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OSUWISKA PODMORSKIE WE FLISZU KARPACKIM

(Tabl. X—XVII i 25 fig.)

Submarine slumping in the Carpathian Flysch

(Pl. X—XVII and 25 fig.)

STRESZCZENIE

W pracy poprzedniej (1950) wyróżniłem dwa typy ruchów masowych na dnie morza fliszowego: powolny spływ świeżego materiału tworzący silne sfałdowania warstw, ale bez przerywania ich ciągłości (warstwowanie spływowe), i ruchy osuwiskowe prowadzące do przerwania ciągłości struktury warstwy. W pracy niniejszej omówiony jest drugi typ ruchów masowych. Obserwacje wskazują, że niemal w każdej jednostce stratygraficznej fliszu zaznaczają się zjawiska osuwiskowe, chociaż w porównaniu do ławic niezaburzonych ławic dotkniętych ruchem osuwiskowym jest bardzo mało.

Można wyróżnić dwa typy osuwisk we fliszu. Typ pierwszy polega na tym, że kilka lub kilkanaście ławic uległo naraz osunięciu. W typie drugim jedna lub co najwyżej dwie sąsiadujące z sobą ławice zostały dotknięte ruchem osuwiskowym.

Typ pierwszy jest we fliszu, o ile można sądzić na podstawie dotychczasowych studiów, bardzo rzadki. Jako przykłady osuwisk o dużych rozmiarach zostały opisane następujące struktury osuwiskowe:

1. Osuwisko w dolinie Czarnej Wisełki w Malince koło Wisły (Śląsk Cieszyński) w górnych warstwach godulskich. Tutaj kilka ławic piaskowcowych osunęło się wraz ze żwirami, wskutek czego powstał utwór złożony ze zlepieńców zawierających bloki, otoczaki i płyty piaskowców. Miąższość utworu osuwiskowego wynosi około 40 m. (Por. fig. 1—5 w tekście oraz tabl. X i XI).

2. Osuwiska na Grojcu koło Żywca w górnych łupkach cieszyńskich. Jest tu kilka osuwiskowych mas na sobie, złożonych z pokruszonych i pomiętych kawałków łupków, piaskowców i syderytycznych margli tkwiących w ilastej masie bez wyraźniejszego warstwowania. (Por. fig. 6—8).

3. Osuwisko w Porębie Wielkiej koło Mszany Dolnej, w warstwach

inoceramowych, złożone z bloków i drobnych fragmentów piaskowców tkwiących w silnie zaburzonych łupkach. Miąższość brekcji osuwiskowej wynosi około 55 m. Kształty fragmentów piaskowcowych w utworze osuwiskowym wskazują, że mogły być osiągnięte tylko wtedy, jeśli były w półplastycznym stanie. (Por. tabl. XII i XIII).

4. Osuwisko w Zadzielu koło Żywca, w warstwach istebniańskich dolnych. Wśród piaskowców występuje tu warstwa iłu wymieszanego z piaskiem i drobnym żwirem, zawierająca bloki piaskowców i sfałdowane fragmenty łupków. Osuwisko w Zadzielu, o niewielkiej miąższości (2—3 m), jest częściowo związane z osadem utworzonym przez spływ mułowy. Osuwiska tego typu częste są w innych warstwach fliszu karpackiego (warstwy babickie, górno-istebniańskie, inoceramowe, grodziskie). (Por. fig. 9—11).

Osuwiska pojedynczych ławic, należące do drugiego typu osuwisk, są znacznie częstsze. Można wśród nich wyróżnić następujące typy:

a. Osunięciu ulega tylko górna część ławicy (fig. 12—13 oraz tabl. XIV, 1), natomiast dolna część ławicy nie jest zaburzona. Jest to typ stosunkowo częsty we fliszu, zwłaszcza w warstwach krośnieńskich, inoceramowych i w piaskowcu magurskim. Nadścielające łupki, czasem z konkrecjami syderytycznymi (tabl. XIV, 1), mogą być objęte ruchem osuwiskowym, często jednak ruch się odbył, zanim łupki się osadziły. Wśród tego typu istnieją przejścia do warstwowania spływowego.

b. Osunięciu ulega cała ławica, w większym lub mniejszym stopniu rozpadająca się na bryły i drobniejsze fragmenty, zwykle zaokrąglone przez zwijanie (fig. 16, 20, 22 i tabl. XV). Zwinięcia można rozpoznać po hieroglifach występujących na obu stronach zwiniętych fragmentów (tabl. XV) lub po ułożeniu przekątnego warstwowania (fig. 20, rysunek prawy). W niektórych przypadkach ruch osuwiskowy objawia się sfałdowaniem ławicy.

c. Osuwająca się ławica rozpada się na płyty, które zsuwając się, zawijają w górę (częściej) lub w dół (rzadziej) swoje przednie krawędzie (fig. 17 i 18).

d. Dolna część ławicy ulega osunięciu, górna nie okazuje zaburzeń osuwiskowych.

e. Osuwiska zaczątkowe można rozpoznać po poprzerywaniu i rozsunięciu poszczególnych części ławicy (fig. 23, 24). Stwierdzono istnienie szczelin przecinających ławice prostopadłe do kierunku prądu (tabl. XVI oraz tabl. XIV, 2) zaznaczonego ripplemarkami, hieroglifami prądowymi lub lineacją prądową. Tworzenie się szczelin prostopadłych do kierunku prądu wskazuje, że rozciąganie odbywać się mogło pod wpływem siły ciężkości w kierunku pochyłu dna. W niektórych przypadkach takie tensyjne szczeliny zostały wypełnione piaskiem wciśniętym od dołu (fig. 25), wskutek czego powstały piaszczyste grzbieciki na górnych (tabl. XIV, 2) lub dolnych (tabl. XVI) powierzchniach ławic. W tym drugim przypadku grzbieciki te przypominają pozornie szczeliny z wysychania (wypełnione), z którymi oczywiście nie mają nic wspólnego.

W wielu wypadkach można na podstawie kierunku zawinięcia osuniętych warstw i innych cech próbować ustalić kierunek osuwania się. W większości przypadków kierunek ten jest zgodny z kierunkiem prądów, które w danym obszarze składały osady. To może wskazywać, że tworzenie się osuwisk było zależne głównie od pochyłu dna. W niektórych jednak przypadkach stwierdzono kierunki skośne względem kierunku prądu albo nawet im przeciwne.

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Kraków, grudzień 1957

Abstract. Submarine slumping in the Carpathian Flysch is described. Two types may be distinguished, in one type only one or two sandstone layers, in the other — several beds are affected by slumping. The second case is much less frequent.

INTRODUCTION

In a previous paper (1950) concerning post-depositional deformations of the Flysch rocks in the Carpathian area two types of sliding movements were distinguished: in one type of sliding that affected sediments just after deposition intense contortion of sandy beds was produced but continuity of layers was not broken; the other type of movement leads to disruption of beds with little or no folding. The first type of deformation was determined as slip-bedding and the contortions ascribed to gravitational gliding. The other type, to which the present note is devoted, is determined as slumping.

Subaqueous slumps have been described from many areas; the papers of Hadding (1931), Henderson (1936), Jones (1937, 1939), Cooper (1943), Kuenen (1949), Biełostocki (1955) may be quoted here only as examples of description of this kind of deformation; many of them contain extensive bibliographies what is not intended to be given in this note. Submarine slumps occur in the Polish Flysch Carpathians as I pointed out in the previously quoted paper. A submarine slump was also described from the Central Carpathian Podhale Flysch by Gołąb (1954). Radomski (1957) mentions also the presence of slumped and disrupted beds in this unit. Closer research shows that nearly every stratigraphic unit of the Carpathian Flysch contains deformation caused by submarine slumping.

In this note it is not intended to give a complete picture of submarine slumping in the Carpathian Flysch as certainly the observations of the present writer do not cover the whole field of this problem in the area. It aims only to present a few examples of structures produced by slumping that the author regards as typical and representative of slumping phenomena in the discussed area.

Generally speaking slumping in the Carpathian Flysch affects either several layers of beds, or only one or two neighbouring beds. Accordingly we treat slumping phenomena within the area under two headings: large scale slumping and one-bed slumping.

I. LARGE SCALE SLUMPS

1. Slump at Malinka
(Upper Godula beds, Upper Cretaceous)

A very interesting case of slumping is well exposed in Cieszyn Silesia south of Wisła. Near the top of the Godula beds which in their upper part consist of thin-bedded and fine-grained sandstones alternating with shales, a belt of conglomerates and coarse-grained sandstones occur. The conglomeratic belt is presented on the map prepared by Miss J. Burtan (in Burtan, Konior, Książkiewicz 1937) as a fairly continuous zone with some interruptions in its course. At the locality Malinka the conglomeratic belt is represented by a lense cut through by the stream Czarna Wisełka (Black Vistula). The deep gorge of this stream offers comparatively good outcrops in its walls and in the river-bed. Also on the hill situated east of the valley they are a few exposures of conglomerates although much poorer than in the valley.

Already at first sight the beds in the gorge exhibit features unusual for Flysch beds. Bedding of the conglomerates is not regular, bedding planes not distinct and even. The conglomerate consists of pebbles 1 — 3 cm in diameter; larger pebbles are rather not frequent. Quartz is the main component, besides black lydites and very rare gneisses and crystalline schists occur among the pebbles. Grading is not visible. At many places the conglomerate contains large boulders, pebbles and slabs of sandstones (Fig. 1—4 and Plate X—XI). These sandstones are fine- to medium-grained, with no conspicuous grading and only with some feebly marked lamination, which appears only in some fragments. The sandstone is glauconitic, contains little mica, and generally resembles thicker sandy layers of the Godula beds. Fragments of sandstones occurring in the conglomerates are of various dimensions. Small fragments below 10 cm in diameter are not frequent; more often the diameter is 20—40 cm and fragments of this diameter are more or less distinctly rounded whilst smaller ones are angular. Larger fragments are again not very frequent, and are generally not rounded but occur as angular blocks or slabs exhibiting sometimes some bedding; such slabs are on the whole parallel to the bedding of the enclosing conglomerates, although some are in oblique position and a few even at right angles to bedding. The largest slab is 6 m long and 1,5 m thick. If sandstone boulders or slabs are removed by stream erosion large holes left after them can be seen in the walls of the gorge or in the river-bed, looking like potholes. A few smaller slabs are distinctly folded (Fig. 1—2) whilst the conglomerate in which they are imbedded shows no folding. Often the contact between the conglomerate and the sandstone boulders is not sharp, but there are apparent gradual passages from the sandstone into the conglomerate so that no distinct boundary can be drawn between them. Small pebbles of quartz stick in the sandstone, evidently pressed into it when the sandstone was still weakly consolidated. Therefore the surface of sandy boulders taken out from the conglomerate is covered with quartz pebbles sticking in the sandstone in a similar way as pebbles stick in the surface of an „armoured clay-ball". Some contacts between the conglomerate and the sandstone fragments are sharp, sometimes one boulder exhibits a tightly welded contact with the conglomerate on one side and a sharply marked boundary on the other (Fig. 2).

The sandstone boulders and slabs are not evenly distributed in the conglomerate. Some parts of it are very rich in sandstone fragments

(Plate X), in others they are scarce or even absent. It does not seem that any rule governs the distribution of sandstone fragments but on the whole it appears that they are more frequent in the conglomerates that are cropping out in the stream-bed than in the conglomerates appearing on the slope of the hill, i. e. that they are more numerous and possibly larger toward the top of the lens.

