. Książkiewicz, Ph. H. Kuenen and St. Dżułyński (in press).

[2] This section might be considered as typical for the lower part of the Krosno beds in the eastern region on the Polish Carpathians.

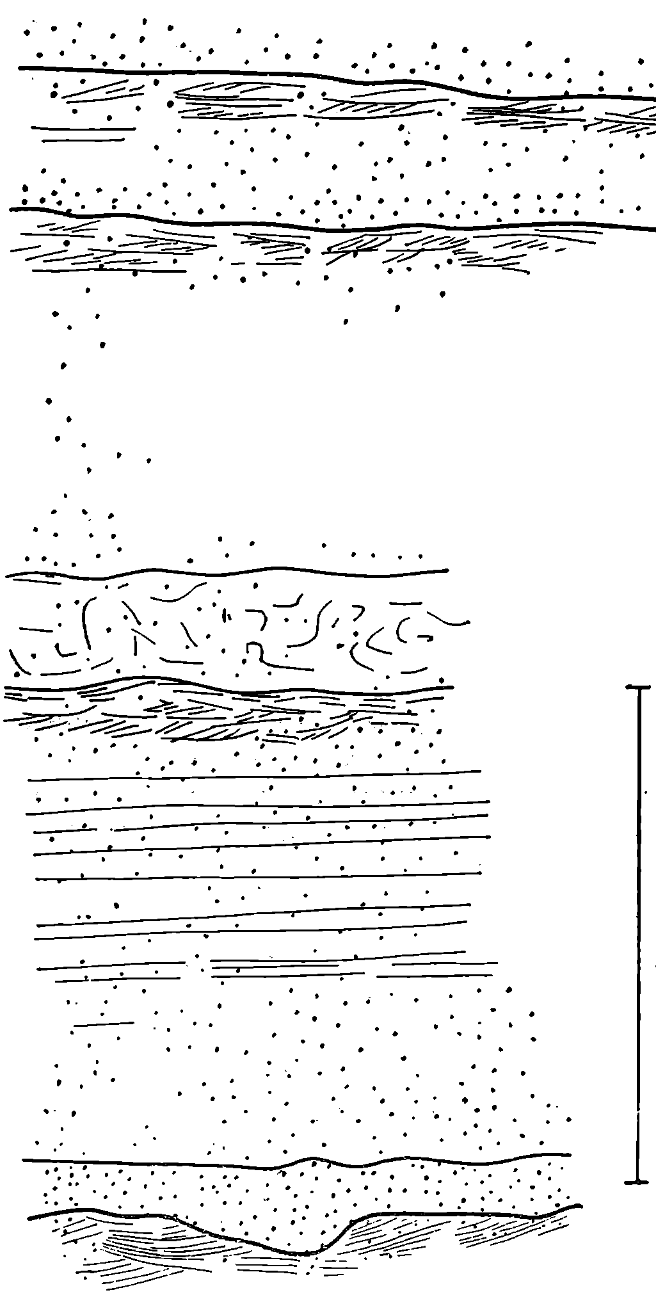

Fig. 3. Fragment odsłonięcia grubolawicowych piaskowców w warstwach dolnokrośnieńskich. Ustrzyki Dl.

Fig. 3. Sketch section of the Lower Krosno beds. Ustrzyki Dolne

protuberances may appear along the boundary surface between these sub-layers. Obviously the protuberances were largely due to the differential sinking of coarse sediment into the soft substratum. Such „load-casts" (Ph. H. Kuenen 1953 a) inside the sandstone layer are identical with those found on the soles of sandstones (flow-casts in the meaning of R. R. Shrock 1948) or with load-casts produced experimental by E. M. Kindle (1917) and Ph. H. Kuenen (see Natland & Kuenen 1951). The structure of the coarse upper component and bending down of laminae in the sub-layer below might help to distinguish the protuberances discussed from short wash-outs produced by erosion.

In many cases both erosion and load-casting occurred. It must be noted that structures produced by these processes do not necessarily indicate a break deposition. They may result from an increase of intensity of the same current [1].

In normal composite beds the material of different sub-layers comes from the same direction.

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[1] Load-casts in the Krosno beds are often deformed by creep of newly deposited sediment. The resulting structures might be classified as „flow-casts" in the meaning of J. E. Prentice (1956) see also Ph. H. Kuenen & J. E. Prentice (1957). Possibly a part of them represent also deformed current markings. They may be named according to G. Kelling & E. K. Walton (1957) „flute-load-casts", „groove-load-casts"... etc.).

There are instances also where different or even opposite transport may occur. An example of such a composite bed is shown in fig 7, Pl. XXIV fig. 1.

The sandstone bed B consists of two distinct sub-layers tightly welded together, the boundary surface between them being uneven. It is evident that the lower part (a) of the composite bed described has in part been cut away by the action of current which subsequently deposited the more coarse component (b). The older sub-layer (a) displays well developed flute casts on its sole. Both current bedding and flute casts indicate that this part has been laid down by a current from NW (310°). The coarse component (b) has no hieroglyphs of its own but the axes of elongate grains dip south- or south-east along the strike 160°. In view of what has been said about the imbrication, the suggestion may be advanced that the upper part of the composite bed in question has been derived from the south or south-east.

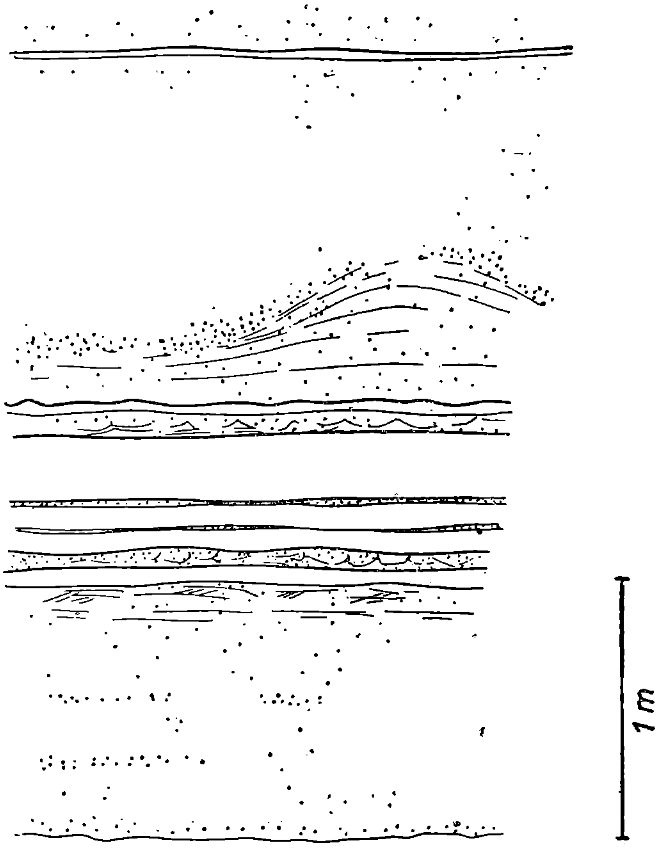

Fig. 4. Ławica złożona. Warstwy środkowo-krośnieńskie. Sieniawa

Fig. 4. Sketch section with composite beds. Sieniawa

As doubt may arise, whether the conclusion drawn from imbrication is reliable, we give here other observations which in our opinion sustain the suggestion set forth above.

In the exceptionally well exposed outcrops of the Krosno beds at Sieniawa both, fine-grained and coarse-grained sandstones occur. The material of the former does not differ essentially from that of the sub-layer (a). On the other hand all the coarse-grained sandstones bear striking resemblance to the upper component of the composite bed described. Flute casts and current bedding in the fine-grained beds indicate that they originated from currents coming from the west or more precisely from NW (310°) whereas the coarse-grained sandstones have been derived from the south (160°) as indicated by current markings on their soles (see fig. 7 and 10). Special emphasis is placed here on the fact that intercalations of sandstones deposited by currents coming from various directions (often from opposite directions) are by no means exceptional in the Krosno beds.

In all the coarse-grained sandstones, the sub-layer (b) included, there is the same imbrication. Conclusions as to the direction of supply drawn from the imbrication are everywhere consistent with the evidence provided by the sole-markings.

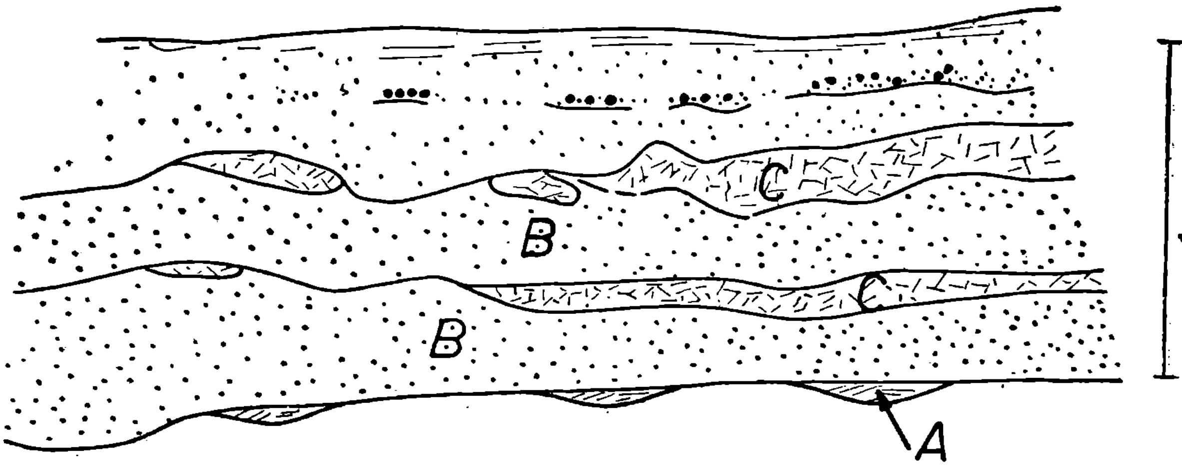

Fig. 5. Ławica złożona. A — pozostałości rozmytej ławicy drobnoziarnistego piaskowca; B — piaskowiec gruboziarnisty; C — soczwy ankerytowe. Besko

Fig. 5. Composite bed. A — remnants of eroded fine-grained sandstone; B — coarse grained sandstone; C — ankerites. Besko

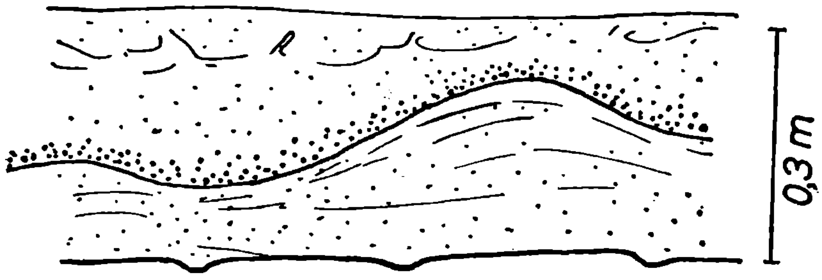

Fig. 6. Ławica złożona. Fragment odsłonięcia warstw środkowokrośnieńskich w Sieniawie

Fig. 6. Composite bed with load-casted erosion surface between fine-grained and coarse-grained components. Sieniawa

Another argument rests upon the essential likeness between the upper component (b) and other coarse-grained sandstones with well established direction of supply.

In summary: Poorly graded or non-graded composite beds might be deposited either by the same turbidity current or watery slide, changing only its intensity and character, or they may originate from different currents. In the latter case the transporting currents might come from various even opposite directions.

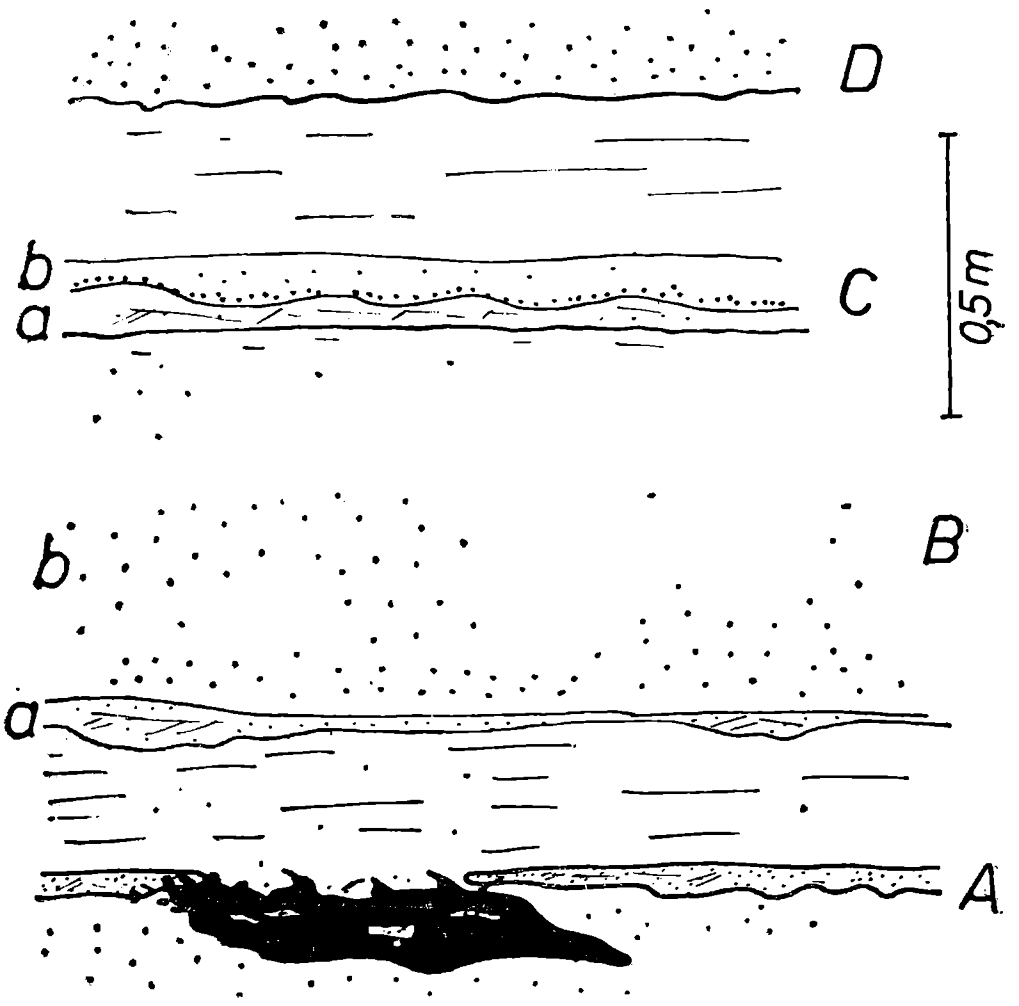

Fig. 7. Fragment odsłonięcia w Sieniawie. Warstwy środkowokrośnieńskie z ławicami, których materiał pochodzi z różnych kierunków

Fig. 7. Sketch section showing interstratification of beds with various direction of supply (Explanation in text)

## THICK-BEDDED SANDSTONES WITH SLUMP-STRUCTURES

One of the most striking features of slumps in the Krosno beds is the predominance of incoherent „slurry" slumps. True gliding, i. e. downward movement of plastic material in which laminae are folded without loss of their identity is comparatively rare. Several factors might account for the widespread occurrence of this type of slumps. One can imagine that the sliding mass, although more or less coherent when first set to move, grew more and more dispersed because of intermixture of sliding masses and water (W. H. Menard & P. C. Ludwick 1951) or by loss of internal cohesion without addition of water (Ph. H. Kuenen 1955). Another explanation is that already set forth by C. Beets (1945), i.e. that the sands forming the present slump bed must have remained poorly cemented until the beginning of the movement.

The above mentioned author proposes the term „flowage of quicksand" for this kind of slide[1]. Possibly both explanations might account for the widespread occurrence of the incoherent slumps in the Krosno beds.

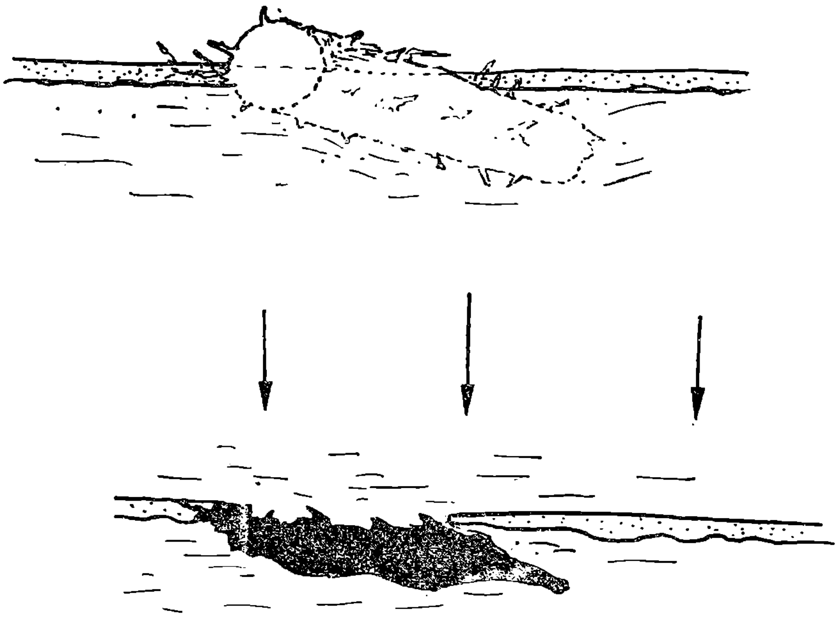

Fig. 8. Rekonstrukcja wycinka pierwotnych osadów dennych wyjaśniająca pochodzenie przerwy w ławicy A na fig. 7

Fig. 8. Reconstruction of a sand layer with a half-burried trunks (Explanation in text)

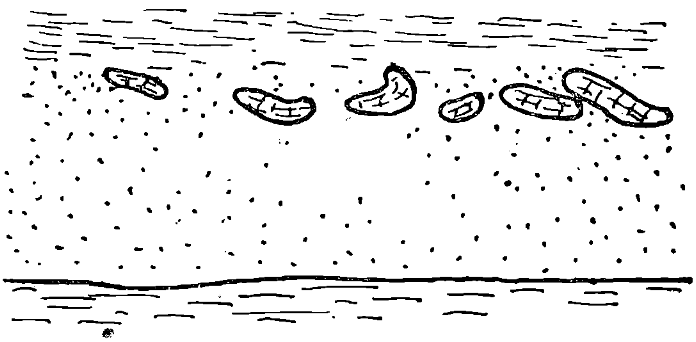

Fig. 9. Fragment ławicy osuwiskowej. Warstwy dolnokrośnieńskie. Besko

Fig. 9. Slump bed with contorted ankerite lenses. Besko

In consideration of various agencies that may have produced such slumps we should take into account the influence of mineralogical composition both of sands and muds and all the conditions of deposition of the Krosno beds.

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[1] We shall use the term „flow of sand" or „sand flow" in this meaning.

Excellent exposures of the Krosno beds along the Wisłok river south of Besko provide abundant examples of slumps. One of them is depicted in fig. 9. The bulk of sediment in this case consists of rather fine-grained muddy sandstone with obscure traces of „fluidal structure". Numerous slabs of shales and contorted lenses of ankerite [1] are scattered in haphazard arrangement within the matrix. Some ankerite lenses show „hook-like" overfolds similar to those described by J. C. Crowell (1957) which provide a good indicator of the direction of movement. The type discussed may be regarded as typical for many slumps in the Krosno beds in the area of the Central Depression.

Another type of slump is depicted on fig. 10. It is probably very much like the „pebbly mudstones" of J. C. Crowell (1957). Such pebbly mudstones and sandstones are well exposed at Sieniawa (the upper part of the Middle Krosno beds). Their thickness ranges up to 2 metres. The beds in question consist of friable, loosely cemented muddy sandstone with numerous slabs of shale, contorted lenses of ankerite and irregular inclusions of better cemented sandstone. All these structures might be classified according to Ph. H. Kuenen (1948) as „slump-balls" „crumpled balls" and „slip-blocks".

The structural details of these slumps vary throughout the bed but the general appearance is the same. The slip-blocks enclosed are somewhat harder than the matrix itself and serve to accent the slumping that has taken place.

The slump-beds in question are of the „slump-sheet" type [2], i. e. their soles are rather flat whereas their upper surfaces tend to be uneven. Generally speaking this kind of slump seems to be very common in the Krosno beds.

