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WARSTWY ISTEBNIAŃSKIE — STUDIUM SEDYMENTOLOGICZNE

(Tabl. V—VIII i 18 fig.)

Istebna Beds-a Fluxoturbidity Formation in the Carpathian Flysch

(*Plate* V—VIII *and* 18 *figs.*)

STRESZCZENIE

Warstwy istebniańskie (kampan — paleocen serii śląskiej fliszu karpackiego) rozwinięte są w postaci gruboziarnistych polimiktycznych zlepieńców egzotykowych, drobnoziarnistych zlepieńców kwarcowych i gruboziarnistych piaskowców skaleniowo-kwarcowych, żwirowców ilastych, czarnych mułowców oraz czarnych, szarych, zielonych i czerwonych łupków ilastych. Wśród skał gruboziarnistych dominują zlepieńce kwarcowe i piaskowce skaleniowo-kwarcowe, wśród skał drobnoziarnistych przeważają czarne mułowce.

Zlepieńce i piaskowce warstw istebniańskich odznaczają się znaczną miąższością ławic i gruboziarnistością materiału klastycznego, obecnością soczewkowatych kompleksów ławic zlepieńcowych oraz bardzo dużym nasileniem erozji podmorskiej. Dominującym typem warstwowania jest warstwowanie frakcjonalne przerywane. Często występuje warstwowanie frakcjonalne wielokrotne, a w ławicach zlepieńcowych warstwowanie bezładne i warstwowanie frakcjonalne pensymetryczne odwrócone. Charakterystyczną cechą zlepieńców i piaskowców jest niska zawartość materiału pelitycznego oraz brak hieroglifów na spągowych powierzchniach większości ławic.

Mułowce towarzyszące ławicom zlepieńców i piaskowców są silnie piaszczyste, laminowane, zawierające często wkładki piaskowcowe oraz obfity zwęglony detritus roślinny (fig. 4—9, i tabele 1—3).

Wymienione cechy strukturalne wskazują, że zlepieńce i piaskowce warstw istebniańskich osadzane były nie przez prądy zawiesinowe, w których materiał klastyczny unoszony jest w suspensji, lecz przez spływy piaskowe, w których materiał przemieszczany jest w postaci podmorskich lawin osuwiskowych. Niektóre spływy piaskowe przekształcały się w prądy zawiesinowe, o czym świadczy występowanie opancerzonych żwirem toczeńców iłowych tworzących regularne poziomy w pobliżu stropu frakcjonalnie warstwowanych ławic piaskowcowych (tabl. VI fig. 2). Opancerzone żwirem toczeńce tworzą się w osuwiskowej fazie ruchu materiału, a ich ułożenie w regularnym poziomie w ławicy jest wynikiem segregacji materiału w prądzie zawiesinowym.

Ławice żwirowców ilastych są zwykle frakcjonalnie warstwowane, przy czym frakcjonalny rozkład dotyczy tylko najgrubszych otoczaków. W stropie ławic żwirowców zalegają zwykle czarne mułowce. Niektóre ławice żwirowców wykazują obecność lineacji otoczaków, w innych występują struktury osuwiskowe, niekiedy z przejściami do warstwowania spływowego. Żwirowce ilaste osadzane były przez podmorskie spływy mułowe i zawierają bądź strukturalne relikty osuwisk, z których te spływy mułowe się rozwijały, bądź penesyndepozycyjne lub postdepozycyjne struktury spływowe (fig. 10 i 11).

Mułowce towarzyszące zlepieńcom, piaskowcom i żwirowcom ilastym oraz tworzące większe kompleksy w górnych warstwach istebniańskich (dolne i górne łupki istebniańskie) są osadami rozcieńczonych prądów zawiesinowych towarzyszących spływom piaskowym i mułowym lub też występujących samoistnie. Czarne łupki ilaste współwystępujące z mułowcami są osadem najdrobniejszych frakcji unoszonych w prądach zawiesinowych, natomiast łupki szare, zielone i czerwone są osadami pelagicznymi tworzącymi się lokalnie w basenie sedymentacyjnym, w obszarach okresowo nie pokrywanych osadami spływów piaskowych bądź mułowych i prądów zawiesinowych (fig. 12 i tabl. VIII fig. 1).

Skład petrograficzny badany we frakcji 2—4 mm jest różny w zlepieńcach kwarcowych i piaskowcach skaleniowo-kwarcowych, żwirowcach ilastych i zlepieńcach polimiktycznych (tabela 4 i fig. 16). Materiał klastyczny zlepieńców kwarcowych i piaskowców skaleniowo-kwarcowych pochodził z centralnej części kordyliery śląskiej zbudowanej głównie z porfirowatych granitów, natomiast materiał klastyczny żwirowców ilastych i zlepieńców polimiktycznych pochodzi głównie z pokrywy metamorficznej i osadowej budującej brzeżne strefy kordyliery. Materiał klastyczny zlepieńców i piaskowców akumulowany był szybko na nasypie litoralnym kordyliery i przemieszczany przez spływy piaskowe do głębokiego basenu sedymentacyjnego, po krótkim pobycie w strefie litoralnej względnie sublitoralnej. Natomiast materiał klastyczny żwirowców ilastych akumulowany był wolniej i pozostawał dłużej w strefie litoralnej względnie sublitoralnej, wskutek czego osiągnął wyższy stopień obtoczenia niż materiał klastyczny piaskowców i zlepieńców (tabela 5). Wzdłuż wybrzeży kordyliery rozwijały się wydmy, a materiał piaszczysty dobrze obtoczony w środowisku eolicznym mieszał się w różnych proporcjach z materiałem akumulowanym na nasypie litoralnym.

Rozkład kierunków transportu w zlepieńcach i piaskowcach oraz w żwirowcach ilastych, rozmieszczenie ławic żwirowców ilastych i rozkład facji prowadzą do wniosku, że gruboklastyczne utwory warstw istebniańskich stanowią szereg zlewających się podmorskich stożków napływowych, usypanych przez spływy piaskowe i prądy zawiesinowe u wylotów podmorskich rynien lub kanionów rozcinających zbocza kordyliery. W dolnych warstwach istebniańskich poszczególne stożki są słabo zindywidualizowane, natomiast w górnych warstwach istebniańskich zaznaczają się wyraźnie dwa wielkie stożki piaskowcowe, w których warstwy istebniańskie wkraczają w obręb basenu sedymentacyjnego serii podśląskiej, przedzielone strefą, w której górne piaskowce istebniańskie są słabo rozwinięte. (fig. 17 i 18).

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Abstract The Istebna beds (Campanian — Paleocene in the Silesian series of the Carpathian Flysch) are composed of alternating conglomerates, coarse-grained sandstones, pebbly mudstones and siltstones. Analysis of sedimentary structures, grain-size distribution, grain morphology and petrographic composition indicate that the conglomerates and sandstones were deposited mainly by sand flows, some of which developed into turbidity currents. The siltstones were deposited by diluted turbidity currents; true pelagic shales are rare. The pebbly mudstones were deposited by submarine mudflows. The Istebna beds were deposited in a trough adjacent to the Silesian cordillera which was the source of the clastic material. The various lithologic types of rocks forming the Istebna sequence are composed of material derived from different regions of the source area, were deposited by different transporting agents, and partly had different sedimentary history prior to redeposition.

INTRODUCTION

Some lithostratigraphic units of the Carpathian Flysch display the presence of sedimentary structures not met with in typical turbidity-current deposited flysch formations. In such units the grain is abnormally coarse, the thickness of beds great, and bedding often much less regular than in typical turbidites. Marks of erosion are plentiful. The sandstones are clean and not muddy as in typical turbidites. Pebbly mudstones deposited by submarine mudflows are an important constituent of such series.

The Istebna beds (Campanian — Paleocene in the Silesian series) are perhaps the best example of a formation differing in sedimentary character from a typical turbidite flysch. The idea of transportation of the clastic material by subaqueous sand flows, and the notion of fluxoturbidites introduced by S. Dżułyński, M. Książkiewicz and Ph. H. Kuenen (1959) on account of the aforementionned sedimentary structures has been based largely upon evidence supplied by the Istebna beds.

A detailed sedimentological study of the Istebna beds was carried out by the author in the years 1958—1961. Attention was given chiefly to sedimentary structures, transport directions of the detrital material, quartz morphology, and facial development. Some petrographic analyses were also made. The integration of these data provided insight into some details of the sedimentary environment.

During the last fourty years the Istebna beds were mapped and described by many authors (J. Burtan 1933, 1936; J. Burtan, K. Konior, M. Książkiewicz 1937; S. Depowski 1956; H. Goblot 1928; K. Guzik, W. Pożaryski 1949; H. Jurkiewicz 1960; P. Karnkowski 1959; K. Konior 1938, 1946; L. Koszarski 1953[1]; 1956; M. Książkiewicz 1951 a; J. Nowak 1925, 1927; W. Nowak 1957; J. Oberc 1950; A. Radomski 1950[1]; K. Skoczylas-Ciszewska 1952; A. Ślączka 1959; S. Sokołowski 1935; H. Świdziński 1950; W. Szajnocha 1925; H. Teisseyre 1947; S. Wdowiarz 1953). A wealth of data is provided by the Geological Atlas of Poland (Stratigraphic and Fa-

[1] Unpubished M. Sc. thesis. Department of Geology, Jagellonian University Cracow.

cial Problems, No. 13 — Carpathians, edited by M. Książkiewicz, in print). The preparation of the present paper would be impossible without these earlier investigations.

STRATIGRAPHY OF THE ISTEBNA BEDS

The Istebna beds have been recognised as a separate formation and defined by L. Hohenegger (1861) in the early period of stratigraphic investigations of the Carpathian Flysch. The type locality is the village Istebna lying in the Beskid Śląski range in the Western Carpathians. The determination of the limits of the Istebna beds as a lithostratigraphic unit and the division of this formation into the Lower and Upper Istebna beds is due to V. Uhlig (in A. Liebus 1902). The name „Czarnorzeki beds" introduced by R. Zuber (1915) was used for a long time to denote the equivalents of the Upper Istebna beds and of the uppermost part the Lower Istebna beds in the Central Carpathians, and the name „Sucha Góra sandstones" proposed by H. Goblot (1928) covered partly the Lower Istebna beds in this region. These local names are no longer used, as continuing research made possible more exact correlation and the standard terminology of the Beskid Śląski profile has been extended on the whole area of occurrence of the Istebna beds.

A more detailed division of the Istebna beds in the standard profile of Beskid Śląski has been proposed by J. Burtan (1936) who distinguished there four members, namely the Lower Istebna sandstones, Lower Istebna shales, Upper Istebna sandstones and Upper Istebna shales. The Lower Istebna sandstones correspond to the Lower Istebna beds in V. Uhlig's division, while the three latter members are equivalent of his Upper Istebna beds. This fourfold division cannot be adopted in the whole area of occurrence of the Istebna beds, as the Lower Istebna shales and Upper Istebna sandstones are wedging out in some regions.

The age of the Istebna beds has been determined as Campanian — Paleocene on the basis of rare macrofossils (A. Liebus 1902, T. Wiśniowski 1902, J. Nowak 1917, S. Sokołowski 1935, M. Książkiewicz 1951 c) and mikropaleontological studies carried out during the last twenty years (F. Bieda 1946, M. Książkiewicz 1951 b, S. Geroch 1960, H. Jurkiewicz 1960, 1961).

PALEOGEOGRAPHIC AND TECTONIC SETTING OF THE ISTEBNA BEDS

This paragraph contains a brief treatment of the subject for the benefit of the reader not familiar with the complex geology of the Northern Carpathians. For a complete picture of stratigraphy, tectonics, paleogeography, and sedimentation of the Carpathian Flysch the reader is referred to papers by M. Książkiewicz (1956 b, 1960 a, 1960 b).

The Late Cretaceous and Early Paleogene times were marked by the strongest facial differentiation of the Northern Carpathians geosyncline. The uniform basin existing in the Early and Middle Cretaceous was divided since the Cenomanian into two throughs.

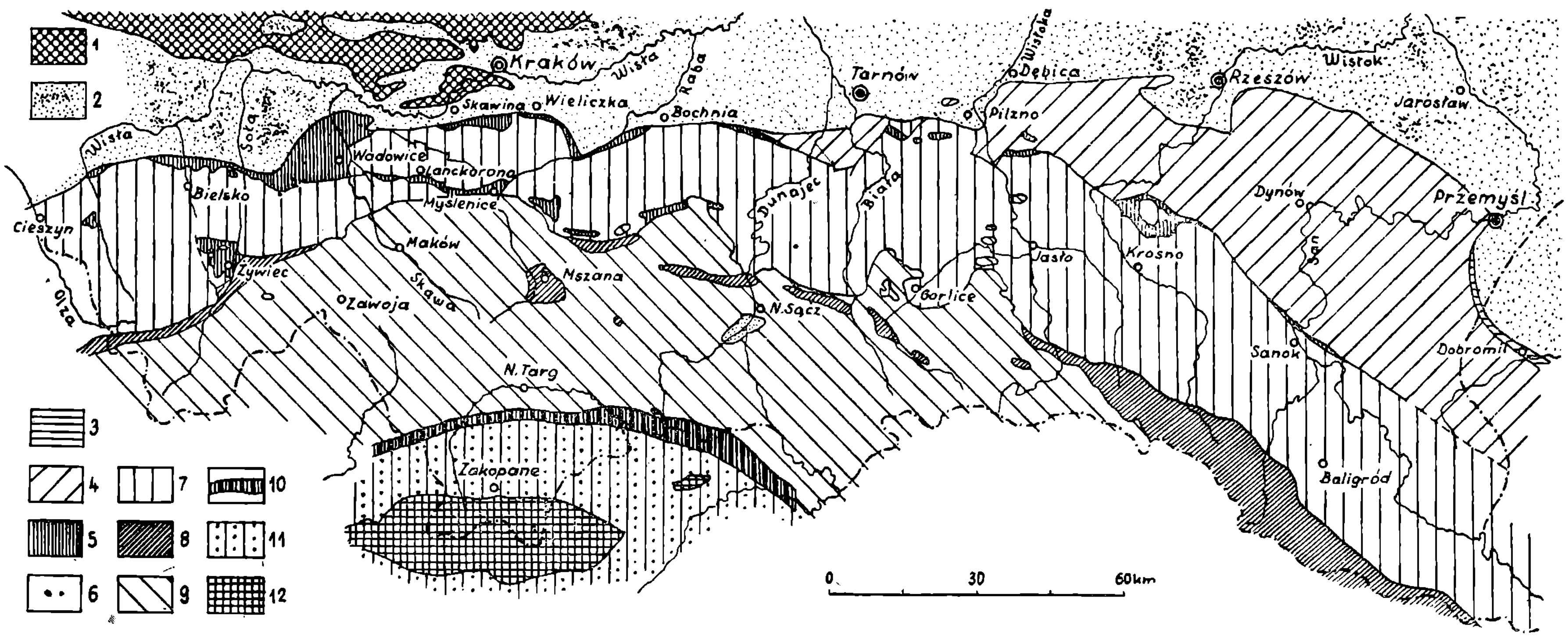

Fig. 1. Schematyczna mapa tektoniczna Karpat polskich (wg M. K s i ą ż k i e w i c z a, 1960 a): 1 — przedmurze, 2 — miocen, 3 — jednostka brzeżna, 4 — płaszczowina skolska, 5 — płaszczowina podśląska, 6 — skałki zewnętrzne, 7 — płaszczowina śląska, 8 — jednostka przedmagurska i fałdy dukielskie, 9 — płaszczowina magurska, 10 — pieniński pas skałkowy, 11 — flisz podhalański, 12 — jednostki tatrzańskie

Fig. 1. Schematic tectonic map of the Polish Carpathians (after M. K s i ą ż k i e w i c z, 1960 a). 1 — foreland, 2 — Miocene, 3 — marginal nappe, 4 — Skole nappe, 5 — Sub-Silesian nappe, 6 — external klippes, 7 — Silesian nappe, 8 — Fore-Magura scale and Dukla folds, 9 — Magura nappe, 10 — Pieniny Klippen belt, 11 — Podhale flysch, 12 — Tatra Mts tectonic units

The northern one, called Main through (M. Książkiewicz 1958 b) was bordered on the south by the Silesian cordillera — an intrageosynclinal tectonic island. The Main through itself was differentiated into smaller units forming separate facial regions. The detrital material yielded by the Silesian cordillera was intercepted in a rather deep trench in which a more than 4 000 metres thick sequence of sandstones, mostly coarse-grained, was deposited since the Cenomanian till the Early Eocene (i.e. the Godula sandstones, the Istebna beds and the Ciężkowice sandstones). On the north this trench was bordered by a shallower zone in which variegated shales and marls were deposited throughout the Late Cretaceous and till the Middle Eocene. Farther to the north existed another trench, in which the sandy Inoceramian beds, coeval with the Godula sandstones and Istebna beds were deposited.

Thus, three facial zones are distinguished in the Main through on account of the development of the Upper Cretaceous sequence. The southern Silesian zone is characterised by the presence of coarse-grained sandstones including the Istebna beds: north of it lies the Sub-Silesian shaly and marly zone. The north-eastern trench with the sandy Inoceramian beds forms the Skole zone.

The development of the large tectonic units of the Northern Carpathians is controlled largely by the facial development of the Upper Cretaceous sequence, and the three facial zones are corresponding almost exactly with three large nappes, i. e. the Skole, Sub-Silesian, and Silesian nappe, thrust over northward one upon another (fig. 1).

LITHOLOGY AND FACIAL DEVELOPMENT OF THE ISTEBNA BEDS

The Lower Istebna beds consist mainly of coarse-grained and thick-bedded, polymictic, exotic-bearing conglomerates, fine-grained quartz conglomerates and corse-grained feldspathic sandstones. All these types of rocks are non-calcareous and have a bluish-grey colour, which turns to rusty-brown on weathered surfaces. The beds of sandstones and conglomerates are often resting directly one upon another, but sometimes they are separated by thin layers of black sandy siltstones containing a large amount of carbonised plant detritus, or less frequently, by dark-grey or green shales.

The conglomerates and coarse-grained sandstones are alternating with thick-bedded and coarse-grained pebbly mudstones. The distribution of the latter is not uniform; they may form up to about 40 per cent of all the beds in some profiles, while in other ones they are rare.