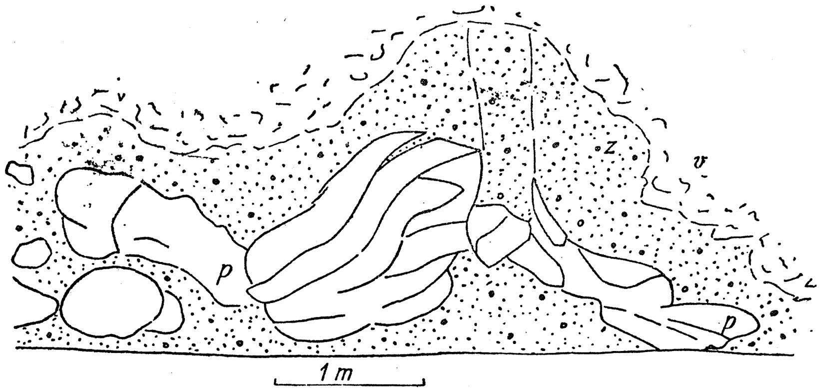

Fig. 1. Slump at Malinka. Sandstone blocks (p) enclosed by conglomeratic sandstone (z); v-denotes screes

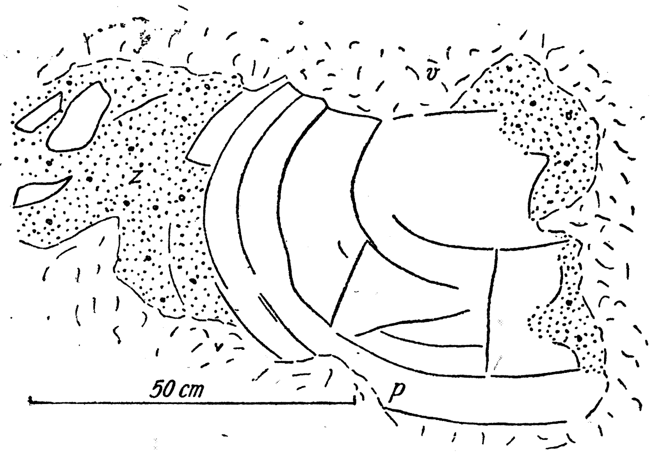

Fig. 2. Slump at Malinka. A folded slab. For explanations, see Fig. 1

One possibility of explaining the occurrence of blocks, pebbles and slabs of sandstones in the conglomerates is that a sandstone bed was eroded, and this erosion produced fragments which were eventually embedded into the conglomerate. This must have happened when the sandstone was only weakly indurated.

However, if boulders and slabs were an erosional product, it would be very difficult to understand why small fragments occur so seldom in the conglomerate; this presumption does not explain either why some fragments are distinctly folded or contorted. The occurrence of large unrounded slabs is also inexplicable.

It is much more simple to attribute the features observed at Malinka to slumping than to erosion. One can presume that conglomerates together with semi-consolidated sandstones slid down a submarine slope.

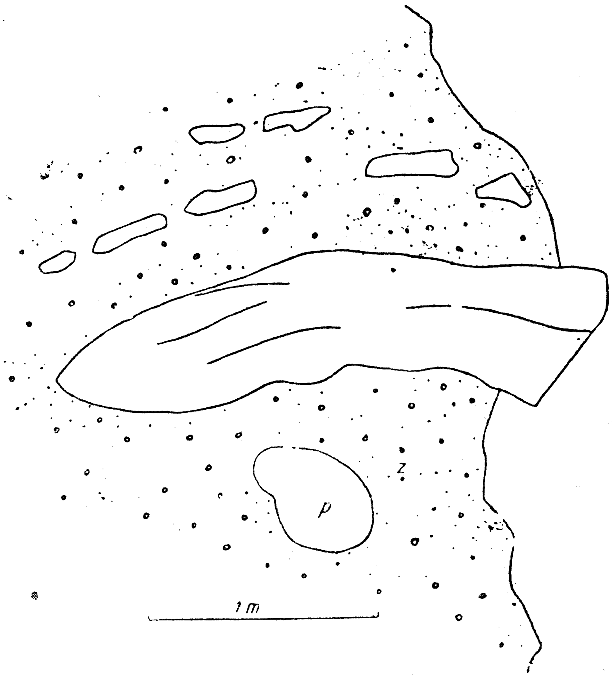

Fig. 3. Slump at Malinka. For explanations see Fig. 1

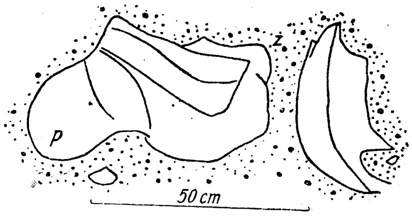

Fig. 4. Slump at Malinka. For explanations see Fig. 1.

The sandstone layer (or layers) were broken into pieces which slipped down together with gravels. It is possible that the sandstone layer was deposited before the deposition of gravels, or formed an intercalation (or a few intercalations) in gravels. Overburdened by subsequent deposition, gravels and sandstone layers slid down. Fragments of the sandstone, if not too large, were rolled within the slumping mass of gravel. Rolling produced more or less developed rounding, and, as the sandstone boulders were not yet quite consolidated, their surface became „armoured" with pebbles.

As it was pointed out above, the beds exhibiting slump structures occur in a lens. The shape of the lens is well given on the map of Miss B u r t a n. The lense is ca. 400 m. long (along the strike) and more than

150 m. wide (across the strike). Its northern end is truncated by a fault owing to which the conglomerates of the lens dipping west (ca. 15°) are in contact with the typical Upper Godula beds (thin-bedded sandstones and shales) dipping east (40°). The southern end of the lens is to all appearance normal, and the conglomerates extenuate among the shaly Upper Godula beds in this direction. Taking the mean dip of the conglomerates as 15°, we obtain the thickness of the slump deposit as ca. 40 m.

The slump structure at Malinka exhibits no features which could indicate the direction of slumping movement, and this can be only indirectly determined.

The underlying beds, composed of thin-bedded sandstones and shales, have sufficiently developed directional features, as both current bedding and flute marks are abundantly present. In a tributary rivulet east of the lens flute marks have a direction 60° [1], i. e. toward NE while the measurements of current bedding give directions contained between 30 and 90°. From this it can be inferred that the sandstones of the Godula beds were deposited by currents flowing from the sout-west.

Covering beds are not exposed sufficiently above the lens for directional examination but just close to the lens at its northern end the Upper Godula beds are well seen in river-bed outcrops. Here the direction 70—75° of flute marks and closely related directions of current bedding could be measured.

Farther downstream, where the strike of beds changes considerably, flute marks have direction 135—145°, i. e. toward the south-east.

Generally it may be stated that in the close vicinity of the slump the underlying and covering beds have features pointing out to the north-east direction of currents. This is consistent with the measurements of the direction of transport within the Godula beds in other areas (Silesia, Soła valley, Wadowice area), where north-eastern and eastern direction of currents has been found by the present writer.

The conglomeratic beds of Malinka exhibit neither flute marks nor current bedding. On the rock wall of the gorge facing a little dam on the river one can see sandstone boulders and blocks arranged in a way suggesting imbrication, with longer axes of boulders dipping west or west-south-west. Similar imbricate arrangement is visible, although less marked, at few other places. This is not a certain proof but seems to point out that if boulders were transported by traction along the sea-floor, they could have been arranged with imbrication dipping up the current. If so, this would mean that sandstone boulders were transported from the west. It should, however, be pointed out that in the Carpathians there are known several cases where pebbles are arranged with imbrication dipping downcurrent. This kind of imbrication in graded beds was found also by K o p s t e i n (1954).

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[1] All directions in this paper are given as azimuths (from the north, clockwise).

The outcrops in question were visited in autumn 1957 in the company of Professor Ph. H. Kuenen who pointed to the author that the conglomerates containing slump boulders exhibit some orientation of longer axes of pebbles. Several measurements have been executed afterwards and it has been found that there is a lineation of longer axes in the conglomerates although not very distinctly marked, i. e. that on a unit area no more than 30—40% of pebbles shows aligned longer axes. The lineation measured in the outcrops with slump structures is contained between values 70/250° and 95/275°. This means that the axis of flow approximates the direction east — west. The first given value (70/250°) refers to a bed possibly not involved in slumping movement as the conglomerate layer showing this lineation does not contain any boulders. It seems that values between 80/260° and 95/275° are most frequent within the slumped mass. Above the slump upstream the conglomerates are well exposed without any slump structures. Here lineation is most perfectly developed; at many places more than 80% of pebbles is aligned with parallel longer axes (Plate XI, 2). Not only alignement of particular pebbles may be observed but also the same lineation is shown by strings of pebbles running on the surface of beds in the same direction [1].

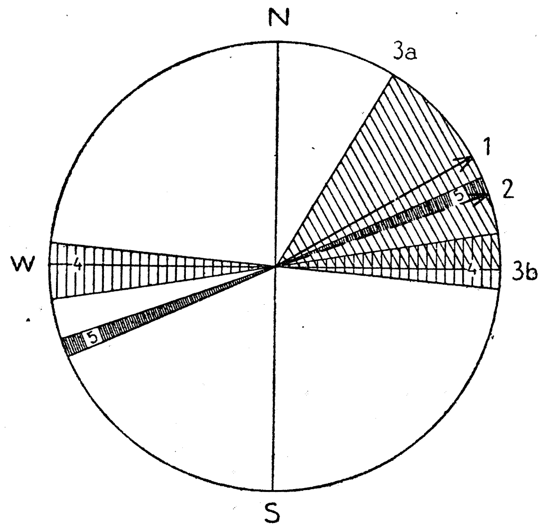

Fig. 5. Orientation diagram of directional features, slump at Malinka. 1-Direction of fluting in underlying beds. 2-Direction of fluting in overlying beds. 3a—3b Range of directions of current bedding in underlying beds. 4-Pebbles lineation in undisturbed conglomerates. 5-Pebbles lineation in disturbed conglomerates

[1] It was thought in the beginning of sedimentary studies in the Polish Flysch Carpathians that linear arrangement of pebbles is rather exceptional and hardly so conspicuous that could be found out without the help of some statistical studies. Moreover, although at a few places imbrication was found, the data given by it were often in conflict with the data furnished by measurements of current bedding and fluting. In this respect Kopstein's work (1954) on pebbles lineation in the Cambrian of Wales evoked a new interest in this method. It appears that in some series there is an apparent concordance of pebbles lineation with fluting resp. current bedding, in others there no such concordance, and in several cases there is no linear arrangement of pebbles. The problem requires further research.

From these measurements it follows that the conglomerates undisturbed by slumping exhibit a much more perfect lineation than the conglomerates involved in slumping movement, and, that even taking into consideration the influence of changes of the strike of beds, on the whole insignificant, there is some difference of the axis of movement of disturbed beds (approaching axis W—E) in comparison with the axis of flow within undisturbed beds (approaching SW — NE direction, comp. Fig. 5).

At any rate, the supposed direction of slumping movement does not differ much from the direction of currents which deposited both the fine-grained sandstones and the conglomerates. This may indicate that the slump occurred in the direction of the slope of the sea floor which controlled the direction of sand and gravel transporting currents.

There are no data permitting the estimation of the distance along which the slump moved. Large and feebly distorted slabs occurring in the slumped mass seem to indicate that the distance was not great, possibly only a few hundred metres.