In the slump-beds depicted in fig. 10, slip-blocks appear at some distance from the base of these layers. There is a progressive diminution in the size of fragments enclosed as we proceed towards the bottom of the bed. While the upper parts of the beds in question are typical semi-coherent slumps, their lower portions resemble turbidite beds. The turbidite character of the lower portions is accentuated by the presence of flute casts and imbrication. This latter disappears upwards. There is no boundary between the turbidite-like lower part and the slump structure above, the former graduating imperceptibly into the unarranged slump. The explanation which can be given of these beds is that they were produced by a combined action of turbidity current and slumping. The latter followed immediately the turbidite current, both phenomena having been the events subordinate to the essentially one mass-movement along the bottom (see Kuenen & Migliorini 1950, Kuenen et. al. 1957).

In the section of the Krosno beds exposed at Sieniawa coarse slump-beds alternate with silty or marly shales and fine-grained sandstones.

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[1] According to W. Narębski (1957) the term „ferrous dolomite" is more adequate.

[2] The term „slump-sheet" is here used in accordance with the definition given by Ph. H. Kuenen (1948).

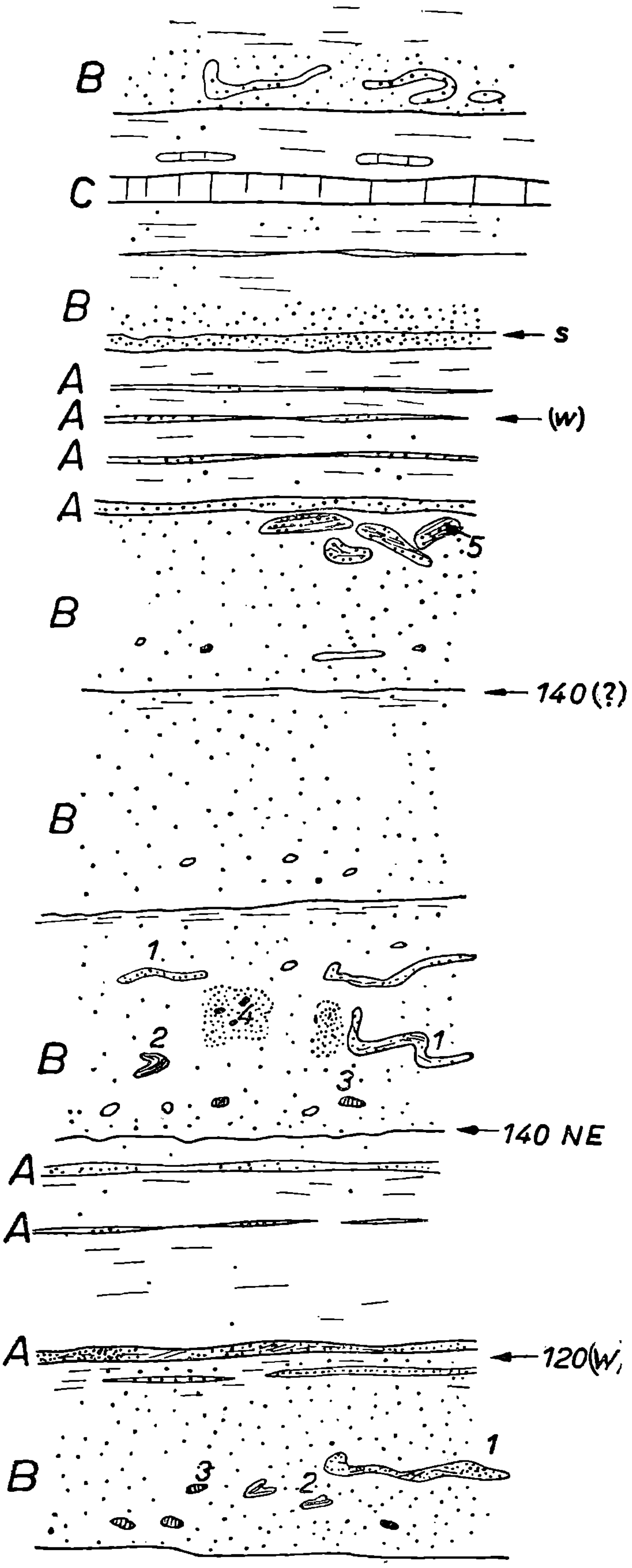

Fig. 10. Fragment odsłonięcia w Sieniawie. A — drobnoziarniste piaskowce. Kierunek transportu z W albo WNW; B — gruboziarniste piaskowce o strukturze częściowo osuwiskowej. Kierunek transportu z S albo SSE; 1 — porozrywane fragmenty ławic drobnoziarnistych piaskowców; 2 — fragmenty łupków; 3 — buły ankerytowe; 4 — nieregularne skupienia gruboziarnistego piaskowca; 5 — fragmenty węglistych piaskowców; C — ławica ankerytu

Fig. 10. Sketch section showing interstratification of beds with different direction of supply. A — fine-grained sandstones. Supply from WNW or NW; B — coarse slump and turbidity beds. Supply from S and SSE. 1 — torn-apart sandstone layers; 2 — fragments of shales; 3 — ankerite lenses (displaced and contortes); 4 — irregular clusters of coarse-grained sandstones; 5 — slip-blocks of soft sandstone with coal seams; C — ankerite layer. Sieniawa

As already noted fine-grained sandstones have been derived from WNW, whereas the slump-beds and other coarse-grained layers came from south or south-east. This means that the bottom has been alternately affected by the action of currents and slumps coming from various directions (see Pl. XXIV fig. 1 and 2). It will be shown later that similar conditions prevailed over vast areas of the original sea-floor in the eastern part of the Central Depression and persisted during rather a long period.

Coaly plant remains tend to be abundant toward the tops of the slump-beds. In most cases the coaly matter appears as thin bands of vitrite [1]. In connection with this there remains an interesting, though on account of its limited occurence not important structural detail revealed by the sandstone layer A depicted in fig. 8. The bed which has been spoken of rests upon the silt on the top of a slump. It is interrupted just above a buried and coalified trunk although there is on evidence of slumping in the broken bed itself. Obviously the pull-apart must not be taken into account. The following explanation is here proposed. The trunk laid down on the bottom obviously projected through the thin cover of sand brought by a turbidity current (fig. 9). Having been more susceptible to the subsequent compaction than the sand itself it changed into a flattened inclusion of vitrified coaly matter. Thus the top surface of this originally half-burried trunk has been pressed down below the sole of the sandstone bed. Only branches or roots enclosed tightly in sand persisted in their original position and form at present tubular coaly apophyses within the sandstone bed.

The slumps previously described contained fragments of rocks similar to, if not identical with those from below and above the slump layer. There are instances, however, that slip-blocks embedded differ in their composition from the surrounding rocks being not necessarily typical exotics, i.e. older than the flysch in which they occur. Some slip-blocks consist of finely stratified sandstones composed of alternating layers of coal and sands, large pieces of coal with numerous fresh-water gastropods or slip-blocks charged with shells of shallow water mollusca are also to be found in the Krosno beds. Such rocks have been derived from littoral zones of the flysch sea and are largely contemporaneous or penecontemporaneous with the turbidite in which they same to rest.

Pebbly mudstones or silts with exotic boulders decidedly older than the enclosing flysch sediments are not so conspicuous in the Krosno beds as in the Cretaceous or Eocene flysch of the Carpathians. They have been found, however, in several places, within the Krosno beds.

As it was pointed out by Schardt (1898) Heim (1909), Bailey, Colet & Field (1928) and others, clays with exotic boulders resulted from submarine mud-flows and slides.

Before closing this part of the subject some consideration will be given as to the nature of mass-movements along the sea floor of the flysch basins.

Judging from the evidence available both turbidity currents and slumps occurred over large areas of the original sea floor. There is an

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[1] Most of this vitrite seams and lenses originated from wood and a part of it possibly from kelp brought down by turbidity currents and slides.

intimate connection and in some instances mingling of slumps and turbidites, the intermediate link between them being the deposits of slurry, incoherent and watery slides or „fluxo-turbidites". Submarine slides initiated turbidity currents and on the other hand, newly deposited turbidites might move farther as slumps. In some instances, as was recently pointed out by Crowell (1957), the „momentum" or „kick" from a vigorous gravel bearing turbidity current may set off sliding masses that otherwise would not take place. Examples of turbidite beds converted into slumps contemporaneous or penecontemporaneous with the deposition of the turbidite layer have been also shown by Dżułyński & Radomski (1957) from the Menilite beds (Carpathians). There are good reasons to believe that in large shifts of sediments various kinds of mass-movements took place simultaneously. The resulting deposits are characterized by far more complex structure than the graded turbidites of pure turbidity currents. Such beds have been observed by Kuenen & Carozzi (1953) in the Alps and by Crowell (1957) in California.

Slumps require slopes steep enough to produce unstable conditions of accumulating sediments [1]. Huge slumps once set in motion might, however, slide over a very gentle slope (A. Heim 1908). Mud-flows heavily charged with argillaceous matter sand and boulders can apparently move on a practically flat bottom for a distance of many kilometres. In some cases the distance travelled by huge slumps and mud-flows must have exceeded 30 km. e.g. large slumps at Bukowiec and Baligród, south east of Sanok [2]. In view of such large distances a vague but yet useful idea may be formed concerning the redeposition of slump sediments over the slopes of migrating submarine swells.

## SANDSTONES WITH CONVOLUTE LAMINATION, CURRENT BEDDING AND LAMINATION

None of the types mentioned in the headline is necessarily confined to a given thickness or texture (grain-size and composition). They appear, however, mostly in the fine-grained and thin- or medium-bedded sandstones.

Convolute bedding (Ph. H. Kuenen 1953), known hitherto among others as „corrugated bedding" has been recorded from the Krosno beds by several geologists. At first impression it appears to have been origi-

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[1] According to A.D. Archanguelsky (1930) slips may occur even if the angle of the slope does not exceed 1°. This, however, applies to rather small slumps or creep of hydro-plastic sediments. Large slumps such as observed in the Krosno beds must have originated on the more steeply inclined slopes. The occurrence of these slumps may indicate tectonic movements within the geosynclinal belt as has been pointed out by several writers, or it may be that oversteepening by rapid sedimentation is responsible. Submarine slumps in the Krosno beds have been named „fossil seismographs" by O. Ganss (1942) and this name might be applied possibly to many of the turbidites in the strata discussed.

[2] The Babica clays, charged with exotic boulders are thought to have been derived from a source situated in the north-east and in this direction they can be traced at a distance of at least 30 km (Bukowy 1957).

nated by small-scale submarine slumps or creep, or resulted from compaction of water-saturated sediments. These conclusions as to the origin of the „corrugations" discussed seem to have been arrived at independently by various geologists. With regard to the convolute bedding in the Krosno beds the first conclusion has been advocated by Ganss (1942), Dżułyński & Radomski (1956) and Obuchowicz (1957).

Elements of weakness in this hypothesis have been pointed out by Ph. H. Kuenen (1953) whose current-rippling hypothesis seems to provide better explanation. Considerations which need not to be set forth in detail indicate that differential pressure upon the crests and troughs of ripples and powerful drag exerted by turbidity currents upon newly deposited and very mobile sediments account largely for the development of the convolute bedding (see Ph. H. Kuenen 1953). Nevertheless gravitational sliding (see Pl. XXXV fig. 2) and compactional changes associated with expulsion of water surplus (Migiorini 1950) must have played an important role in the final development of the convolute bedding (see also ten Haaf 1956).

In some cases convolute bedding may be traced throughout the whole layer but in most instances it occupies only a part of it and is associated with current bedding and lamination. In the case when the convolute bedding occupies the whole bed its bottom surface may be undulated and the shale pushed upwards between troughs of convolution in the manner described by Kopstein (1954). In the known cases the strike of these undulations is perpendicular to the direction of flow. A great variety of forms is exhibited by weathered surfaces of convolute bedding. These surfaces are divided into innumerable elevations and depressions in shapes of irregular knobs, hillocks and pockets. Sometimes these knobs associated with depressions are scattered randomly over the surface; more often, however, they appear arranged in furrows and ridges. The latter run parallel or at right angle to the direction of flow, the former arrangement being predominant. The shapes of elevations and depressions are widely diverse and in many cases the rugose belt of hillocks and depressions grades into an irregular wavy surface. In rare cases, strongly individualized conical knobs project over a comparatively flat or gently undulated surface. In sections cut at right angle to the bedding plane the convolute bedding in the Krosno beds does not differ from that described by Migliorini (1950), Signiorini (1936), Kuenen (1953), ten Haaf (1956) and others.

We shall give now consideration to some features associated with current bedding and convolute bedding, the importance of which in the flysch rocks has not perhaps been recognized hitherto. The soles of sandstones with combined current and convolute bedding often display arcuate bands. Observation in oblique lighting of the soles of fine-grained sandstones in the Middle Krosno beds hardly ever fails to disclose the delicate pattern of these arcuate bands. (Pl. XXVIII fig. 1). They always show their convex sides towards the direction whence the current came from. This has been proved trustworthy by a comparison with other current indicators. Hence we have a criterion of current direction of much value since the arched bands are sufficiently common in the Krosno beds to give them wide application [1].

The bands described are evidently imprints of foreset laminae of current bedding. Such a pattern has been discovered by J. Schmidt (1932) on the horizontal sections of current bedding. G. Gürich (1933) had observed similar arcuate bands in a sandstone in the Nama--Transvaal system and W. Häntzschel (1935) in the recent sediments of the Watten Meer. The term „Schrägschichtungsbögen" introduced by G. Gürich is used in the German literature for these structures. R. Richter (1932) pointed out that „Schrägschichtungsbögen" appear to be formed by current rippling and this explanation holds true for all the cases in the Krosno beds.

Successive arched bands appear either on the surfaces devoid of markings and smoothed or on the surfaces, sculptured by flute casts. These latter do not influence the shape and orientation of arched bands but the axes of flute casts and those of the arcs are parallel and apices turned in the same direction (up-current).

The origin of the arcuate bands on the soles of the Krosno sandstones appears from a comparison of sections cut parallel and at the right angle to the direction of flow (see fig. 11). The former section displays a typical current bedding with steeply inclined foreset laminae and gently dipping top-set laminae. The section cut at right angle to the direction of flow and at the same time perpendicularly to the axis of the arcs shows criss-cross bedding of the „lenticular type" (see R. Shrock 1948) or trough-cross stratification (Mc Kee, G. W. Weir 1953).

The main conclusion arrived at with regard to the arcuate bands in the Krosno beds is that already reached by Richter (1932) and shown experimentally by Kuenen, Bagnold, Mc Kee and others that ripples formed by steady flow of water consist of „hillocks and pockets which show no tendency to straightness" (Bagnold 1954 l.c. page 163). By moderate supply of sand barchan-like dunelets appear. The arcuate bands in question point out the actual position of slip-faces of these submarine crescent-shaped dunelets or „cusp ripple-marks" (Mc Kee 1954).

It is of interest to note that the depressions embraced by the crests and slip-faces of these dunelets coincide in many cases with broad „synclines" of the convolute bedding and wings of the adjacent „barchans" with narrow „anticlines". These latter as seen on sections cut at right angle to the direction of flow are truncated by another set of laminae or bent down and twisted towards the depressions. The same applies to the crests which are overfolded in the direction of flow. Such a diversion out of normal position is suggestive of the combined action of drag, current rippling and gravity which is consistent with the explanation given by Ph. H. Kuenen with regard to the origin of convolute bedding. Innumerable small submarine crescentic dunelets provide thus the basis upon the convolute bedding is built up.

It is in rare occasions only when ripples appear on the top surfaces of the Krosno sandstones. They have been found at Sieniawa on the

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[1] Similar structures have been observed also by Dr. A. Smith in the Silurian flysch of Aberystwyth (personal communication).

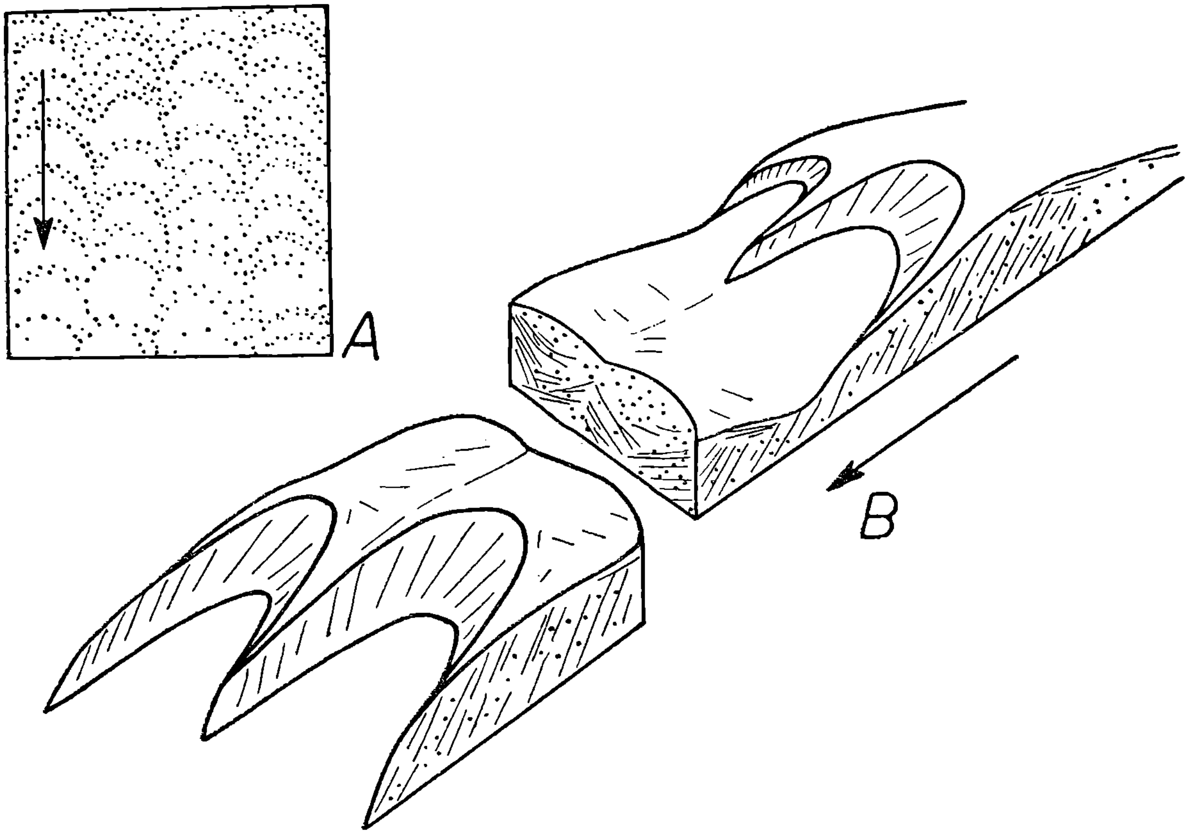

Fig. 11. Schemat struktur łukowych na spągu piaskowców

Fig. 11. Sketch showing arcuate bands (A) and crescent dunelets in newly deposited sand (B)

top-surface of the bed with arcuate bands on its sole. Unlike the „barchan-like" structures on the sole, the ripples on the top-surface were bent down-current, i. e. they showed their convexities in the direction of flow, hence they are of the normal linguloid type [1].

Obviously, in aqueous environments like under subaerial conditions crescentic dunes result from moderate supply of sand laid down upon the comparatively hard and immobile ground.

Emphasis should be laid once again on the fact that the arcuate bands provide a reliable method of reading the direction of current and current bedding, minimum expenditure of time being required.

Laminated bedding will now be discussed. This kind of bedding is of widespread occurrence in the Krosno beds. It is also combined with convolute, current and graded bedding. It is not necessary to give a detailed description here of the lamination in the strata described as it does not differ from that described by M. Książkiewicz (1954) from various units of the Carpathian flysch. All the types described by the above mentioned author seem to exist in the Krosno beds.

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[1] The pattern of arched bands as seen on the horizontal section cut in the top-part of the bed in question was similar to that from below but with the difference that the apices of arcs pointed down-current.

Although lamination might be independent of turbidity currents, most of the beds with lamination in the Krosno beds appear to have been produced by turbidity currents. Some of them were laid down by dilute turbidity currents flowing along the bottom, others, especially those more fine-grained, might have resulted from the suspended currents (see Dżułyński & Radomski 1956). Most of the laminated beds in the Krosno beds are to be accounted for in the manner suggested by Ph. H. Kuenen (1953) and Kopstein (1954) i.e. they originated from clouds differing slightly in density of turbulence and velocity in the same turbidity current and during tractional transport.

### SANDSTONES WITH GRADES BEDDING

Sandstones with distinct graded bedding are not so common as the types discussed previously. It must be remembered, however, that there is almost in every case the accumulation of coarse grains at or near the base of the sandstone layers and a fine grading is easy to detect in thin sections. All the types of graded bedding described by various authors seem to be present in the Krosno beds.