Intercalations of thin-bedded and fine-grained calcareous sandstones alternating with grey marly shales and marls are present generally in the upper part of the Lower Istebna beds over large areas extending from the environs of Baligród in the east to the Pogórze Wiśnickie in the central part of the area studied. Farther west a shaly horizon is present in the upper part of the Lower Istebna beds in the Beskid Mały range, (M. Książkiewicz, 1951 a), and an intercalation of non-calcareous thin-bedded sandstones and grey shales occurs in a similar stratigraphic position in the Beskid Śląski range. The intercalations of calcareous sand-

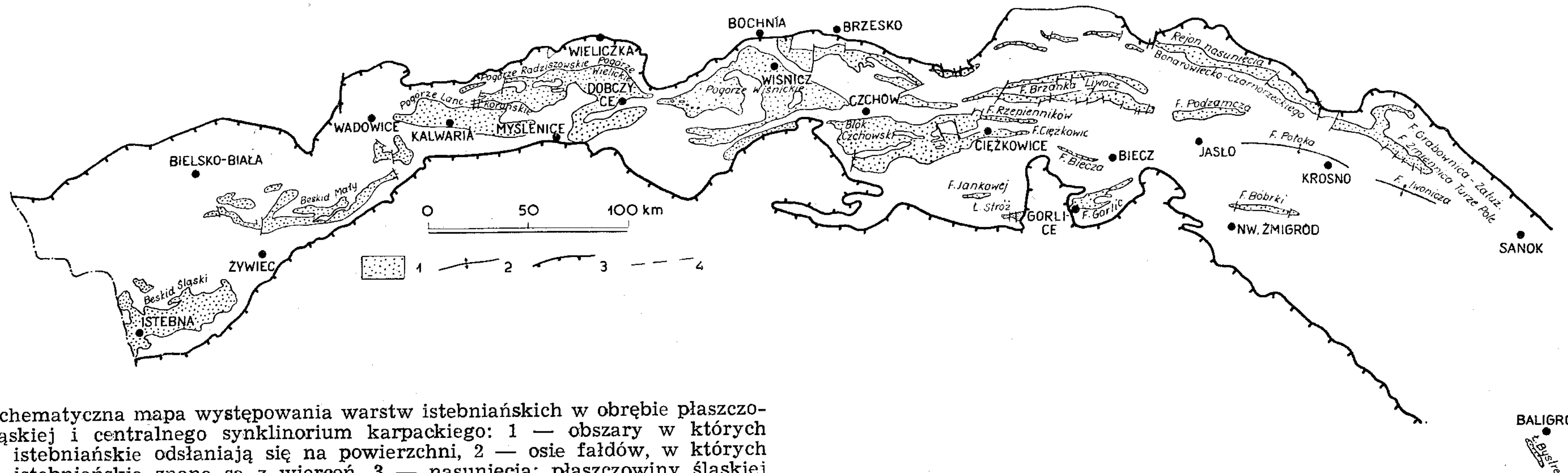

Fig. 2. Schematyczna mapa występowania warstw istebniańskich w obrębie płaszczowiny śląskiej i centralnego synklinorium karpackiego: 1 — obszary w których warstwy istebniańskie odsłaniają się na powierzchni, 2 — osie fałdów, w których warstwy istebniańskie znane są z wierceń, 3 — nasunięcia: płaszczowiny śląskiej (na północy), płaszczowiny magurskiej i jednostek przedmagurskich (na południu), 4 — granica polsko-czechosłowacka

Fig. 2. Schematic map of occurrence of the Istebna beds in the Silesian nappe and in the Central Carpathian Synclinorium: 1 — outcrops of the Istebna beds, 2 — axes of folds in which the Istebna beds were reached by bore-holes, 3 — overthrusts — of the Silesian nappe (on the north) and of the Magura nappe, Fore-Magura scale and Dukla folds (on the south) 4 — Polish-Czechoslovakian boundary. In the names of the tectonic elements: F. — fold, Ł — scale

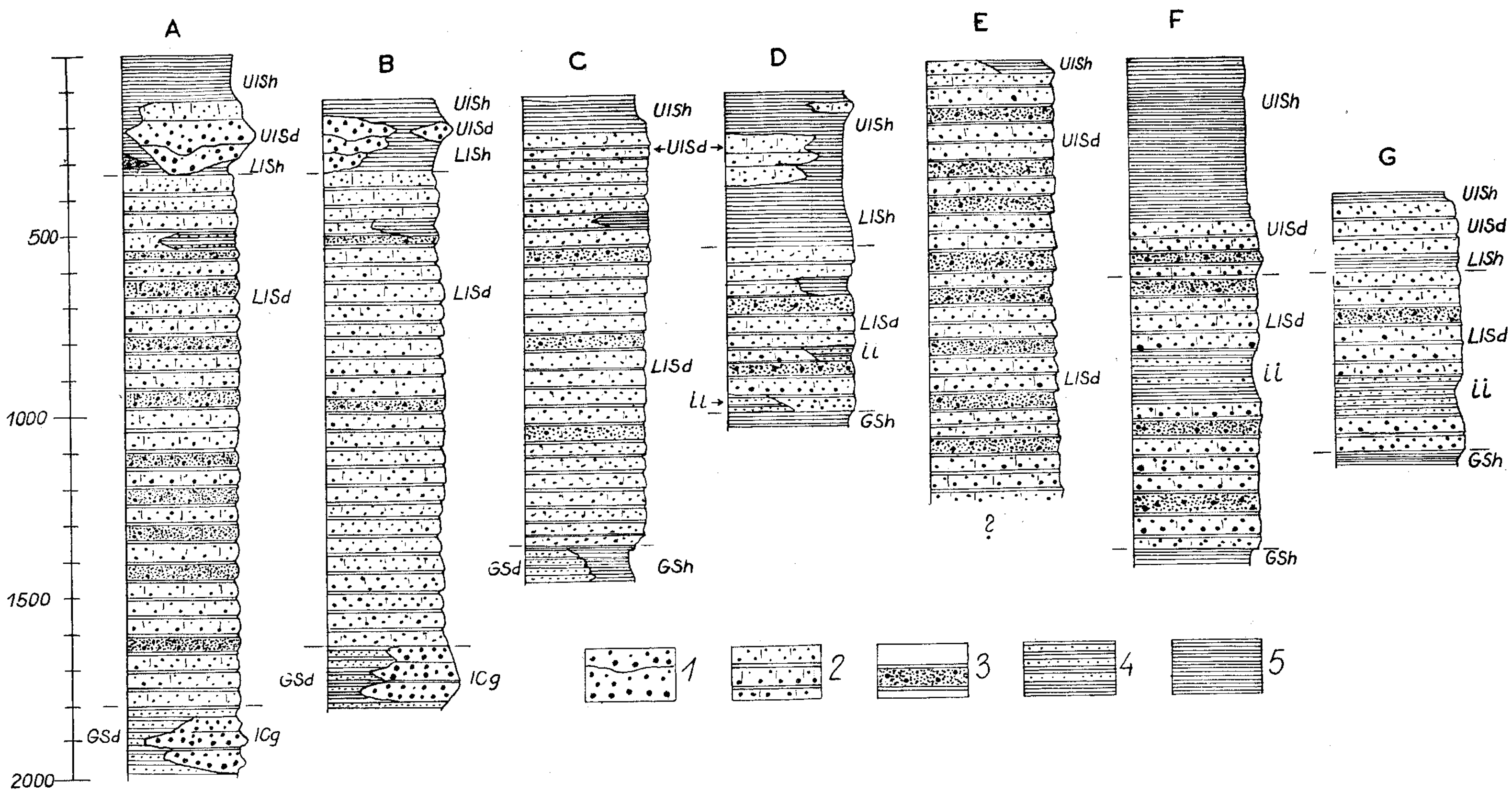

Fig. 3. Wybrane profile litostratygraficzne warstw istebniańskich: A — Beskid Śląski, B — Beskid Mały, C — Podgórze Lanckorońskie, D — północna część Pogórza Wiśnickiego, E — fałd Gorlic, F — rejon Czarnorzek, G — Łuska Bystrego. 1 — zlepieńce gruboziarniste, 2 — zlepieńce drobnoziarniste i piaskowce, 3 — żwirowce ilaste, 4 — piaskowce cienkoławicowe i mułowce, 5 — mułowce i łupki. GSd — górne piaskowce godulskie, GSh — pstre łupki godulskie, ICg — zlepieńce typu istebniańskiego w obrębie górnych piaskowców godulskich, LISd — dolne piaskowce istebniańskie, LISh — dolne łupki istebniańskie, UISd — górne piaskowce istebniańskie, UISh — górne łupki istebniańskie, ii — wkładki typu inoceramowego skala miąższości w metrach

Fig. 3. Selected lithostratigraphic profiles of the Istebna beds: A — Beskid Sląski, B — Beskid Mały, C — Pogórze Lanckorońskie, D — Northern part of Pogórze Wiśnickie, E — Gorlice fold, F — Czarnorzeki region, G — Bystre scale (Ł. Bystrego on Fig. 2). 1 — coarse-grained conglomerates, 2 — fine-grained conglomerates and sandstones, 3 — pebbly mudstones, 4 —thin-bedded sandstones and siltstones, 5 — siltstones and shales. GSd — Upper Godula sandstones, GSh — Godula variegated shales, ICg — Istebna-type conglomerates in the Upper Godula sandstones, LISd — Lower Istebna sandstones, LISh — Lower Istebna shales, UISd — Upper Istebna Sandstones, UISh — Upper Istebna shales ii — intercalations of Inoceramian type. Thickness scale in metres

stones bear a striking resemblance to the coeval Inoceramian beds, and were described as „intercalations of the Inoceramian type" (R. Zuber, 1909; J. Nowak, 1927). H. Goblot (1928) considered them as a key horizon separating the Sucha Góra sandstones and the Czarnorzeki beds. Further research proved however, that the intercalations of Inoceramian type occur in various stratigraphic positions. The thickness of the intercalations of Inoceramian type ranges from a dozen metres up to about 150 metres (K. Skoczylas-Ciszewska and M. Kamieński, 1959; H. Teisseyre, 1947).

The Lower Istebna beds are lying on the Godula sandstones (Cenomanian — Lower Senonian) and on the coeval variegated shales. In the ranges of Beskid Śląski and Beskid Mały lenticular bodies of polymictic conglomerates of Istebna type are forming intercalations within the uppermost part of the Godula sandstones (J. Burtan, K. Konior, M. Książkiewicz, 1937; M. Książkiewicz, 1951 a, W. Nowak, 1957). Near the northern margin of the Silesian nappe intercalation of red shales are present in the lowermost part of the Istebna beds (Fig. 3).

The Lower Istebna shales consist of black siltstones with rare beds of siderites and thin-bedded sideritic sandstones. Rare lenticular beds of pebbly mudstones containing huge exotic blocks and thin local intercalations of red shales are also present in this member.

The Upper Istebna sandstones consist of thick-bedded and coarse-grained polymictic exotic-bearing conglomerates, thick-bedded and coarse-grained pebbly feldspathic sandstones, grey coloured, and turning to greenish-brown on weathered surfaces, and of black pebbly mudstones. The sandstones and conglomerates are often slightly calcareous. The distribution of the calcareous cement is not uniform, and the presence of large hard spherical concretions of calcareous sandstones with diameters ranging up to about 2,0 m is revealed during weathering.

The Upper Istebna shales consist of black siltstones and shales with numerous siderite beds and spherosiderite horizons. Thin-bedded, fine-grained sandstones decreasing in number towards the top of this member are also present. Local intercalations of red and green shales are present at the base and at the top of the Upper Istebna shales.

A few very thin intercalations of white illite shales are present in the Istebna beds (M. Kamieński and K. Skoczylas-Ciszewska, 1956). These authors suggested a tuffogenic origin of the clays in question. Late Cretaceous volcanic activity in the Carpathian geosyncline is discussed by M. Książkiewicz and T. Wieser (1954).

The development of the Upper Istebna beds provides a useful criterion for the determination of facial zones in the sedimentary basin during the Paleocene. Two principal facial zones parallel to the borders of the arcuate sedimentary basin may be distinguished: in the southern zone the Lower Istebna beds form a well developed but not continuous horizon. Thick lenticular bodies of Upper Istebna sandstones are locally contacting with the Lower Istebna sandstones, replacing the Lower Istebna shales. The Upper Istebna shales are forming a thick continuous horizon (with the exception of the Gorlice fold). In the areas where the lenses of the Upper Istebna sandstones are wedging out the Lower and Upper Istebna shales are joining into one shaly complex. This zone comprises the Beskid Śląski and Beskid Mały ranges, the Gorlice fold, the Czchów region, the Ciężkowice fold, the Rzepienniki fold, and the Bystre scale. Folds of the central synclinorium with the Istebna beds in their cores are probably also belonging to this zone, but the exposed profiles are not covering the whole Upper Istebna beds.

In the northern zone the Lower Istebna shales are absent. The Upper Istebna sandstones are lying directly upon the Lower Istebna beds, and are covered in turn by the Upper Istebna shales. It is often difficult to place the boundary between the Lower and Upper Istebna beds in this zone.

In the northern zone the facies changes also in the east-west direction. The Upper Istebna sandstones are strongly developed both in the western and eastern parts of the northern facial zone, while in the central sector siltstones and shales are predominating in the Upper Istebna beds, and the Upper Istebna sandstones are poorly developed. An interpretation of the facial development of the Istebna beds will be presented later in this paper.

SEDIMENTARY STRUCTURES

Introductory remarks

The lithologic types of rocks described in the preceding paragraph are characterised by the presence of different sedimentary structures. Therefore, the following discussion of sedimentary structures will refer to the various lithologic types of rocks.

The grain size terminology used in this paper is that of C. K. Wenthworth (1922). The logarithmic phi scale of W. C. Krumbein (1938) in also used. Terminology for types of bedding is that of M. Książkiewicz (1954), unless reference is made in the text to another one.

Polymictic conglomerates

Polymictic conglomerates occur chiefly in the lowermost part of the Lower Istebna beds and in the Upper Istebna sandstones.

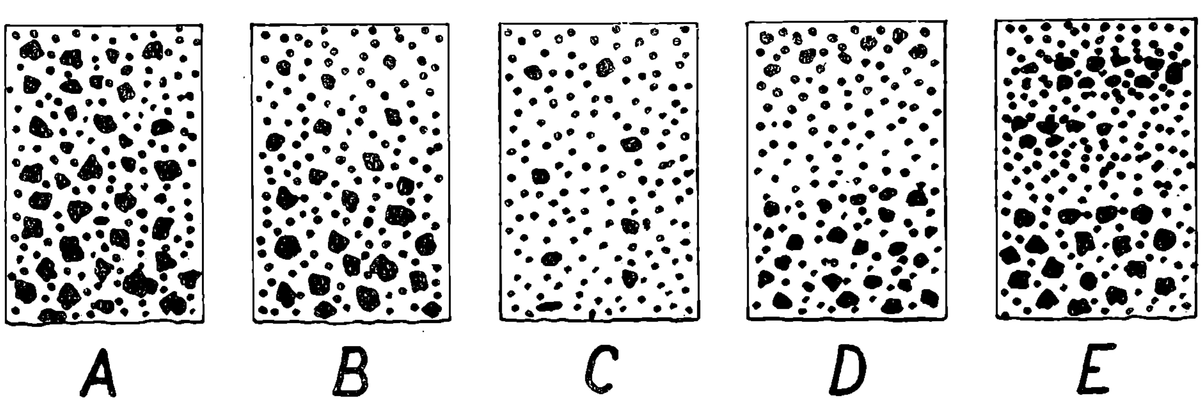

Fig. 4. Typy warstwowania zlepieńców polimiktycznych: A — warstwowanie bezładne, B — niewyraźne warstwowanie frakcjonalne, C — warstwowanie bezładne z rzadko rozrzuconymi otoczakami, D — warstwowanie frakcjonalne odwrócone pensymetryczne, F — warstwowanie frakcjonalne odwrócone pensymetryczne z soczewkami gruboziarnistego materiału przy stropie ławicy

Fig. 4. Types of bedding of polymictic conglomerates: A — Structureless bed, B — indistinct graded bedding, C — structureless bed with widely spaced pebbles, D — inverted pensymmetric graded bedding, E — inverted pensymmetric graded bedding with lenses of coarse grain near the top of the bed

The thickness of beds of these conglomerates ranges from a few to a dozen metres. The grain is coarse, and cobble- or boulder-sized blocks are present frequently (Plate V, Fig. 1). The coarse and poorly rounded pebbles and cobbles are irregularly dispersed in a sandy matrix. The beds are structureless, or the coarse clasts are forming irregular concentrations. Graded bedding is very rare and indistinct. Rare beds with inverted pen-symmetric graded bedding were described by M. K s i ą ż - k i e w i c z (1954). In this type of bedding the coarse grains present in the top part of the bed form usually lenses (Fig. 4, Plate V Fig. 2). Sorting of the conglomerates is poor, and mica occurs abundantly throughout the beds, but the content of pelite is very low (Fig. 5).