It may only be guessed what was the cause of the slump. Possibly the direct cause was an overloading of the sea-floor with regard to its profile. The profile was generally in equilibrium during the deposition of the fine- grained Godulą beds as they contain comparatively infrequent slumped beds. It is possible that the deposition of thick conglomerates disturbed this equilibrium and caused local slumping. On the other hand the appearance of coarse-grained sediments after the prolonged period of the deposition of fine-grained sediments certainly points out to some uplifting movements in the neighbouring areas, possibly as the first singns of the Laramide orogeny (K s i ą ż k i e w i c z 1954 a). These movements might have increased the slope of the sea-floor. It is possible that this was the cordillera bordering the Silesian basin from the south which was raising; its uplift could have steepened the declivity of the southern slope of the trough in which the Godula sands were deposited what could have caused the observed difference between the direction of transport and the presumed direction of slumping.

A striking feature of the slump at Malinka is the absence of any clay balls or shale fragments, so numerous in other slump deposits in the Carpathian Flysch. Actually, the conglomerates in which the Malinka slump structure occurs, contain very few if any shaly interbeddings.

It is doubtful whether such a large slump could be formed by slumping of a single bed. It is more likely that several conglomeratic beds interbedded with sandstones were involved in slumping. It is possible that originally sandstone beds were terminations of graded conglomerates, but in no case primary transition from the conglomerate into the sandstone has been observed. If such transitions existed they were obliterated during slumping.

This type of slumping seems to be very infrequent in the Carpathian Flysch. Similar structures can be observed in the Silesian Carpathians in conglomeratic beds of the Upper Godula beds which contain sometimes fragments of sandstones and shales with obvious signs of contortion. These are, however, small scale features e. g. a conglomeratic layer occurring in the Malinka valley downstream from the great slump. The layer is only 40 cm thick and contains lumps of laminated sandstones and fragments of shales. Contortions visible in sandstone lumps suggest that they were slid down together with conglomeratic material.

2. Slumps at Grójec
(Cieszyn beds, Neocomian)

The right bank of the Soła river at Żywiec (Polish Western Carpathians) exhibits excellent outcrops of intensely folded Lower Cretaceous beds (Cieszyn = Teschen beds). The outcrops that are of special interest are situated opposite the paper factory.

Here the Upper Cieszyn shales (Valanginian) are folded into an anticline, the axis of which passes through a small tributary valley, occupied by a landslide. In the core of the anticline there occur the typical Upper Cieszyn shales (fine-grained and thin-bedded sandstones). In both limbs of the anticline thick intercalations of silts containing numerous fragments and pebbles of limestones occur in the Upper Cieszyn shales. In the southern limb the intercalation is ca. 28 m. thick, in the northern limb two layers of „pebble-clays" are intercalated, the lower 3 m., and the upper 15 m. thick, separated by typical Upper Cieszyn shales.

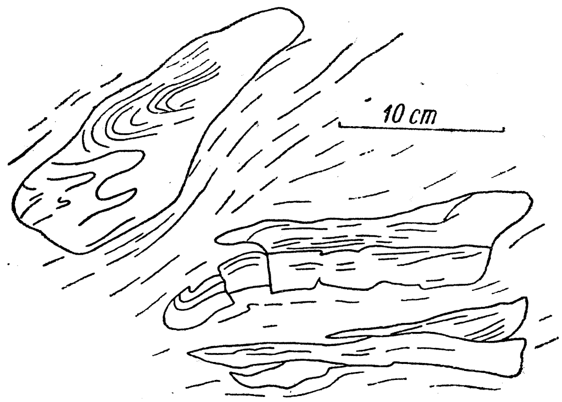

Fig. 6. Slump at Grojec. Lumps of marls in shales

The „pebble-clay" contains pebbles of various limestones, mainly dark Tithonian limestones, white oolitic limestones, Cieszyn limestones (both pelitic and detrital varieties), and also fragments of sandstones from the Upper Cieszyn shales. Pebbles, some of them only very slightly worn, are chaotically arranged in a mass of structureless hard marly silt with numerous small grains and fragments of limestones. This deposit may be regarded as a mudflow sediment (Książkiewicz 1954).

In the northern limb of the anticline a thin (ca. 2 m.) intercalation of pelitic limestones may be seen followed again by the Upper Cieszyn shales 8 m. thick. Above them lie marly shales without sandy intercalations but containing large blocks of sideritic marls and limestones. Shales are strongly compressed and contorted. Their thickness is about 1 m. They are covered by a 8 m. thick layer of strongly contorted mass of marly clays without schistose cleavage usual for the Cieszyn shales. These clays are compact, hard and break into irregular lumps. Weathering discloses their strong internal contortion, for the clay is nearly black but is laminated owing to the presence of very thin whitish layers which are better seen on weathering. There are also very thin layers of sand. It can be seen that the clay consists of irregular lumps of well laminated clay cemented by a clayey mass with poorer lamination (Fig. 6). The size of lumps is larger nearer the bottom. Sand strings are folded and their continuity is broken, and if sideritic marls occur within the contorted mass they are broken into irregular pieces (Fig. 7).

Fig. 7. Slump at Grojec. Contorted clays. Black — sideritic marls

Above the contorted clay rest a few layers of limestones which are detrital and graded, as usually the Cieszyn limestones are, but contain in their upper part unusual amount of fragments of shales and even of laminated sandstones. Their thickness is 3 m. They are covered by a 30 cm. thick sheet of clay mixed with grains and pebbles of limestones resembling the sediment described above as mudflow deposit, but pebbles are neither so large nor so numerous. The mudflow deposit is surmounted by 1,5 m. thick bed of laminated contorted clay, above which lies a bed 2 m. thick consisting of strongly contorted shaly clays containing numerous lumps of well laminated fine-grained sandstone. The lumps, a dozen cm. or so in length and only a few cm. thick are often internally folded (Fig. 8), they are also often bent and crumpled (Fig. 21). Their shapes, wedging out and contortions independent from the enclosing clays indicate that they were deformed when not yet quite consolidated. They strongly resemble „crumpled balls" described by Kuenen (1949) but are more flat than roundish. The layer with crumpled lumps is covered by contorted laminated clays without sandstones which gradually pass upward into shales with no internal disturbances.

The described beds are strongly tectonically engaged, and there are several features as slickensides, small scale faults, calcite veins etc., due to tectonics. But there is little doubt that contortions, crumpling, breaking of siderites and marls and sandstone layers into separate lumps and strings was caused by slumping before the deposition of overlying shales. Probably there occurred a few slumps in quick succession which deposited these disturbed beds, summarily ca. 20 m. thick.

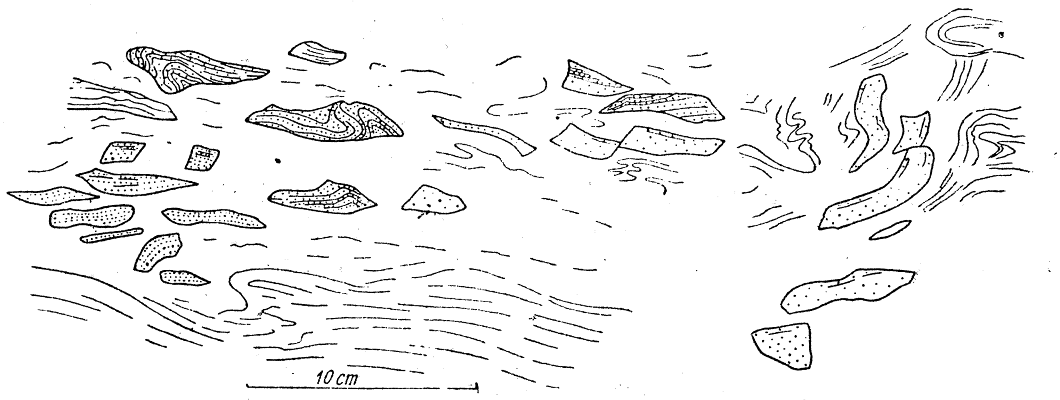

Fig. 8. Slump at Grojec. Crumpled sandstone lumps in a structureless clay

There are few features assisting in determination of the direction of slumping movement. Both clays and the imbedded lumps of sandstone have bends and folds closing generally toward the north-west. This would mean that the sliding mass moved from the south-east. As flute marks in the Cieszyn limestones in neighbouring outcrops are directed toward east-south-east (95—110°), current bedding in the Upper Cieszyn shales toward south-east and fluting in these beds in a similar direction (95°), it may be presumed that the slumps took place obliquely and nearly from an opposite direction with regard to the direction of flow.

3. Slumps at Poręba Wielka
(Inoceramian beds, Upper Cretaceous)

In the southern fringe of the tectonic window of Mszana, mapped by Świderski (1953) there occurs a narrow band of the Inoceramian beds. South of Poręba Wielka the main stream (Poręba) exposes a very good cross-section of these beds and their contact with the Oligocene Krosno beds and black shales of the window series. The contact is strongly disturbed, and the Krosno beds and black shales are folded together with Cretaceous beds. A cross-section of an overturned fold may clearly be seen with the Oligocene in the core and the Cretaceous in both limbs (in the northern inverted limb with hieroglyphs on upper sides). In the southern limb of the fold the Cretaceous begins with a few sandstone beds dipping south; above them crop out strongly disturbed beds well observable in the streambed along a distance of 110 m. They consist of strongly contorted and pressed calcareous shales containing numerous small and large blocks of sandstones (Plate XII and XIII). The sandstones are of the type occurring normally in the

Inoceramian beds: fine-grained, calcareous and micaceous with fine lamination and often current bedded. The lumps are of variable size, but the largest hardly exceed 1 m. in diameter and generally are much smaller. Their shapes are variable too; some are fairly well rounded but most is more or less angular, their edges, however, are not sharp but slightly rounded or obliterated. Many of these lumps are twisted, and some are finely folded (Fig. 20, center); both large and small lumps may be twisted or folded (Plate XIII, 1). Shapes of lumps indicate that sandstones were still plastic during deformation.

The dimensions of the slump mass and the appearance of particular lumps indicate that the slump was formed by sliding of several sandstone beds together with intervening shales. During slumping beds were broken into pieces which were either dragged or rolled with some folding and twisting.

The thickness of the slumped beds is about 55 m. The length (along the strike) is not known, but in neighbouring streams at a distance of a few hundred metres no such strata are visible. At any rate this slump may be regarded as the largest slump that so far has been discovered in the Polish Carpathians, and possibly it is only in length exceeded by the slump of Malinka.

The direction of slumping may be to a certain extent determined. Most of the lumps, if they are folded, have their bends closed in the western direction [1]. The same is the direction of flow in the Inoceramian beds within the area. In the cross-section of the stream above the slump I found the following directions of flute marks: 310°, 300°; in the Koninka valley (a stream east of the Poręba stream): 280°, 340°, 310°, 350°, 345° (but also 110°, 195°, 120°, these directions were found solely in thick-bedded sandstones with coarser grain). As the direction of currents was controlled by the slope of the sea-floor, it can be concluded that the slump moved with the slope.

It should be stressed that the slump mass together with the beds below and above is strongly tectonized. Numerous slickensides, small scale faults, calcite veins cutting both sandstone lumps as well as shales, compression of shales etc., are evident features of strong tectonic engagement and introduction of additional distortion to already disrupted and contorted beds. The slumped beds occur at the very base of the Magura nappe, and it is not surprising that tectonic influence is so strong in this case.

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[1] Naturally, if bent lumps are only broken limbs of folds, no conclusion can be drawn from this fact, as bends should be closed in this case either way. However, from the observations made on single slumped beds, as it is pointed below (p. 144), the conclusion may be borne out that folding rarely preceds disruption of beds during sliding; at first a bed is broken into lumps or sheets, probably owing to stretching, and subsequently they slid down; during sliding the frontal part of a sliding sheet bends upward or downward, and in this way folded lumps are formed. Thus the predominance of one direction of closures in lumps may be helpful in determining the direction of slumping.