## SOLE MARKINGS IN THE KROSNO BEDS

Although hieroglyphs on the soles of the flysch sandstones have been known and described for more than a century, it is only within the last few years that they have been widely recognized as important indicators of the directions of supply. The rapid extension of the theory of turbidity current (Ph. H. Kuenen & C. I. Migliorini 1950, Ph. H. Kuenen 1953, 1957) stimulated new investigations of various hieroglyphs which after the first brilliant work of J. C. Hall (1843), T. Fuchs (1895) and others have often been overlooked in the investigation of flysch rocks.

The importance which the sole markings, especially those of inorganic origin have for the theory of turbidity currents and other types of mass-movements along the sea-bottom is undisputable. A considerable importance must also be attached to these features as guides to paleogeography of the geosynclinal belts.

We give below a review of various types of hieroglyphs found on the soles of the Krosno sandstones. Particular attention will be given to those markings which to our knowledge have not yet been described.

### ORGANIC HIEROGLYPHS

The soles of the Krosno sandstones display usually numerous hieroglyphs. Those of organic origin are remarkably scanty. It does not imply, however, that the floor of the Krosno basin was devoid of benthonic life. As a matter of fact there is good reason to believe that benthonic life flourished and that the conditions for living organisms had improved as compared with the period of the Menilite beds accumulation. Nevertheless violent turbidity currents and slides inflicted a temporary destruction upon vast areas of the bottom inhabited by various animals. Hence the scarcity of biohieroglyphs and abundance of inorganic current markings is indicative only of destruction of trails and tracks. Turbidity currents and slides stirred up the water and brought down oxygen and must have been important and powerfull ventilating agents. Disappearance of euxinic conditions in the Main trough [1] during the Oligocene should be largely accounted for by frequent occurrence of large mass-movements along the bottom. That the conditions for living organism were favourable seems to be indicated by the presence of numerous biohieroglyphs on the soles of sandstones laid down by slow turbidity currents incapable of bottom erosion. Such sandstones, however, are subordinate in number to those deposited by violent and large currents.

It is beyond the scope of this paper to give a detailed description of organic hieroglyphs which occur in the Krosno beds. We note only that trails of *Paleobullia* and worms are of widespread occurrence. Possibly short ridges resembling imprints of ice crystals are also of organic origin. They appear in large amounts in the Middle Krosno beds. *Paleodiction* is remarkably rare. Hitherto only few specimens have been found in the strata discussed.

It is often hardly possible to draw a sharp line of distinction between organic and inorganic sole markings. Casts of gouges shown on the left side of the specimen depicted on Pl. XXIX fig. 1 [2] have been produced by an object which cut the bottom at intervals, skipping the intermediate space. These tracks are similar to those described by O. Abel (1931) and thought to be produced by fish brushing against the bottom (tracks of *Undina penicillata,* see O. Abel 1935 fig. 165). Particular casts of gouges bear also striking resemblance to some top-surface hieroglyphs recorded from the Belovesa sandstones in the Carpathians by Dżułyński & Kinle (1957). Nevertheless even more pronounced resemblance to such organic tracks does not prove that the markings discussed might not have been produced by inorganic objects forced rhythmically against the bottom while carried by a turbidity current.

The hieroglyph on the right side of the specimen illustrated on Pl. XXIX fig. 1 seems to be more enigmatic than previously discussed. However improbable it might look at first impression, it may be tentatively suggested that the hieroglyph in question was produced by a fish turned toward the course of the current and brushing the bottom with its fins. Whatever is the true nature of the objects brushing and striking the bottom in the cases discussed, it must be stated that these objects were carried by turbidity current because the alignment of markings is strictly parallel to the lineation [3] exhibited by all current indicators.

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[1] The term introduced by M. Książkiewicz for the trough situated to the north of the Silesian Cordillera and Marmaros Massif.

[2] All the specimens illustrated in this paper are now in the collection of hieroglyphs in the Museum of the Geological Laboratory of the Polish Academy of Sciences in Cracow.

[3] The term „lineation" is used here in the meaning of Crowell (1956).

The markings shown on Pl. XXXI fig. 3 are precisely opposite. Here the gouging object has been forced against the bottom at an angle of 70° to the current lineation. The rills produced by the current are distorted by the striking object in such a way that its course may be precisely determined. It may be confidently assumed that the structure described is of organic origin. One can suggest that the trace was left by a fish trying to escape destruction when caught by a turbidity current.

In some instances, organic hieroglyphs are to be found in subparallel orientation to the direction of flow. It seems probable that the slow currents might have controlled to some extent the orientation and movement of benthonic animals for a very short time before their final burial. We note also that numerous organic remains, especially fish-bones have acted as graving tools, while carried down by the turbidity current.

## INORGANIC HIEROGLYPHES PRODUCED BY TURBIDITY CURRENT[1]

We shall discuss them from the point of their applicability to determination of current direction. For the sake of convenience the markings named below are divided into two groups: 1- markings which resulted directly from the action of the turbidity current, 2- markings produced by various objects, touching the bottom while transported by the turbidity currents[2]. To the first group belong: flute casts, crescent casts, current ripple casts, rill-casts. The second comprises, bounce casts, impact casts, brush casts, groove casts, vibratory marks, roll- and saltation imprints etc.

### Flute casts (turboglyphs)

Under this term advanced by J. C. Crowell (1956) are embraced structures called „lobate current marks" (Shrock 1948) „Gefliessmarken" (Gürich 1933), „turboglyphs" (Vassojevic 1953), „Fliesswulste" (Häntzschel 1935), „vortex casts" (Wood & Smith 1957), „flow marks" (Rich 1950).

Flute casts or turboglyphs in the Krosno beds show a great variety of forms. All the types recognized by H. Rücklin (1938) and others are present[3].

Most of flute casts show marked asymmetry. This pertains especially to those types which have been named by Rücklin „Flach-Zapfen". In

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[1] Hieroglyphs here discussed belong to the group of markings named by N. B. Vassojevic „synglyphs" to set them in contrast with „diaglyphs" which have been formed after the deposition of the sandstone bed (Vassojevic 1953).

[2] „Eindrücke passiv bewegter Körper" according to the classification of K. Krejci-Graf 1932.

[3] It is known that flute casts may be localized by pits or mounds of organic origin (see Crowell 1956). They have been observed commencing at various organic remains by A. Wood and A. Smith in the Silurian flysch of Aberystwyth. Similar cases are known also from the Krosno beds.

typical cases such flute casts consist of two widening and fading out „arms" one of them being much longer than the other. This is to be accounted for in the following manner. The current lines passing over some objects resting upon the bottom or small irregularities of the sea floor, are split into subordinate current lines (Pl. XXV fig. 1) which are diagonal to the main course of flow. It is at rather rare occasions only when the original shapes of „germs" of flute marks permit symmetrical splitting. The asymmetry discussed has bearing upon the development of flute casts arranged in diagonal rows which have been described and illustrated by Ph. H. Kuenen (1957). Along these longer arms new localized vortices tend to develop. Their origin is analogous to that of the first flute marks. The direction of subordinate current lines determined by the first flute marks may persist over long distances. In such cases long rows oblique or diagonal to the main direction of flow appear (Pl. XXV. fig. 2).

If the flute markings are superimposed upon the preexisting grooves, the former tend to be arranged in rows parallel to the direction of flow. This type of arrangement has been recently illustrated by Ph. H. Kuenen (1957).

In some cases, various fragments are found entrapped in the flute gouges. They must nót be confused with objects around which the flute marks develop.

In rare cases contour lines appear on the surfaces of the turboglyphs (Pl. XXV. fig. 1.). The explanation offered by Ph. H. Kuenen, that the contours discussed are imprints of lamination exposed originally on the walls of gouges possibly accounts for most cases. In connection with this we note that various scratches and small grooves may be superimposed upon the contour line pattern, the former thus being later structures.

The surface of some flute casts has been scratched by objects transported by the turbidity current. Alignment of these scratches is parallel to that of the subordinate current lines and to the main direction of flow (Pl. XXVI. fig. 1). As obviously the tools responsible for scratching have been brought into action by subordinate currents, they must not be confused with those markings produced by the main flow.

Flute casts are usually closely parallel to the main direction of flow. Nevertheless local deviations may appear. The explanation offered is that the deviations from the normal course of the current are due to some stationary turbulences of short duration which appear in the turbidity current above morphological irregularities of the bottom. The deviations discussed which have drawn our attention during field investigation might produce some errors in local determination of the supply.

### Crescent casts

Turbidity currents flowing down the slope may scour crescent gouges in front and at the sides of various obstacles (pebbles, fragments of shale fish-bones, twigs etc.). These channels may reunite behind the obstacle forming thus an elongate gouge divided by a keel-like ridge (Pl. XXVII fig. 1). It is evident that the structures in question are closely akin to the flute casts. The crescent casts shown their convex sides towards the point whence the current came. Hence they are of importance for the estimation of the direction of supply.

Fossil current crescents have been described by several writers (K. Fiege 1942, F. E. Peabody 1947, J. L. Rich 1950, A. Radomski, in press).

### Current ripple casts

(PL. XXVIII Fig. 2).

Current ripple casts are rather exceptional features on the soles of the flysch sandstones. They seem, however, to be more frequently encountered in the Krosno beds that in other flysch units of the Carpathians. This may be partly explained by the fact that the shales in the Krosno beds contain comparatively large amounts of sand [1].

In the cases hitherto known, the direction of supply established from the current ripple-casts was consistent with that deduced from other current indicators such as flute casts, groove casts etc. Therefore it is suggested that the current ripple casts on the soles of the Krosno beds owe their origin to the same factors which produced other inorganic sole markings. This seems to be supported by the fact that no organic hieroglyphs have been found superimposed upon these current-ripples, i.e. these latter should be contemporaneous with the deposition of the sandstone layers. According to M. L. Natland & Ph. H. Kuenen (1951) current ripples result from dilute turbidity currents.

### Rill-casts

The term refers to the closely spaced furrows running parallel to each other or joining at places (Pl. XXVI. fig. 3). According to Ph. H. Kuenen (1957) rills may also result from turbidity currents.

Rill-casts represented in Pl. XXVI fig. 3 antedate impact markings or bounce casts with obscure flute casts, those latter developed just behind the impact markings. The alignment of rills is parallel to that of other current markings. Hence the general course of the current may be established from the hieroglyphs discussed.

Rills often appear in a dendritic pattern and bifurcate up-current (see also Ph. H. Kuenen 1957). In Łukowe, south of Sanok, the present writers have observed rills changing course continuously from SW-NE to NNW-SES along a distance of about 5 m. The strike of rills as measured at three different points was 70°, 130° and 170°. With the exception of problematic „cabbage leaf" structures (see pag. ) the well exposed surface with the rills in question was devoid of any other markings. There is no doubt, however, that the change described must be considered as a primary feature.

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[1] Ripple marks are very rare in pure muds (Ch. Epry 1913). Those described by van Straaten (1951) have been formed in muds which contained comparatively large amounts of sands. A large part of the shales in the flysch series resulted from rather pure muds and this may account for the scarcity of true ripple-marks on the flysch sea bottom.

## HIEROGLYPHS PRODUCED BY OBJECTS TRANSPORTED BY TURBIDITY CURRENTS AND SLIDES

To the group discussed belongs a great variety of markings produced by various objects touching the bottom while transported by currents or watery slides.

### Bounce casts

The term bounce casts has been proposed by A. Wood & A. Smith (1957) for rather short ridges made by objects striking the bottom while carried by turbidity currents. Structures of the kind discussed have been described by Dżułyński & Radomski (1955) and assigned to the action of shale fragments forced into the bottom and then lifted above it, (l. c. fig. 16). In the present paper the term „bounce casts" is used to mean elongate ridges fading out gradually at either end. However, as it is hardly possible to find whether the striking object came from one end or the other, the bounce casts in this meaning give us only the general course of the current.

Probably the first comprehensive explanation of these structures is that given by J. Hall (1843), i.e. that these „furrows" were made „by some heavy objects striking the bottom for a short distance and then lifted above it" (J. Hall 1843, pag. 236).

In the Krosno beds bounce casts belong to the most common hieroglyphs and have been widely used by the authors to determine the general course of the currents. Most of the bounce casts seem to be produced by fragments of shale, pieces of wood and fish-bones.

### Brush casts

The term „brush casts" is here applied to mean bounce casts with crescent depressions at one end (Pl. XXX fig. 1). Those latter are counterparts of mud ridges heaped in front of objects brushing against the bottom while carried by the current. Crescent depressions point always to down-current side and thus give to the brush casts wide applicability as valuable criteria of the direction of supply.

In most cases the true nature of objects brushing against the bottom remains unknown but the suggestion set forth in connection with the bounce casts holds true also for the brush casts. It should be noted, however, that a part of them might have been produced also by living organisms.

There are numerous cases in which brush casts appear repeatedly along a straight line parallel to the direction of flow as if the striking body has been again and again forced into the bottom and lifted above it (Pl. XXIX fig. 1). The markings discussed might be named „skip casts" [1].

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[1] The term „skip casts" has been proposed by Ph. H. Kuenen (see St. Dżułyński & M. Książkiewicz & Ph. H. Kuenen, in press).

## Prod casts

The term „prod casts" (according to the suggestion of Prof. Ph. H. Kuenen [1]) is here applied to mean asymmetrical ridges on the soles of flysch sandstones fading out in the direction whence the current came. The striking peculiarity of these hieroglyphs remains in the fact that they end abruptly on the down-current side, i. e. the opposite to flute casts (see Pl. XXV fig. 1). They are very often bent towards the deep end. This may be explained if one assumes a stick that is swung round by current as it comes to a standstill [2].

The only possible explanation of these markings is that they have been produced by objects striking with force against the bottom. In some cases the „tool" responsible for prod casts is still left at the end of the ridge. More often the striking body was lifted and taken away by the current. The nature of tools was probably somewhat different from that which was responsible for brush casts.

Prod casts are of wide occurence in the Krosno beds and supply an important criterion for current reading.

## Groove casts

The origin of groove casts is still a matter of debate. The general explanation suggested by J. Hall (1843) that they are due to the action of current flowing over the surface upon which the subsequent deposits were laid down, holds true for most cases.

Dżułyński & Radomski (1955) have found fragments of shales and pieces of wood in the end of some groove casts. This led them to the conclusion that groove casts owe their origin to the fragments of shales dragged along the bottom by the turbidity currents. A similar conclusion has been arrived at independently by A. Wood and A. Smith (1957). Ph. H. Kuenen (1957) proposes to use the term „groove casts" in a general meaning only and divides the whole group of markings comprised by this therm into „drag marks" and „slide marks" (see also Kuenen & Sanders 1956). Although no objection can be raised against this proposition it must be emphasized that in many cases it is very difficult if at all possible to tell true slide marks from drag marks.

The difficulty arises when two or more sets of closely crowded, parallel groove casts appear on the same surface. Considering such „cross-groove-casts" we must assume that a slight degree of abrasion took place. Cross-grooves could not have appeared if the sand masses moved as normal slides over the muddy bottom. It seems therefore reasonable that the groove casts themselves must involve more than one mode of origin.

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[1] In place of our field term „impact casts" used by present writers and A. Radomski. The name „impact casts" is a free translation of the polish term „ślad uderzenia" (see A. Radomski 1958 and Dżułyński & Książkiewicz & Kuenen, in press).

[2] Photographs of these markings are to be found in several papers dealing with the flysch deposits (see Vassojewic 1953, 1956). From the Carpathian flysch they have been described by Dżułyński & Radomski 1955, (see also Radomski, in press) from the silurian flysch of Aberystwyth by Wood and Smith (1957).

It might be supposed that some groove casts, especially those isolated or single casts of furrows originated by dragging of twigs, kelp, boulders entangled in kelp etc. (see J. L. Rich 1950, Ph. H. Kuenen 1957), turbidity current having been the chief agent of transport.

Pieces of wood have been recorded from the terminations of groove casts (Dżułyński & Radomski 1955). Other evidence which might be interpreted as indicating relation between twigs and groove casts is shown in Pl. XXXIII fig. 1,2. In the first case it is tentatively suggested that the three isolated but closely parallel groove casts have been produced by a single twig, brushing against the bottom with its off-shoots. One of these latter was apparently broken and a fragment of it left behind. Rough stration illustrated on Pl. XXXIII fig. 2 is also supposed to be due to brushing the bottom by a branch of a tree, twig or something of this kind. In connection with this it should be noted that short and long grooves from the Triassic rocks of Germany have been recently interpreted by O. Linck (1956) as due to dragging of trunks of *Equisetacea* along the bottom by normal marine currents.

The second group of groove casts are those formed by sliding of sediments as was suggested by Vassojevic (1953) and shown experimentally by Ph. H. Kuenen (1957). The explanation offered by the above mentioned authors holds true for intrastratal grooves found within some composite beds.

To the third group belong groove casts which resulted from the scouring action of various fragments like pieces of shale and wood, fish-bones, kelp and moving masses of dense sediments etc. propelled by a turbidity current along the bottom. This view with regard to the fragments of shales has been set forth by Dżułyński & Radomski (1955) and independently by Wood & Smith (1957). Such an origin of groove-casts is to be expected especially in those mass-movements which are of intermediate type between the true turbidity currents on one hand and slides and mud-flows on the other. The main force necessary to overcome the friction is, however, provided directly by the turbidity current. Possibly the scouring tools were imbedded in the mobile sands having the properties of quick-sands and propelled by turbidity currents. To this conclusion, Kuenen (1957) also agrees only if two forces, i.e. that of the slide and turbidity current combine. One can imagine that in a moving turbidity current a part of its load creeps along the bottom being propelled by the current whereas the other part is carried in suspension.

Pl. XXXIV fig. 2 shows the begining of groove casts. They commence at an irregular bulge on the sole of a sandstone. This latter is a typical turbidite and does not show any features indicative of slumping. The direction of flow as indicated by the arrow on Pl. XXXIV fig. 2 is from left to the right side. The bulge must be a counterpart of an irregular depression on the bottom scoured by the action of turbidity current or a combined action of turbidity current and small slide. The motion of the mass charged with chunks which plowed the grooves was accomplished by the propelling action of the turbidity current. The groove casts may be traced as a broad band over a distance of 2 m. until they disappear beyond the limit of the outcrop. It is to be expected that they continue farther over a considerable distance.

Some groove casts in the Krosno beds are spirally striated as if the graving tool rotated round its axis like a screw while shifted along the bottom. Pl. XXXI fig. 1. The breadth of groove casts may also change as if the ploughing object became unstable and changed its position Pl. XXXI fig. 2. This is suggestive of seaweed acting as a tool.

## Vibration marks (chatter marks)

The term „vibration marks" is here proposed for markings closely allied to the groove casts or superimposed upon them (see Pl. XXX fig. 1). It happens that the surface of one or more groove casts becomes wavy. Crescent depressions appear turning their concavities to the direction whence the flow comes.

The markings discussed seem to bear resemblance to the „jagged grooves" or „chatter marks" found on the glaciated rock-surfaces. These „jagged grooves" result when the gouging tool (pebble, rock fragment) is not firmly set in the moving ice and makes vibratory motions when dragged along the rock surface. (T. C. Chamberlin 1885—86). Similar explanations might be applied to markings from the Carpathian flysch. One can imagine them to originate when the „tool" set in a mass of flowing sand or the sand itself becomes unsteady and makes vibratory movements.

Some vibration marks bear resemblance to the „herringbone pattern" superimposed upon the groove casts (which has been recently described by Ph. H. Kuenen 1957). Perhaps a similar mode of origin might be here involved.

## Drag striae

The sole of Krosno sandstones exhibit often sharp-edged very narrow ridges. They tend to be arranged in sets of parallel lines. Some of them are rectilinear, other curved or angulated (see Pl. XXXII fig 1). All these markings are closely allied to the groove casts and no doubt their mode of origin is very similar to that of the grooves. It has been established that some striae were produced by dragging of fine fish-bones and angular grains of sand and seaweed.

The striation discussed is most apparent on smoothed surfaces[1] and may be of applicability for the determination of general course of movement. Nevertheless care should be taken due to the possible deflections from the main trend.

## Roll- and saltation marks[2]

As already noted a series of similar marks may appear in a line parallel to the direction of flow. In some cases the interspaces separating

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[1] Flat, surfaces free from roughness are often displayed by the soles of the Krosno sandstones. Probably these flat surfaces owe their origin to attrition of sand moving gently along the bottom under light pressure. The erosive nature of these surfaces appears from the fact that in some cases vague remains of the previously existing biohieroglyphs are to be found.

[2] „Roll-Spuren" in the meaning of K. Krejci-Graf 1932.

particular markings may be short and equal. The explanation plausible is that they have been produced by some objects rolled along the bottom by the turbidity current. Nevertheless rolling was evidently always combined with saltation. The interspaces may widen and become less regular. In a few instances the markings have been identified as imprints of rolled fish-bones.