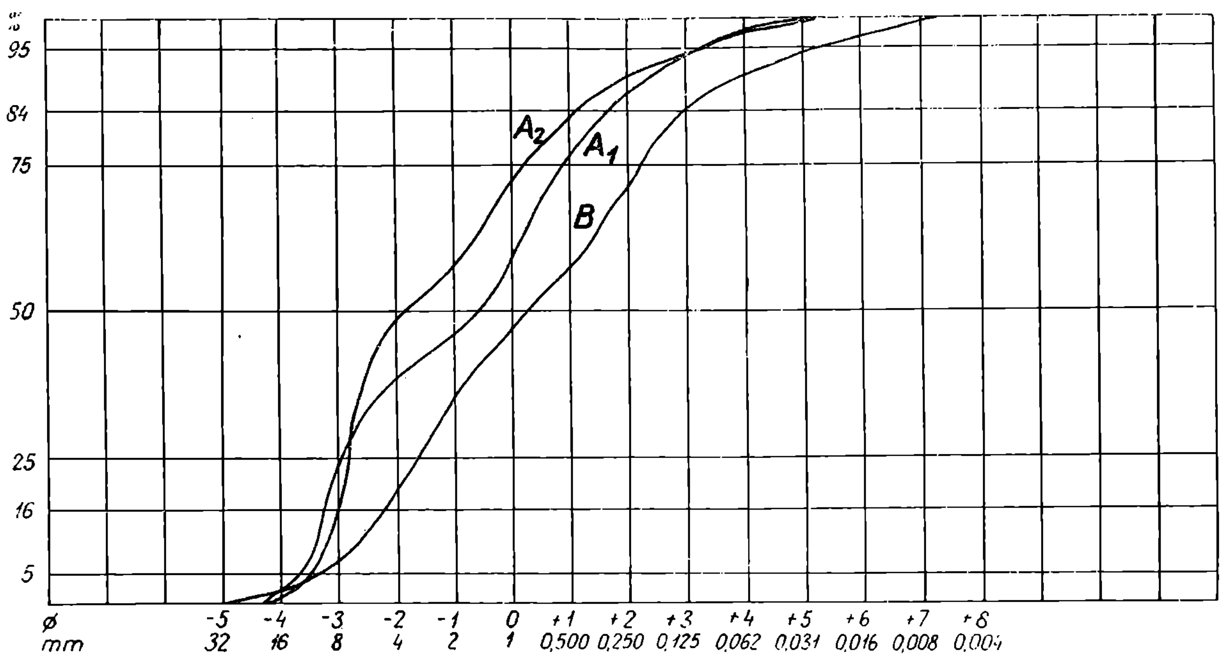

Fig. 5. Krzywe składu ziarnowego ławic zlepieńców o warstwowaniu bezładnym: A_1 — spąg, A_2 — strop ławicy, B — krzywa składu ziarnowego ławicy o warstwowaniu bezładnym z rzadko rozrzuconymi otoczakami

Fig. 5. Grain-size distribution curves of structureless conglomerates: A_1 — lower part, A_2 — upper part of one bed, B — grain-size distribution curve of a structureless conglomerate with widely spaced pebbles

Quartz conglomerates and feldspathic sandstones

These two types of rocks are closely related, and both frequently occur within more or less distinctly graded beds. The diameter of pebbles in the quartz conglomerates ranges up to 20—30 mm, with an average size about 10 mm. The sandstones are medium- and coarse-grained. Single discontinuous graded bedding and multiple graded bedding are the predominating types. The beds with single grading are 0,5—3,0 m thick, but the thickness of beds with multiple grading may reach a dozen metres or even more.

The frequency of thickness of beds has a logarithmic normal distribution (Fig. 6). Such a distribution has been observed in various types of sediments of different origin (F. J. P e t t i j o h n, 1957, pp. 160—161), but its cause remains still obscure.

Two types of incomplete graded bedding may be distinguished in the Istebna beds: in the first one the lower part of the bed consists of a graded quartz conglomerate with grain diameters ranging from a few dozen to a few mm, and the upper part is formed of a graded sandstone coarse-grained in the middle part of the bed, and medium-grained at the top. The boundary between the sandstone and the overlying siltstone is sharp.

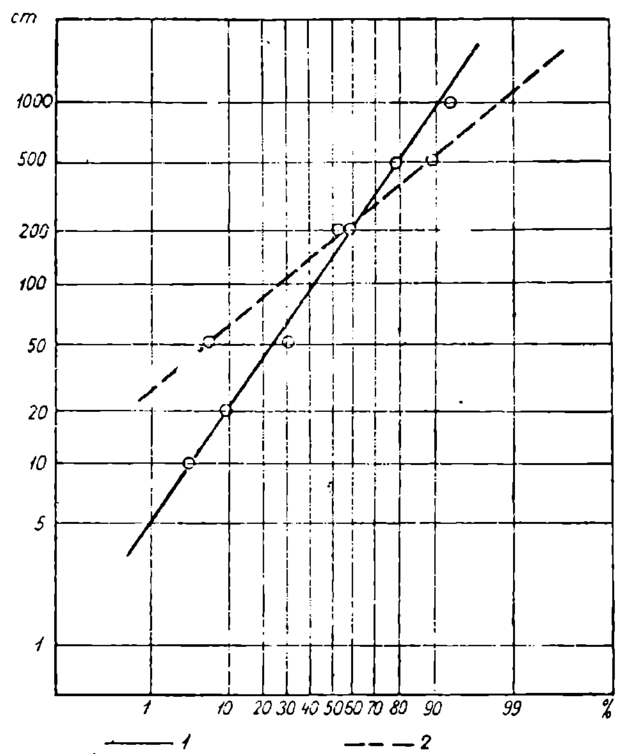

Fig. 6. Wykres rozkładu miąższości ławic zlepieńców i piaskowców frakcjonalnie warstwowanych oraz żwirowców ilastych. Dolne warstwy istebniańskie, Kamesznica, potok Bystra (Beskid Śląski): 1 — zlepieńce i piaskowce frakcjonalnie warstwowane, 2 — żwirowce ilaste

Na osi rzędnych miąższość ławic w cm; na osi odciętych częstość występowania ławic w procentach kumulowanych

Fig. 6. Bed thickness distribution of graded conglomerates, sandstones and pebbly mudstones. Lower Istebna beds, Kamesznica, Bystra creek (Beskid Śląski): 1 — graded conglomerates and sandstones, 2 — pebbly mudstones

Thickness of beds on ordinate in mm, frequency in cumulated percentage on abcissa

Thus two surfaces of discontinuity of grading placed between the conglomerate and the sandstone and between the sandstone and siltstone are present in such beds. In the second type the beds are composed of sandstone, coarse-grained and pebbly at the base, and medium-grained at the top; the boundary between the sandstone and the overlying siltstone is sharp (Plate VI, Fig. 1), and forms the plane of discontinuity of grading.

Cumulative curves of grain size distribution of graded quartz conglomerates and feldspathic sandstones and of the sandy siltstones overlying such beds are presented on Fig. 7. The most striking feature shown by these curves is the low content of pelite, which amounts in conglomerates to about 2 per cent, and in sandstones rarely exceeds 5 per cent. A high content of pelite throughout the graded beds has been considered as a typical feature of turbidity-current deposited sediments (Ph. Kuenen, 1953; M. Książkiewicz, 1954). From published granulometric analyses of both fossils and recent graded turbidites it follows that the content of pelite in this type of sediment ranges from 10 to 25 per cent (A. Radomski, 1958, Fig. 2; D. S. Gorsline and K. O. Emery, 1959, Fig. 4).

Multiple discontinuous graded bedding is frequent in the Istebna beds. The individual graded layers are separated by load-casted surfaces. The thickness of such beds ranges up to about a dozen metres.

Laminated beds, fine-grained and less than 50 cm thick, and cross-bedded beds with thicknesses not exceeding a dozen cm are sporadically encountered amount thick-bedded sandstones and conglomerates.

Composite beds graded in the lower part and laminated near the top are rarely met with. The light laminae are 5 to 30 mm thick, while the dark ones are very thin (about 1 mm) and marked by accumulation of mica flakes and sometimes also of fine carbonised plant detritus. The top surface of such beds is usually sharp, but in some beds of this type the upper laminated part grading into laminated siltstone was observed.

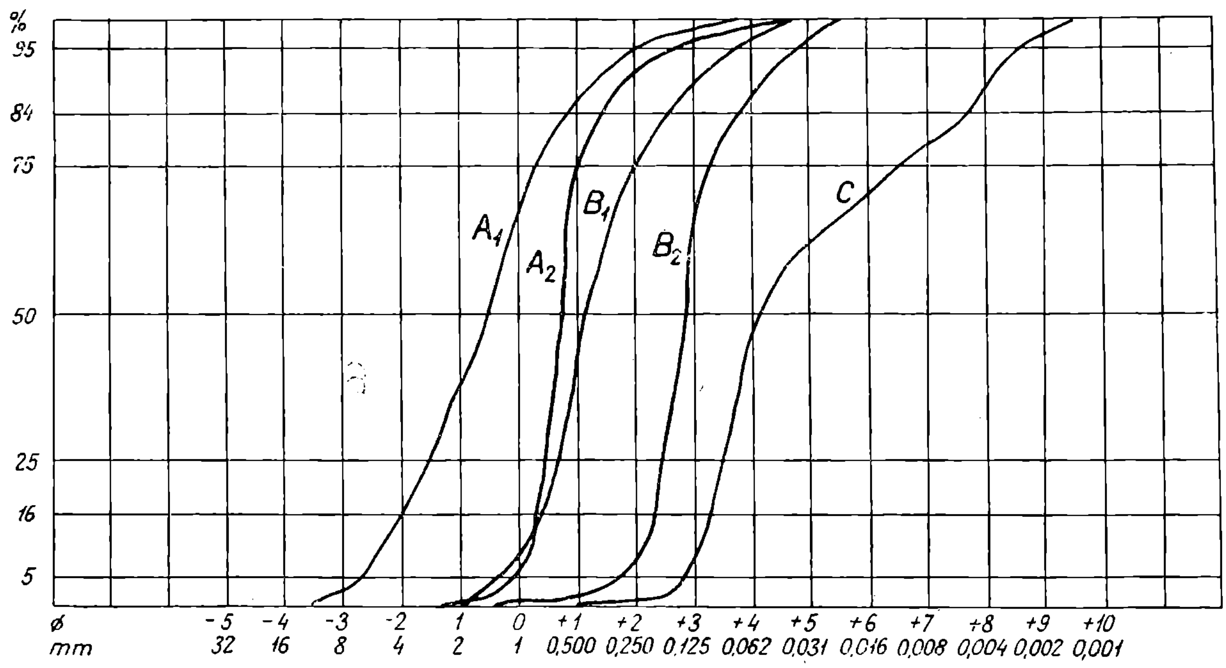

Fig. 7. Krzywe składu ziarnowego zlepieńców i piaskowców frakcjonowanych: A_1 — spąg, A_2 — strop ławicy zlepieńca, B_1 — spąg, B_2 — strop ławicy piaskowca, C — mułowiec z sieczką roślinną z nad ławicy frakcjonowanego zlepieńca

Fig. 7. Grain-size distribution curves of graded conglomerates and sandstones. A_1 — lower part, A_2 — upper part of a conglomerate bed. B_1 — lower part, B_2 — upper part of a sandstones bed. C — siltstone with plant detritus overlying a conglomerate bed

The lower surface of beds is very often erosional. If the erosion removed the siltstone layer, and if the grain size is similar in two successive beds the erosional boundary between them becomes often indistinct. Beds formed in this way and reaching a thickness of a dozen metres or more, are termed here „complex beds". The complex beds should not be confused with the composite beds which were deposited by one current (cf. E. ten Haaf, 1959). The complex nature of the described beds is easily recognisable owing to their great lateral variability caused by changing depth of erosion. Thus some layers present in one profile of a complex bed may be completely missing in another profile. Large quarries, e.g. the quarries at Droginia, Tursko, Rożnów (Plate VII), at Bieśnik, and in other localities, offer the best possibilities of study of the complex beds. Various types of complex beds are presented in Fig. 8. Some coarse cross-bedding is often present in the complex beds.

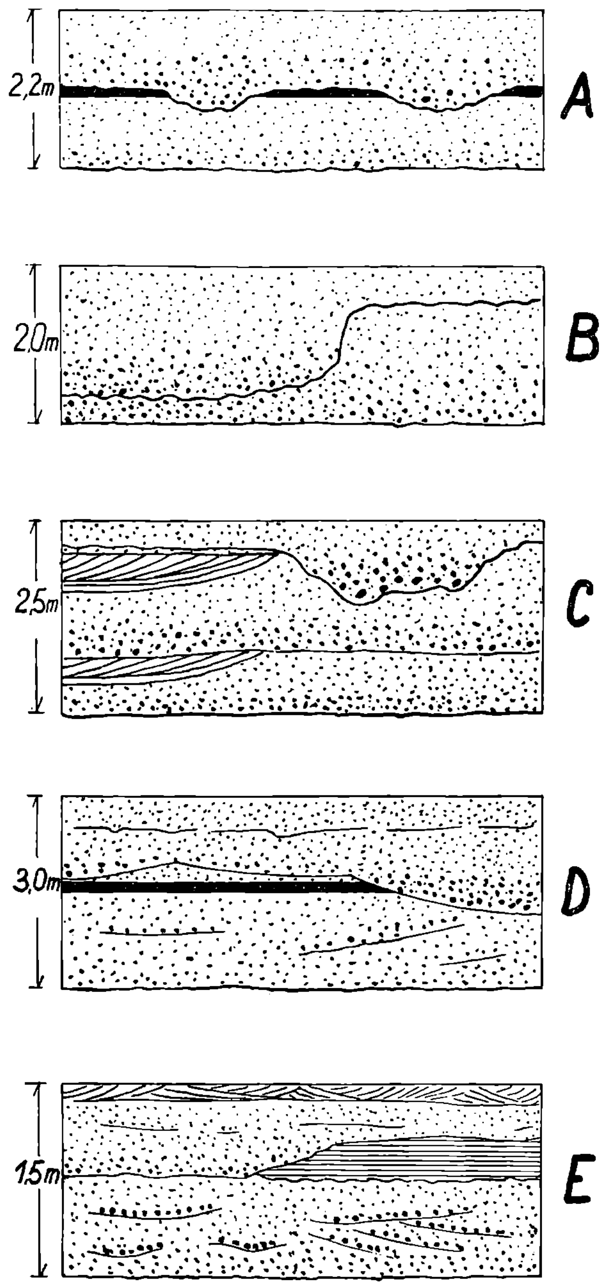

Fig. 8. Przykłady erozji w ławicach złożonych: A — dolne warstwy istebniańskie, dolina Olzy poniżej Istebnej, B — dolne warstwy istebniańskie, potok Rabego, Łuska Bystrego, C — dolne warstwy istebniańskie, Rożnów, kamieniołom, D — Dolne warstwy istebniańskie, Osieczany, dolina Raby na E od Myślenic, E — dolne warstwy istebniańskie, dolina potoku Paleśnica na S od Zakliczyna, kamieniołom przy leśniczówce

Fig. 8. Erosion in complex beds: A — Lower Istebna beds, Olza valley, below Istebna, B — Lower Istebna beds, Rabe creek (Bystre scale). C — Lower Istebna beds, quarry at Rożnów (south of Czchów), D — Lower Istebna beds, valley of the Raba river, Osieczany, east of Myślenice, E — Lower Istebna beds, Paleśnica creek, quarry

Structures of siltstones separating the coarse-grained beds

The thick beds of conglomerates and coarse-grained sandstones are separated by thin layers of laminated sandy siltstones which contain up to 30 weight per cent of carbonised plant detritus. This is the simplest type, but often the fine-grained intercalations have a more complicated structure.

In such cases the thick, coarse-grained bed is covered by a siltstone layer 5—10 cm thick overlain in turn by a thin bed of fine-grained sandstone, frequently laminated and grading into siltstone. In some cases the fine-grained thin-bedded sandstone displays the presence of convolute lamination. Sometimes the siltstone layer contain lenses of coarse sand (Fig. 9). These structures are likely to be the result of repeated slumps developing from the same slump-scar with decreasing intensity. A similar phenomenon was proposed by A. Wood and A. J. Smith (1959) for explanation of the origin of the repeatedly graded beds.

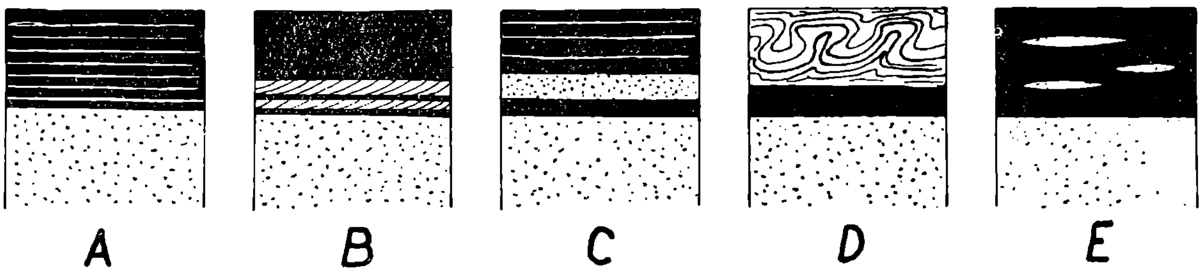

Fig. 9. Struktury mułowców rozdzielających grube ławice piaskowcowe: A — piaszczysty mułowiec laminowany (typ pospolicie występujący), B — mułowiec z cienkimi ławiczkami piaskowca o przekątnym warstwowaniu, kamieniołom w Kalwarii, C — mułowiec i cienkoławicowy piaskowiec frakcjonalnie warstwowany, przechodzący ku górze w laminowany mułowiec, odsłonięcia nad jeziorem Czchowskim, D — mułowiec i drobnoziarnisty piaskowiec o warstwowaniu konwolutnym, kamieniołom w Cieszynie k. Frysztaka, E — mułowiec z soczewkami piaszczystymi, potok Rabego, łuska Bystrego

Fig. 9. Structures of siltstones separating the thick sandstone beds: A — laminated sandy siltstone, B — siltstone with two thin beds of cross-laminated sandstone, quarry at Kalwaria, C — siltstone and thin sandstone bed grading upwards into laminated siltstone, outcrops on the shores of the Czchów reservoir, D — siltstone, and fine-grained sandstone with convolute bedding, quarry at Cieszyna near Frysztak, E — siltstone with sand lenses, Rabe creek, Bystre scale

Orientation of pebbles in conglomerates

Pebbles in conglomerates of the Istebna beds have often their longest axes arranged parallel to the direction of transport and dipping upcurrent. This type of pebble fabric is common in the Carpathian Flysch, and has been described recently by several authors (M. Książkiewicz, 1954, 1958 a; L. Koszarski, 1956 a; S. Bukowy, 1956; A. Radomski, 1958; S. Dżułyński and A. Ślączka, 1959); T. Wieser (1954) used the pebble fabric as an indicator of the direction of currents depositing the coarse clastic material. F. H. H. W. Kopstein (1954) described another type of fabric of the coarse grains consisting in a downcurrent dip of the longest axes. However, his conclusions were criticised recently by D. A. Basset and E. W. Walton (1960).