4. Slump at Zadziele

(Lower Istebna beds, Senonian)

North of Żywiec, in the Soła valley, a large quarry is situated close to the road between Zadziele and Tresna. Thick-bedded and coarse-grained sandstones with very thin intercalations of shales, and often without them, are exposed here. The sandstones in this quarry are feebly graded, not very regularly bedded and contain fairly numerous shale fragments. Some of them are typical „armoured clay-balls", i. e. with the surface covered with larger quartz grains and pebbles. If the clay is removed, the hole after it is lined with pebbles stuck into the enclosing sandstone. This feature, fairly common in the Carpathian Flysch (Grodziszcze sandstone, Istebna beds, Ciężkowice sandstone), seems to be particularly common in this quarry.

In the upper part of the wall exposed in the quarry a dark band is visible, contrasting with the light colour of the sandstone. This band consists of a clayey layer exhibiting intense slumping features. The layer is not of constant thickness which in average is 2,50—3,00 m., and diminishes rapidly toward the north. The main body of the layer consists of clayey mass mixed with a large proportion of quartz sand (ca. 50%). The grain size of quartz sand is ca. 0,1 mm., but there are also fairly numerous larger quartz grains and even pebbles of 5—8 cm. in diameter. Such type of sediment may be regarded as a mud-flow deposit, very common in the Carpathian Flysch.

In this mixture of clay and sand, however, there are numerous lumps of shales and sandstones with apparent features of slumping (Fig. 9). Lumps of shales are folded into regular anticlines and synclines, or rolled into balls, some of them perfectly closed, spherical or roundish. There are also blocks of sandstones, some of them also roundish and showing internal closing of lamination what points out that they were rolled into sand-balls, others are irregular in shape or rounded but with no stratification or, if any stratification is seen, there is no internal contortion of it. Some of the lumps consist of thin layers of shale and fine-grained sandstone, and remind much the top part of the graded sandstone beds below the slump bed. Also some of the sandstone blocks have the same composition and appearance as the uppermost part of the Istebna sandstones. This indicates that these blocks and sheets, both of sandstones and shales, were torn away during the slumping movement from the underlying sandy bed. It may be noted, however, that some sandstones, occurring always as well rounded pebbles, are different from the Istebna sandstones; they are coarse-grained and contain mica and glauconite, absent in the normal Istebna beds.

A very significant feature is the presence of clay-balls, spherical or ellipsoidal (flattened probably by compaction), armoured with quartz pebbles packed closely on their surface and in upper layers.

Fig. 9. Slump at Zadziele. Fragment of the slumped pebble-clay with sandstone balls and blocks, folded lumps of shales and armoured clay-balls

The origin of this slump is clearly connected with a mudflow. Presumably a normal submarine mudflow consisting of clay, sand and gravel when moving on the sea-bottom either tore away some sheets of shales covering a sandstone bed together with some pieces of the sandstone, or exerting drag on them caused their slumping. The underlying sandstone must have been partly consolidated as it did not disintegrate into sand; also shales must have been well consolidated as their stratification is well preserved, and evidently they did not crumble back into clay when slumping. It is rather difficult to imagine that well compacted clays were forming the sea-bottom; they must have had above them some beds which caused their compaction. It may be, therefore, presumed that they were covered by a few beds of sandstones and clays poorly yet consolidated, which slumped and disintegrated into a mixture of clay and sand. This mixture developed into a mudflow which was tearing away lumps of underlying better consolidated beds.

It is characteristic that most of the sandstone blocks and shales lumps occur in the upper part of the layer while the bottom part is nearly devoid of them. Possibly this indicates that the slump travelled some distance, so that the lumps torn away from the base, had time to accumulate in the upper part, similarly as shale chunks in graded sandstones tend to accumulate in top part (K u e n e n 1957) after travelling some distance in a turbidity current [1].

There is no evidence as to the distance covered by this mudflow, but there are indications from other areas of the Carpathians that some submarine mudflows could travel a distance of at least 30 km (K s i ą ż k i e w i c z, in press).

The slump layer is covered by a layer of shales 1 to 2 m thick with no slump structures. This shaly layer is much thicker than the shaly layers covering each sandy bed below and above the slump. It seems that the mudflow and the resulting slump were accompanied by suspended clouds of clay from which the covering shales were deposited.

There are no directional features in the described slump structure, and nothing can be said about the direction of slumping. Neither the covering and underlying sandstones furnish any hints as to the direction of currents which deposited them. Little is known of the direction of fluting in the Istebna beds within the area, but not far from here, in the Wadowice district north-east directions may be noticed. In the surmounting Upper Istebna beds small-scale current bedding points toward the north or north-east. Two pictures (Fig. 10) from the quarry at Zadziele represent asymmetrical flow casts which presumably indicate sand movement also to the north. Whether the slump had also this direction, it is difficult to say.

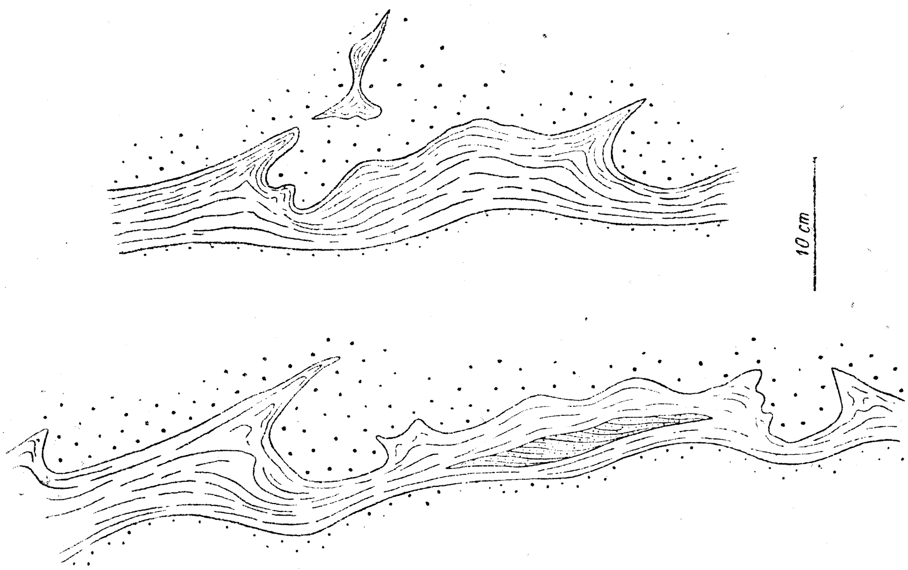

Fig. 10. Upper Istebna beds at Zadziele. Flow casts at the base of sandstone beds. Some current bedding visible in fine-grained layers

[1] It should be noted here, however, that shale fragments occur fairly frequently in many of the Carpathian sandstones near the bottom surface. Possibly this may indicate these sandstones were not deposited far from the source.

Mudflow deposits are very frequent in the Carpathian Flysch, and there is hardly any stratigraphic unit without them. The Grodziszcze beds (Hauterivian-Barremian), both Lower and Upper Istebna beds and the Babica beds abound in these deposits. The latter have been described in some detail by Bukowy (1956) who noticed that mudflows could erode their bottom [1]. There are fairly numerous cases of slumping connected with mudflow deposits, similar to that of Zadziele, e. g. in other occurrences of the Istebna beds, also in the Grodziszcze beds etc. Fig. 11 presents an example from the Inoceramian beds. In this instance it seems to be clear that the slump moved from

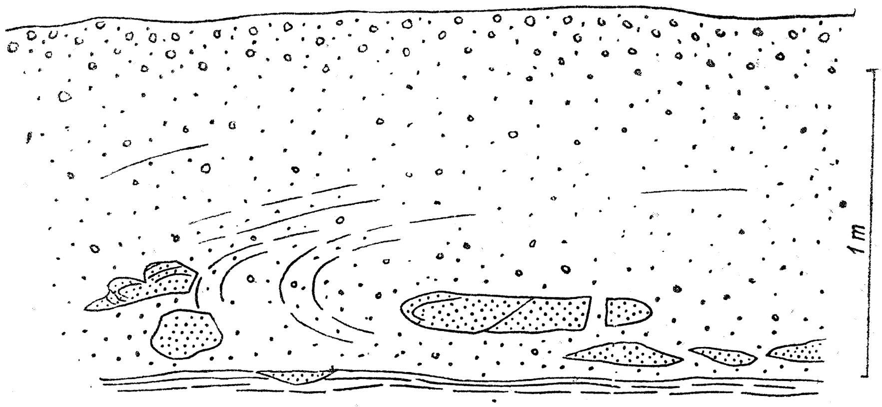

Fig. 11. Slump structure at Binczarowa, Inoceramian beds. Bed is inverted. Pebble--clays with slumping in top part

left to right (beds are overturned, the picture should be reversed), i. e. toward the west, in conformity with the sense of transport in the Inoceramian beds in the area.

II. ONE-BED SLUMPS

In the instances described above several beds were involved at once in slumping. It should be underlined that such cases are rather exceptional. Much more frequent are the cases in which only one or at most two layers of sandstones underwent slumping.

As an example of this type of slumping a distorted single bed is described first. At Tresna in the Soła valley (Western Carpathians) there is a good outcrop in the Godula beds near the bridge. The Godula beds consist here of evenly bedded sandstones which are not conspicuously graded, but the top part of sandy layers is always more fine--grained, laminated and richer in mica and plant detritus.

One sandstone bed exhibits different features. At the base it is evenly bedded but a few cm. above the sole shows contortions and inter-

[1] After giving this paper to the Editor I came across the paper of J. C. Crowell (Origin of pebbly mudstones, Bull. Geol. Soc. Amer., vol. 68) in which he described plowing action of submarine mudflows (p. 999).

nal folding, which becomes more intense toward the top (Fig. 12). The coherence of the sandstone changes toward the top too. At the base the sandstone is firm and compact while the distorted part is more friable

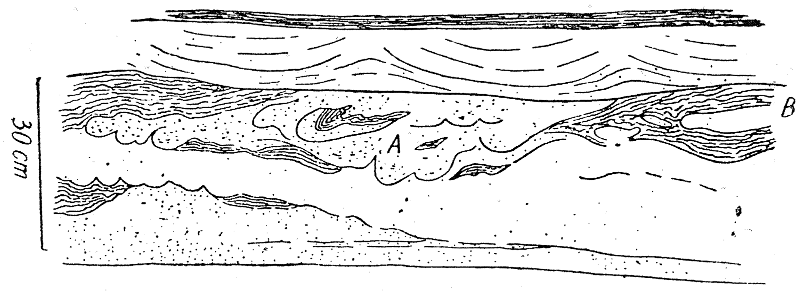

Fig. 12. One-bed slump at Tresna, Godula beds

although still comparatively hard, more muddy, and contains much more mica and plant detritus than the lower part. Bands of shales, apparently deriving from the covering shales are folded together with the sandstone. There are several closures of small overturned and even plunging folds, all closures bent toward the east. This would mean that this was the direction of slumping. The general autlook of the bed seems to confirm such an inference, as the folded mass at *A* in Fig. 12 seems to be a rootless „nappe" which slumped to the left from beyond the shales at *B*. Its composition, plentiful mica and plant detritus indicate actually that the slumped mass belonged to the upper part of the originally graded bed. The direction of slumping coincides with the direction of flute marks (30—80°) in the outcrop. This means that the slump followed the general slope of the sea-floor.