### Imprints of fish vertebrae rolled along the bottom

Ring-like ridges which appear in a line on the soles of the Krosno sandstones are highly suggestive of spinal-joint imprints. They are very abundant in the Krosno beds although to our knowledge these markings have not yet been described. The diameter of rings is usually about 1 — 2 cm but larger ones measuring up to 5 cm. occur. Those which appear in a line have always the same diameter although their shape and degree of preservation may change (see Pl. XXX fig, 1).

It is suggested that many of them have been produced by the spinal joints of sharks or other fish. An experimental check on the assumption that this might hold true can be made by comparing the imprints of spinal joints of fish pressed upon some soft material with the casts of rings found on the soles of sandstones. The results are surprisingly similar if not identical. This is confirmed by the following consideration. The striking and rolling objects must have been cylindrical bodies. If the interspace between particular rings is everywhere the same the interspace might correspond to the supposed height of the cylinders. The conclusion arrived at is that these cylinders must have been rather short and their bottoms concave. This latter conclusion appears from the fact that no protuberant structures occur inside the rings. Cylindrical bodies touched the bottom mostly with their top and bottom sides. It in on rare occasions only when imprints of side walls occur. One can suggest that these latter have been provided with short off-shoots situated in the middle, which controlled the movement of cylindrical bodies.

By elimination of various possible objects existing on the sea bottom which could produce the imprints in question we come to the conclu-

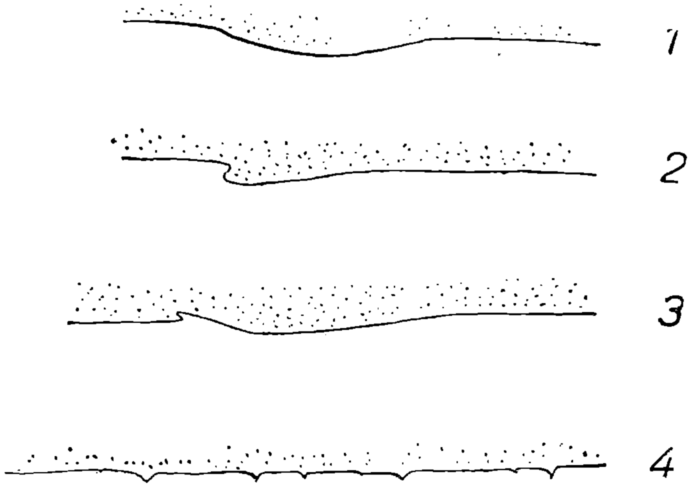

Fig. 12. Przekroje hieroglifów uderzeniowych (1, 2, 3) oraz śladów toczenia kręgów rybich

Fig. 12. Profiles of bounce casts (1), prod casts (2), brush casts (3) and saltation marks left by fish vertabrae

sion that fish vertebrae seem to be the most probable tools responsible for ring-like hieroglyphs. This is supported by the occurrence of numerous teeth of fish in the Krosno beds and especially in those sandstones which exhibit ring-marks on their soles. The vertebrae presumably disappeared before fossilisation.

The ring-marks discussed may also furnish the clue to the determination of the direction of supply. Careful examination of these hieroglyphs reveals that in most cases one side of the ring is more distinct and elevated above the sole surface than the other one. A comparison with other current indicators leads to the conclusion that the higher side is invariably the up-current one. In some cases this side only is preserved and instead of a complete ring a semi-circle appears which points its concavity downcurrent. This seems to depend on the angle of descent. The rolled spinal joint, especially when it is lifted and then strikes the bottom again, is forced into the soft mud obliquely and this part which first reaches the bottom plunges into the mud deeper than the opposite one (fig. 12). In some cases the fish vertebrae may leave traces which are hardly to be distinguished from normal bounce casts or prod markings produced by unidentified bodies. Alternate, wide and narrow markings illustrated in Pl. XXXII fig. 2, were probably produced by a body striking alternately against the bottom with its two ends.

## PROBLEMATIC HIEROGLYPHS OF THE „CABBAGE LEAF" TYPE

The term „cabbage leaf" is from Ph. H. Kuenen (1957). The hieroglyphs named above have been observed in several horizons of the Carpathian flysch [1].

In the Krosno beds these featherlike structures are very common. The question arises whether they can be used as current indicators or not. Kuenen (1957) found them in oriented pattern and states that the „stem" of the „cabbage leaf" points up-current. Indeed such cases have been observed also in the Krosno beds. Nevertheless opposite orientation is also to be found and orientation inconsistent with current direction is very frequent.

The origin of the „cabbage leaf" hieroglyphs is still not clearly understood. K. Birkenmajer (1958) considers them as due to the flow of unconsolidated lutite when the newly deposited sand covers a depression of the bottom. The present writers are inclined to consider them as structures caused by local mobilisation of quick-sand on the bottom of newly deposited sandstone bed, i. e. these feather-like structures are of early post-depositional origin. An additional evidence of this suggestion seems to be given by the fact that current markings never occur on the top of the cabbage leaf. They seem to cover all known pre- and syn-depositional sole markings. However, this does not prove, that the cabbage leaf can not have an oriented position. Nevertheless

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[1] A. **Radomski** (in press) noted their occurrence in the Podhale flysch and named them „deltoidal hieroglyphs". **Birkenmajer** (1958) decribes these markings from the Podhale flysch and Zlin beds (Eocene). M. **Książkiewicz** observed them in the Magura beds (Eocene-Oligocene) and the first writer in the Menilite beds (**Dżułyński** & **Radomski** 1957).

until a satisfactory explanation of their origin is found, inferences as to the direction of flow drawn from the „cabage leaves" are not safe.

## CURRENT INDICATORS WITHIN THE TURBIDITE BEDS

Current bedding and a new method of its reading on the soles has been already described above. We note here only that in most cases the results obtained are consistent with the direction of flow drawn from the sole markings. This has been proved true also for the Podhale flysch (A. Radomski 1957).

As already noted in most cases when imbrication occurs the axes of elongate grains dip up-current. Opposite inclination is found in those sandstones which show obscure current bedding. In this case the grains have been deposited on the surfaces of the foreset laminae. According to Kopstein (1954) down-current inclination is strongly predominant in the turbidite beds of the Cambrian flysch of Harlech Dome.

It need hardly be said that general orientation of the longest axes of coarse grains is parallel to the direction of flow as was first pointed out by Kopstein (1954).

We give now some consideration to the applicability of „sand shadows" for determination of current direction. The term „sand-shadow" is used for „deposits caused directly by fixed obstruction in the path of the sand-driving wind (R.A. Bagnold 1954 p. 188). Sand shadows in the Krosno beds consist of accumulation of more coarse grains behind such obstacles as fragments of shales, fish-bones etc. resting upon the bottom in a partly buried position. They appear as flame-like bands of more coarse material fading out in the direction of flow (fig. 13). „Sand-shadows" on the soles of turbidites must not be considered identical „sand-traps" because these latter are merely depressions filled with more coarse material. Structures for which we have adopted the term „sand-shadows" are not necessarily connected with casts of depressions of the original bottom with coarse grains entrapped.

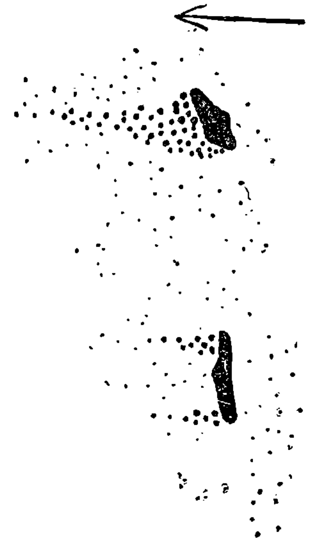

Fig. 13. Skupienia gruboziarnistego piasku utworzone za przedmiotami spoczywającymi pierwotnie na dnie

Fig. 13. „Sand-shadows" on the soles of sandstones

## DEPOSITION OF SHALES AND SILTS IN THE KROSNO BEDS

The upper boundaries of sandstones in the Krosno beds are either sharply defined or there is a transition between the sandstone and the overlying shale. The latter type of contact is of special interest as it is indicative of a comparatively rapid deposition of at least a part of the present shales. Indeed there is good reason to believe that a part of the shaly layers did not result from very slow „pelagic" sedimentation as it is often accepted.

Gradual change from sandstones to shales has been observed by several writers (Sujkowski 1938, 1957, Książkiewicz 1954, Vašiček 1954, Crowell 1956, Dżułyński, Książkiewicz & Kuenen, in press).

Although no statistical studies have been as yet performed it seems that gradual passage from sandstones to shales is very common. Observations hitherto made reveal several types of transition between sandstones and shales.

1) If current bedding occurs in the upper part of the sandstone bed, the dip of foreset laminae may decrease gradually until the current bedding passes into lamination. This latter becomes more and more fine with continuous decrease of grain size in each subsequent lamina. The lamination then disappears imperceptibly in the shale.

2) When the upper part of the sandstone shows lamination there may be the same relation to the covering shale as previously described.

3) The third type of transition results from simple and gradual decrease of grain size of quartz particles and the sandstone merges into the shale. This is the ideal type of graded bedding. The existence of such transitions has been pointed out by Ph. H. Kuenen and described from the Carpathian flysch by M. Książkiewicz (1954).

4) In non-graded and very poorly graded fine-grained sandstones which are of approximately of one grain-size only, the transition may be accomplished by continuous increase of clayey matter. The sandstone passes into pure shale. It should be noted that mud-flows in the Passage beds pass in this way into pure black shale (Dżułyński & Radomski & Ślączka 1957).

In all the cases described it is hardly possible to indicate where the rapid sedimentation of the turbidite cease and slow „pelagic" accumulation began. The most conclusion plausible is that already reached by J. C. Crowell (1956) that „much of the muddy material was also laid down by small, slow and dilute turbidity currents" (Crowell l.c. p. 1368). It is suggested here that this part of the shale which directly covers the turbidite sandstone, belongs still to the same act of deposition which laid down the sand layer (see also Vašiček 1954). It originated from a cloud of muddy water following the main turbidity current.

It should be noted that a part of mud might have been carried into the open sea by fresh water spreading on the surface of the sea (overflow — see Bell 1941 and Gould 1951).

## EROSIVE ACTIVITY OF THE TURBIDITY CURRENTS

Much has been written about the possibility of erosion by turbidity currents. Nevertheless little is known about erosion within the flysch basins, although flute casts themselves provide a clear proof that at least a slight erosion has operated. It should be remembered that a buried erosional surface is easy to recognize only when it cuts obliquely the subjacent strata. Had erosion operated uniformly over large areas it might be oevrlooked.

There are good reasons for believing that such uniformly operating erosion happened within the flysch basins. Numerous composite beds in the strata here described provide a clear evidence of such processes. It is suggested that thick-bedded sandstones with large grooves, flute casts etc. have been laid down by turbidity currents of great erosive power. It is however, hardly possible to establish the amount of mud removed before the deposition of sand took place.

M. Vašiček (1954) claims that some lenticular bodies of sandstone („herms") which occur in the Carpathian flysch resulted from the erosive activity of turbidity currents. In connection with this we note that large erosion channels about 1.5 m deep and several metres wide have been found in the Carpathian flysch in the vicinity of Komańcza south of Sanok [1].

The problem of bottom erosion due to turbidity currents is connected with the question of transport without immediate deposition [2]. Were the turbidity currents able to erode the bottom they would also produce markings without covering them immediately by sand.

Divergences between various current markings exposed on the same sole are well known. The present writers have found drag-marks crossing each other at angle of 70 ° (in the Middle Krosno beds exposed in Kąty). The discrepancy between impact casts seen on the same sole may amount occasionally to 50°. All these cases would be difficult to explain without the assumption that the bottom was scoured by a turbidity flow changing locally its course, which, however, did not drop its load immediately after hollowing the first groove or set of grooves.

It must be admitted that the objections raised by Ph. H. Kuenen (1957) against the suggestion of Dżułyński & Radomski (1955) that the current may have left the bottom uncovered and that the sandstone was deposited by another latter current seem to be largely justified.

In connection with the evidence of bottom erosion given above a suggestion can be set forth that in some instances the turbidity currents may undercut the slope flanking the trough. This would account for some slides which display the direction of movement inconsistent with that of the turbidity currents. For want of statistical studies concerning the direction of slumps in the flysch basin this must be taken as a working hypothesis only.

Before closing this chapter we note that the exceptionally large amount of erosion displayed by numerous composite beds in the Krosno beds is indicative of sedimentation near the slopes of rather narrow troughs.

## DIRECTIONS OF TURBIDITY CURRENTS IN THE KROSNO BEDS

Pl. XXXVI and XXXVII show the directions of supply in the lower and upper parts of the Krosno beds. They have been synthesised from the data collected by the present writers and those of Prof. M. Książkiewicz who kindly supplied the results of his as yet uncompleted survey

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[1] The description of these channels will be given in a forthcoming joint paper.

[2] Some remarks have been given elsewhere (Dżułyński & Radomski 1955).

of current directions in the western part of the Polish Carpathians. Evidence for this generalisation is shown on more detailed Pl. XXXVIII and XXXIX.

The maps attached are largely based upon the flute casts and arrows show their directions. Those marked by broken lines refer to the fine-grained thin-bedded sandstones only. This distinction has been limited to the eastern part only to show differences in the direction of supply between the fine-grained and coarse-grained sandstones.

As measurements relate to the turbidity layers, the arrows show at the same time the directions of the turbidity currents at a given place. Mapping of current markings covered most of the Krosno beds exposed. Along the northern border of the Carpathian flysch the maps are admittedly incomplete. In this area the outcrops are usually low and small. They are masked also by Quaternary clays. Moreover the marly facies dominates over vast areas.

Distribution of turbidity currents in the lower part of the Krosno beds implies the existence of at least three major source lands. This idea is not entirely new. The existence of these source areas has been suspected before the turbidity current hypothesis was introduced into the study of the Carpathian flysch. Geologists arrived at this conclusion from the study of facies and exotic boulders [1].

The application of the turbidity current hypothesis to the paleogeography contributes to much more accurate localization of the source lands for the flysch rocks. Conclusions arrived here independently are in harmony with those of previous authors and confirm their suggestions.

On the western side of the Main trough [2] the turbidity current pattern and distribution of the sandy facies show that the area on the south was emergent and provided a source of clastic material to the depositional basin. This indicates that the first source of clastics was the „Silesian Cordillera" (M. Książkiewicz 1956). It separated the Main trough from the Magura trough. The existence of this „tectonic land" [3] has been postulated by M. Książkiewicz (1935) see also Książkiewicz & Ciszewska (1937).

The Silesian Cordillera began to rise in the Middle Cretaceous and continued until the close of the Oligocene. During the Oligocene turbidity currents flowing down from this source spread fan-like over the bottom. Their influence extended to the west, north and to the east.

The active source discussed was encircled by a sandy facies grading farther into the more shaly facies, devoid of thick-bedded sandstones (Fig. 14).

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[1] Black dots on he map Pl. XXXVI show the distribution of the exotic blocks in the Krosno beds according to H. Świdziński (1935, 1950) Gaweł (1931), Burtan & Sokołowski (1956), St. Wdowiarz (1950), Krajewski (1935) and A. Ślączka (1956 and in press).

[2] The term „Main trough" has been introduced by M. Książkiewicz (in press). During the Oligocene the Carpathian geosyncline was separated into three major throughs i. e. Podhale flysch trough, Magura trough and the Main trough.

[3] According to M. Kay 1951 the term „tectonic land" aplies to lands raised by tectonic forces in contrast to „volcanic lands" and deltal plains (l. c. page 5).

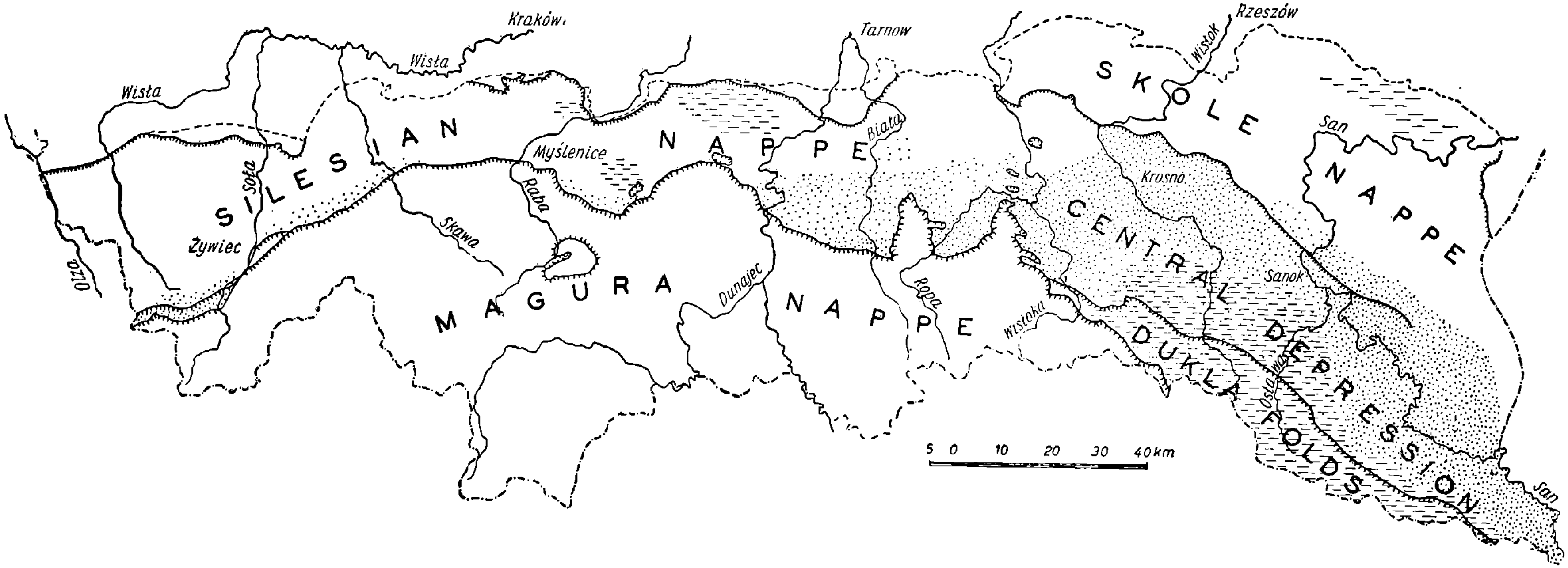

Fig. 14. Rozkład facji w niższych warstwach krośnieńskich. Obszar zakropkowany — facja piaszczysta, kreskowany — facja marglista

Fig. 14. Distribution of facies in the Lower Krosno beds. Dotted area — sandy facies, brocken lines — marly facies

The second important source is that of the Marmaros massif. Its significance as an important contributor of sediments for the Carpathian flysch was recognized many years ago (see Zuber 1918, Nowak 1927). The geological history of this land goes back into the remote past (see paleogeographic maps of M. Książkiewicz 1956 b). Probably during most of the flysch sedimentation this source exerted an influence upon the distribution of sediments. In the Oligocene this influence extended to the north west and reached the area of the Osława river (see Pl. XXXVI).

There are no published data on turbidity currents eastward from the San river. According to regional reports the Krosno beds near the Marmaros massif are developed largely of sandy facies (St. Krajewski 1935). It is not improbable that the turbidity current pattern from the Marmaros massif would show analogies with that of the Silesian Cordillera region.

The Krosno beds within the Dukla Folds and along their northern margin consist of marly shales with subordinate sandstones. The relation between this „marly facies" and extremely sandy facies of the Krosno beds in the southeastern part of the Central Depression is not yet clearly understood. It is here inferred that the marly facies area was separated from the Central Depression by a submarine swell or a narrow island-festoon. Whether emerged or not it must have contribute sediments to the north as it is indicated by the orientation of current marks.

Another source land for the Krosno beds as indicated by current markings lay somewhere between the Central Depression and the Skole unit (see Fig. 15). It was becoming defined as emerged cordillera rather late in the history of the Carpathian geosyncline. The proximity of an island in this area during the deposition of the Krosno beds was suggested by St. Wdowiarz (1953) and suspected by A. Gaweł from the distribution of exotic boulders[1] (A. Gaweł 1931, 1932).

The influence of this source was possibly more pronounced in the northern basin (i.e. the Skole unit) than in the southern area.

In the south-eastern part of the Polish Carpathians coarse grained and thick-bedded sandstones show undisputable evidence of having been derived either from the south or from south-east. In the lower part of the Krosno beds in this area those thick-bedded and coarse-grained sandstones predominate. In the middle part of the stratigraphical column here exposed, alternating deposition of sediments from opposite direction occurred. Rather thick and coarse beds show southeastern or southern direction of supply whereas the fine-grained and thin-bedded sandstones between them have derived their material largely from south-west or west (see Pl. XXXVI). Such alternating deposition from various

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[1] St. Jucha and J. Kotlarczyk (in press) arrived at a similar conclusion, from a study of distribution of diatomites and Jasło shales. The diatomites occur only in the Skole unit whereas the Jasło shales seem to be limited to the Central Depression.

sources persisted over some period during the sedimentation of the upper part of the Lower Krosno beds [1].