Investigations of the origin of some types of sole markings (S. Dżułyński and I. E. Sanders, 1959; S. Dżułyński and A. Ślączka, 1959, 1960) permited to state that the coarsest grains and other objects carried by a turbidity current are transported by saltation and rolling i.e. similarly as in rivers. Thus, the imbrication of grains with upcurrent dips of longest axes, comparable to that of river sediments is a normal feature of turbidites. A conspicuous imbrication of the described type occurs also in non-graded conglomerates of the Istebna beds. Its presence suggests rolling on the sea floor as the principal type of transportation of the clastic material of these conglomerates.

Imbrication with downcurrent dip of the longest axes of grains is formed when the grains are deposited on the foreset laminae during the formation of a cross-bedded sandstone layer by „lateral sedimentation" (L. M. J. U. Van Straaten, 1951). Some rare cases of occurrence of such type of imbrication in the coarse-grained, thick-bedded sandstones of the Lower Krosno beds were noted by S. Dżułyński and A. Ślączka (1959). This type of imbrication has been found in the Istebna beds only in one loose block.

Shale lumps and balls in thick-bedded sandstones and conglomerates

Thick graded and complex beds of conglomerates and coarse-grained sandstones contain often numerous lumps and balls of shales. Shale lumps, more or less angular, occur always near the bottom of the graded beds (or graded layers in complex beds), while rounded balls concentrate near the top of the beds, forming there distinct layers. The balls frequently bear an armor composed of pebbles and coarse sand grains (Plate VI, Fig. 2). They differ from recent armored balls described from fluvial sediments (H. S. Bell, 1940) only by their flat shape which is obviously due to compaction.

In the Carpathian Flysch armored shale balls occur both in sandstones and in pebbly mudstones (M. Książkiewicz, 1958 a; K. Grzybek and B. Halicki, 1958).

The pebbly armor cannot form on shale lumps neither in a turbidity current, in which the light shale lumps tend to concentrate in the tail of the current (Ph. H. Kuenen, 1957), nor in slides in which there is little turbulence. The formation of such an armor on shale balls is possible when the whole clastic material is rolled along the sea floor in avalanche-like slumps or in sand flows. On the other hand, the position of the armored shale balls within the graded beds indicate that the slumps or sand flows were transformed into turbidity currents in which the armored shale balls concentrated in the tails and subsequently were deposited in the top part of the graded beds.

Therefore armored mud balls occurring in regular layers in the top part of graded beds are an important structure, as they indicate the transition of currents transporting the detrital material from the fluxoturbidite phase to the turbidite phase. The problem of such a transition was recently discussed by A. Radomski (1961).

Submarine erosion

There is ample evidence of the erosive action of the currents transporting the detrital material in the sedimentary basin of the Istebna beds. Erosion of the sea floor is clearly marked in the complex beds (Fig. 8). Erosion localised along narrow belts is easily recognisable in outcrops, but erosion affecting large areas of the sea floor can be often overlooked as pointed out by M. Książkiewicz (1954). Many observations are suggesting that erosion reached frequently greater depth than it would be inferred from the dimensions of the outwashes in the complex beds.

In the Beskid Śląski range the coarse-grained conglomerates contain quite often large blocks of typical Istebna sandstones undoubtedly eroded from the sea floor. Such blocks are present in the outcrops in the Olza river valley at Istebna and in the Bystra creek valley at Kamesznica. Lumps of siltstones and shales forming intercalations separating the coarse-grained beds are present everywhere in conglomerates and coarse-grained sandstones. Recently M. Książkiewicz (1958 a) pointed out, that the presence of shale and siltstone lumps in sandstone beds indicates a rather deep erosion which removed from the sea floor the superficial layer of loose sediment and reached at least partly consolidated beds. The same pertains to the aforementionned blocks of sandstones. The presence of unconsolidated pelites on the slopes of deep-sea trenches was recently reported by G. Houot (1959).

Small-scale slumps

Small scale slumps are present sometimes below thick beds of sandstones and conglomerates. They form small lenses up to 1 m thick, and a few to several metres long, composed of angular sandstone and siltstone lumps cemented by a sandy-silty paste. Such slumps were observed in the Olza valley below Istebna, in the profile exposed along the Ropa river valley at Gorlice, in the outcrops on the left side of the Czchów reservoir, and in the quarry at Cieszyna.

The occurrence of fragmented sandstones and siltstones indicate, that the slumping affected several beds of sandstone separated by siltstone intercalations. Nothing can be said about the direction of slumping, and the origin of the described type of slumps remains obscure.

Structures present on the bedding planes

The conglomerates and coarse-grained sandstones of the Istebna beds are rather poor in sole-markings. The soles of coarse-grained conglomerates are either adjusted to the shapes of washouts, or smooth. The fine-grained conglomerates and coarse-grained sandstones have soles either smooth or deformed by load casts. Flow casts were noted by M. Książkiewicz (1958 a) from the quarry at Zadziele (Beskid Śląski range) but this structure is rare in the Istebna beds.

Load casts are especially well developed on soles of conglomerate and sandstone beds overlying sandy siltstones and pebbly mudstones. Instead, beds overlying clayey shales have in most cases smooth soles. A similar relation of the load casts to the character of the underlying beds was noted by S. Dżułyński and Cz. Żak (1960). Probably the clayey shales were more rapidly indurated than the siltstones owing to cohesion acting upon the fine particles of pelite, and this prohibited the formation of load casts.

Flute casts, drag marks and various tool markings (term introduced by S. Dżułyński and I. E. Sanders, 1959) are rarely met on soles of coarse-grained and pebbly sandstones, while they are absent on soles of conglomerates. It should be stressed that the majority of sandstone beds have no sole markings, but in some beds the sole markings appear in profusion. This suggests, that in most cases the currents transporting the sand were eroding the sea floor so intensely that flute casts and tool markings could not be formed. Only rare beds were deposited by currents in which erosion did not pass beyond the fluting stage, making thus possible the preservation of various sole markings.

The top surfaces of sandstone and conglomerate beds are usually smooth. In rare cases linguoid ripples were found on top surfaces of medium-grained sandstones.

Origin of thick-bedded conglomerates and coarse-grained sandstones

From the description presented above it follows that the thick-bedded conglomerates and coarse-grained sandstones of the Istebna beds are differing strongly from typical turbidites. The following features are important for the reconstruction of the conditions of sedimentation of the Istebna beds: lenticular shape of beds, especially conspicuous in the case of the coarse-grained conglomerates, occurrence of exceptionally coarse material and great thickness of beds, low pelite content, lack of grading in the conglomerates, presence of symmetrical, multiple, and discontinuous grading, and of complex beds, poor development of siltstones and shales separating the beds of sandstones and conglomerates.

All these features point out to a powerful supply of clastic material which was not transported in suspension by turbidity currents, but rather by watery slides of sand and gravel. Deposits of such sand flows which constitute an intermediate type of mass movement between true slumps and turbidity currents were called fluxoturbidites by S. Dżułyński, M. Książkiewicz, and Ph. H. Kuenen (1959). These authors regard as essential conditions of deposition of this type of sediment the low content of pelite, because of which the clastic material could not be raised in suspension, and steep slope of the sea floor which forced it to spread in a layer. The low content of pelite in the coarse-grained detrital Istebna beds was already discussed (see p. 58) and the evidence of steep slopes of the sea-foor in the sedimentary basin of the Istebna beds will be considered below (p. 66).

Pebbly mudstones

Black, more or less cemented poorly sorted silty conglomerates and pebbly silts or „symmiotites" (K. Flint, I. E. Sanders and I. Rogers, 1960) occurring abundantly in the Istebna beds, are termed here pebbly mudstones after J. C. Crowell (1957). They contain large pebbles of quartz and exotic rocks. Their black colouration is due to abundant fine carbonised plant detritus.

The pebbly mudstones occur in the whole profile of the Istebna beds, among thick-bedded sandstones and conglomerates, and in the siltstone members, with the exception of the uppermost part of the Upper Istebna shales. Instead, they are absent in the intercalations of thin-bedded sandstones alternating with shales and siltstones.

The thickness of beds of the pebbly mudstones ranges from 0,5 m up to about 8 metres. Similarly as in the sandstones and conglomerates the thickness of beds displays a logarithmic normal distribution (Fig. 6). In most cases graded bedding is present in the pebbly mudstones, but only the cobbles and pebbles show a graded distribution, while the finer grades do not (Fig. 10). In this respect the grading of the pebbly mudstones differs from that of the sandstones and conglomerates, in which the whole grain-size distribution curves for the top parts of the beds are shifted towards the finer grades in comparison with the curves for the lower parts of the beds. A similar distribution of the coarsest grades was stated by S. Bukowy (1956) in the pebbly mudstones of the Babica clays.

Some pebbly mudstone beds consist of two graded layers. The pebbles display usually a distinct lineation, their longest axes being arranged parallel to the direction of flow.

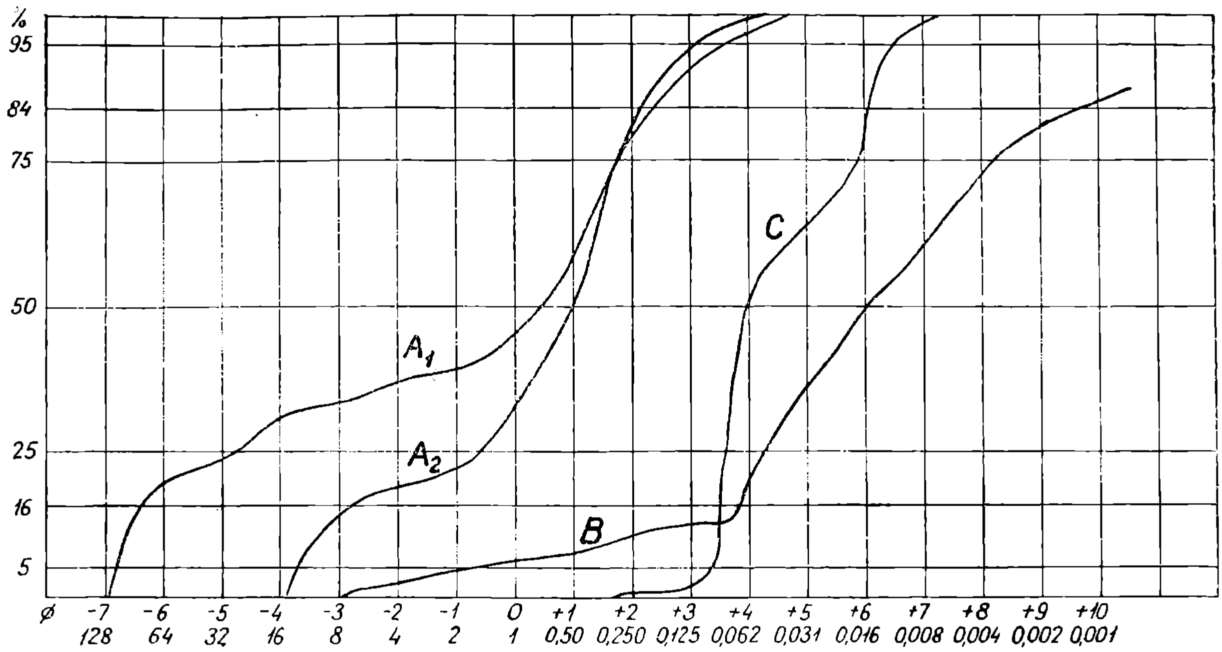

Fig. 10. Krzywe składu ziarnowego żwirowców ilastych: A_1 — spąg, A_2 — strop ławicy żwirowca frakcjonalnie warstwowanego, B — żwirowiec ilasty z zewnętrznej (północnej) strefy facjalnej, C — mułowiec z nad ławicy żwirowca frakcjonowanego

Fig. 10. Grain-size distribution curves of pebbly mudstones: A_1 — lower part, A_2 — upper part of a graded pebbly mudstone bed, B — pebbly mudstone from the external facial zone, C — siltstone overlying a graded pebbly mudstone bed

The pebbly mudstones are usually covered by black siltstones, which are as a rule thicker than those covering beds of sandstones and conglomerates. The siltstones occurring above the pebbly mudstone beds are often laminated and contain thin layers of laminated sandstone with ill-defined boundaries; irregularly distributed small lenses of conglomerate, and single pebbles below which the laminae are bent downwards are present sometimes.

In some areas the pelite content in the pebbly mudstones strongly increases (Fig. 10, curve B), and the rock becomes a micaceous pebbly silt. A. Radomski (1950, unpublished M. Sc. thesis, Department of Geology, Jagellonian University, Cracow) was first to call attention to this variety of pebbly mudstones occurring in the Istebna beds in the Brzanka-Liwocz fold. Such pebbly silts are present in the external facial zone.

Pebbly mudstones with slump structures

Numerous beds of pebbly mudstones display the presence of slump structures. Such beds contain blocks of sandstone, lumps of shale, fragmented siderites, armored shale balls, and spiral balls, distributed in a haphazard manner. Slump folds and small-scale structures due to slipping of the sediment are also present. The sandstones and siltstones occurring as blocks and lumps in such beds are typical Istebna rocks. A slumped bed of pebbly mudstone exposed at Gorlice, containing large slabs of siltstone, spiral balls and small slip-folds is presented on Fig. 11.

Some pebbly mudstones beds contain large blocks of Istebna sandstones and exotic rocks whose volumes range from 1 to about 10 cubic metres. Such large blocks occur as a rule in the top part of the pebbly mudstone beds, often protruding into the overlying siltstone. Observing such beds one gets the impression that these large blocks were floating on the surface of the dense submarine mudflow similarly as it is the case in subaerial mudflows.

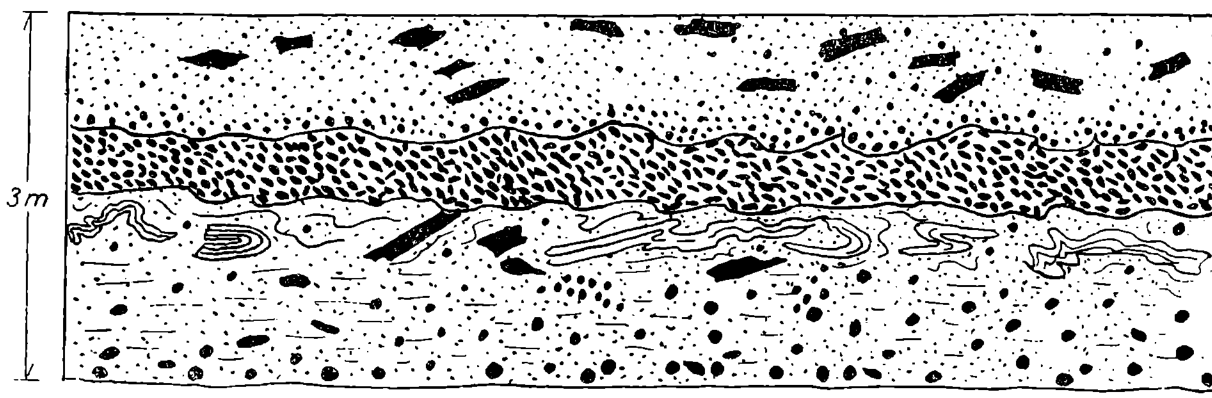

Fig. 11. Osuwisko w ławicy żwirowca. Gorlice
Fig. 11. A slumped pebbly mudstone bed. Gorlice

Slump folds are often developing in the upper part of pebbly mudstone beds with transitions from slipping of the uppermost part of the bed to slumps in which the whole bed is involved. Deformations of this type were recently described by M. Książkiewicz (1958 a), and termed „slump-bedding". Slump bedding is common in the pebbly mudstones of the Istebna beds in the southern facial region, while they were not observed in the northern one. Initial slumping affects sometimes also the siltstones overlying the pebbly mudstone beds. An example of such type of deformation is provided by a pebbly mudstone bed 70 cm thick cropping out in the Bystra creek at Kamesznica. Several small sandstones dikes are protruding from the pebbly mudstone bed into the overlying siltstone. These sand dikes were obviously formed by filling from below, as the siltstone was fissured because of stretching in the initial phase of slumping. Similar structures were recently described from sandstone beds by M. Książkiewicz (1958 a) and S. Dżułyński and A. Radomski (1956).

Origin of pebbly mudstones

Pebbly mudstones were described during the last few years by numerous authors (I. M. Dorreen 1951; J. C. Crowell 1957; S. Bukowy 1956; M. Książkiewicz, 1958 a; Radomski 1958, S. Dżułyński and A. Ślączka, 1959; S. Marchant and C. P. G. Black, 1960; K. Grzybek and B. Halicki, 1958) who regarded this type of rock as deposited by submarine mudflows, conformably with earlier opinions of A. Heim (1908) and others.

In the sedimentary basin of the Istebna beds the mass movements leading to the formation of pebbly mudstones were initiated by slumps developing in the sedimentary apron covering the steep submarine slopes of the cordillera. Pebbly mudstone beds displaying a graded distribution of the coarse -grained material and lineation of pebbles should be regarded as deposited by submarine mudflows representing a type of mass movement intermediate between slumps and turbidity currents. The black siltstones covering the pebbly mudstone beds were obviously deposited by clouds of suspension accompanying the dense mudflows. This is indicated by their grain-size distribution (Fig. 10, curve C), as well as by the presence of lamination and of lenses of coarse-grained material.

The slumps initiating the mudflows which deposited the pebbly mudstone beds could develop either in the superficial layer of the sedimentary apron, composed of poorly consolidated material which was subject to disintegration during transportation, or involve also deeper lying consolidated sediments which were fragmented in the slump and developed into various kind of slump balls. On the other hand the dense mudflows developing from slumps could erode deeply the sea floor (S. Bukowy, 1956; J. C. Crowell, 1957). Numerous beds of pebbly mudstones in the Istebna beds contain angular slabs of siltstones, lumps of siderites, and sandstone blocks without any traces of deformations connected with slumping. It seems that siderites were subject to strong grinding during transport, as angular grains of siderite are abundant in the sand grades in the pebbly mudstones.

Some of the pebbly mudstone beds were subject to penesyndepositional or postdepositional slumping, leading to the formation of slump folds and to fragmentation of beds and formation of clastic dikes. This suggest deposition on an inclined bottom, but the development of such slumping processes is also connected with hydroplastic properties of the sediments depending on its grain size distribution.