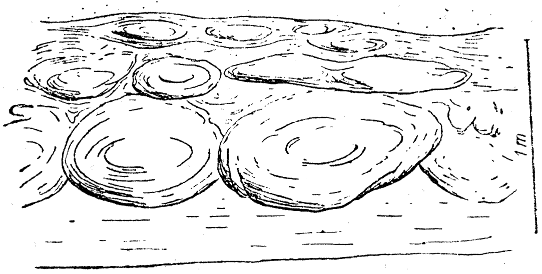

Fig. 13. One-bed slump, Magura sandstone, Skawica. Note the undisturbed base of the bed

In the described case only the top part of the bed underwent slumping, whilst the bottom part does not show any trace of distortion. There are numerous cases of this sort, and two kinds may be distinguished depending on whether the covering shales are involved or not into slumping movement. Plate XVII, 3, 4 and Fig. 13 represent a fairly frequent case in which slumping produced large balls pushed one on another. Probably to this type of internal slumping belong the features presented on Fig. 14 where no other signs of slumping are visible except the trace of contact between the lower unaffected part and the upper slid portion of the bed. Such features may be observed in thick- and

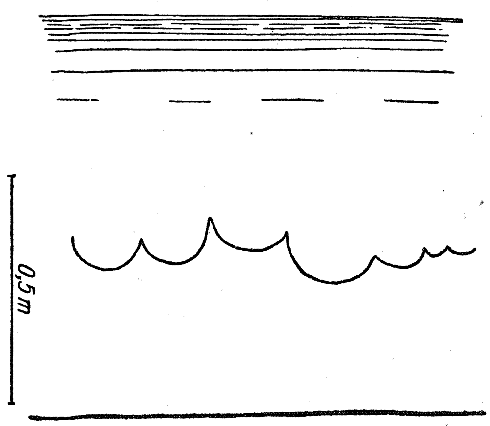

Fig. 14. Trace of internal slumping in sandstone bed. Inoceramian beds, Zaryte

medium-bedded sandstones; I observed them in the Lower Godula basal sandstone (e. g. quarry at Porąbka), in the Inoceramian beds, in the Hieroglyphic beds and in the Magura sandstone in which they seem to be particularly frequent. Sometimes one can see on the contact some minute corrugation (Pl. XVIII, 6) or some sort of contortion but usually the surface is smooth and both portions are well welded.

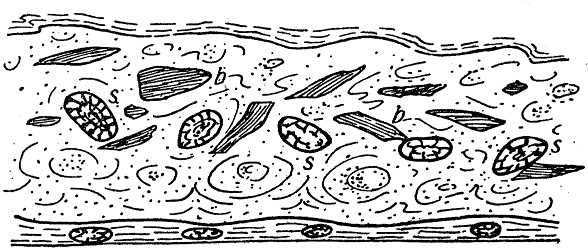

Fig. 15. One-bed slump. Krosno beds, Besko. Slumped bed contains siderites (s) and shale fragments (b)

A remarkable case belonging to the type of slumping where only the upper part of a single bed underwent slumping together with covering shales may be given here from the Krosno beds, so well exposed at Besko. In my previous paper (1950, p. 494) an instance was reported in which sideritic concretions occurring as a rule in shales, occur in sandstones owing to slumping of a sandstone bed together with covering shales. Plate XIV, 1 and Fig. 15 present this case where concretions and shaly lumps are mixed with a strongly corrugated sandstone. Incidentally, the presence of concretions in slumped beds points out that these concretions must have been formed very early, at any rate before the deposition of the covering sandstone, and are then probably of a syngenetic, and not a diagenetic origin.

Slumps involving only the upper part of the sandstone bed, with or without covering shales, are numerous in the Carpathian Flysch, and probably occur in all stratigraphic members. I know examples of this kind of slumping from the Lgota beds, Godula sandstone, Inoceramian beds, Hieroglyphic beds, Krosno beds and the Magura sandstone. This type seems to be closely related to the structures of contorted beds, described by the present writer (1950) as „slip-bedding". On the other side, slip bedding is related and to a certain extent, identical, with „convolute bedding" of Kuenen (1953, cf. also Ten Haaf 1956). There are certainly cases where slip bedding is difficult to separate from convolution, particularly if chunks and lumps of shales are absent in the deformed bed, and when contortions are expressed in regular folding. At any rate, if a corrugated bed contains fragments of shales, what means that some slipping occurred after deposition of covering shales, such a case may be regarded as an intermediate link between convolute bedding and slump structures. Thus the following distinction can be made:

Convolute bedding — no horizontal slipping.
Slip bedding — convolution distorted by slipping, but continuity of bedding (lamination) is not broken. Numerous recumbent folds, in extreme cases chunks of shales folded together with sandstone.
Slump bedding — top part of beds slipped horizontally (Pl. XVIII, 5).
One-bed slump — whole single beds slumped and disrupted.

When the whole bed is slumped, it is usually broken into smaller or larger pieces with all features of slumped sandy sediments. The main feature of such beds is rolling into sand-balls, or more often, into sand-cylinders. Dimensions of such forms are variable: from small lumps a few cm thick to large blocks ca. 1 m. in thickness. Sometimes the balls and cylinders are packed closely and more or less welded, with no shales between (Pl. XVII, 1, 2) but much more frequent are cases when they are mixed with shales (Fig. 16). Sometimes beside roundish blocks there occur also angular sandstone blocks, that did not undergo rolling when sliding. In a few cases the slumped bed consists only of angular blocks scattered in shales.

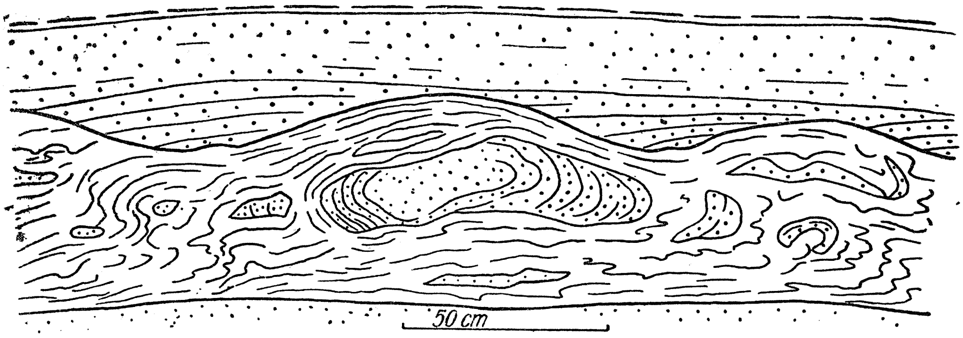

Fig. 16. One-bed slump. Godula beds, Malinka

In several instances the slumped bed consists of flat sheets of sandstone separated from each other, with their edges bent up and rolled back on one side. Fig. 17 demonstrates such a case. Here a shaly layer

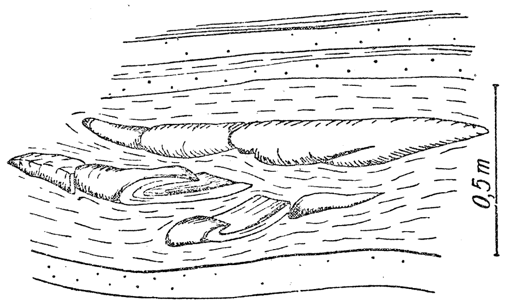

Fig. 17. Sheet-like slump, Inoceramian beds, Poręba Wielka. Note the upturned noses of sandstone sheets

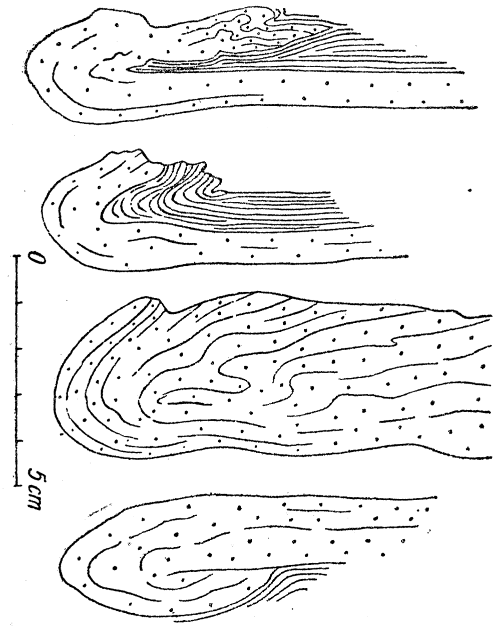

Fig. 18. Various types of terminal bends in slumped sheets

ca. 0,5 m. thick, contains two sandy layers with bent up terminations. Both layers are only a few cm. thick. The terminations are bent backward so that they look like recumbent folds with their noses upturned. Backward bends of these noses may be more or less closed (Fig. 18) but usually there are shales infolded. It seems that the described type of slumping may be regarded as an uncompleted slump: a sandstone layer when slipping down was disrupted into a few flat sheets, the edges of which rolled up a little during slumping, but otherwise sliding sheets became neither distorted nor folded. If slumping movement continued, they would probably have been rolled up completely into balls or cylinders. The upper slumped layer in Fig. 17 represents a more advanced stage towards complete rolling up. These cases remind much beds folded back on themselves described by Cooper (1943, Fig. 3—4).

Examples of this type of slumping are fairly numerous in the Carpathian Flysch, particularly in the Krosno-and Inoceramian beds. It should be added that noses of sliding sheets are not necessarily bent upward, in some cases, although seemingly less numerous, they are bent downward (Fig. 18, below). In either cases the presence of bends helps in determining the direction of slumping. In all examined cases the determined direction of slumping is approximately conformable with the direction of currents, what allows to infer that slumping followed the slope of the sea-floor.

More frequent than sheet-like slumps are cases when slumped beds were disrupted into numerous pieces which during slumping became bent, twisted, folded, rolled up etc. In these cases we have a discontinuous layer composed of lumps sticking in shales. There are instances when one can surmise that more than one bed was disrupted into lumps but mostly there are indications that only one bed produced slumped lumps.