It is probable that some fine-grained sandstones with convolute bedding are prolongations of coarse and thick-bedded sandstones near the southeastern margin of the Silesian Cordillera. If this is true it would be an example of horizontal grading which is theoretically expected, but hitherto seldom proved by the field evidence (see Kopstein 1954).

The area south and south-east of Krosno is of special interest. The lower part of the Krosno beds in this area consists of marls and sandstones, these latter less conspicuous than in the surrounding areas. Thick-bedded sandstones practically disappear farther to the east.

The existence of this marly facies was perhaps first recognized by Fleszar (1919) but more detailed observations have been given by J. Wdowiarz (1946, 1949). It should be also noted that the Krosno beds attain their maximal thickness here (about 3000 m, according to H. Świdziński).

The maps of currents (Pl. XXXVI and XXXVII) reveal that the „marly facies" coincided with the area where the currents coming from various directions met. In other words, the area discussed was the deepest part of the Main trough during the sedimentation of the lower part of the Krosno beds. The existence of the „marly facies" south-east of Krosno may be explained by the loss of the large part of sandy load from turbidity currents before these could reach the central and deepest part of the trough. Only very strong currents succeded to drop their sandy cargo in this region.

As already noted the Sanok Cordillera contributed most of its clastics in the north-eastern direction. North of the present tectonic border between the Skole unit and the Central Depression, the Krosno beds consist largely of thick-bedded sandstones although lateral gradation into the less sandy facies has been observed. Farther from the source area marly intercalations become more prominent.

Maps (Pl. XXXVII and XXXIX) show the distribution of current markings and current directions in the upper member of the Krosno beds. The Middle Krosno beds are here included. The current pattern on the western side of the Main trough is largely similar to that of the lower member but in the eastern part of the trough there is a marked change in the distribution of current markings. The filling of the trough became longitudinal and the western of northwestern supply extended south-east to the San river and even farther to the east.

When studying a stratigraphical sequence one can see the direction of current markings gradually changing. It was Obuchowicz (1957)

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[1] The stratigraphic position of the whole sequence of the Krosno beds in this area is still a matter of debate. According to Opolski (1933) and others thick-bedded coarse sandstones at the lower part of the stratigraphical column belong to the Lower Krosno beds. St. Wdowiarz (personal information) is inclined to consider them as the Middle Krosno beds. If this is true we should place at least a part of our measurements on Pl. XXXVII and XXXIX, i. e. on those which show the direction of supply in the upper part of the Krosno beds. This will not invalidate the general picture of current distribution as on the western side of the Central Depression there is no marked difference in the direction of supply throughout the period of deposition of the Krosno beds.

who first called attention to this marked change and to the difference between the lower and upper members of the Krosno beds in the section exposed at Besko. Similar observations have been made by K. Żytko in the section south of Rajskie (personal information).

Absence of south-eastern supply in the upper member of the Krosno beds in the area of the Central Depression is suggestive of a downward movement within the Marmaros source area.

Longitudinal transport pertaining to the sedimentation of the upper part of the Krosno beds was interrupted sometimes by violent interaction of transversal turbidity currents and slides. Those which came from the Sanok land-area carried down large amount of glauconite sands (see Pl. XXXVII). Inclusions of the glauconite sandstones occur in the middle part of the Krosno beds. All these phenomena have important bearing upon the considerations concerning the problem of bottom relief and submarine orogeny [1] they are, however, subordinate to the main trend of transport which is roughly parallel to the axis of the Main trough.

In the uppermost member of the Krosno beds the distribution of currents show an approach to more uniform longitudinal filling and transport within the vast areas of the geosyncline.

## SEDIMENTARY ENVIRONMENT OF THE KROSNO BEDS

The opinion here given is that already held by numerous geologists (Sujkowski, Kuenen, Książkiewicz... etc.), i.e. that the flysch deposits have been laid down in rather deep water. This applies also to the Krosno beds. The uppermost part only of the strata discussed might be considered as an approach to the shallow water environment.

According to the opinion of M. Książkiewicz (in press a and b) the flysch zone consisted of parallel troughs dipping in opposite directions. During the sedimentation of the Krosno beds, the Carpathian geosyncline was already separated into three major troughs i.e. the Podhale flysch trough, Magura trough and the Main trough [2].

The plunge of the trough axis seems to be largely responsible for the longitudinal transport exhibited by the upper part of the Krosno beds [3].

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[1] The section exposed at Sieniawa is of special interest. In the column of the Krosno beds of about 100 m. thickness directions of supply change alternately from north, north-west to south and the south-east.

[2] The Main trough included sediments which are now to be found in the Silesian and Skole nappes.

[3] According to M. Książkiewicz, turbidity currents flowing down the slopes of flanking cordilleras would change their course in the more central part of the trough following the general inclination of the bottom. It is not improbable that the predominance may be dependent also on the degree of preservation of the original floor deposits. The marginal parts of troughs with the transversal filling as well as near-shore deposits of the flysch basins have been mostly washed away by erosion when uplifted or carried down during down-buckling of geanticlinal segments (E. Argand 1916).

Reference has already been made to the wide extension of the Krosno beds. This youngest unit of the Polish Carpathians flysch is certainly the best preserved one. It should be presumed also that in the course of growing compression, the troughs have been narrowed. The area occupied by slopes grew greater in relation to the whole area occupied by the trough. This probably accounts for the occurrence of marked transversal filling and very characteristic interstratification of sandstone layers showing different or even opposite directions of supply.

In some cases the plunge of the axis of the trough might be attributed to transversal elevations inside the troughs. If such elevation existed and was rising during the sedimentation of the flysch, vast shifts of clastics in sub-parallel directions would result. It is not improbable that such a transversal elevation of the western side of the Main trough largely contributed to the longitudinal filling of the basin during the deposition of the Upper Krosno beds.

The explanation of the longitudinal filling offered by Ph. H. Kuenen (1957) obviously does not apply to the Krosno beds. This however, does not invalidate the suggestion set forth by the above named author, for at least the measurements show that longitudinal transport was significant, a possibility that had been overlooked previously. So far as available evidence warrants the drawing of any conclusion several factors appear to have been involved in the process of filling of the flysch troughs and various conflicting deduction, if only not generalized would account for particular cases.

Before closing this chapter we note that the results of numerous observations provide evidence of the marked asymmetry of troughs and cordilleras. In most cases the supply from one side is more pronounced than from the opposite.

It is also conjectured that the asymmetry of geanticlinal belt is largely responsible for the fact that intra-geosynclinal tectonic lands might shed different clastics into different troughs flanking it on both sides. The same view has been held by M. Książkiewicz (personal communication).

## THE PROBLEM OF INTRA-GEOSYNCLINAL TECTONIC LANDS

Having thus gained a general picture of the direction of supply in the Krosno beds, we shall turn now to some general problems connected with the evolution of geosynclinal belts. We shall approach these problems from the sedimentological point of view only. Therefore the references to the very extensive literature will be omitted.

The first important problem which emerges from the study of the turbidity current directions is that of the tectonic lands within the geosynclinal belt. There can be little doubt that the clastic material for the Krosno beds and particularly for their lower member has been derived from within the geosyncline. Only one external land-area could be taken into account as the possible source land for the Krosno beds, i.e. the land bordering the Carpathian geosyncline from the north and northwest (see Fig. 15). It stood above sea level troughout the Lower Tertiary until the Middle Miocene. There is also an old river drainage pattern preserved, the history of which goes back into the pre-Tortonian times (see St. Dżułyński 1952). The rivers were running SW-SE to the Carpathian Sea. Nevertheless so far as the evidence from the current markings warrants any inference, this external source could hardly have influenced the sedimentation of the Krosno beds. During the deposition of their lower member, the supply was from the opposite direction as shown by the currents markings (see maps Pl. XXXVI and XXXVIII). The distribution of turbidity currents during the sedimentation of the upper part of the strata discussed implies the transport from northwest (see maps Pl. XXXVII and XXXIX). Nevertheless it would be difficult to find well founded evidence of the direct influence of this northwestern land area upon the deposition of the upper member of the Krosno beds. Over vast areas the foreland formations are largely composed of the Triassic, Jurassic and Cretaceous limestones which could hardly be responsible for the sandy flysch facies. It can not be denied that in Silesia this Mesosoic cover has been eroded in some places even before the ingression of the Tortonian sea. Nevertheless the upper part of the Krosno beds shows no consanguinity with Carboniferous sandstones exposed (Coal Measures). It is hardly possibly that the Carboniferous sandstones could lose entirely their identity even if various processes of weathering and transport were involved [1]. On the other hand the upper member of the Krosno beds exhibits striking resemblance to the lower part of these beds, the latter having been derived from the south.

For all these reasons the northwestern external land area should be excluded as the possible source land for the Krosno beds. In order to explain their origin we must turn to the „intra-geosynclinal" tectonic lands. We agree with the interpretation given by M. Książkiewicz (1956 and in press) that „intra-geosynclinal" cordilleras largely contributed to the sedimentation to the Carpathian flysch [2].

Apparent contradiction lies, however, in the fact that an enormous amount of flysch sediments requires rather a large source lands. Obviously very small islands would help the matter but a litle. If the flysch sediments and particularly the Krosno beds did come from islands, the latter must have had a coast line of many tens of kilometres. On the other hand if it be admitted that there is everywhere compelling evidence of large crustal shortening within the geosynclinal belts it is not improbable that large island festoons disappeared having been down-falted before the growing compression squeezed off the contents of the troughs.

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[1] As a matter of fact the Silesian Carboniferous sediments influenced the Carpathian flysch during the sedimentation of the Grodischt beds (Hauterivian-Barremian). This influence is clearly visible in the mineralogical composition of the Grodischt beds.

[2] In a joint paper (Dżułyński & Książkiewicz & Kuenen, in press), some difficulties against accepting this view are given.

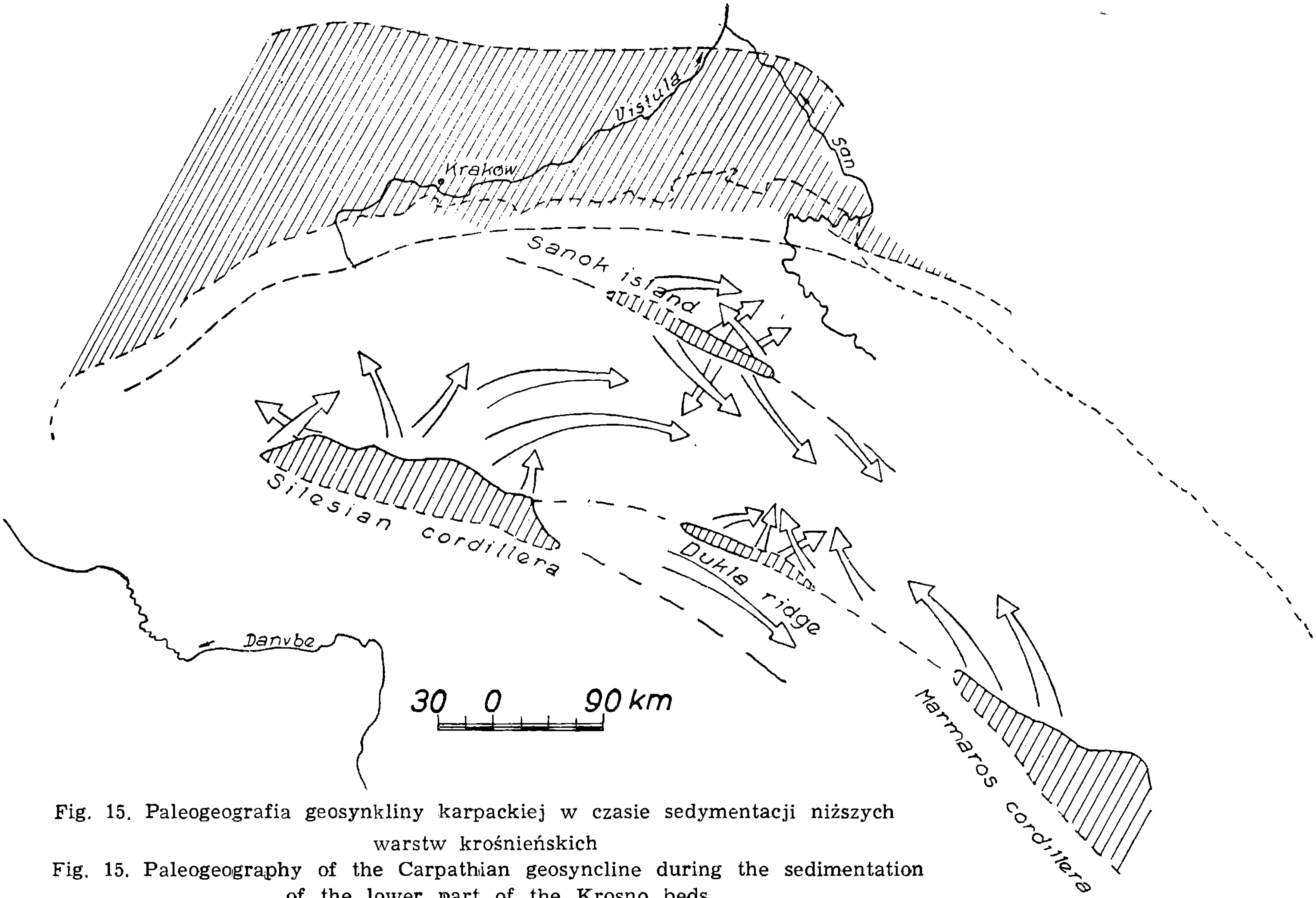

Fig. 15. Paleogeografia geosynkliny karpackiej w czasie sedymentacji niższych warstw krośnieńskich

Fig. 15. Paleogeography of the Carpathian geosyncline during the sedimentation of the lower part of the Krosno beds

This conclusion seems no more difficult to assume than the large overthrusts in the Western Carpathians [1].

Hence the question arises what processes are available to counterpart such a shortening. No satisfactory solution of this problem has yet been given but the explanation must be sought in the areas bordering the geosynclinal belts and within these belts themselves [2].

Turning to the problems of the source islands within the flysch zone we must note that although small islands can not explain the accumulation of large amount of rock-debris no extensive land areas are required. Continuously rising island-festoons if only composed largely of friable sedimentary rocks would provide sufficient amount of rock-debris to account for the filling of the sinking troughs.

Both assumptions, i. e. the continuous rising over long periods and the suggested composition of cordilleras seem to be well founded by the geological evidence. That the rising was concurrent to the subsidence appears from the classic theories of mountain building. Although it may have happened in changing rates it must have continued over long periods.

The mineralogical composition of some Cretaceous members of the Carpathian flysch suggest consanguinity with Culm, Coal Measures, Permian arkoses etc. This does not apply to the Krosno beds which might have been derived either from some typical Variscian flysch or from a still older flysch. A part of the Krosno beds has been derived also from the older horizons of the Carpathian alpine flysch [3].

According to M. Książkiewicz (1956) the sedimentation in the Carpathian geosyncline during the Oligocene approached the „cannibalistic" stage when older flysch deposits were intensely eroded [4].

Only a part of the rockdebris came directly from the coast line washed out by the action of waves. The greatest erosive action is exerted by streams, especially by short and violent mountain streams with large transporting power.

The distribution of current markings suggests the existense of several river outlets discharging clastics during the sedimentation of the Krosno beds.

Considering islands as possible source areas for the Krosno beds we should assume a subordinate condition, but an essential one to the accu-

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[1] The proved amount of thrust in the Magura Nappe is about 20 to 30 km. (according to M. **Książkiewicz**).

[2] Compressional changes within the orogenic zone might be to some extent compensated by the tension in the foreland. Fault-tectonics in the Cracow Upland provide numerous evidences of tension which possibly operated simultaneously with the compressional distortions within the geosyncline (see **Dżułyński** 1952). Nevertheless the main compensating processes must be sought in the area of the „hinterland" bordering the alpine chains on the south.

[3] Pebbles of the Cretaceous flysch rocks and marls have been found in some places (see St. **Wdowiarz** 1953).

[4] It has been also suggested that a part of Lower Tertiary flysch deposits has not been yet completely cemented and hardened while uplifted on rising cordilleras and washed down to the subsiding troughs (St. **Dżułyński** & A. **Radomski** 1955).

mulation of sand in large quantities, i. e. that these islands were not fringed with reefs, save perhaps very insignificant ones. This seems to be well supported by the fact that the true coralline debris are rare in the Carpathian flysch and practically absent in the Krosno beds.

Objections which can be raised against the intra-geosynclinal islands as source areas for the flysch are that numerous recent islands have little influence on the bottom sediments laid down in their surroundings [1]. May be that the present islands within the active orogenic belts cannot be wholly identified with „tectonic lands" within the flysch geosynclines (see also N. B. Vassojevic 1948). This problem, however, remains still unsolved.

The results obtained from the sedimentological studies of the Krosno beds seem to be consistent with some fundamental ideas concerning the development of the geosynclines and the rôle played by cordilleras. It would be, however, far beyond the scope of this paper to discuss this interesting problem in detail.

There remains one question to be solved, i. e. the problem of apparent uniformity of the Krosno beds in spite of various directions of supply. For lack of sufficient mineralogical and petrological data it would be difficult to find a well founded answer concerning this problem. Large amount of work hitherto devoted to the petrological composition of the Krosno beds would help the matter a little. In all hitherto published petrological studies determinations of directions of supply were generally omitted. In view of this no attempt could be made to fit the results of previous petrological studies together with our own investigations [2].

Judging from the data available we can only suspect that there are some important differences in the mineralogical association between various sandstones deposited by currents coming from different directions. Hence we can also suspect that various source lands showed some small differences in their mineralogical composition.

Apart from these small differences it is conjectured that the apparent uniformity displayed by the Krosno beds is to be largely accounted for by the flysch and flysch-like character of their source rocks.

## OROGENIC MOVEMENTS DURING THE SEDIMENTATION OF THE KROSNO BEDS

Reference has been already made to the change in the sedimentary basin of the Krosno beds which was reflected on the upper member of the strata discussed. This upper part of the Krosno beds consists of rather fine-grained material with marked increase of marly shales as compared with the lower member. Inclusions of thick-bedded sandstones which appear in the Middle Krosno beds practically disappear in the

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[1] This problem is discussed at length from various points of view in a joint paper by Dżułyński & Książkiewicz & Kuenen, in press.

[2] No one can be blamed for this situation as the importance of directional structures has not been understood until quite recently.

top part. Generally speaking this might be considered as an approach to the more stable conditions before the final orogenic paroxysmal movements took place. Nevertheless the development in the Carpathian geosyncline seems to be much more complicated than it appears at first impression from the occurrence of marls and diatomites in the uppermost horizons of the Krosno beds.

Before we approach this problem from the sedimentological point of view we shall dwell on the subject of subsidence in the Main trough.

During the accumulation of the Cretaceous flysch rooks the site of maximal subsidence and sedimentation was situated in the western part of the Polish Carpathians (see isopachous maps by M. Książkiewicz 1957 and M. Książkiewicz in press). At the beginning of the Tertiary it shifted eastward: A new area of subsidence and most extensive accumulation has been formed in the Central Depression (according to the isopachous maps of. M. Książkiewicz (1957). The downward movement of this new area of accumulation was evidently dependent on the relative rising of the western part of the Main trough. This shift of the site of subsidence importantly influenced the distribution of turbidity currents. It is here tentatively suggested that the dominant longitudinal transport exhibited by the upper member of the Krosno beds should be largely accounted for by redeposition of sediments from the rising bottom on the western side of the trough [1]. Compensation of this uprising is held to be effected by the downward movement of cordilleras. This process led to the steady lowering of the relief within the geosynclinal belt although the tectonic processes were not only still in action but the rate of orogenic movements increased. The downward movement has been reflected in the sedimentation by the appearance of marly facies which corresponds with this period of very active tectonic movements. The lowering of cordilleras and the decrease of their areal extension must have been followed by a decrease in volume of rock-debris carried sea-wards by streams. The supply from the sea shore still continued but one could readily conceive that the conditions for accumulation of large amounts of thick-bedded sandstones deteriorated.

The critical point is arrived at when the last land areas plunge beneath the sea level. This turning point in the history of the Carpathian geosyncline seems to have occurred at different times in various parts of the Main trough. This fact is of importance for the distribution of facies in the upper part of the Krosno beds.

We shall now consider the problem of large slumps and turbidity currents which have occurred at the closing stage of the accumulation of the Middle Krosno beds. Some examples of these deposits have been already mentioned i. e. slumps exposed in Sieniawa or glauconite sandstones.