Some pebbly mudstone beds are directly covered by conglomerates, the boundary between them being ill-defined. Such beds were probably deposited by a mudflow and a sand flow (or turbidity current) developed from slumps initiated simultaneously in different material — and triggered perhaps by a common cause e.g. an earthquake.

Thin-bedded sandstones

Thin-bedded sandstones occurring as single beds or forming thick intercalations among the thick-bedded sandstones and conglomerates are typical turbidites. Laminated bedding prevails over other types in the thin-bedded sandstones, while composite bedding of the laminated and cross-laminated type and graded and laminated type, graded bedding, and cross-laminated bedding are rare. Convolution is common in the laminated beds.

Some composite beds laminated in their upper part, and some laminated ones, are grading upwards into the overlying siltstone, but a majority of laminated beds and all graded and cross laminated beds have clearly defined upper surfaces. The lower surfaces of all sandstone beds are sharp.

Sole markings are abundant in the thin-bedded sandstones. Flute casts, small drag marks and various tool-markings were observed. The biohieroglyphs will de described in a separate paragraph.

The thin-bedded sandstones are usually fine-grained, but pebbles with diameters ranging up to 1—2 cm are occasionally present in the lower part of some graded beds. Such coarse-grained beds are particularly common in the intercalation of fine-grained sandstones „of Inoceramian type" cropping out at Czchów on the right bank of the Dunajec river immediately below the dam.

Analyses of grain-size distribution in the thin-bedded sandstones were not made, as disintegration of the samples by repeated crystallisation or freezing was practically impossible because of abundant cement, and the results of analyses made by sieve and thin-section techniques are not comparable (M. A. Rosenfeld, L. Jacobsen and I. C. Ferm 1953).

Siltstones and shales

Pelitic rocks are represented in the Istebna beds by black siltstones and black, grey, green and red clayey shales, grey and green marly shales and grey marls. The distribution of these types of rocks in the sedimentary basin is irregular, and the frequency of their occurrence is very variable.

Black siltstones are markedly predominating over other types of pelitic rocks. They alternate with the thick-bedded sandstones and conglomerates, accompany the beds of pebbly mudstones and form larger complexes in the Lower and Upper Istebna shales. The siltstones are micaceous and sandy. Grains belonging to the fine sand grade may constitute more than 50 weight per cent. The black colouration is due to abundant carbonised fine plant detritus, which may form up to 30 weight per cent of the rock. Lamination and occasional presence of sandstone and even conglomerate lenses are conspicuous features. Granulometric analyses and sometimes also careful observation reveal the presence of graded bedding (Fig. 12). The cumulative curves of grain-size distribution of the siltstones are very steep and similar to those of graded sandstones (Fig. 7 curve C, Fig. 10 curve C and Fig. 12).

Black shales are closely related with the black siltstones and contain also abundant carbonised plant detritus.

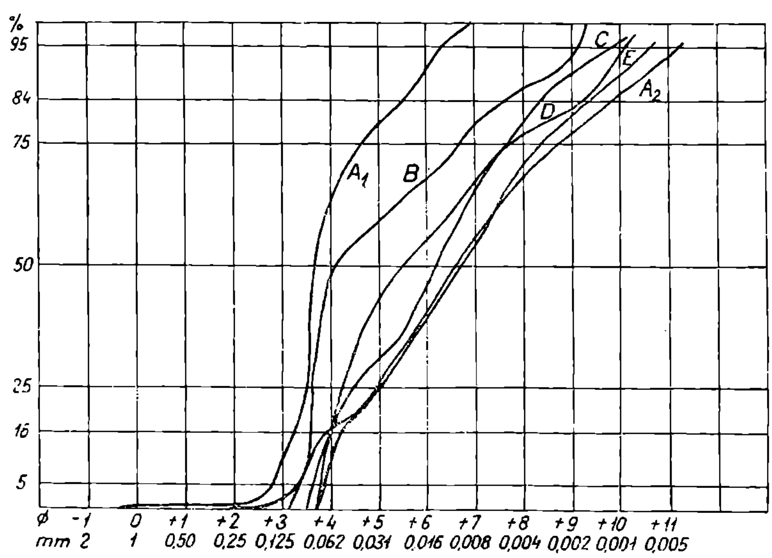

Fig. 12. Krzywe składu ziarnowego mułowców i łupków: A_1 — spąg, A_2 — strop ławicy czarnego mułowca frakcjonalnie warstwowanego, B — czarny mułowiec (próbka z całej miąższości ławicy), C — łupek ilasty czarny, D — łupek ilasty zielony, E — łupek ilasty zielony

Fig. 12. Grain-size distribution curves of siltstones and shales: A_1 — lower part, A_2 — upper part of a graded black siltstone bed, B — black siltstone (whole bed), C — black shale, D — green shale, E — green shale

Grey and green clayey shales are accompanying usually the thin-bedded non-calcareous sandstones, and the marly shales the calcareous ones (Inoceramian type). Green clayey shales form also some intercalations between coarse sandstone beds. Red shales form intercalations among sandstones in the lowermost part of the Lower Istebna beds in some regions, and occur as locally developed lenses in the Upper and Lower Istebna shales.

All these types of shales do not contain carbonised plant detritus, are almost devoid of sands grains, and muscovite occurs in them in much smaller quantities than in the siltstones. The grain-size distribution of the shales is closely resembling that of recent pelagic clays alternating with sands deposited by turbidity currents off California (D. S. Gorsline and K. O. Emery, 1959, Fig. 4).

Origin of siltstones and shales

On account of the evidence presented above the siltstones should be regarded as deposited by diluted turbidity currents. The main facts indicating this are: large content of sand grades and of carbonised plant detritus, presence of graded and laminated bedding, and the character of grain-size distribution. Recent pelitic sediments deposited by turbidity currents were described by D. B. Ericson, H. Ewing and B. C. Heezen (1952), and D. S. Gorsline and K. O. Emery (1959). A. Radomski (1960) stated that many flysch „shales" are graded and were deposited by the same turbidity currents which laid down the underlying sandstone beds. Similar suggestions were expressed already by J. C. Crowell (1955) and by S. Dżułyński and A. Ślączka (1959).

The siltstones of the Istebna beds are almost always separated by a plane of discontinuity from the underlying coarse-grained beds. This can be easily explained, if one takes into account that a majority of coarse-grained beds were deposited by sand flows and mudflows in which the pebble and sand grades were not raised in suspension (with the exception of the fine sand), but transported along the sea floor. Instead, the pelites were forming clouds of suspension accompanying the flows loaded with coarser grades. This distribution of material during transportation is reflected in the sediment by the abrupt change of grain size on the discontinuity plane forming the boundary between the conglomerate, coarse-grained sandstone or pebbly mudstone and the siltstone. Largest clouds of suspension accompanied problably the mudflows depositing the pebbly mudstones and this accounts for the greater thicknesses of siltstones overlying the pebbly mudstone beds.

The black shales are probably composed of finest grades carried by turbidity currents, as indicated by their content of carbonised plant detritus. Instead, the grey, green and red shales are normal pelagic sediments, forming in these parts of the sedimentary basin which temporarily were not flooded by turbidity currents. This conclusion is supported by the presence of a rather rich arenaceous benthonic (and sometimes also planctonic) microfauna in the shales, while the siltstones and black shales are devoid of microfossils (S. Geroch, 1960; H. Jurkiewicz. 1960, 1961; M. Książkiewicz, 1961; A. Ślączka 1959).

The red and green colouration of the shales are probably depending upon the oxydation and type of bounding of iron in minerals of the glauconite type (cf. A. Gaweł, 1928).

GRAIN-SIZE DISTRIBUTION IN VARIOUS TYPES OF SEDIMENTS

Parameters of the grain-size distribution were calculated for 22 granulometric analyses of non-graded polymictic conglomerates (2 analyses) quartz conglomerates and feldspathic sandstones (5 analyses), pebbly mudstones (5 analyses), siltstones (5 analyses) and shales (5 analyses). The phi scale (W. C. Krumbein, 1938) and formulas for grain-size parameters given by L. R. Folk and W. C. Ward (1957) were used. The results are presented in Table I and in Fig. 13, 14 and 15.

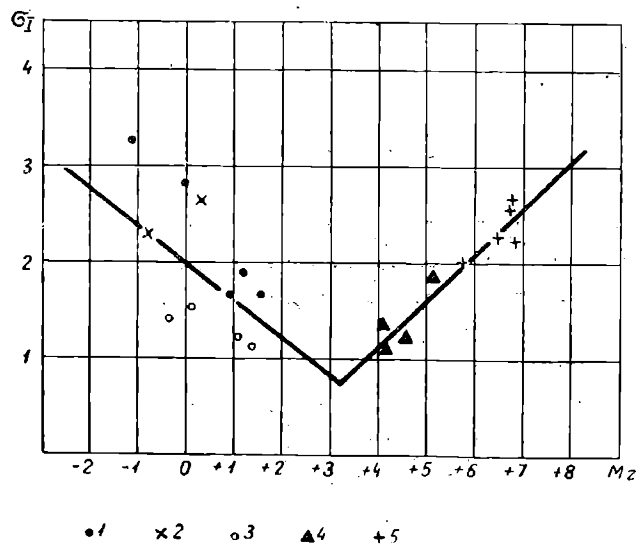

Fig. 13. Wykres zależności współczynnika dyspersji rozkładu wielkości ziarn od średniej średnicy ziarn. Na osi rzędnych współczynnik dyspersji, na osi odciętych średnia średnica: 1 — żwirowce ilaste, 2 — zlepieńce o nieuporządkowanej strukturze, 3 — zlepieńce i piaskowce frakcjonalnie warstwowane, 4 — mułowce, 5 — łupki

Fig. 13. Standard deviation versus mean grain diameter (Mz): 1 — pebbly mudstones, 2 — structureless conglomerates, 3 — graded conglomerates and sandstones, 4 — siltstones, 5 — shales

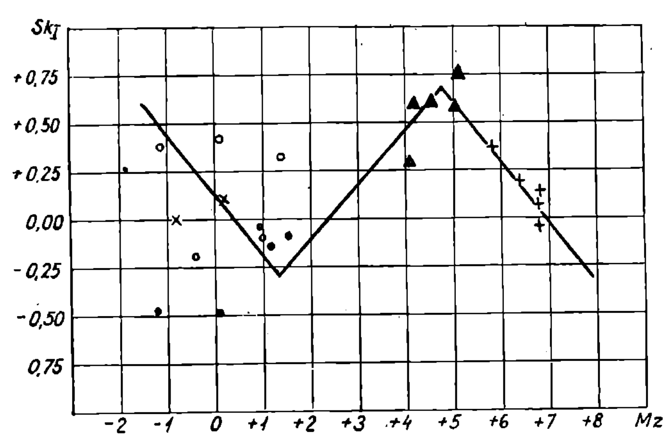

Fig. 14. Wykres zależności współczynnika asymetrii (Sk_I) od średniej średnicy ziarn (Mz). Oznaczenia jak na fig. 13

Fig. 14. Coefficient of skewness (Sk_I) versus mean grain diameter (Mz). For explanations see Fig. 13

The standard deviation is closely correlated with the mean size. A less distinct correlation appears also to occur between the skewness coefficient and the mean size. These correlations appear to follow the pattern described by L. R. Folk and W. C. Ward (1957). The kurtosis displays no correlation with the mean size.

The scope of the granulometric analyses is very modest, as they were intended only to illustrate the grain-size distribution in various types of sediments, yet, from Table I it appears, that the shales are characterised by the greatest consistency of values of parameters of grain-size distribution. This suggests fairly uniforms conditions of sedimentation which are to be expected in pelagic deposits laid down in one sedimentary basin. In all other types of sediment the grain-size parameters are more or less scattered, and their dispersion reflects the variation of hydrodynamic conditions between currents which deposited the sampled beds,

Tabela (Table) 1

Granulometria warstw istebniańskich
Granulometry of the Istebna Beds

Próbka Sample	średnia średnica Mz w jednostkach Ø Mean diameter	współczynnik dyspersji I Standart deviation	współczynnik asymetrii Sk_I Skewness	eksces KG Kurtosis
Żwirowce — Pebbly mudstones				
Wisła 5a	−1,18	3,27	−0,48	0,71
Bieśnik 3	+0,07	2,82	−0,50	1,36
Droginia 1	+1,17	1,93	−0,13	0,85
Kamesznica B25	+0,90	1,64	−0,07	1,16
Ciecień 7	+1,53	1,65	−0,10	1,07
Zlepieńce i piaskowce frakcjonalnie warstwowane Graded conglomerates and sandstones				
Kalwaria 1a	−1,12	1,81	+0,39	0,99
Biertowice 2	+0,10	1,52	+0,42	0,71
Droginia 2	+1,03	1,25	−0,11	0,91
Wisła 3a	+1,35	1,13	+0,32	1,16
Kamesznica B22a	−0,40	1,42	−0,20	1,11
Zlepieńce niefrakcjonowane Non-graded conglomerates				
Janoska 1/59	−0,72	2,27	0,00	0,75
Gorlice 2/11	+0,33	2,62	+0,10	0,91
Mułowce — Siltstones				
Kamesznica B26	+4,54	1,18	+0,60	0,56
Wisła 2a	+4,14	1,10	+0,58	1,32
Kamesznica B24	+5,10	1,86	+0,75	0,77
Biertowice 1	+5,03	1,99	+0,57	0,79
Wisła 1	+4,03	1,36	+0,29	1,59
Łupki — shales				
Wisła 2c	+6,78	2,67	+0,14	0,85
Izdebnik BZ	+6,78	2,54	+0,08	0,82
Bystre ŁZ	+5,79	2,00	+0,37	0,70
Czarnorzeki ŁC	+6,46	2,27	+0,17	0,85
Cieszyna 4	+6,82	2,21	−0,08	0,66

abstracting from other causes, as e.g. the position of the sampling site in relation to the distance travelled by the current. Thus the results of granulometric analyses are supporting the distinction made between pelagic sediments and sediments deposited by various types of density currents made on account of structural and textural features.

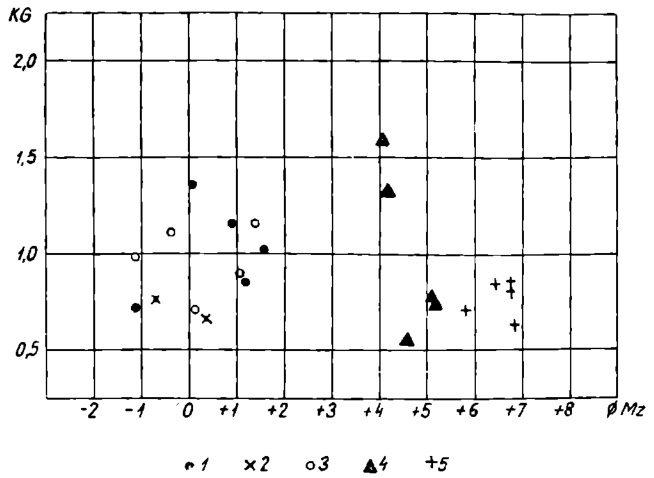

Fig. 15. Zależność ekscesu (KG) od średniej średnicy ziarn (Mz) oznaczenia jak na fig. 13

Fig. 15. Kurtosis (KG) versus mean grain diameter (Mz). For explanation see Fig. 13

ORGANIC HIEROGLYPHS

Organic hieroglyphs are less frequent in the Istebna beds than in other formations of the Carpathian Flysch, but in some beds they are fairly abundant. Several types can be distinguished among them.

Casts of pre-depositional trails occur only on the soles of fine-grained thin-bedded laminated and cross laminated sandstones. The *Spiroraphe* and *Cosmoraphe* types (T. Fuchs, 1895) are most frequently met with. The preservation of these delicate trails is obviously due to lack of erosion prior to the deposition of the thin-bedded sandstones.

Post-depositional burrows filled with sandy „coprolite sausage" are frequent on the soles and within thick sandstone beds. Horizontal burrows occurring on the soles of beds are identical with those termed by Ph. H. Kuenen (1957) „entrapment burrows", and described also by E. ten Haaf (1959) from the Northern Appenines. Another type are vertical burrows traversing the bed — and corresponding to the „escape burrows" of Ph. H. Kuenen (l. cit.). The diameters of the burrows are ranging from 1 to 2 cm, and the length of the vertical burrows may exceed 2 metres.

The described burrows are considered since the times of T. Fuchs (l. cit.) as made by mud-eating annelids. The terminology proposed by Ph. H. Kuenen for the horizontal and vertical burrows is based on the assumption that these animals were essentially living in the superficial layer of the sediment, and if entrapped suddenly under a sand layer rapidly implaced by a turbidity current or a sand flow, they escaped upwards to the new level of the sea floor.

However it seems quite possible that the annelids could live within a layer of sediment several metres thick, and not exclusively in the proximity of the sea floor (E. ten Haaf, 1959). In some thick-bedded sandstones vertical burrows appear in profusion (M. Książkiewicz, 1961) and they are rather witnessing normal feeding activity than the escape of the survivors of the passage of a turbidity current or sand flow.

Thus the terminology based on the presumed behavior of the burrowing animals is likely to be erroneous.

The greatest number of burrows is present in the siltstones abundant in plant detritus which separate the sandstone beds; these layers especially rich in organic matter were preferred by the mud-eating organisms. Some burrows present in the siltstones are filled with a coarse — or medium-grained sandy coprolite. Evidently they were made by organisms which just passed through a sand bed and excreted the sand eaten on the way.

DIRECTIONS OF TRANSPORT OF THE CLASTIC MATERIAL

Directional structures

Directional sole markings are rather rare in the Istebna beds, because of the strong erosional activity of the currents depositing the coarse-grained beds. The scarcity of directional sole markings is balanced to a certain degree by frequent occurence of lineation and imbrication of pebbles, especially in conglomerates and coarse-grained pebbly sandstones. Lineation of coarse plant detritus, current bedding, cross lamination and ripple marks were also used for determination of transport directions.

Directions of transport

A general picture of the transport directions of the clastic material in the Carpathian Flysch geosyncline was presented recently by M. Książkiewicz (1960 a, 1960 b). A wealth of data on current direction in the Istebna beds were collected during the preparation of the Carpathian volume of the Stratigraphic and Facial Atlas of Poland (edited by M. Książkiewicz, in press). The following description of the current directions in the Istebna beds based largely on these publications, is completed by observations of the present writer.