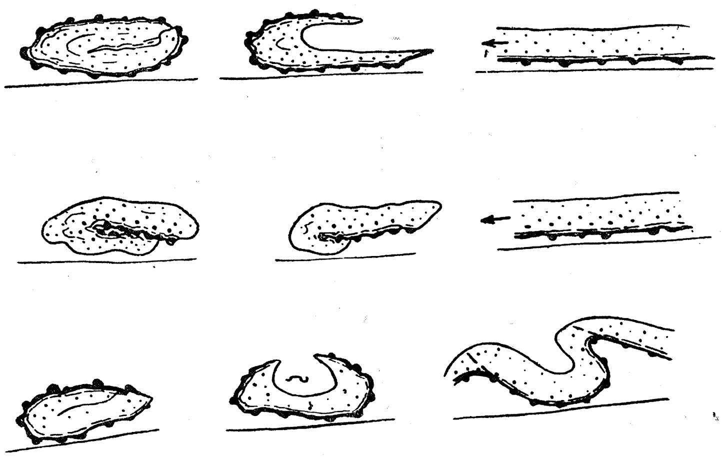

Fig. 19. Sliding and rolling up of sandstone layers

Slumping lumps may be rolled up in more than one way: their downslope end may be bent upward or downward (Fig. 21); in the first case hieroglyphs and other bottom features occur on both sides of the rolled lump (Fig. 19 and Plate XV). When grading or current bedding are visible, it is easy to find out whether the original bottom is inside of the lump or, as the case is in Fig. 20, right, it is now the outer surface of the lump. So far no case has been found with hieroglyphs inside, while lumps with hieroglyphs on the outside surface are fairly numerous. Rolled lumps may also be formed by folding of the slumping bed and subsequent disruption (Fig. 19, bottom); in this case one can expect to find lumps rolled either ways, their bottom surfaces on external surface of some lumps, and inside in others, but curiously, I do not know such instances what probably indicates that disruption into lumps is generally not preceded by folding. Fig 22 presents the case in which

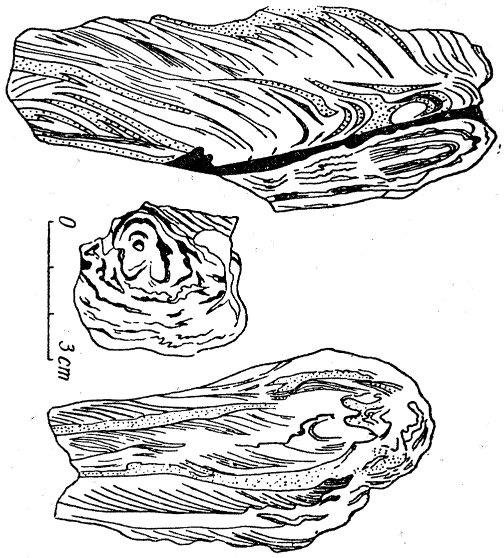

Fig. 20. Rolled up slumped sandstone lumps. First and third specimen from the Magura sandstone, Sidzina, second from the Inoceramian beds, Poręba Wielka. Note bent current bedding in the third specimen. × 0,5

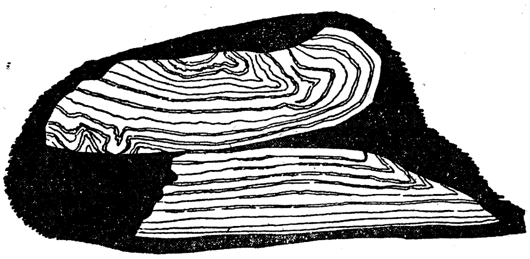

Fig. 21. Folded sandstone lump in shales, slump of Grojec, Cieszyn beds. × 0,5

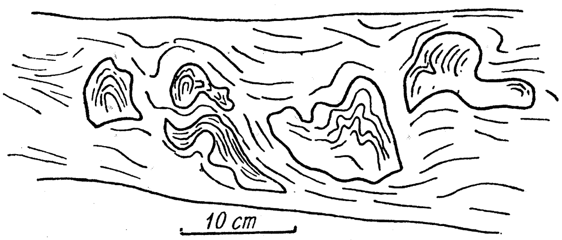

Fig. 22. Folded and disrupted bed by slumping. Magura sandstone, Skawica

disruption was probably preceded by folding. Very few examples are known to me, in which the whole bed is folded by slumping, but with no disruption.

In all these cases, if hieroglyphs are present at the bottom surface, they are clearly deformed, bent or twisted, but curiously, in spite of evident sliding and rolling their shapes are fairly well preserved (Plate XV), although in some instances they may be strongly flattened.

Single beds disrupted by slumping into small pieces are fairly numerous in the Carpathian Flysch, particularly in the Inoceramian beds, Krosno beds and Magura sandstone, they also occur, but less frequently, in the Godula and Lgota beds, and in the Upper Cieszyn shales.

While one-bed slumps in which the whole bed or the top part is slumped are fairly frequent, very rare is the case when the bottom part exhibits slump structures, whilst the top part is not disturbed. The origin of such beds is not quite clear. Two explanations are possible; either the bed slumped before the top part was deposited, i. e. that over the slumped bed a turbidity current passed and deposited its normal sediment in such a way that it smoothed the slump and covered it with its material which welded to the slumped material; or, that the just deposited bed before the end of deposition, began to slump and roll. The second explanation is less satisfactory, as it would mean that the freshly deposited material had already such a coherence that it could slide and roll without disintegration into sand.

III. INITIAL SLUMPING

Comparing various types of slumping one can trace stages through which a slumped bed goes through, until it becomes only a mass of loose lumps. Not all slumped beds arrived at this stage, having stopped at earlier stadia.

From all available evidence one can infer that rather disruption and not folding is the mechanism of slumping, therefore one can imagine that in the first stage of slumping stretching fractures should appear along which the bed parcels out in sheets or lumps. In fact, there are several instances when such initial stages of slumping may be observed in Flysch rocks.

Fig. 23. Initial slumping expressed in disruption. Magura sandstone, Skawica

One type of stretching is the occurrence of thin lense-like sheets of sandstone (Fig. 23) separated by distances of a few cm.; some of them show downbuckling and extenuation (Fig. 24); if bottom hieroglyphs are present, they are deformed, flattened or twisted. These features point out to sliding that has not gone too far, with some initial bending and deformation. The type of deformation represented in Fig. 23 may be determined after K u e n e n (1953, 1953 a), as „pull-apart" structure.

It should, however, be emphasized that structures like those in Fig 24 may be caused also in purely sedimentary way, if freshly deposited sand sinks into underlying yielding clay already during deposition by some sort of load casting, while the depositing current has sufficient

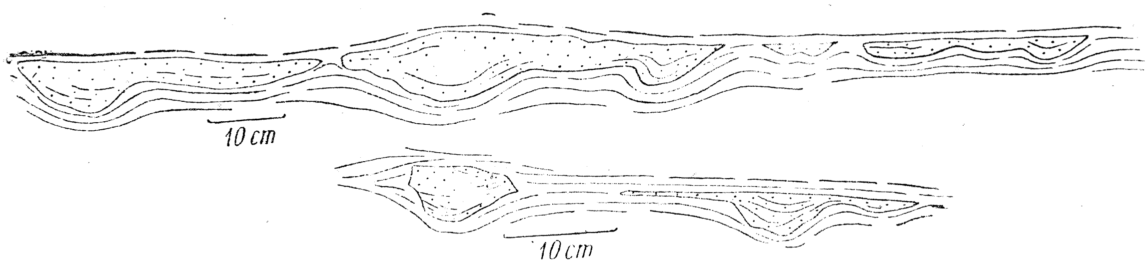

Fig. 24. Initial slumping, Lgota beds, Rzyki

velocity for transporting finer grades farther away. Truncations transverse to bedding in the lower part of Fig. 24 points clearly to disruption and lateral movement. Combined action of downsinking and sliding was described by P. Macar (1948). It may be noted here that in the Krosno beds there occur ellipsoidal bodies of laminated sandstones imbedded in clays and rolled up from all sides upward which seem to be produced only by downsinking of sand into clay without lateral movement.

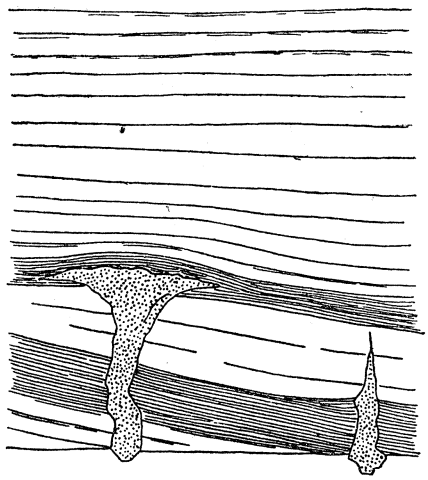

Fig. 25. Cracks in sandstone bed, filled by sand from below. Krosno beds, Kamesznica. Drawing refers to cross-section of the bed figured in Plate VII, 1

Another symptom of initial stretching is the presence of cracks filled from below, or possibly also from above, by sand. Cracks may fissure the sandstone bed to the very top, and in this case the infilling sand forms small dikes or veins sticking out as sand ridges above the upper surface of the fissured bed. Cracks may also be closed from above, and in these instances sand intrusions form miniature neck-like veins, dikes or even lakkolithic intrusions (Fig. 25). In this case only the lower surface of the bed is covered by narrow sand ridges, resembling „mudcracks". (Plate XVI). Evidently they are not mudcracks, as the infilling is from below, and also, as the polygonal pattern is only feebly marked. These sand ridges cut across organic and mechanical hieroglyphs and also for this reason must be regarded as post-depositional features. In Plate XIV, 2 ripplemarks of the upper surface are traversed by sand ridges, while in Plate XVI flute marks or lineation of the lower surface are cut across by bottom sand ridges. In these cases, and many others observed in the field, it may be seen that sand ridges run nearly at right angle to the current direction. This shows that stretching acted along the axis of flow, then presumably in the direction of the slope of the sea-floor.

Sand ridges of the described type are not very frequent, but occur nearly in all stratigraphic members of the Carpathian Flysch. They are particularly often in the Krosno- and Inoceramian beds, and the Magura sandstone, i. e. in beds in which slumping is frequent. These small-scale sand dikes and veins have evidently different origin than the similar forms described recently by Dżułyński and Radomski (1957).

CONCLUSIONS

In the Carpathian Flysch there are generally two types of submarine slumping: large-scale slumps embracing several beds, and small-scale slumps affecting only single beds. The first type is much less frequent, and may be even termed as an exceptional phenomenon in the Carpathian Flysch. The second type is, it is true, more numerous, but in comparison with undisturbed beds its occurrence is also exceptional. It may be roughly estimated, that in the Godula beds less than one sandy layer in hundred undisturbed layers is slumped, in the Krosno beds possibly this relation is 1 in 100, in the Magura sandstone and in the Inoceramian beds the relation is intermediate, whilst in other stratigraphic members the number of slumped beds is even much smaller than in the Godula beds.

Frequency of slumping depends, in the first line, on slope, and it is logical to infer that beds with increased number of slumped beds were deposited on a steeper slope. It seems, however, that also another factor must be borne in mind. In all instances slumped beds have strongly calcareous cement; if beds have other kind of cement, no slumping is visible. The conclusion should then be drawn that the calcareous cement enables slumped beds to preserve their coherence, and since they are more firmly cemented in the early stage of consolidation, they do not disintegrate into loose sand during slumping.

There is strong evidence that many of the Flysch units, as the Istebna beds or Ciężkowice sandstone have been deposited on steeper slopes than the Inoceramian, Krosno or Magura beds, but in spite of this, they exhibit very few, if any slump structures. It seems that sliding and slumping occurred often in these beds but sandy layers when slumping disintegrated into sand and clay, and the mixture of sand and clay could form secondary turbidity current under some circumstances, and be redeposited elsewhere, but no slump structures could be formed. In this respect the slump of Malinka should be recalled here. There in spite of obvious slump features the enclosing mass of coarse sand and gravel exhibits fairly distinct alignment, what points that it moved not as a chaotic mass of sand, but as a mixture of sand, clay and water.

It also seems that the more convolution is developed in a series the more numerous are instances of slumping. This would mean that convolution, whatever its origin, is depending on slope, but it also would mean that the formation of convolute bedding and related slip bedding is possible only in beds with calcareous cement (Książkiewicz 1950), which mixed with sand and some clay sets so quickly that allows the formation of more or less overturned steep folds and prevents disintegration.

A point of general significance is that if the direction of slump is detectable, it coincides approximately with the direction of currents. There are exceptions to this, but so far as the problem is known, they pertain only to the cases in which slumping is somehow connected with mudflows.

It is possible that careful and detailed mapping of slump occurrences in particular stratigraphic members will make possible to establish not only slumping index of beds, i. e. the proportion of slumped to undisturbed layers, but also its areal variability. Already to-day it seems that some areas are more infested with slumps than others in the same stratigraphic unit. It is possible that in this way we may obtain a better insight in the conditions and shape of Flysch troughs at various periods of their history.