It is here conjectured that they originated during the short period of total submergence of the land. If only flat parts of the subsiding islands reached sea-level, extensive areas must have been won by the

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[1] It should be remembered that the folding in the Carpathians has been first accomplished in the western part of the chain.

sea almost immediately. The growing rate of marine transgression has been followed by dragging slope-ward vast amounts of unconsolidated rock-debris. It accumulated in the upper parts of the slopes and from there it was moved downwards as huge submarine slides or large turbidity currents. Washing out of rock-waste continued until the depth of the sea became too great to make possible shift of material by waves. Afterwards the supply from cordilleras practically ceased. Only few turbidity currents flowed down over the rapidly vanishing slopes.

According to the considerations just mentioned one could expect the land to have stand low at the final stages of the cordilleras before their total submergence. Such conditions should have favoured the development of morasses and sea-coast swamps. Indeed the growth of swamps in a certain way may be regarded as characteristic feature of a subsiding land.

Remnants of such swamps occur in these last submarine slides. Reference has been already made to the slip-blocks of coals with freshwater mollusca and soft sandstones with coal seams suggestive of shallow water environment of beach swamps.

As soon as the last land areas have disappeared a new period of sedimentation began. Over vast areas of the bottom, marls have accumulated and at some places diatomites have been deposited (Kotlarczyk 1957). This is generally assumed to indicate an approach to fresh-water or brackish conditions.

In the course of farther evolution the sea bottom had become a shallow basin or swampy lowland but the last deposits have been evidently removed by erosion.

Summing up we should say that starting from the sedimentological investigations we were forced to consider fundamental problems of tectonics.

At the closing stages of geosynclinal evolution deep troughs, hitherto negative segments within the geosynclinal belts began to rise. On the other hand, geanticlinal belts, hitherto positive segments, changed into the subsiding zones. This change is reflected on the sedimentation and the critical point of submergence is indicated by the last huge submarine slides and turbidity currents followed by sedimentation of marls. These latter should not be considered as the signs of stabilisation. There is good reason to believe that during the sedimentation of these marls orogenic movements have accelerated. The final folding and thrusting within the troughs seems to have been accomplished near or even above the sea level.

In connection with sedimentological results obtained several problems arise which cannot be discussed in this paper. We mention only once again the problem which seems to be the most important, i.e. the problem of tectonic lands which must have disappeared beneath the earth crust (see also Kraus 1942) not only inside the geosynclinal zone but evidently in front of it. It should be remembered that no traces of the northern margin of the Carpathian flysch sea are to be found. As far as the available sedimentological evidence warrants any suggestion it seems to supports strongly the concept of large horizontal shifts and overthrusts. The problem of space which arises is here exactly so intriguing as in the case of the granite controversy.

We have tried to give a sequence of events preceding the final folding in the geosynclinal belts as it is seen from the sedimentological point of view. It has been deduced from the development observed in the Carpathians but it might also account for some other flysch zones.

Whatever might be said about the conclusion reached, it seems now to be firmly established that the turbidity current hypothesis of. Ph. H. Kuenen and C. I. Migliorini provides an important clue to the solution of some fundamental tectonic problems.

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## OBJAŚNIENIA TABLIC

## EXPLANATIONS OF PLATES

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### Plate XXIV

Fig. 1. Przeławicanie się piaskowców drobno- i gruboziarnistych wykazujących przeciwne kierunki sedymentacji. Sieniawa. Warstwy krośnieńskie.
A — piaskowiec drobnoziarnisty, kierunki z WNW; B — ławica złożona, a — składnik drobnoziarnisty, kierunek z południa; D — piaskowiec gruboziarnisty, kierunek z SSE

Fig. 2. Różne kierunki dostarczania materiału do piaskowców krośnieńskich. Wernejówka

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A — Fine-grained sandstone. Supply from WNW,
B — Composite beds, a — fine-grained component, supply from WNW,
b — coarse-grained component, supply from the south,
D — Coarse-grained sandstone, supply from SSE,

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### Tablica XXV
### Plate XXV

Fig. 1. Ślady uderzeniowe (1), hieroglify prądowe (2) oraz ślady wleczenia. Rymanów. Warstwy krośnieńskie

Fig. 2. Hieroglify prądowe wytwarzające fałszywe ripple-marki prądowe. Tylawa. Warstwy krośnieńskie

Fig. 1. Prod casts (1), flute casts with incipient row arrangement (2) and drag striae. Note the contour-lines in the upper left corner. Rymanów. Krosno beds

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### Tablica XXVI
### Plate XXVI

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## Tablica XXVII
## Plate XXVII

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## Tablica XXIX
## Plate XXIX

Fig. 1. Różne rodzaje hieroglifów uderzeniowych oraz zagadkowy ślad, być może wytworzony przez rybę (w prawym rogu). Kąty. Warstwy krośnieńskie
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## Tablica XXX
## Plate XXX

Fig. 1. Różne typy śladów uderzeniowych, hieroglify deltoidalne (pierzaste), odciski kręgów rybich, ślady wleczenia itp. Wetlina. Warstwy krośnieńskie
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## Tablica XXXI
## Plate XXXI

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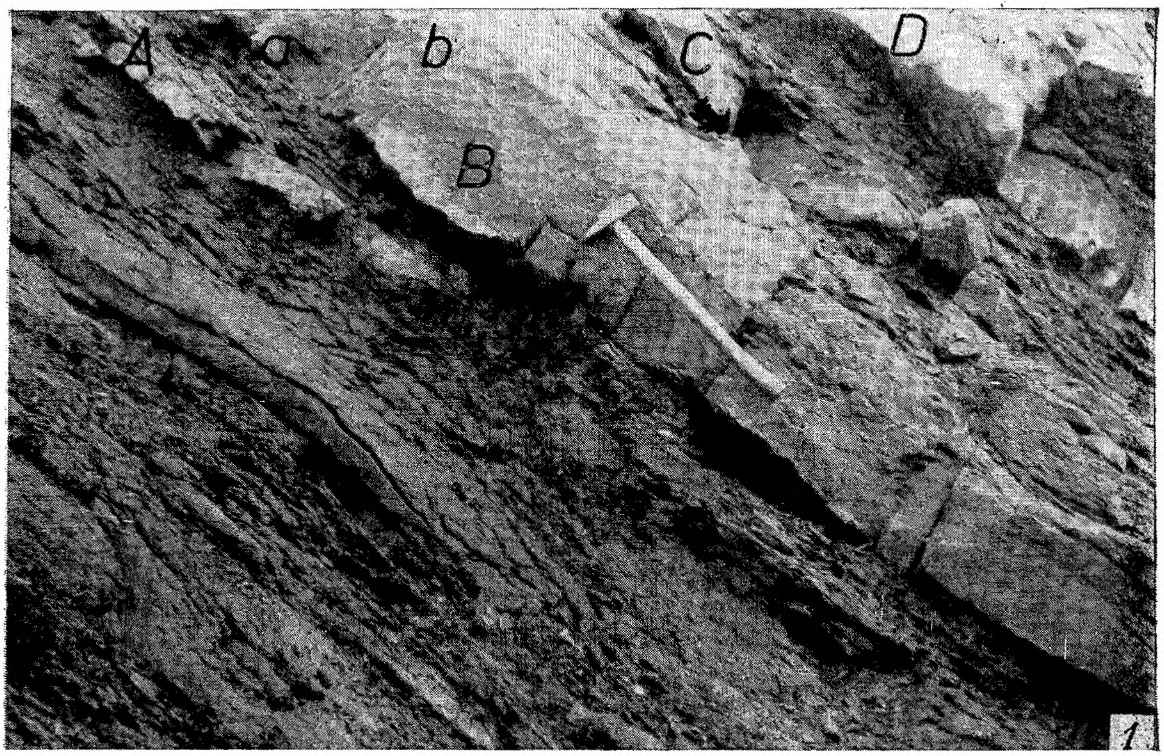

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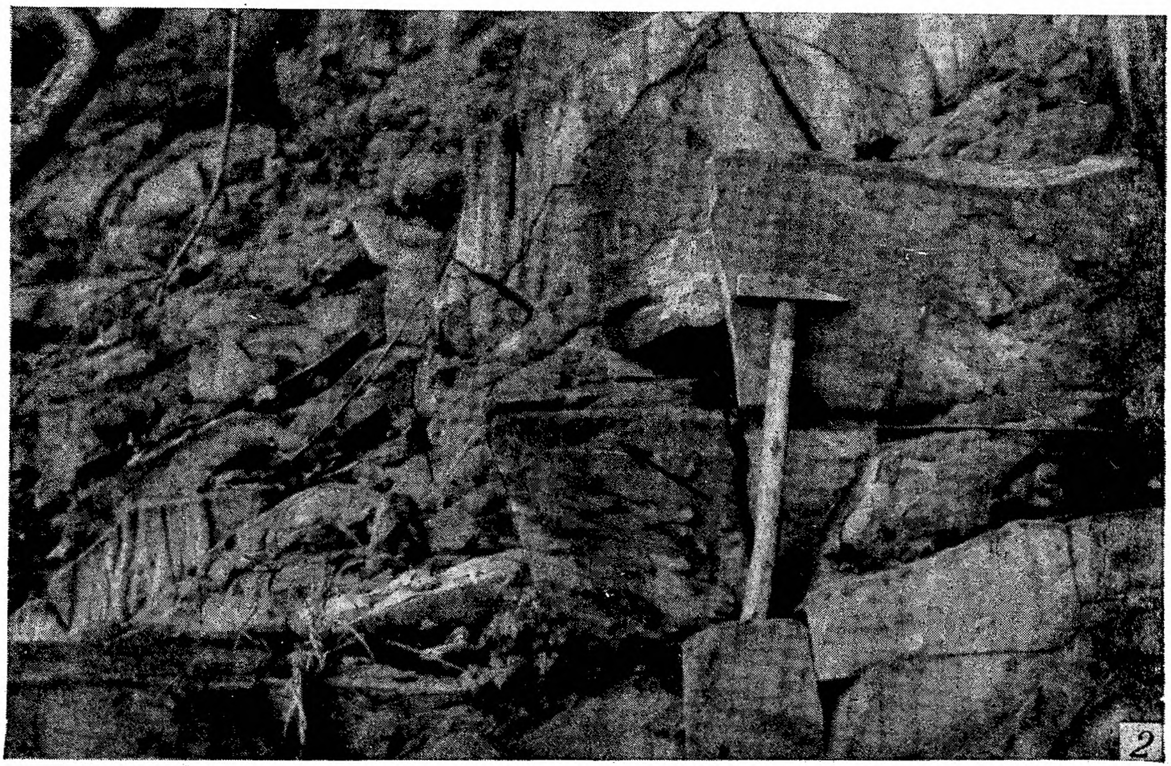

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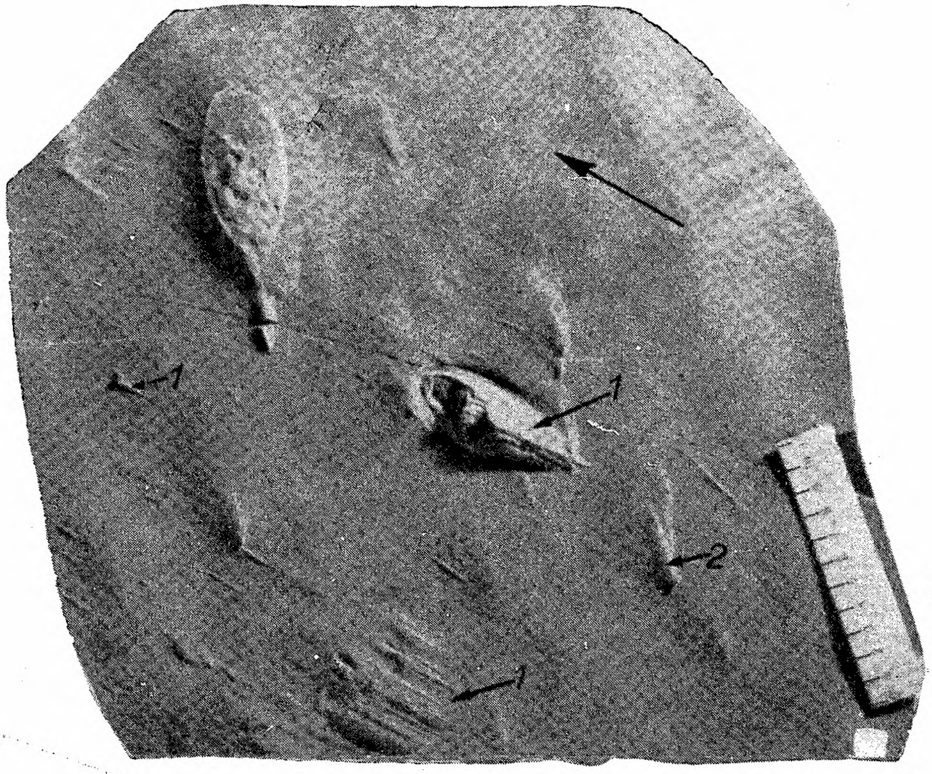

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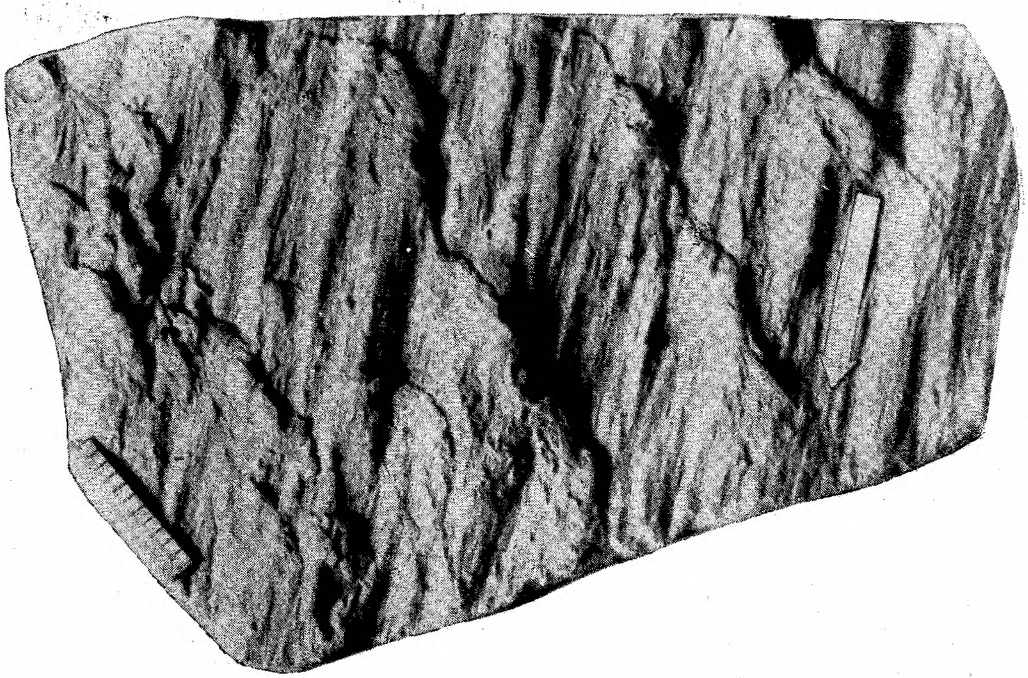

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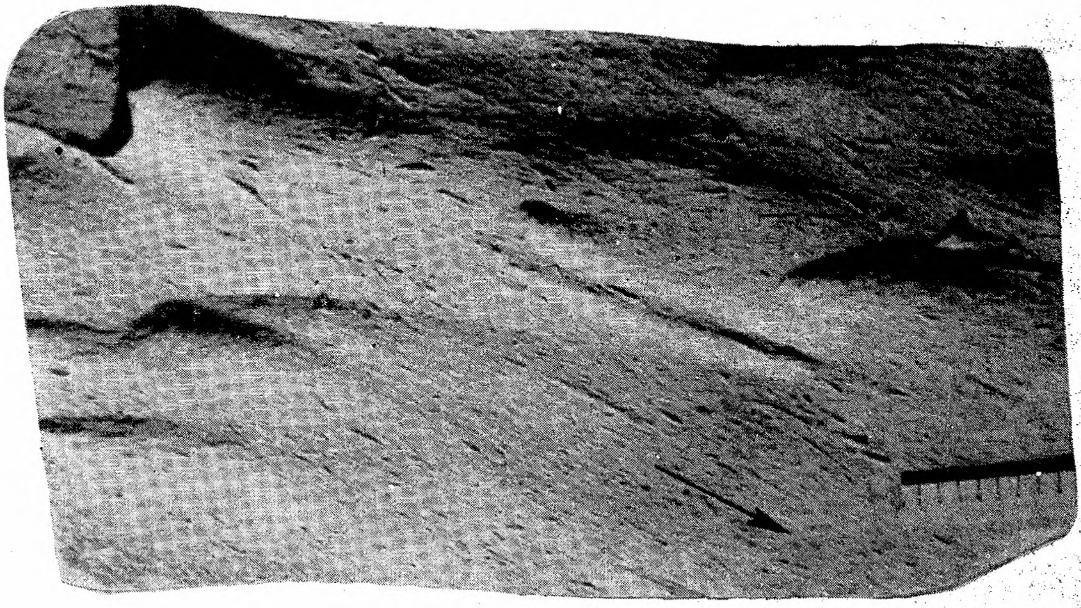

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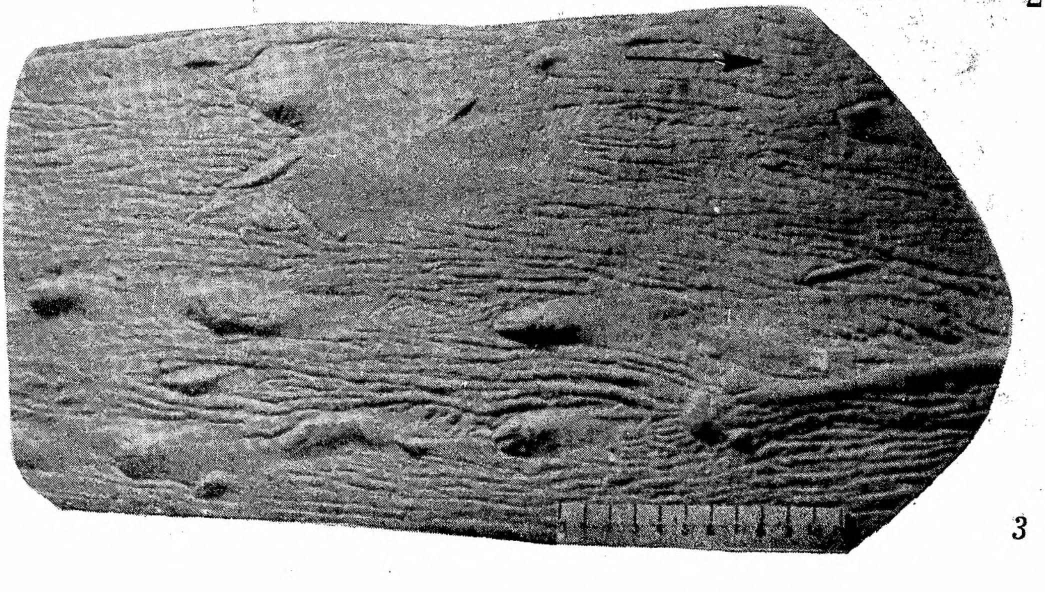

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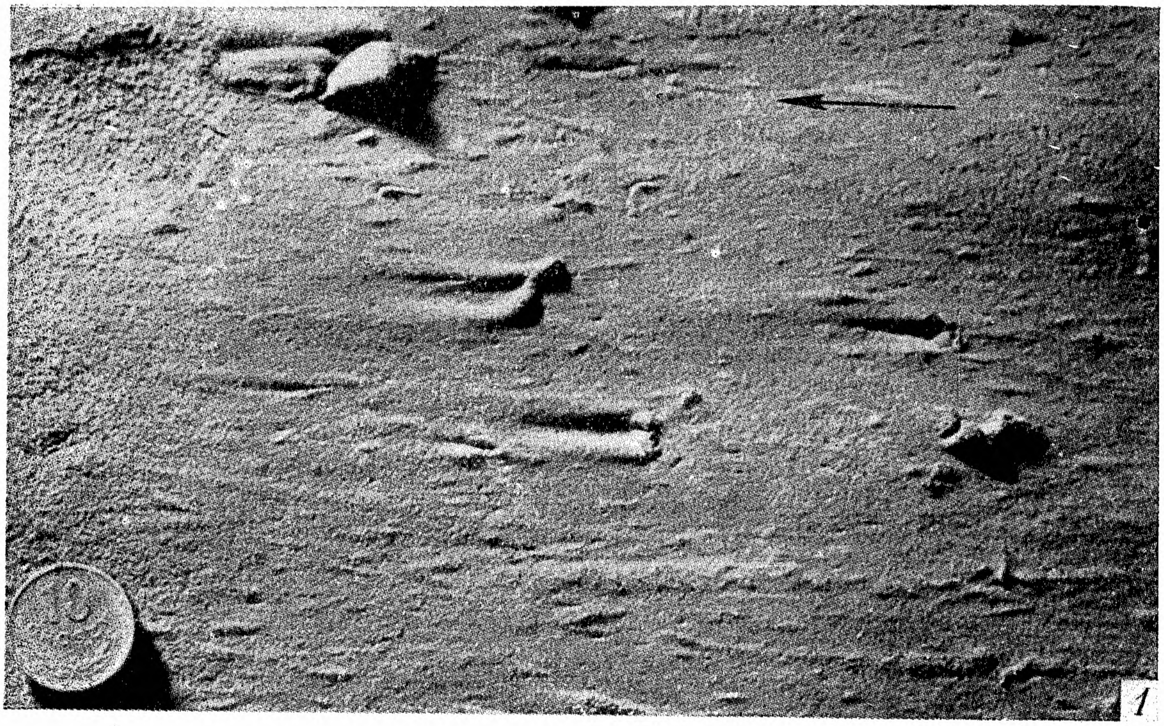