Generally speaking, the clastic material of the conglomerates and coarse-grained sandstones supplied by the Silesian cordillera flanking on the south the sedimentary basin of the Istebna beds was transported by currents turning to the north-east and east, and flowing subparallel to the long axis of the basin. In the western part of the Polish Carpathians currents flowing towards the north-east are prevailing while farther east the currents flowed to the east, and then to the south-east.

It is assumed that the current flowed down the slopes of the cordillera and then turned east following the slope of the basin floor (M. Książkiewicz, 1958). This idea is strongly supported by the results of oceanographic studies off California where D. S. Gorsline and K. O. Emery (1959) demonstrated clearly, that turbidity currents emerging from submarine canyons into the basin are adjusting their direction of flow to the slope of the basin floor.

Currents flowing to the south-east in the central part of the investigated area were probably deflected by the submarine rise forming the northern border of the through in which the Istebna beds were deposited. The south-eastern direction of currents in the extreme east are probably reflecting the arcuate shape of the Istebna through.

Current directions in the thin-bedded sandstones are more complicated. As a rule all the calcareous thin-bedded sandstones forming intercalations „of Inoceramian type" display current directions different from that of the thick-bedded conglomerates and coarse-grained sandstones. Currents depositing the thin-bedded calcareous sandstones flowed to the south-west, west, and north-west, and in rare cases to the north, and to the south-east. Within the particular intercalations the current directions are consistent.

Thin-bedded, non-calcareous sandstones forming intercalations in the Beskid Śląski area were deposited by currents flowing to the south-east and south. Similar directions were stated in single beds of fine-grained non-calcareous sandstones occurring among thick, coarse-grained beds south of Dobczyce and in the Ciężkowice area. Current directions to the north were recorded in such single thin beds in the Bystre scale.

Finally, some intercalations of thin-bedded non-calcareous sandstones display the same current directions as the neighbouring thick-bedded conglomerates and coarse-grained sandstones.

Measurements of current directions in the pebbly mudstones are not numerous, as lineation and imbrication of pebbles are the only valuable directional structures so far known in this type of sediment. Lineation of pebbles determined in the Beskid Śląski range, in the Pogórze Lanckorońskie area and in the Gorlice fold indicates transport in the NNW—SSE and NNE—SSW direction. As the number of beds, bed thickness, and grain size of the pebbly mudstones are decreasing northward, it is concluded, that the mudflows depositing the pebbly mudstones transported the clastic material northward. Transport directions in the pebbly mudstones differ from that in neighbouring beds conglomerates and coarse-grained sandstones.

Structural changes of sandstone beds related to distance of transport

Frequencies of various types of bedding and thickness of beds of fine-grained quartz conglomerates and coarse-grained feldspathic sandstones are changing with increasing distance of transport. In order to illustrate this variation two profiles of the Istebna beds were compared: the profile exposed in the Bystra creek at Kamesznica (Beskid Śląski), and the profile exposed in the creek at Chrostowa south-east of Gdów (Pogórze Wiśnickie area). In the western part of the Polish Carpathians the clastic material of the conglomerates and coarse-grained sandstones was transported towards the north-east. The Pogórze Wiśnickie area lies north-east of the Beskid Śląski range, so the profile at Chrostowa represents the distal part of the sedimentary basin in relation to the profile at Kamesznica. Changes of frequency of various types of bedding are presented in Table 2, and changes of thickness of beds in Table 3.

At Kamesznica the following types of bedding occur listed in order of decreasing frequency: graded, multiple graded, composite: graded and laminated, laminated, composite: laminated and cross-laminated.

At Chrostowa graded bedding remains the predominant type but its relative frequency is much smaller than at Kamesznica. The frequency of multiple graded bedding is also smaller than at Kamesznica, while the frequencies of the remaining types of bedding are larger than at Kamesznica. Moreover two types of bedding absent at Kamesznica appear in the Chrostowa profile: monofractional bedding, and cross-laminated bedding, the latter forming 24,5 per cent of all beds. The term monofractional bedding is used here after K. Birkenmajer (1959).

The mean thickness of graded beds is slightly larger at Chrostowa than in the Kamesznica profile, while the maximum thickness is twice larger. The mean and maximum thicknesses of beds with multiple grading and of composite — laminated and cross-laminated-beds are smaller at Chrostowa, while those of laminated and composite — graded and laminated-beds are larger than at Kamesznica. The monofractional beds appearing at Chrostowa have a mean thickness of 81 cm, while the mean thickness of the cross-laminated beds amounts only to 7,1 cm.

Maximum grain size is distinctly smaller at Chrostowa than at Kamesznica.

These changes of frequency of types of bedding and of bed thicknesses are suggesting that graded bedding, strongly predominating in the part of the basin proximal to the source of clastic material, is partly replaced by other types of bedding in the distal parts of the basin. Some graded

Tabela (table) 2

Częstość występowania różnych typów warstwowania w piaskowcach warstw istebniańskich

Frequency of various types of bedding in sandstones of the Istebna beds

Typ warstwowania Type of bedding	Beskid Śląski (Kamesznica potok Bystra (Bystra Creek) Frequency per cent Częstość występowania w %	Pogórze Wiśnickie (Chrostowa, na wschód od Gdowa East of Gdów)
Frakcjonalne, Graded	61,0	32,7
Frakcjonalne wielokrotne, Multiple graded	19,4	6,6
Jednorodne, Homogenous	—	6,6
Złożone: frakcjonalne i laminowane Composite: graded and laminated	9,6	11,5
Laminowane, Laminated	5,0	11,5
Złożone: laminowane i przekątnie laminowane Composite: laminated and cross laminated	5,0	6,6
Przekątnie laminowane, Cross laminated	—	24,5
Computed for Zestawiono na podstawie	41 ławic (beds)	61 ławic (beds)

beds pass into the monofractional ones, as the coarse grades are dropped along the course of the depositing current, and only the material of the modal grade reaches the distal part of the basin. In other graded beds lamination appears in the upper part, producing composite bedding-graded and laminated type. Going one step farther lamination replaces graded bedding throughout the bed, and finally lamination is replaced by cross--lamination. To explain the larger values of mean and maximum thickness

Tabela (table) 3

Miąższość ławic piaskowców o różnych typach warstwowania
Thickness of sandstone beds with various types of bedding

Typ warstwowania Type of bedding	Beskid Śląski (Kamesznica, potok Bystra, Bystra Creek)			Pogórze Wiśnickie (Chrostowa, na wschód od Gdowa, East of Gdow)		
	miąższość w cm thickness cm					
	średnia mean	min. mini- mum	maks. maxi- mum	średnia mean	min. mini- mum	maks. maxi- mum
Frakcjonalne, Graded	178	8	300	198	5	600
Frakcjonalne wielokrotne Multiple graded	830	430	1200	197	60	360
Jednorodne, Homogenous	—	—	—	81	28	200
Złożone: frakcjonalne i laminowane Composite: graded and laminated	50	40	70	170	10	360
Laminowane, Laminated	7,5	5	10	13,8	5	28
Złożone: laminowane i przekątnie laminowane Composite: laminated and cross laminated	55	10	100	11,8	8	15
Przekątnie laminowane Cross laminated	—	—	—	7,1	3	30
Zestawiono na podstawie Computed for	41 ławic			61 ławic		

of the graded beds in the distal part of the basin two possibilities are taken into account; first, some of the very thick beds with multiple grading present in the proximal part of the basin might loose along the course of the depositing current their coarse-grained basal parts of the graded layers, with the exception of the lowermost one, which is usually the coarsest of all: siltstone partings being absent, the composite nature of these beds cannot be detected. Second, some of the currents might deposit throughout their courses beds graded, and increasing in thickness with increasing distance of transport. Such currents deposited only the coarsest grades near the source area, while the bulk of the clastic material was carried to the distal parts of the basin.

PETROGRAPHY

Studies of the pebbles of exotic rocks occurring in the Istebna conglomerates by S. Kreutz (1927), T. Wieser (1949), E. Głowacki (1959) and S. Wdowiarz and T: Wieser (1960) provided insight into the petrographic composition of the Silesian cordillera which was the source of the Istebna clastics. The Silesian cordillera yielded pebbles of various types of granites and quartz monzonites, porphyries, migmatites, gneissic granites, various ortho- and paragneisses (kata-mezo- and epigneisses are present), granulites and various shists, quartzites, and rare kersantites and diabases. Exotic pebbles of sedimentary rocks are also present, but they received less attention. W. Szajnocha (1925) mentioned the presence of pebbles of black chert, black quartzite, light-coloured quartzite, and grey and white limestones. Pebbles of Stramberg limestones of Tithonian age are common in the Istebna beds, with the exception of the western part of the investigated area.

The character and distribution of pebbles of exotic rocks suggests that the Silesian cordillera consisted of a crystalline core, and a metamorphic and sedimentary cover (T. Wieser 1949). In the Late Senonian the crystalline core was unroofed by erosion and provided

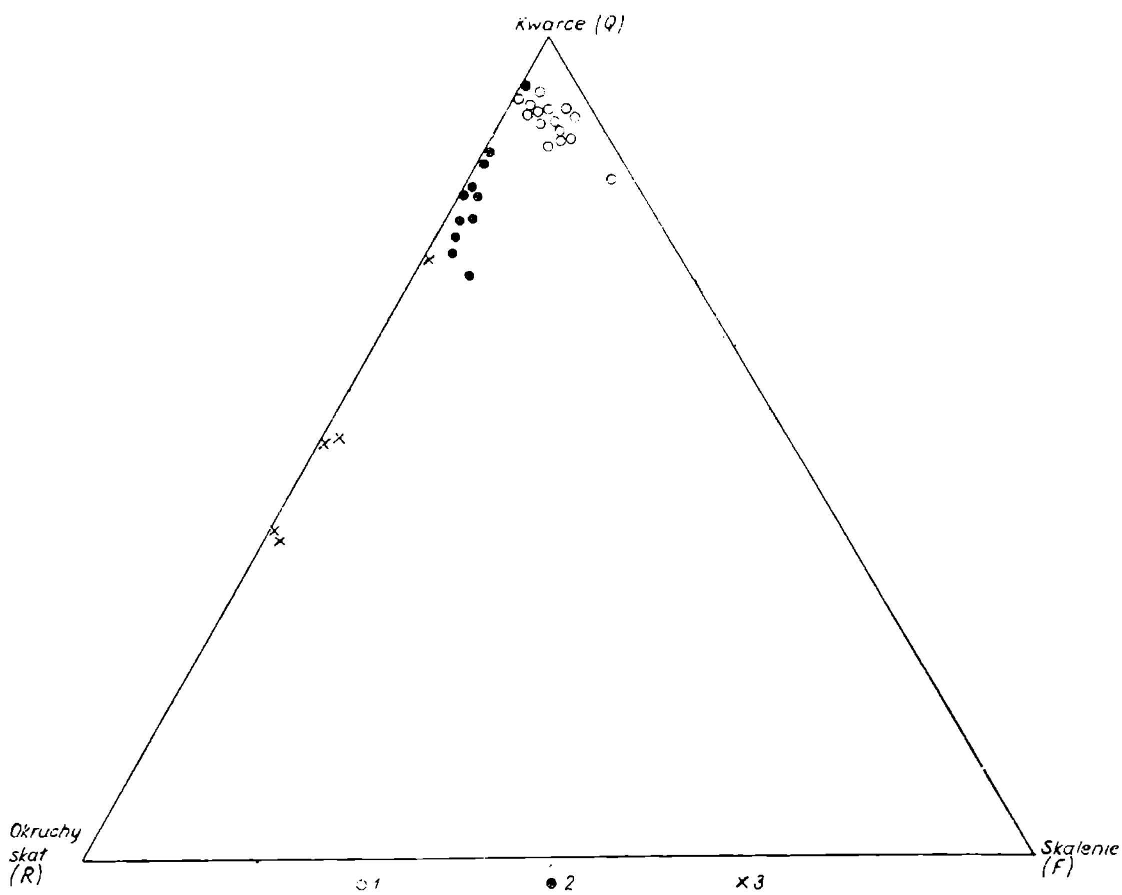

Fig. 16. Diagram składu petrograficznego zlepieńców kwarcowych i piaskowców skaleniowo-kwarcowych, żwirowców ilastych i zlepieńców egzotykowych we frakcji 2—4 mm: 1 — zlepieńce kwarcowe i piaskowce skaleniowo-kwarcowe, 2 — żwirowce ilaste, 3 — zlepieńce egzotykowe

Fig. 16. Petrographic composition of quartz conglomerates and feldspathic sandstones pebbly mudstones and polymictic conglomerates in the 2—4 mm grade: Q — quartz, F — feldspars, R — rock fragments. 1 — quartz conglomerates and feldspathic sandstones, 2 — pebbly mudstones, 3 — polymictic conglomerates

Tabela (table) 4

Skład petrograficzny zlepieńców i żwirowców
Petrographic composition of conglomerates and pebbly mudstones
Frakcja, Grade 2 — 4 mm

Próbka Sample	Zawartość w %% content per cent kwarc quartz	Skalenie feldspars	Okruchy skał rock fragments
Zlepieńce kwarcowe Quartz conglomerates			
Droginia 2	92,7	—	7,3
Kalwaria 1a	86,6	6,2	7,2
Biertowice 2	88,3	8,1	3,6
Wisła 3a	90,6	4,0	5,4
Kamesznica B28	89,0	4,8	6,2
Dziekanowice 7	82,8	15,0	2,2
Kombornia 7	90,0	7,6	2,4
Izdebnik K2	92,3	3,6	4,1
Cieszyna 2	88,9	6,0	5,1
Rożnów 8	90,7	7,1	2,2
Ciężkowice 101	87,2	7,7	5,1
Rzepiennik 1	92,7	2,6	4,7
Czarnorzeki 8	87,1	8,7	4,2
Rożnów 4	91,5	2,1	6,4
Izdebnik K1	91,1	3,6	5,3
Średnio zlepieńce kwarcowe Mean, quartz conglomerates	89,43	5,80	4,77
Zlepieńce egzotykowe Polymictic conglomerates			
Kamesznica B22	38,6	1,3	60,1
Kamesznica B8	52,0	2,0	46,0
Gorlice 2/11	73.0	1,0	26,0
Gorlice 7/11	51,0	—	49,0
Janoska 1/59	40,5	—	59,5
Średnio zlepieńce egzotykowe Mean, polymictic conglomerates	51,02	0,86	48,12
Żwirowce Pebbly mudstones			
Ciecień	77,8	2,4	19,8
Kamesznica B18	75,7	1,8	22,5
Wisła 5a	80,2	1,9	17,9
Bieśnik 2	84,7	0,7	14,6

Ciąg dalszy tabeli 4
table 4 continued

Próbka Sample	Zawartość w %% content per cent kwarc quartz	skalenie feldspars	okruchy skał rock fragments
Bieśnik 3	81,3	1,1	17,6
Droginia 1	71,0	4,4	24,6
Kamesznica B25	78,3	1,0	20,7
Bystre R1	70,0	5,0	25,0
Ciężkowice 1	86,0	1,0	13,5
Czarnorzeki 2	94,7	—	5,3
Gorlice 6/11	82,5	—	17,5
Średnio żwirowce Mean, pebbly mudstones	80,20	1,73	18,09

material for the quartz conglomerates and feldspathic sandstones of the Istebna beds.

In the present study emphasis was put on the provenance of the clastic material of the principal lithologic types of rocks occurring in the Istebna beds. i.e. of the quartz conglomerates and feldspathic sandstones, polymictic exotic-bearing conglomerates, and pebbly mudstones. Analysis were made of 31 samples of these three types of rocks collected over the whole investigated area. The samples were disaggregated by multiple crystallisation in Glauber's salt, and the grade 2—4 mm was separated by sieving for analysis. This grade was chosen for detailed study, as it was presumed that it will contain both particles of fine-grained rocks, and monomineral grains coming from coarse-grained rocks. In each sample 300—400 grains were counted, and the content of quartz, feldspar, and rock fragments was determined. The results are presented in Table 4, and in Fig. 16.

The quartz grains are belonging to transparent, grey, and white varieties. Feldspars are represented chiefly by pink orthoclase and microcline. The rock fragments comprise particles of igneous, metamorphic, and sedimentary rocks. Fine-grained quartz-feldspar-biotite rocks representing granites and probably also gneisses (the distinction between granites and gneisses is difficult in small fragments belonging to the grade studied), porphyries, biotite-shists, muscovite shists, sericite shists, and chlorite shists, quartzite-graphitic shists, black chert, fine-grained sandstones, greywackes, and white and grey limestones occur in this group. Particles of metamorphic and sedimentary rocks are more numerous than those of igneous rocks.

The quartz conglomerates and the feldspathic sandstones have the highest percentage of quartz and feldspar. The rock fragments are represented chiefly by quartzite shists and sedimentary rocks. The quartz conglomerates contain also some coarse feldspar grains, with diameters ranging up to 10 mm. This suggests strongly that the clastic material of the quartz conglomerates and feldspathic sandstones was derived from coarse-grained porphyric granites, probably of the type of the Bugaj granite described by S. K r e u t z (1927).