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Kraków, December 1957

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EXPLANATION OF PLATES X—XVII

PLATE X

Slump at Malinka, Godula beds. Sandstone boulders in conglomerates

PLATE XI

1. Slump at Malinka, Godula beds. A boulder in conglomerates
2. Lineation of pebbles. Conglomerates at Malinka

PLATE XII

Slump at Poręba Wielka, Inoceramian beds

PLATE XIII

Slump at Poręba Wielka, Inoceramian beds

PLATE XIV

1. Slumped sandstone with siderite concretions and shale fragments. Besko, Krosno beds
2. Ripplemarks on the upper surface of a sandstone bed. Kamesznica, Krosno beds. Note sand ridges (s) perpendicular to the direction of current. Direction of current is to the west (left)

PLATE XV

1—2. Both surfaces of a slumped and rolled up sandstone lump, only 10 cm thick. Note contorted flute casts on either sides. Żabnica, Magura sandstone. This specimen was collected during a trip with Mr. S i k o r a and Ż y t k o. × 0,5

3—4. Both surfaces of a slump lump. Note distorted hieroglyphs and minute corrugation. The cross-section of this specimen is shown on Fig. 20, right. Sidzina, Magura sandstone. × 0,5

PLATE XVI

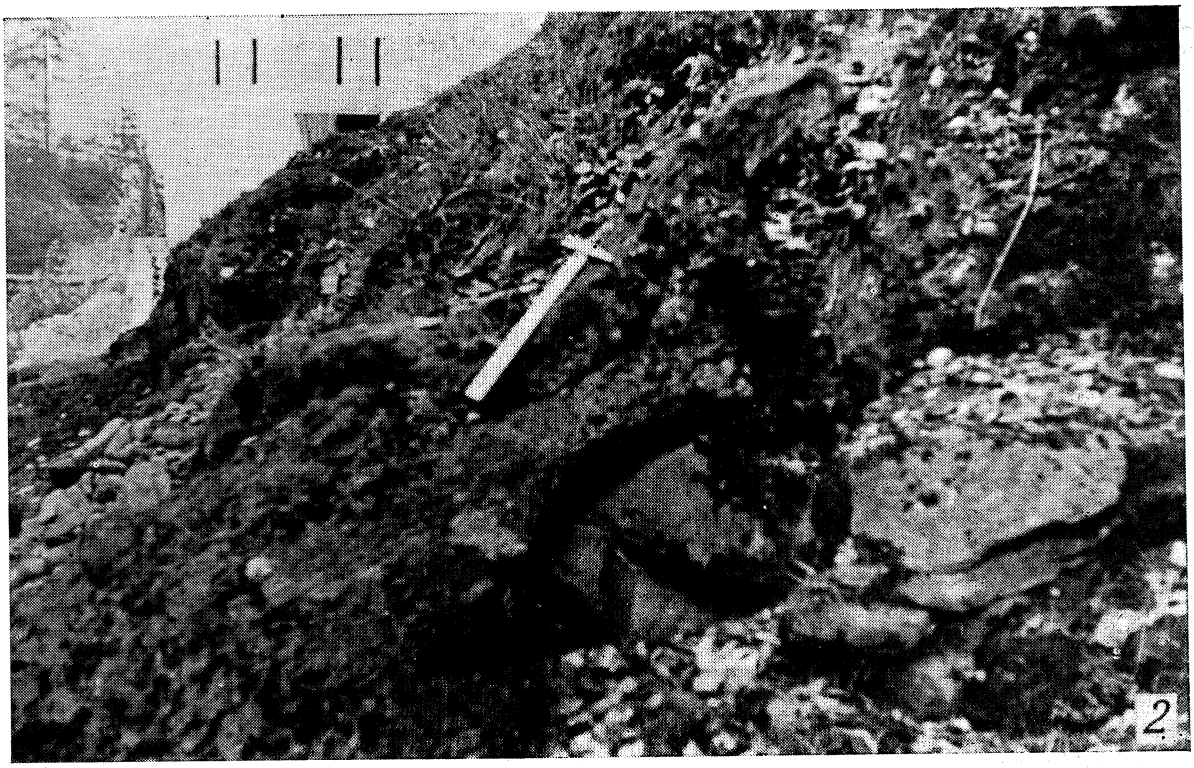
1. Sand ridges (pseudo-mudcracks) on the lower surface of a sandstone layer. Sand ridges (s) are approximately at right angles to flute marks. The cross-section of this layer is shown in Fig. 25. Kamesznica, Krosno beds
2. Sand ridges (s) on the lower surface cutting flow lineation at right angle. Florynka, Magura sandstone

PLATE XVII

1—4. Slumping and slump balls in the Magura sandstone. Tylmanowa.

5. Slump contortions in the upper portion of a sandstone bed. Magura sandstone. This case may be regarded as an intermediate form between slumping and slip bedding

6. Sandball produced by slumping in a sandy bed. Zawoja, Magura sandstone. Diameter of the ball ca. 40 cm.



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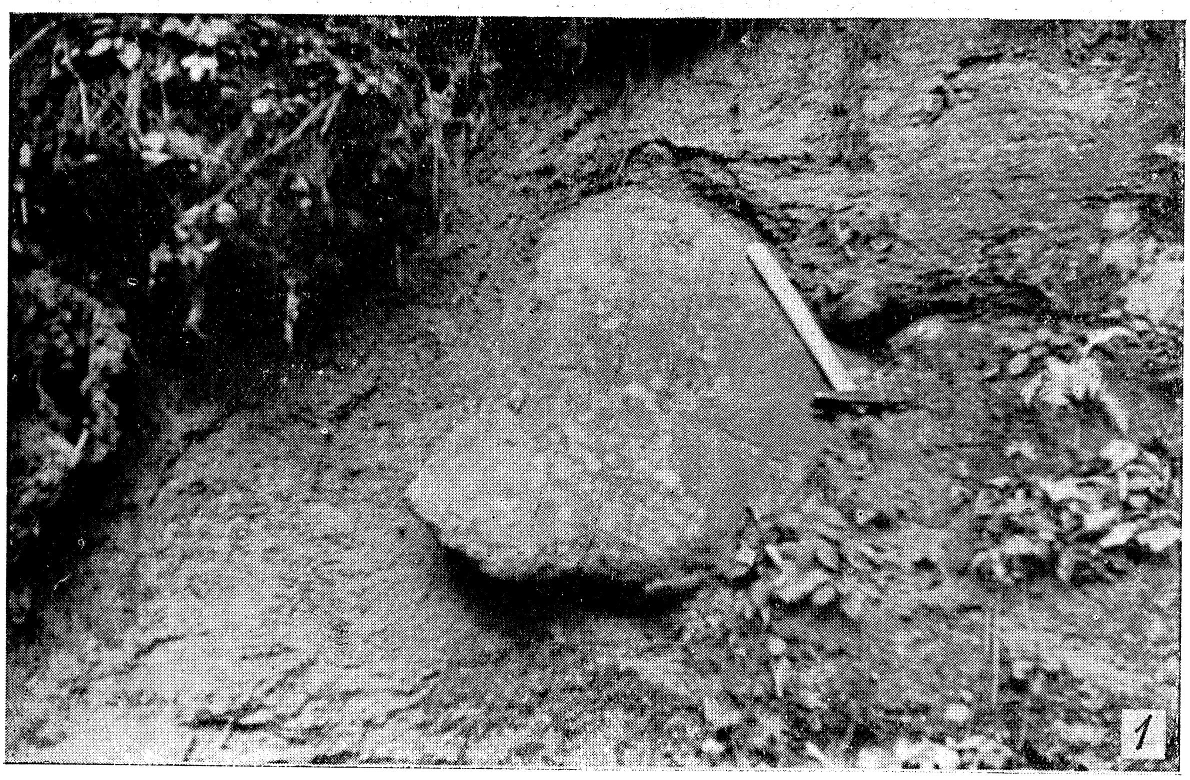

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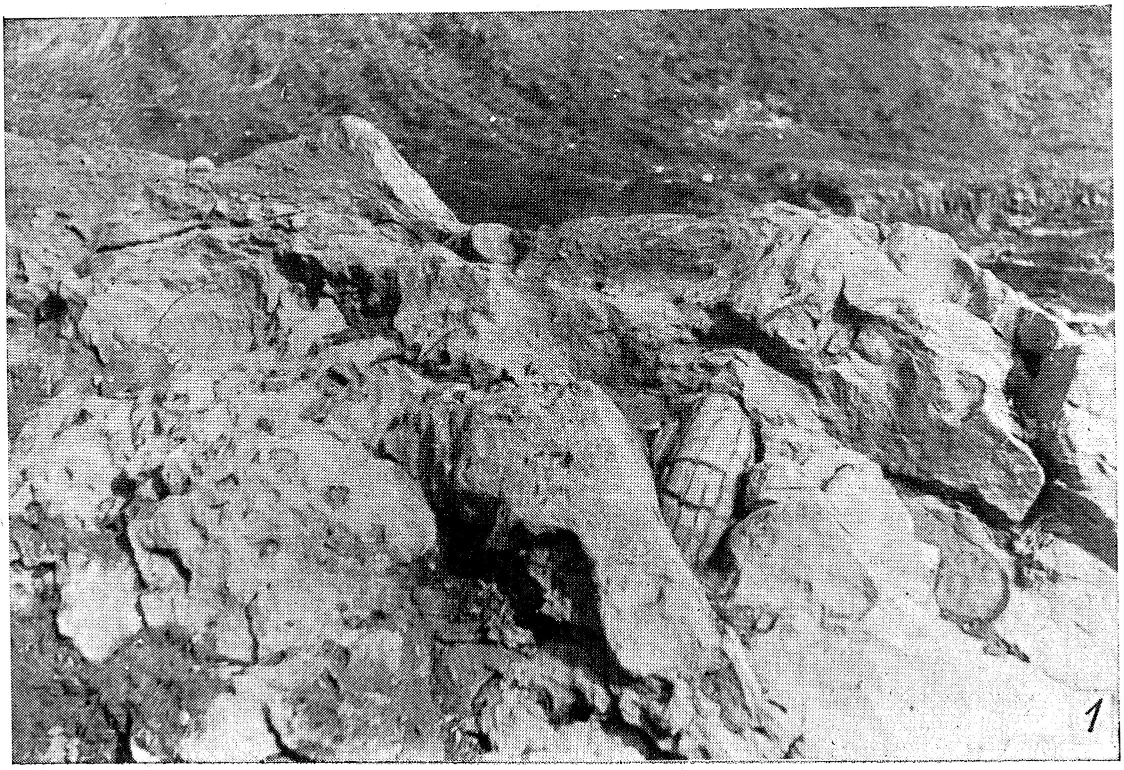