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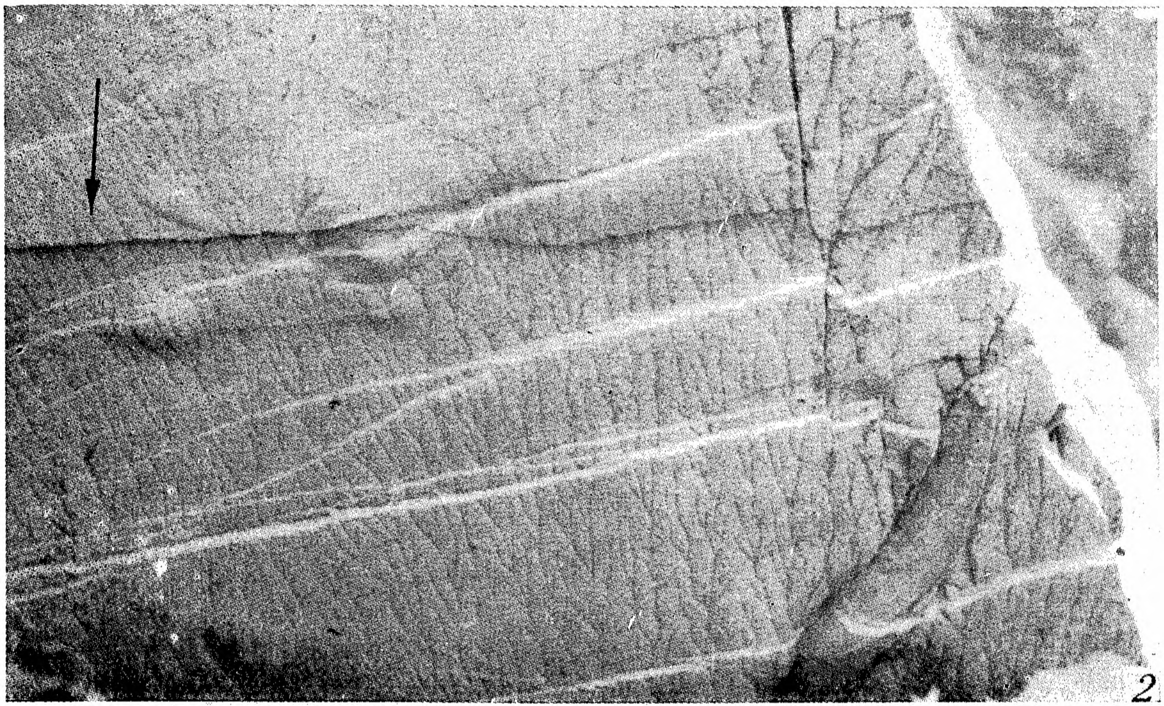

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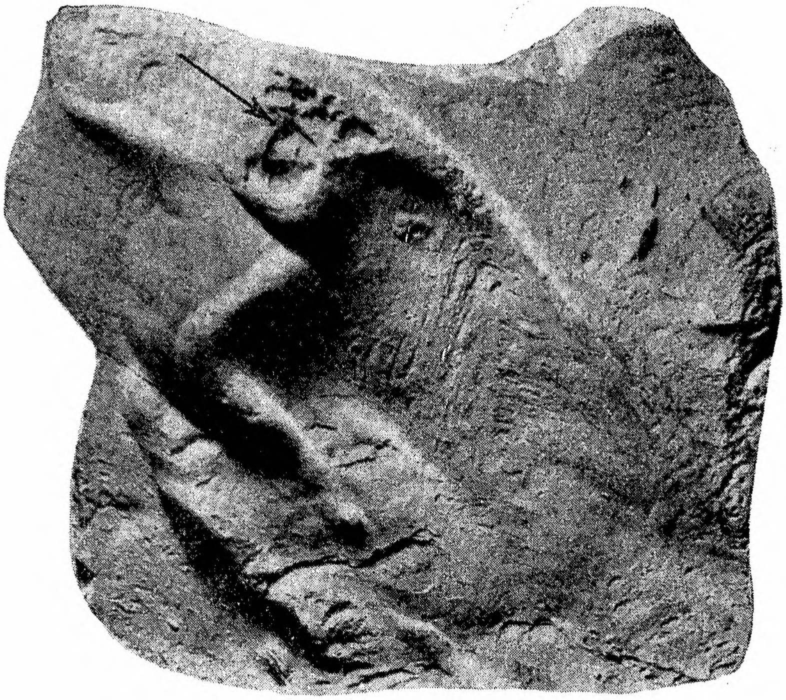

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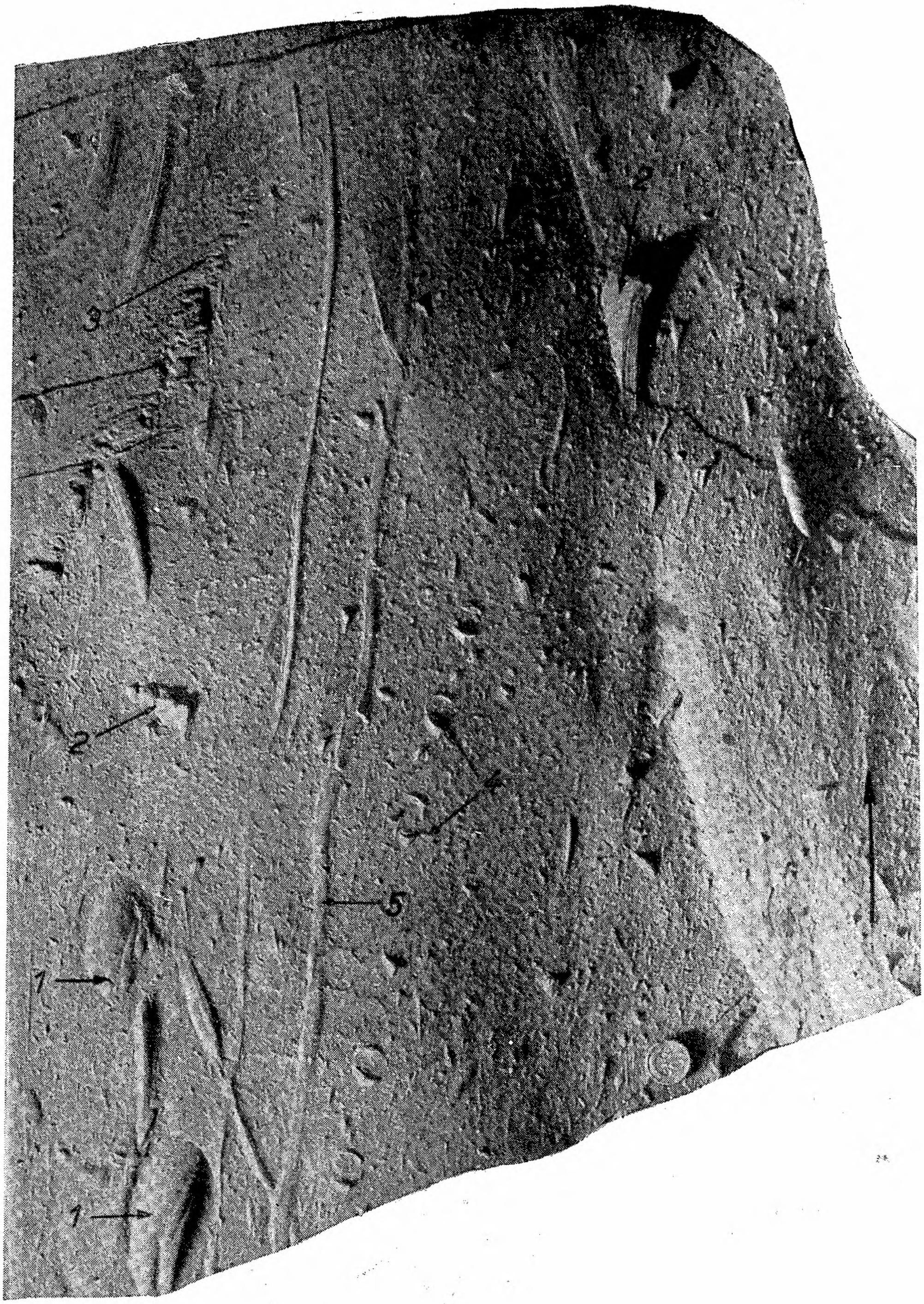

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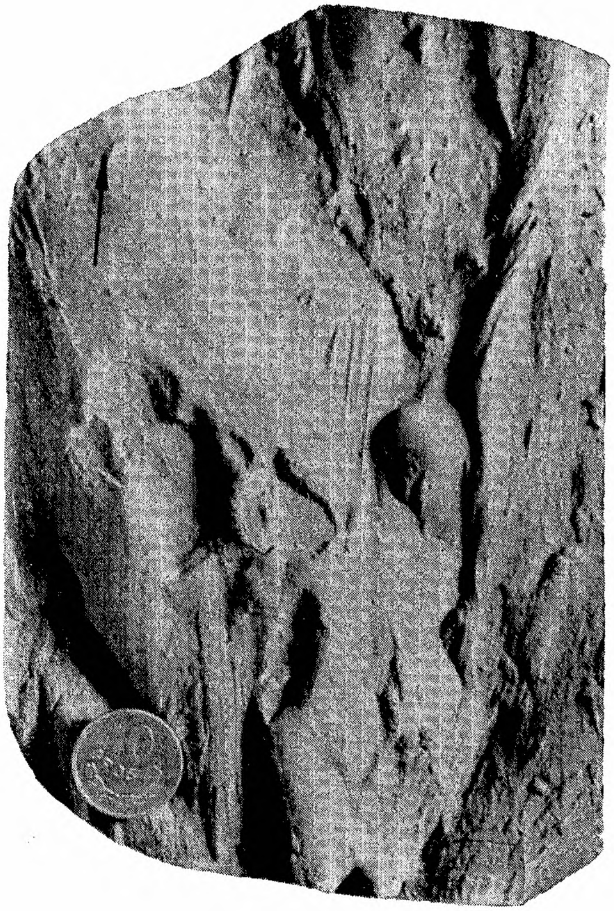

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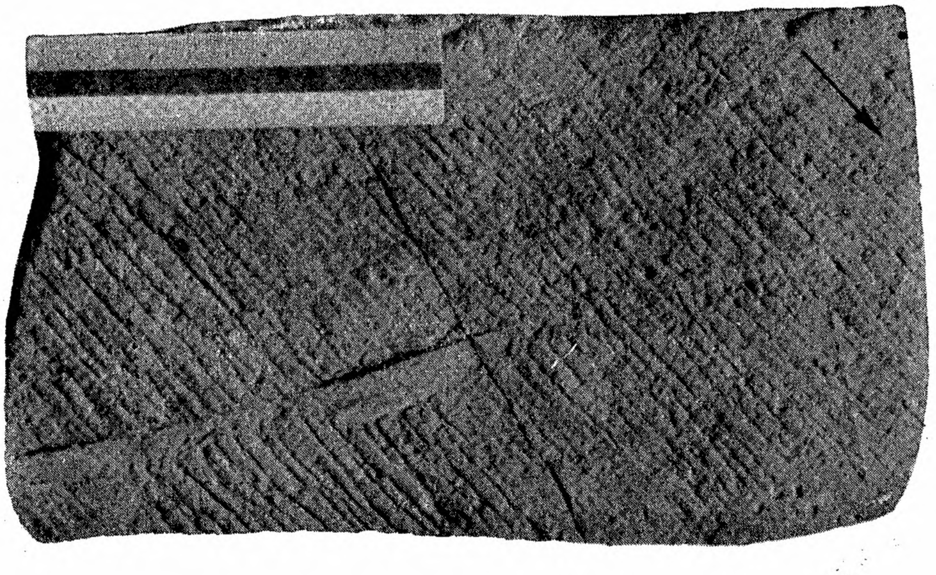

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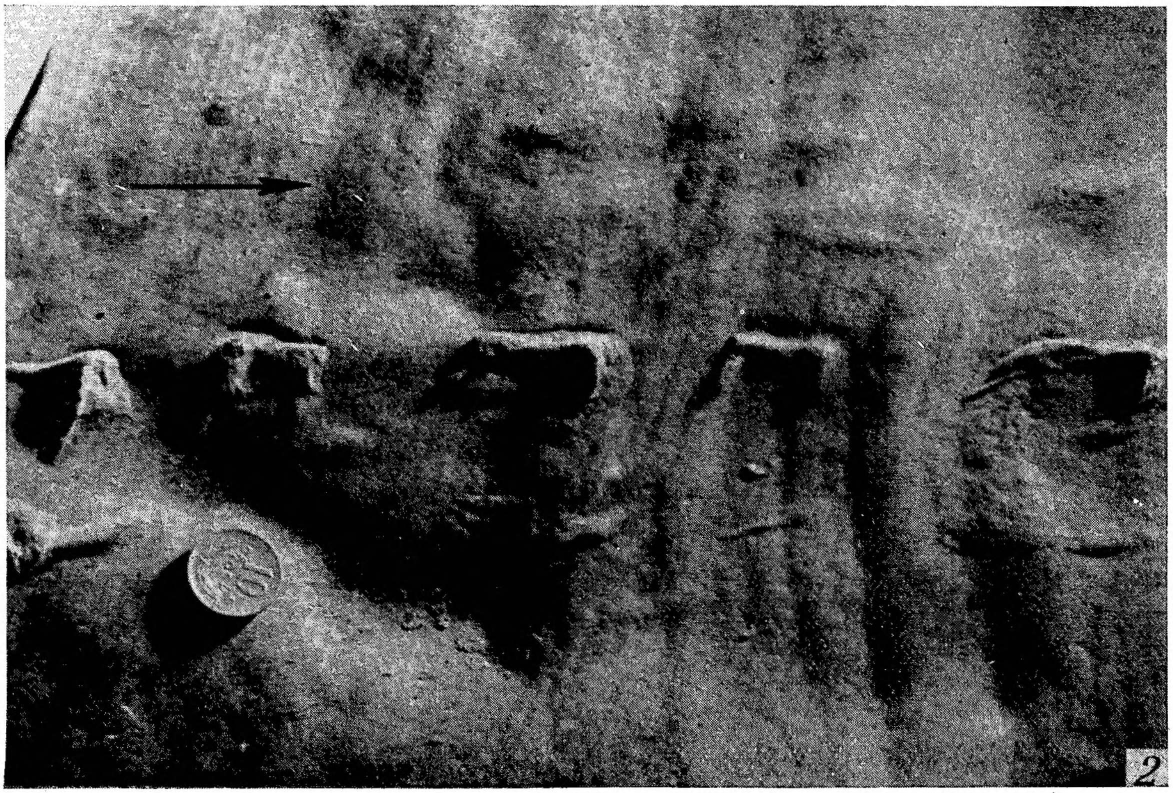

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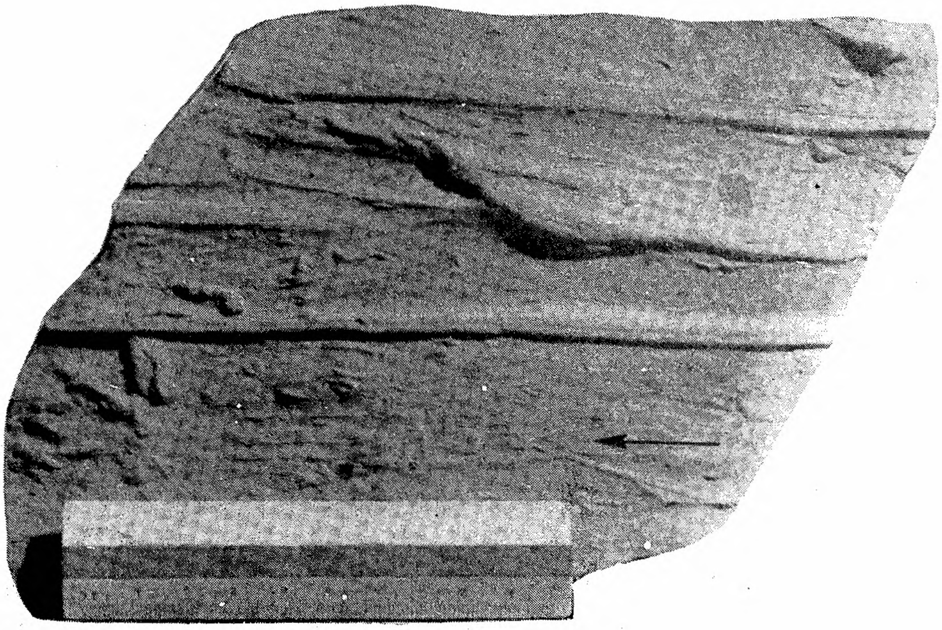

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*S. Dżułyński, A. Ślączka*

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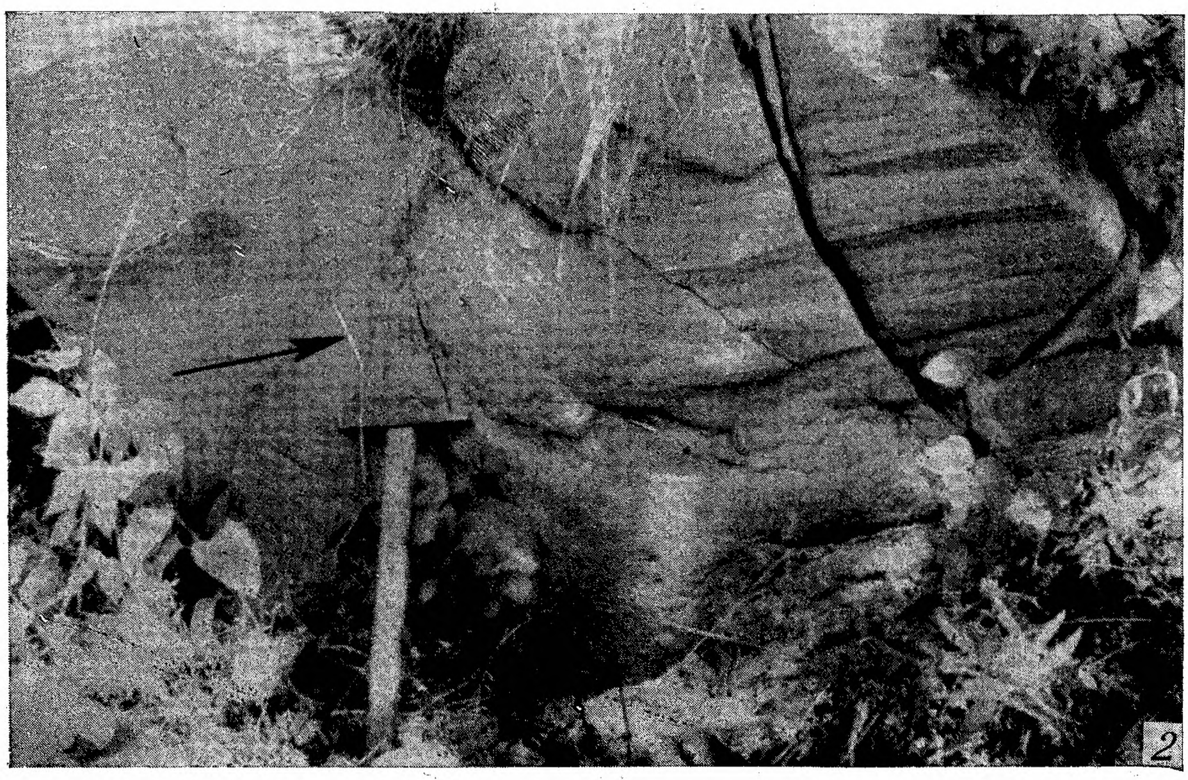