Tabela (table) 4

Stopień obtoczenia ziarn kwarcu w zlepieńcach, piaskowcach i żwirowcach
Roundness of quartz grains in conglomerates, sandstones and pebbly mudstones

Frakcja, Grade 0,5 — 1,0 mm

Próbka Sample	Ziarna — Grains						
	ostro krawędziste angular	pół-ostro-kraw. subangular	pół-obtocz. subrounded	obtoczone rounded	dobrze obtoczone well rounded	średni stopień obtocz. mean roundness	zawartość ziarn pochodzenia eolicznego content of dune sand grains
Zlepieńce Conglomerates							
Gorlice 2/11	56	43	1	—	—	0,159	—
Bystre R11	41	48	11	—	—	0,182	—
Kamesznica B28	45	43	12	—	—	0,180	—
Kalwaria 1a	33	53	13	2	—	0,193	2
Kamesznica B22	54	45	1	—	—	0,161	—
Biertowice 2	35	58	16	1	—	0,194	1
Kombornia 7	69	26	3	2	—	0,158	2
Kamesznica B8	54	37	12	—	—	0,179	—
Średnio zlepieńce Mean conglomerates						0,175	0,82
Piaskowce Sandstones							
Wisła CW 3	3	32	21	25	19	0,415	44
Kamesznica B23	13	22	30	17	17	0,384	34
Dziekanowice 1	27	51	19	2	2	0,218	4
Droginia 2	39	42	17	1	—	0,191	1
Droginia 3	44	35	9	4	10	0,253	14
Kombornia 3	27	56	16	1	—	0,201	1
Średnio piaskowce * Mean sandstones						0,216	5,00
Żwirowce Pebbly mudstones							
Kamesznica B25	1	28	71	—	—	0,281	—
Kamesznica B18	—	20	68	5	7	0,335	12

*) Bez próbek Wisła CW 3 i Kamesznica B 23.
Without the samples Wisła CW 3 and Kamesznica B 23.

ciąg dalszy tablicy 5
table 5 continued

Próbka Sample	Ziarna — Grains						
	ostro krawędziste angular	pół ostrokraw. subangular	półobtocz. subrounded	obtoczone rounded	dobrze obtoczone well rounded	średni stopień obtocz. mean roundness	zawartość ziarn pochodzenia eolicznego content of dune sand grains
Bieśnik 2	—	11	81	7	1	0,320	8
Ciecień 7	1	22	63	14	—	0,314	14
Jodłówka Tuch. 2	1	54	38	6	1	0,267	7
Droginia 1	9	45	34	6	4	0,283	10
Wisła CW 5	2	48	45	1	4	0,270	5
Bystre R7	36	56	5	1	2	0,198	3
Średnio żwirowce Mean pebbly mudstones						0,284	7,37

The pebbly mudstones are characterised by a lower percentage of quartz and feldspars, and a higher rock fragments content, with a marked predominance of metamorphic rocks over other types. Evidently the clastic material of the pebbly mudstones was derived principally from metamorphic rocks mantling the igneous core of the Silesian cordillera.

In the exotic-bearing polymictic conglomerates of the Upper Istebna beds the content of quartz and feldspars is still lower, while the content of rock fragments is the highest, averaging 48,12 per cent. Here the metamorphic rocks were the principal if not the only source of the clastic material.

ROUNDNESS OF QUARTZ GRAINS

The degree of rounding of the quartz grains was studied in the 0,5—1,0 mm grade, and the roundness scale of F. J. Pettijohn (1957) was used. The 0,5—1,0 mm grade was selected for detailed analysis as a „sensitive" coarse sand grade, as preliminary inspection indicated that in the finer grades practically all grains are angular. Twenty two samples of conglomerates, sandstones, and pebbly mudstones were analysed, and one hundred grains were examined in each sample. The results are presented in Table 5.

The rounded and well rounded grains present in the analysed samples as a rule have frosted surfaces, and probably attained the high degree of rounding in an aeolian environment.

The conglomerates, notwithstanding their petrographic composition, are characterised by prevalence of angular and subangular grains. Few rounded and well rounded grains occur in some samples. The mean roundness averages 0,176, and is the lowest in comparison with those of other analysed types of rocks.

In the sandstones angular and subangular grains are still prevailing, but the content of well rounded grains is somewhat higher, and the mean roundness rises to 0,216. Exeptionally two of the sandstone samples contained a very high percentage of well rounded and rounded grains.

The pebbly mudstones are characterised by the prevalence of subangular and subrounded grains, and by a higher content of rounded and well rounded grains. The mean roundness is distinctly higher than in the conglomerates and sandstones, and averages 0,284.

The data presented above lead to the conclusion that the clastic material of the pebbly mudstones remained longer in a littoral or sublittoral environment than that of the conglomerates and sandstones, and thus attained a higher mean roundness. Dunes were probably present along the coasts of the cordillera, and well rounded and frosted grains of dune sand mixed in various proportions with the clastic material accumulating on the littoral fringe.

CHARACTERISTICS OF THE SEDIMENTARY ENVIRONMENT OF THE ISTEBNA BEDS

In the preceding paragraphs evidence was presented of the different provenance history of the clastic material of pebbly mudstones, and quartz conglomerates and feldspathic sandstones. To summarise briefly the differences between these two types of rocks: the pebbly mudstones were deposited by submarine mudflows flowing to the north, and are composed of material derived in a large part from the metamorphic cover of the Silesian cordillera, and displaying an appreciable amount of abrasion prior to redeposition. Instead, the quartz conglomerates and feldspathic sandstones were deposited by sand flows and turbidity currents flowing to the north-east, east, and south-east, and are composed of material derived from the igneous core of the Silesian cordillera and displaying little abrasion before redeposition.

Results of recent oceanographic investigations indicate that sand flows and turbidity currents are developing from slumps occurring in submarine canyons (F. P. Shepard and K. O. Emery 1941; D. B. Ericson, H. Ewing, B. C. Heezen, 1951; J. C. Crowell, 1952; H. W. Menard 1955, 1960; D. S. Gorsline and K. O. Emery, 1959; J. Bourcart, M. Genesseau, E. Klimek 1960). Many authors assumed that the turbidity currents depositing sandstone beds in flysch series flowed into the sedimentary basins through submarine canyons (J. C. Crowell, 1955, S. Dżułyński, M. Książkiewicz, Ph. H. Kuenen, 1959; J. L. Knill, 1959; A. Radomski, 1962).

Sandstones and conglomerates deposited by turbidity currents and pebbly clays deposited by slumps occurring within one sedimentary basin (The Santa Monica basin off Southern California) were recently described by D. S. Gorsline and K. O. Emery (l. cit.). The turbidity currents flowed into the basin through submarine canyons, while the slumps depositing the pebbly clays were formed in the sedimentary apron covering the continental slope.

Thus,[5] extending the results of recent oceanographic studies on the sedimentary environment of the Istebna beds, the author is inclined to summarise the conditions of sedimentation of this formation in the following way:

The detrital material of the quartz conglomerates and feldspathic sandstones derived from the central igneous core of the Silesian cordillera rich in coarse-grained rocks with porphyric texture and in pegmatites (cf. T. Wieser, 1949), and transported to the sea by streams with steep gradients and large transporting power, accumulated rapidly in the littoral zone, and was periodically redeposited into the deep trench adjacent to the cordillera by sand flows and turbidity currents flowing through submarine furrows dissecting the slopes of the cordillera, and more or less similar to recent submarine canyons. Strong supply of detrital material caused frequent slumping and leaved no time for any stronger abrasion of the sand.

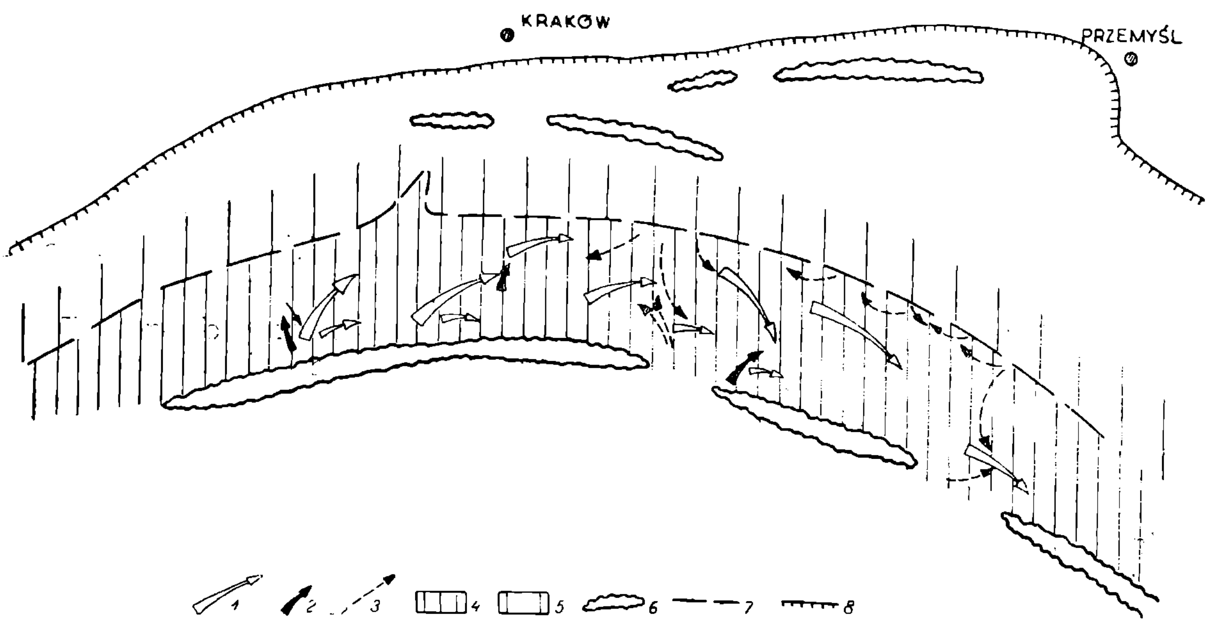

Fig. 17. Rozkład facji i kierunków transportu w dolnych warstwach istebniańskich (kampan — mastrycht): 1 — kierunki transportu w zlepieńcach i piaskowcach grubołwicowych, 2 — kierunki transportu w żwirowcach ilastych, 3 — kierunki transportu w piaskowcach cienkoławicowych. 4 — basen sedymentacyjny warstw istebniańskich, 5 — basen sedymentacyjny pstrych margli węglowieckich (seria podśląska), 6 — kordyliera śląska, 7 — granica basenu sedymentacyjnego śląskiego i podśląskiego, 8 — brzeg nasunięcia karpackiego

Fig. 17. Facies distribution and directions of transport of the detrital material in the Lower Istebna beds (Campanian — Maestrichtian): 1 — transport directions of conglomerates and thick-bedded sandstones, 2 — transport directions in pebbly mudstones, 3 — transport direction in thin-bedded sandstones, 4 — sedimentary basin of the Istebna beds, 5 — sedimentary basin of the variegated Węglówka marls (Sub-Silesian series), 6 — Silesian cordillera, 7 — boundary of the sedimentary basins of the Silesian and Sub-Silesian series, 8 — northern border of the Carpathian overthrust

The clastic material of the pebbly mudstones was derived from the metamorphic outer zone of the cordillera, and accumulated on such sectors of the littoral fringe where no larger streams entered the sea. On such sectors the accumulation was slower and the clastic material was subject to pronounced abrasion before redeposition in deep water. Slower accumulation made also possible the formation of a large admixture of dune sand grains. The very high content of dune sand grains in some sandstone beds may be easily accounted for, if one imagine that dunes present along the coasts of the cordillera entered sometimes the heads of submarine canyons.

It is well known that the clastic material carried by turbidity currents flowing through submarine canyons is accumulated in the form of submarine fans. Some fossil submarine fans were described from the Carpathian Flysch — in the Pasierbiec sandstones (S. Dżułyński, M. Książkiewicz, Ph. H. Kuenen, 1959), in the Szydłowiec sandstones (M. Książkiewicz, 1962), and from the Modelo formation in California (H. H. Sullwold, 1960). In all these cases the detrital material was carried from the sides to the elongated sedimentary basins. The fossil fans are recognised on account of the shape of sandstone bodies, and of the distribution of the current directions.

In the Lower Istebna beds there is no appreciable variations of grain size along the longest axis of the basin, i.e. in the east-west direction. This suggests that the detrital material was supplied to the sedimentary basin along the whole cordillera, probably through several submarine furrows.

Direct evidence of the existence of submarine fans in the Lower Istebna beds are lacking, but two features can be explained easily, assuming that several coalescent fans were formed in the sedimentary basin. In some areas (Beskid Śląski, Gorlice fold) transport directions in neighbouring sandstone beds show a difference of about 45° [1]. Possibly such areas are representing the coalescing margins of two submarine fans.

The distribution of the pebbly mudstones in the Lower Istebna beds is not uniform. In some areas (Beskid Śląski, Gorlice fold) the pebbly mudstones are numerous, and may form up to about 40 per cent of all beds. Elsewhere (e.g. in the Beskid Mały) the pebbly mudstones are much less frequent. Possibly the zones with rare pebbly mudstone beds are representing axial portions of the submarine fans, while those rich in pebbly mudstones represent the marginal parts of the fans.

In the Upper Istebna beds there is better evidence for the existence of submarine fans. In the external facial zone two large sandstone fans are present in the western and in the eastern part of the area studied, separated by a zone in which the Upper Istebna sandstones are poorly developed and replaced by siltstones. Within the fans, the sandstones of the Upper Istebna beds are entering into the sedimentary basin of the Sub-Silesian series (Fig. 18). In the western fan wedges of Upper Istebna sandstones are present in the Sub-Silesian series in the area of Bielsko (W. Nowak 1956, 1959) in the tectonic window of Żywiec (S. Geroch and R. Gradziński, 1955) and in the Wadowice area (M. Książkiewicz, 1951 a). The central shaly zone separating the two fans covers the northern part of the Silesian nappe south of Bochnia (K. Skoczylas-Ciszewska, 1952) south of Brzesko and Tarnów (K Konior, 1946), and the Brzanka—Liwocz fold (A. Radomski 1950, unpublished M. Sc. thesis). In the eastern fan occurrences of Upper Istebna sandstones

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[1] These differences in directions of various currents should be not confused with variations of direction of one current marked by sets of groove casts with various orientation, and other directional structures within one bed (E. ten Haaf, 1959).

within the Sub-Silesian series south of Pilzno, and in the Sanok area were noted by L. Koszarski (1956).

The origin of the intercalations of thin-bedded sandstones („Inoceramian type" and others) remain not clear. The thin-bedded sandstones are typical turbidites. The detrital material of the major part, if not of all of them, was derived not from Silesian cordillera, but from some other sources. As indicated by transport directions these sources lay somewhere north of the sedimentary basin of the Istebna beds. In the east the existence of some connections of the Silesian basin with the Skole basin is probable, and some detrital material might be carried through them, while in the west the appearance of the intercalations of thin-bedded sandstones may be related with movements which led to the formation of the Inwałd cordillera. The solution of the problem of provenance of the detrital material of the thin-bedded sandstones requires further petrologic studies.

Further consideration will be given now to the facial development of the Upper Istebna beds. As stated before, in the southern facial zone lenticular bodies of the Upper Istebna sandstones are locally replacing the Lower Istebna shales. In the northern facial zone the Lower Istebna shales are generally absent, while the Upper Istebna sandstones are lying directly on the Lower Istebna sandstones, forming two large fans.

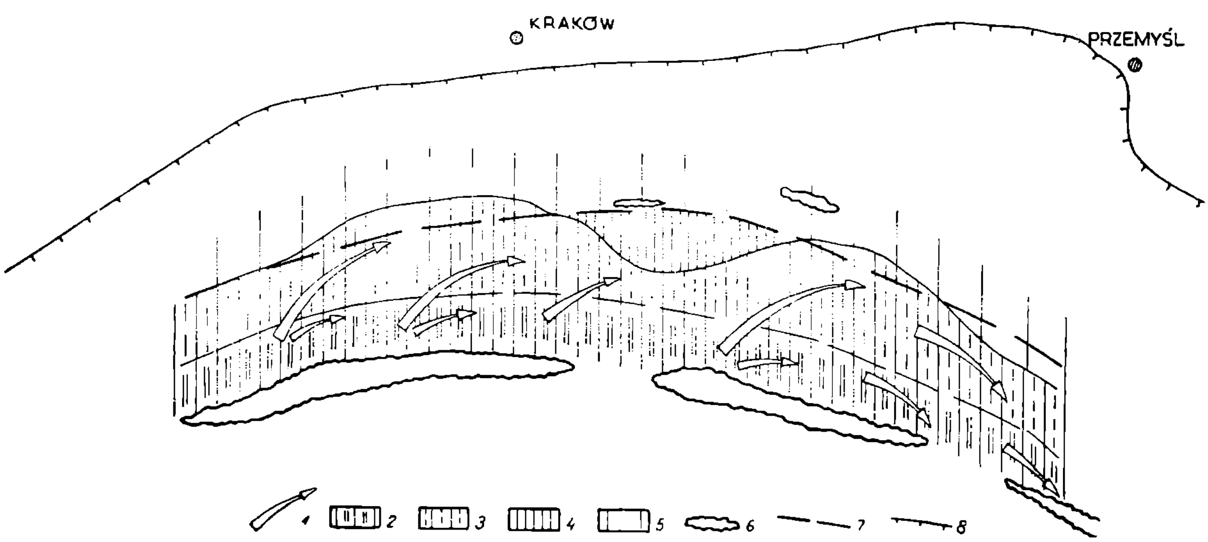

Fig. 18. Rozkład facji i kierunków transportu materiału klastycznego w górnych warstwach istebniańskich (paleocen): 1 — kierunki transportu w piaskowcach i zlepieńcach, 2 — wewnętrzna strefa facjalna basenu sedymentacyjnego warstw istebniańskich, 3 — zewnętrzna strefa facjalna basenu sedymentacyjnego warstw istebniańskich — rejony o wykształceniu piaskowcowym bez dolnych łupków istebniańskich, 4 — zewnętrzna strefa basenu sedymentacyjnego warstw istebniańskich, rejon o wykształceniu głównie łupkowym, 5 — basen sedymentacyjny pstrych margli węglowieckich (seria podśląska), 6 — kordyliera śląska, 7 — przyszła granica płaszczowiny śląskiej i podśląskiej, 8 — brzeg nasunięcia karpackiego

Fig. 18. Facies distribution and directions of transport of detrital material in the Upper Istebna beds (Paleocene): 1 — transport directions in sandstones and conglomerates, 2 — internal facial zone of the sedimentary basin of the Istebna beds, 3 — external facial zone of the sedimentary basin of the Istebna beds — regions in which the Lower Istebna shales are absent, 4 — external facial zone of the sedimentary basin of the Istebna beds, region with poor development of sandstones, 5 — sedimentary basin of the variegated Węglówka marls (Sub-Silesian series), 6 — Silesian cordillera, 7 — future boundary of the Silesian and Sub-Silesian nappe, 8 — border of the Carpathian overthrust

The lenticular bodies of the Upper Istebna sandstones present in the southern facial zone are tentatively interpreted as the fill of several submarine furrows through which the coarse-grained detrital material was transported by sand flows and turbidity currents befor spreading out and forming the fans in the northern zone. The silstones and pebbly mudstones of the Lower Istebna shales were deposited by submarine mudflows and diluted turbidity currents between the furrows which acted as localised conveyors of the coarse-grained detrital material.