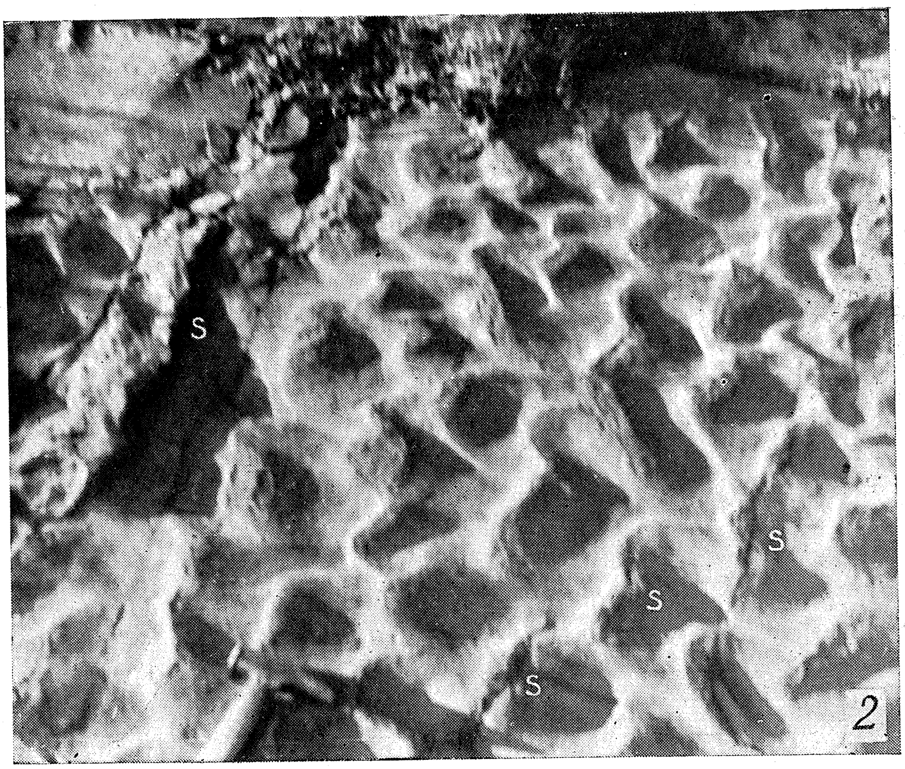

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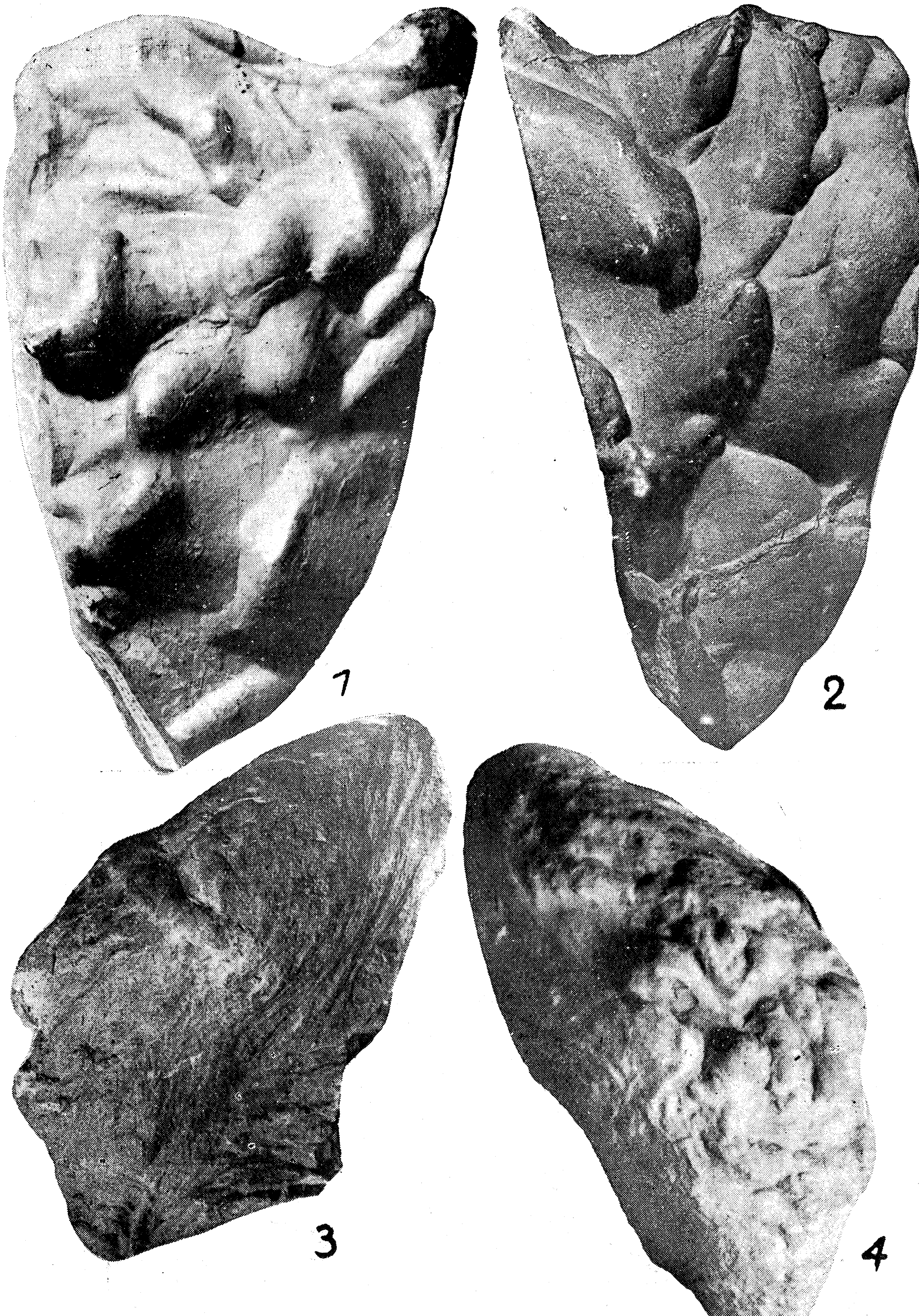
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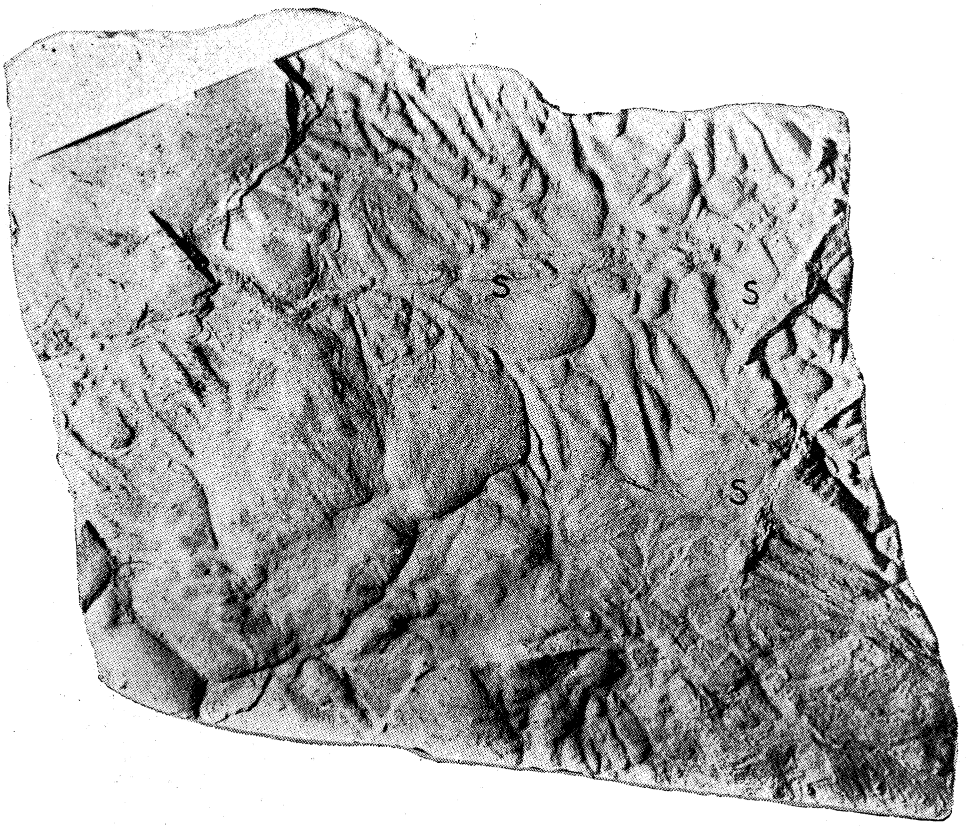

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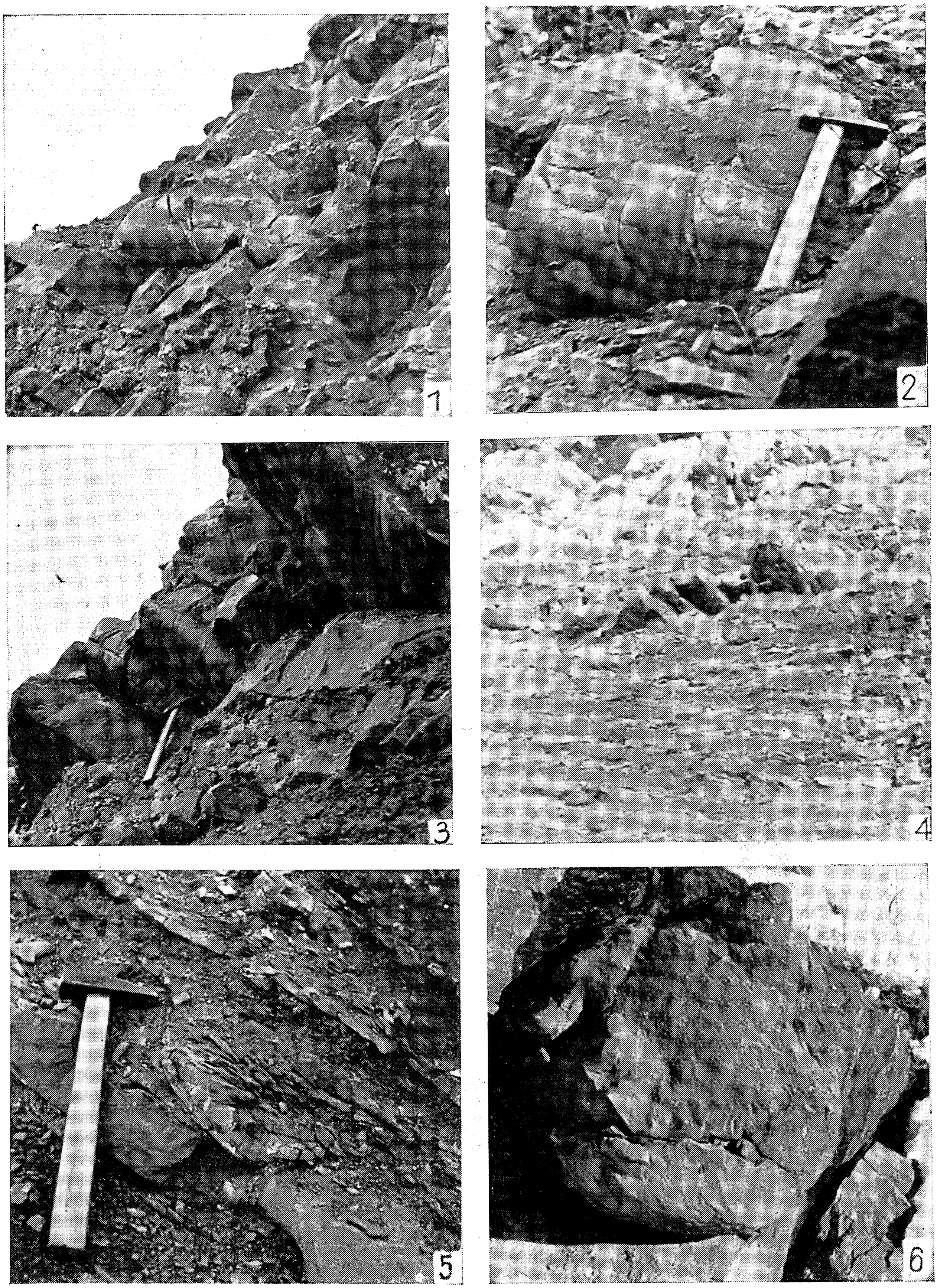

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