2

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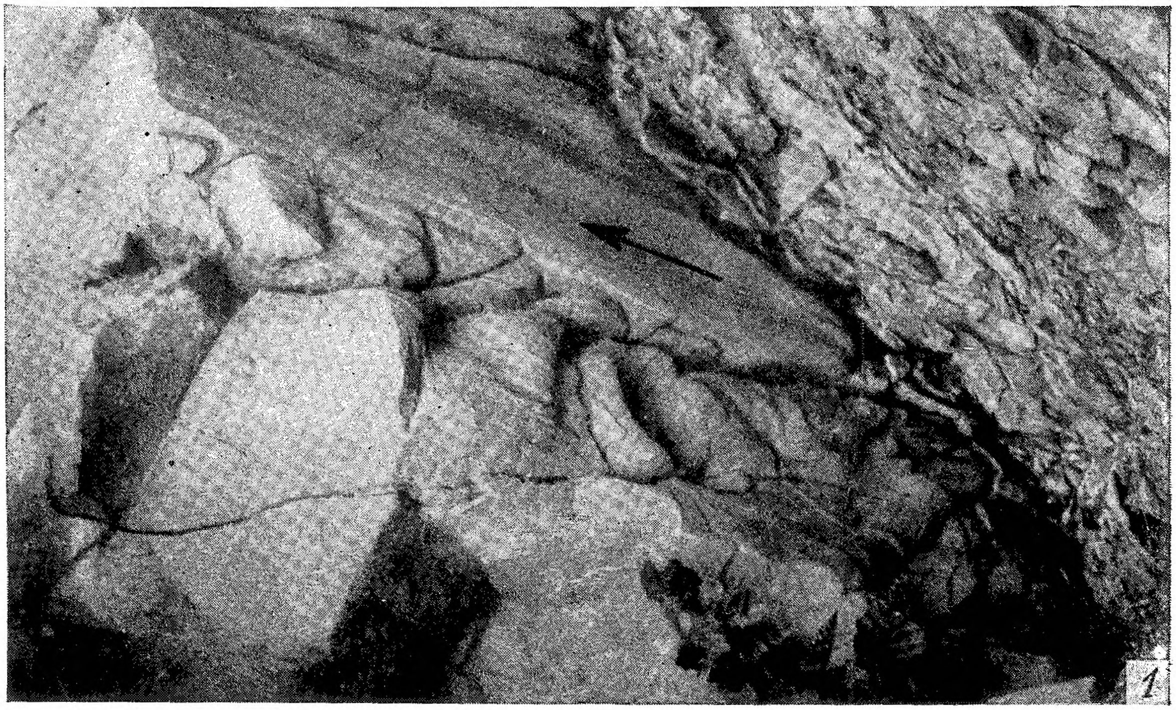

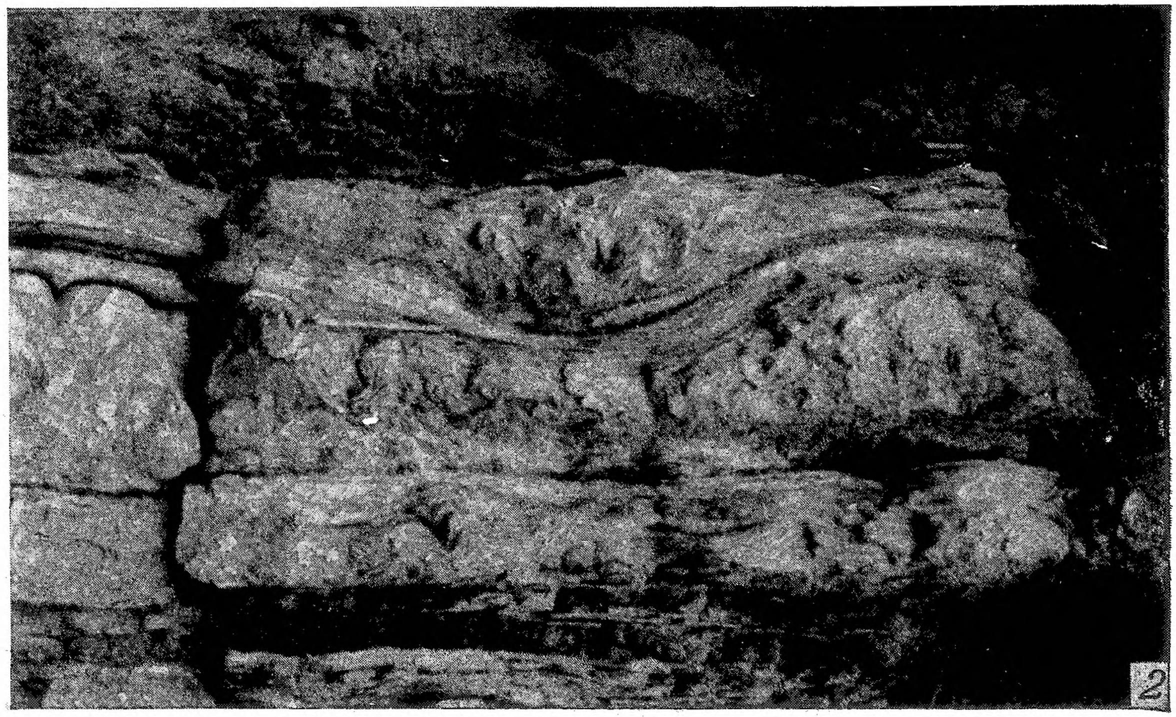

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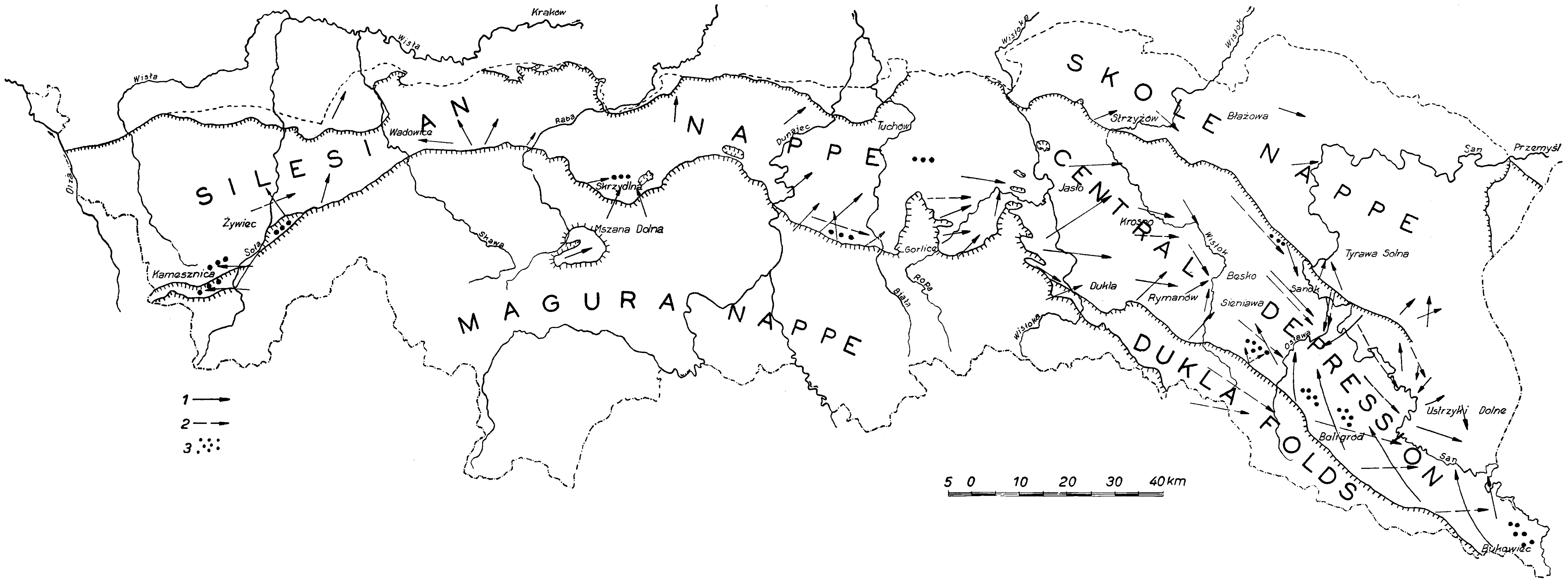

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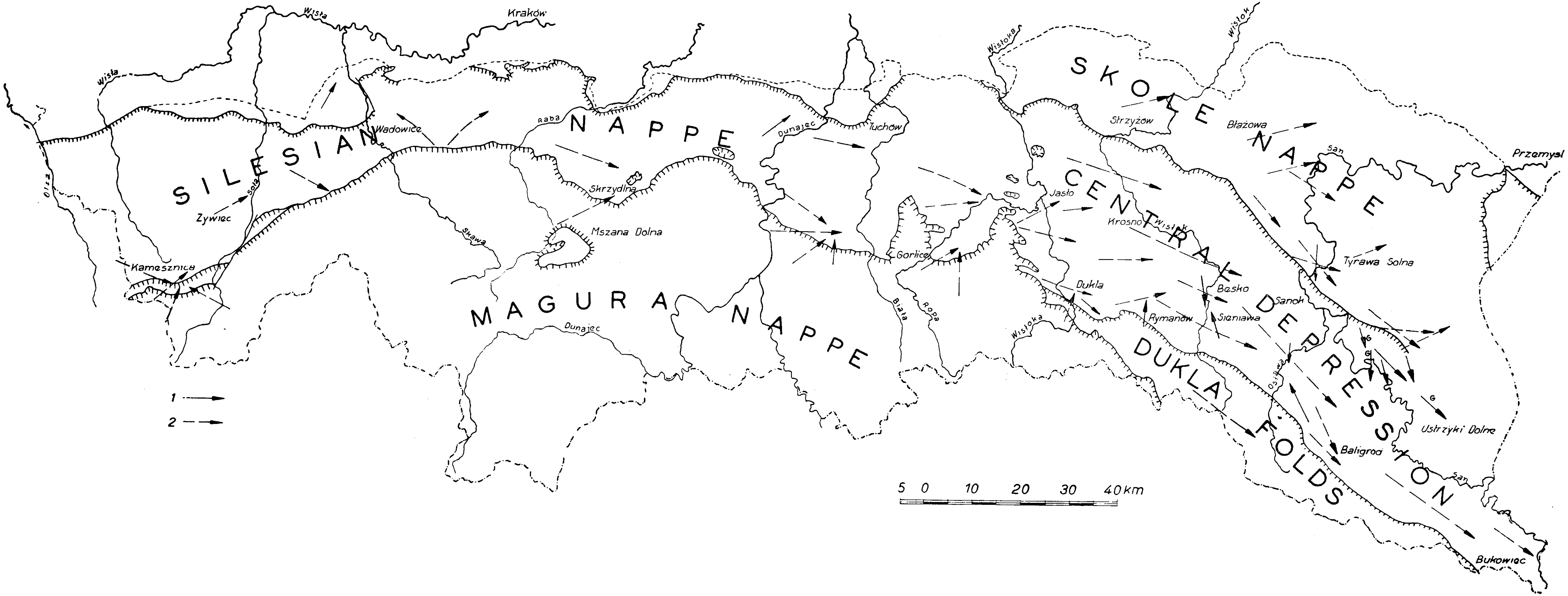
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Wisła
Olza
Sola
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Wadowice
Raba
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Skrzydlna
Mszana Dolna
MAGURA NAPPE
Dunajec
Dunajec
Tuchów
Biała
Ropa
Gorlice
Wisłoka
Wisłoka
Jasło
Krosno
Wisłok
Dukla
Rymanów
Besko
Sieniawa
Sanok
Wisłok
Strzyżów
Błażowa
SKOLE NAPPE
San
Przemyśl
Tyrawa Solna
CENTRAL DEPRESSION
DUKLA FOLDS
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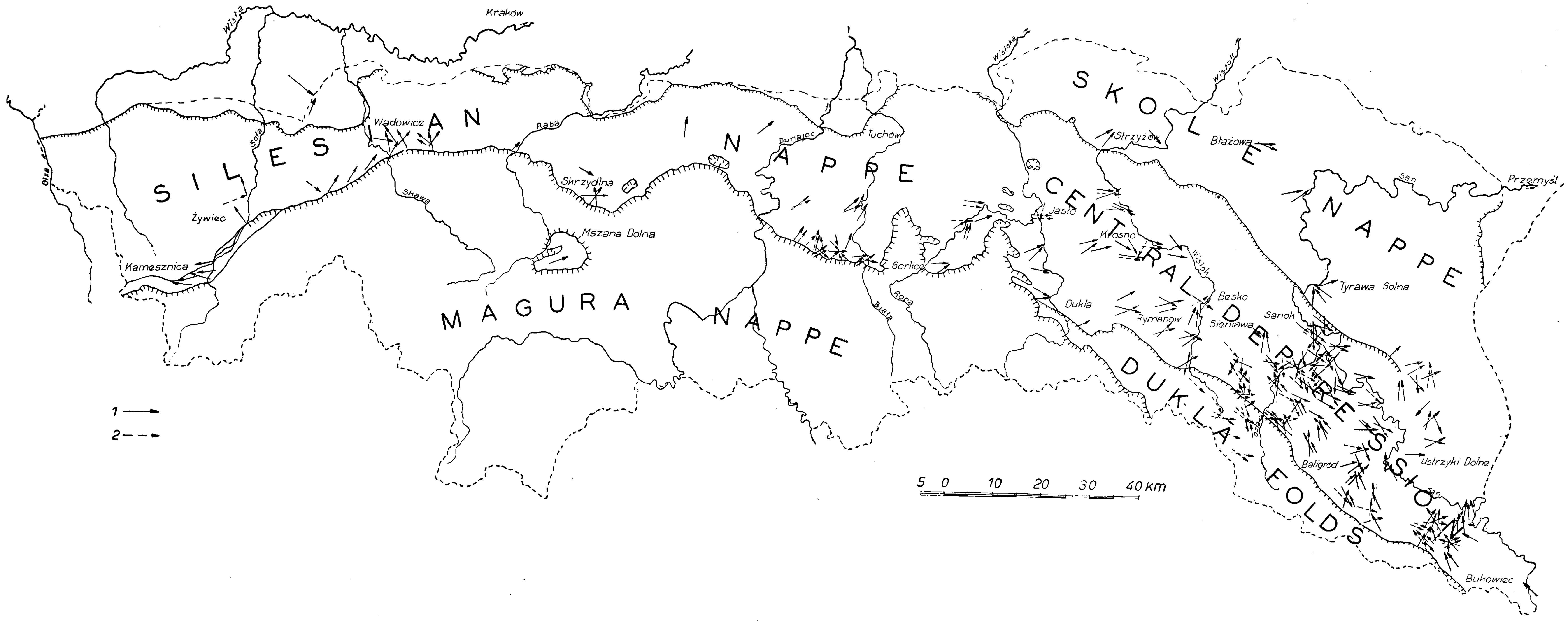

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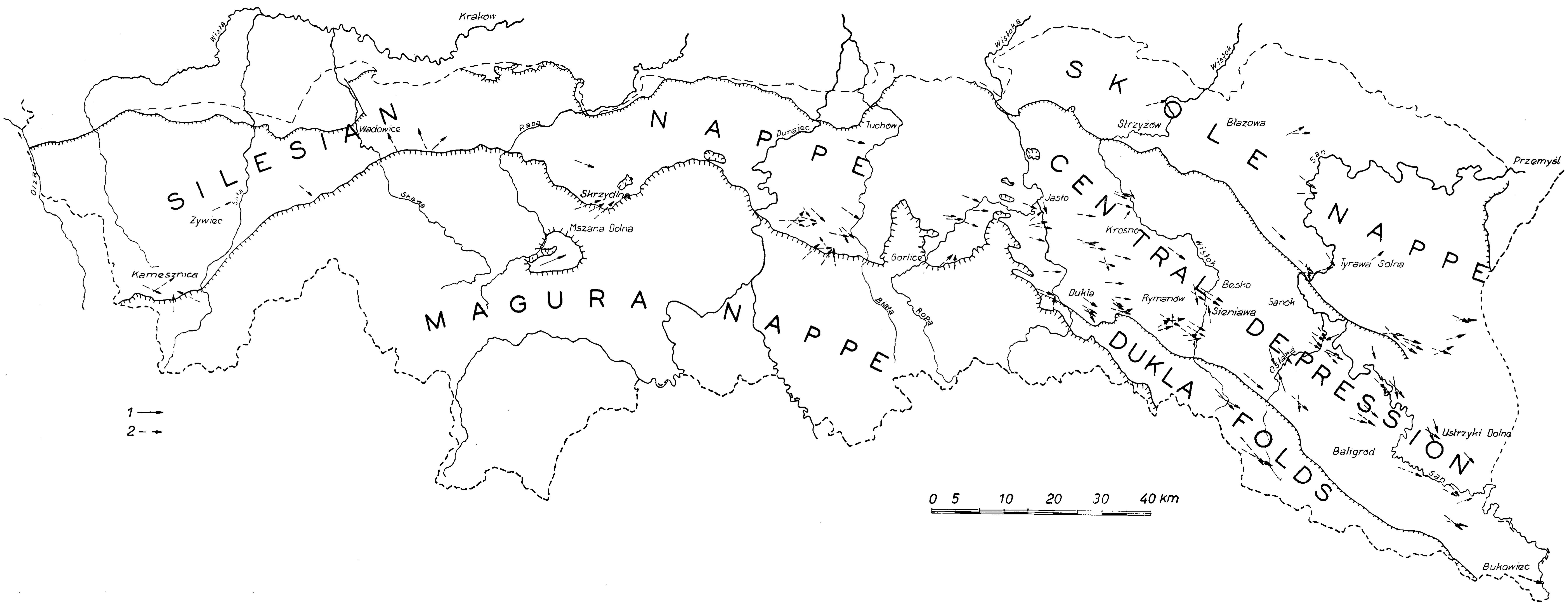

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## Tablica XXXII
## Plate XXXII

Fig. 1. Różnokierunkowe ślady wleczenia. Rudawka Rymanowska. Warstwy krośnieńskie
Fig. 2. Zagadkowe ślady saltacji. Kąty. Warstwy krośnieńskie
Fig. 1. Drag-striae. Rudawka Rymanowska. Krosno beds
Fig. 2. Problematic saltation marks. Kąty. Krosno beds

## Tablica XXXIII
## Plate XXXIII

Fig. 1 i 2. Ślady wleczeniowe wytworzone przez kawałki drzewa. Rudawka Rymanowska. Warstwy menilitowe
Fig. 1 and 2. Striation and drag marks produced by twigs. Rudawka Rymanowska. Menilite beds

## Tablica XXXIV
## Plate XXXIV

Fig. 1. Rowki i grzbieciki na piaskowcu skorupowym z warstw krośnieńskich, biegnące równolegle do kierunku prądu. Besko
Fig. 2. Początek hieroglifu wleczeniowego. Rajskie. Warstwy krośnieńskie
Fig. 1. Furrows and ridges of the convolute bedding in the Krosno beds running parallel to the direction of flow. Besko
Fig. 2. „Birth-places" of groove casts. Rajskie. Krosno beds

## Tablica XXXV
## Plate XXXV

Fig. 1. Skomplikowany ślad wleczenia. Komańcza. Piaskowce cergowskie
Fig. 2. Warstwowanie spływowe w piaskowcu skorupowym. Mokre. Warstwy krośnieńskie
Fig. 1. Vibration marks and groove casts. Komańcza. Menilite beds
Fig. 2. Cooperation of sliding in the formation of convolute bedding. Mokre. Krosno beds

## Tablica XXXVI
## Plate XXXVI

Rozkład prądów zawiesinowych w czasie sedymentacji niższej części warstw krośnieńskich. Czarne kółka wskazują rozkład egzotyków
1 — piaskowce gruboławicowe (gruboziarniste)
2 — piaskowce cienkoławicowe (drobnoziarniste)

Distribution of turbidity currents during the sedimentation of the lower part of the Krosno beds. Black circles show the distribution of exotic boulders.
1 — Thick bedded rather coarse-grained sondstones,
2 — Fine-grained thin-bedded sandstones

## Tablica XXXVII
## Plate XXXVII

Rozkład prądów zawiesinowych w czasie sedymentacji wyższej części warstw krośnieńskich
G — piaskowce glaukonitowe

Distribution of turbidity currents during the sedimentation of the upper part of the Krosno beds.
G — Glauconite sandstones

## Tablica XXXVIII
## Plate XXXVIII

Rozkład i kierunki śladów prądowych w niższej części warstw krośnieńskich

Distribution and directions of current markings in the lower part of the Krosno beds

## Tablica XXXIX
## Plate XXXIX

Rozkład i kierunki śladów prądowych w wyższej części warstw krośnieńskich

Distribution and directions of current markings in the upper part of the Krosno beds