The facial changes occurring on the Senonian-Paleocene boundary, and the characteristic petrographic composition of the conglomerates of the Upper Istebna beds, are marking the beginning of the tilting movement of the Silesian cordillera which stopped the supply of detrital material from the igneous core of the cordillera (M. Książkiewicz 1960 a), and exposing successively its metamorphic and Cretaceous Flysch cover during the Paleogene resulted in the quite different petrographic composition of the Paleogene formations overlying the Istebna beds in the Silesian series.

CONCLUDING REMARKS

The Istebna beds were deposited in a trench adjacent to the Silesian cordillera which was the source of the detrital material. The quartz conglomerates and the feldspathic sandstones are composed of material derived from igneous rocks forming the core of the cordillera, while the polymictic conglomerates and the pebbly mudstones are composed of material derived from the metamorphic outer zone of the cordillera. The detrital material of the conglomerates and sandstones was subject to only slight reworking before redeposition, while that of the pebbly mudstones to a more pronounced one. The material of the conglomerates and of the sandstones was transported from the littoral fringe of the cordillera into the trench by sand flows and turbidity currents flowing through submarine furrows more or less similar to recent submarine canyons. Instead, the submarine mudflows depositing the pebbly mudstones developed in the sedimentary apron covering the insular slope of the cordillera. Dunes were present along the coasts of the cordillera, and the well rounded dune sand grains mixed in various proportions with the material accumulated on the littoral fringe. Pelites are represented chiefly in the Istebna beds by siltstones deposited by diluted turbidity currents, while true pelagic shales are rare.

Fluxoturbidite deposits are characterised by lenticular shape of beds, coarseness of detrital material, great thickness of beds, low pelite content, prevalence of symmetrical, multiple, and discontinuous grading over other types of bedding, and occurrence of non-graded beds, traces of strong erosion, lack of sole markings, and poor development of pelitic sediments. Occurrence of armored shale balls arranged in regular layers parallel to the bedding planes within sandstone beds points out to the transition of sand flows into turbidity currents.

Siltstones and shales should be carefully distinguished in redeposited sequences. The silstones characterised by a large admixture of sand grades, good sorting, high positive skewness of grain-size distribution, presence of graded and laminated bedding, large content of carbonised plant detritus, and lack of authochtonous microfauna, were deposited by tenuous clouds of suspension accompanying the sand flows and mudflows. The shales do not contain appreciable amounts of sand grades, are structureless, poorly sorted, have low skewness of grain-size distribution, are devoid of carbonised plant detritus, and contain authochtonous microfauna. They represent the normal pelagic sediment of the basin, but in fluxoturbidite sequences they are poorly developed in comparison with the turbidity-current-deposited siltstones.

Pebbly mudstones deposited by submarine mudflows may form an important constituent of fluxoturbidity sequences.

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OBJAŚNIENIA TABLIC

EXPLANATION OF PLATES

Tablica (Plate) V

Fig. 1. Fragment ławicy zlepieńca o warstwowaniu bezładnym. Widoczny brak wysortowania i słabe obtoczenie materiału. Górne piaskowce istebniańskie, Kamesznica, potok Janoska. Długość główki młotka 14 cm.

Fig. 1. Fragment of a structureless conglomerate bed. Note poor sorting and poor rounding of the detrital material. Upper Istebna sandstones, Kamesznica, Janoska creek (Beskid Śląski). The head of the hammer is 14 cm long.

Fig. 2. Soczewki grubcziarnistego materiału przy stropie grubej ławicy o warstwowaniu frakcjonalnym odwróconym pensymetrycznym. Górne warstwy istebniańskie, Kamesznica, potok Janoska (Beskid Śląski). Długość młotka 40 cm.

Fig. 2. Lenses of coarse-grained material near the top of a thick bed with inverted pensymmetric graded bedding. Upper Istebna sandstones, Kamesznica, Janoska creek, (Beskid Śląski). The hammer is 40 cm long.

Tablica (Plate) VI

Fig. 1. Cienka warstwa piaszczystego mułowca bogatego w sieczkę roślinną w stropie ławicy zlepieńca kwarcowego. Dolne piaskowce istebniańskie, Biertowice koło Kalwarii, kamieniołom.

Fig. 1. A thin layer of sandy siltstone with abundant plant detritus at the top of a quartz conglomerate bed. Lower Istebna sandstones, Quarry at Biertowice near Kalwaria

Fig. 2. Odsłonięta śródławicowa powierzchnia pokryta kolistymi wgłębieniami po wypadłych toczeńcach łupkowych. W jednym ze śladów zachowany pancerz gruboziarnistego materiału pokrywający powierzchnię toczeńca. Dolne piaskowce istebniańskie, kamieniołom w Rożnowie, poniżej zapory. Długość młotka 40 cm

Fig. 2. Exposed surface of a shale balls horizon, covered with casts of flattened shale balls. A pebbly armor is preserved in one of the casts. Lower Istebna sandstones, quarry at Rożnów (south of Czchów). The hammer is 40 cm long

Tablica (Plate) VII

Kamieniołom w Rożnowie powyżej zapory. Widoczne ścięcia erozyjne cienkich ławic oraz ławice o warstwowaniu złożonym. Dolne piaskowce istebniańskie

The quarry at Rożnów (south of Czchów). Note the erosional character of the sole of the upper thick bed, and the presence of complex beds. Lower Istebna sandstones

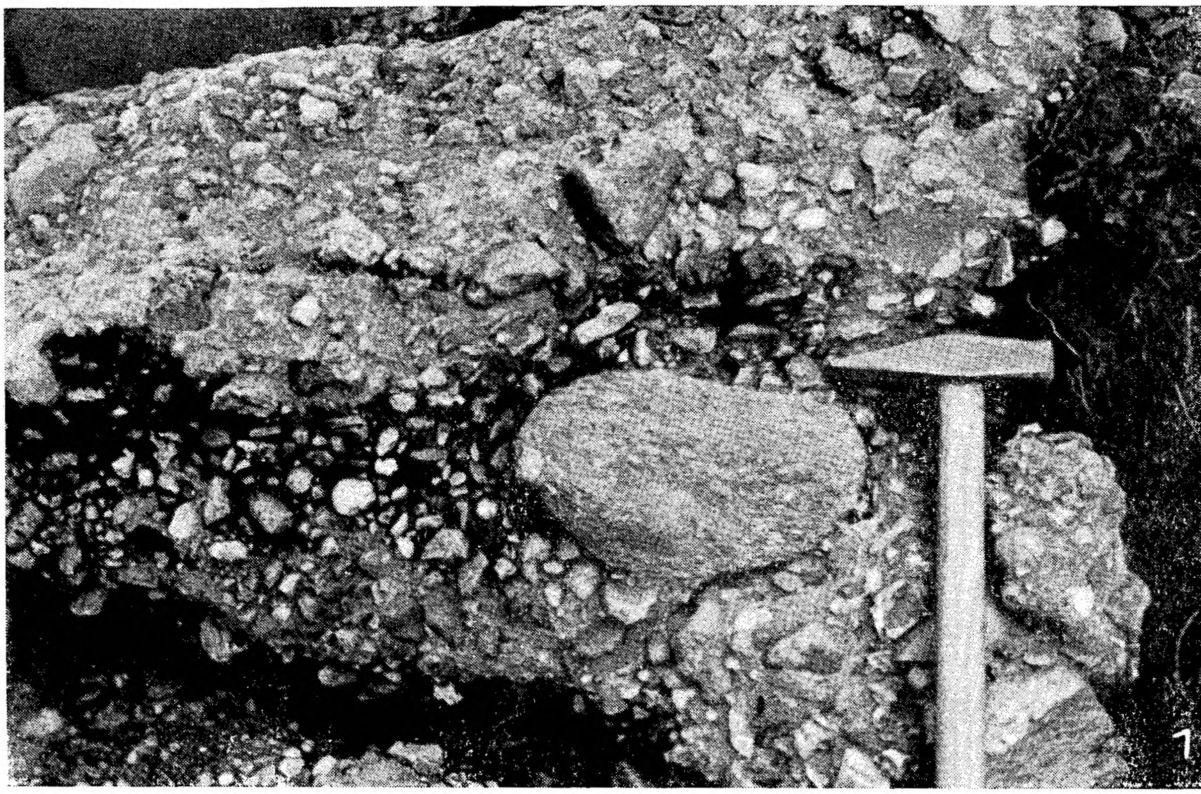
Tablica (Plate) VIII

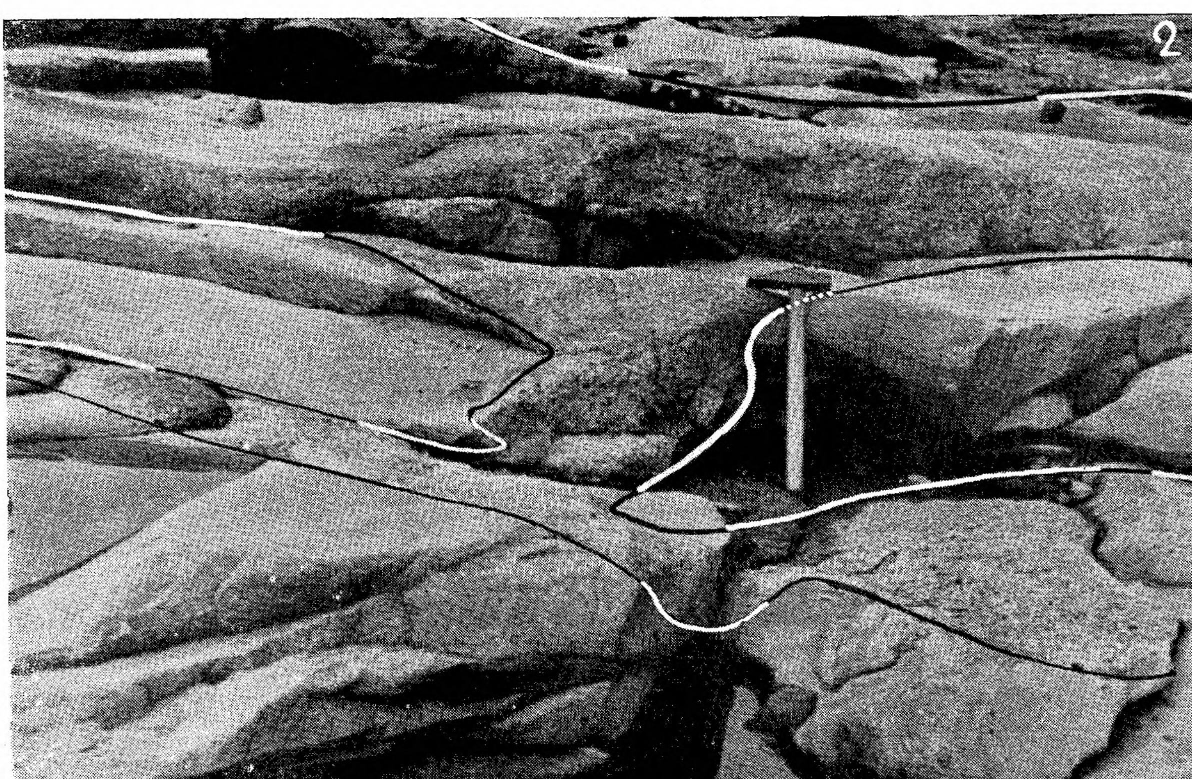
Fig. 1. Górne łupki istebniańskie z cienkimi ławicami syderytycznych piaskowców i soczewkowatą żyłą piaskowcową. Kamesznica, potok Janoska (Beskid Śląski)

Fig. 1. Upper Istebna shales, with thin beds of sideritic sandstones, and a lenticular clastic dike. Kamesznica, Janoska creek (Beskid Śląski)

Fig. 2. Kanały żerowiskowe na spągu grubej ławicy piaskowca. Dolne warstwy istebniańskie, Kamesznica, potok Bystra. Długość młotka 40 cm

Fig. 2. Burrows on the sole of a thick sandstone bed. Lower Istebna beds, Kamesznica, Bystra creek. The hammer is 40 cm long





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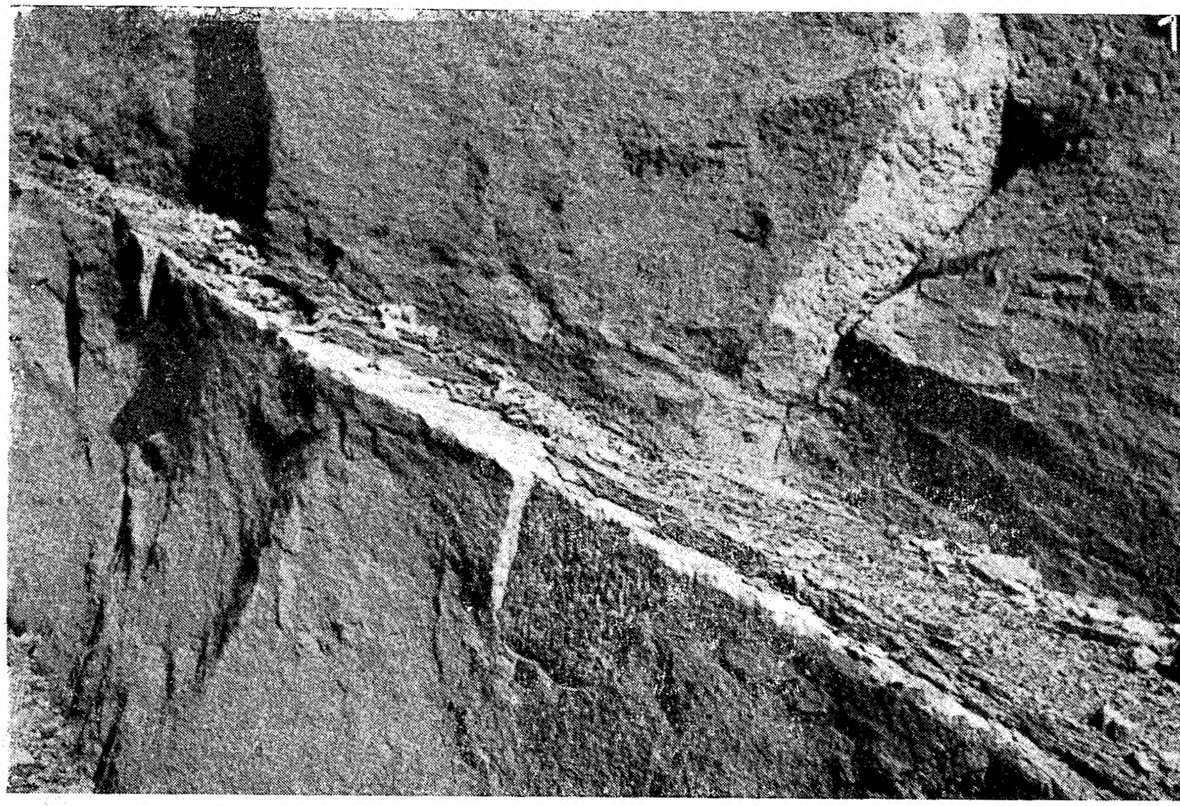

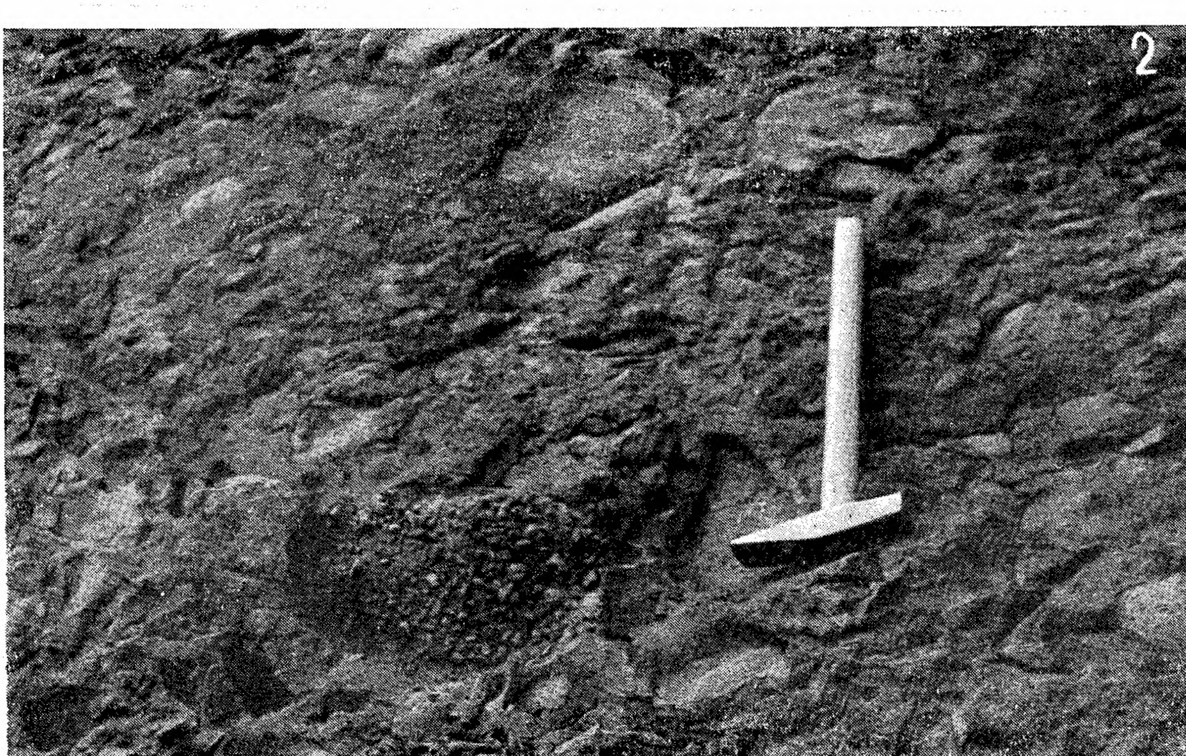

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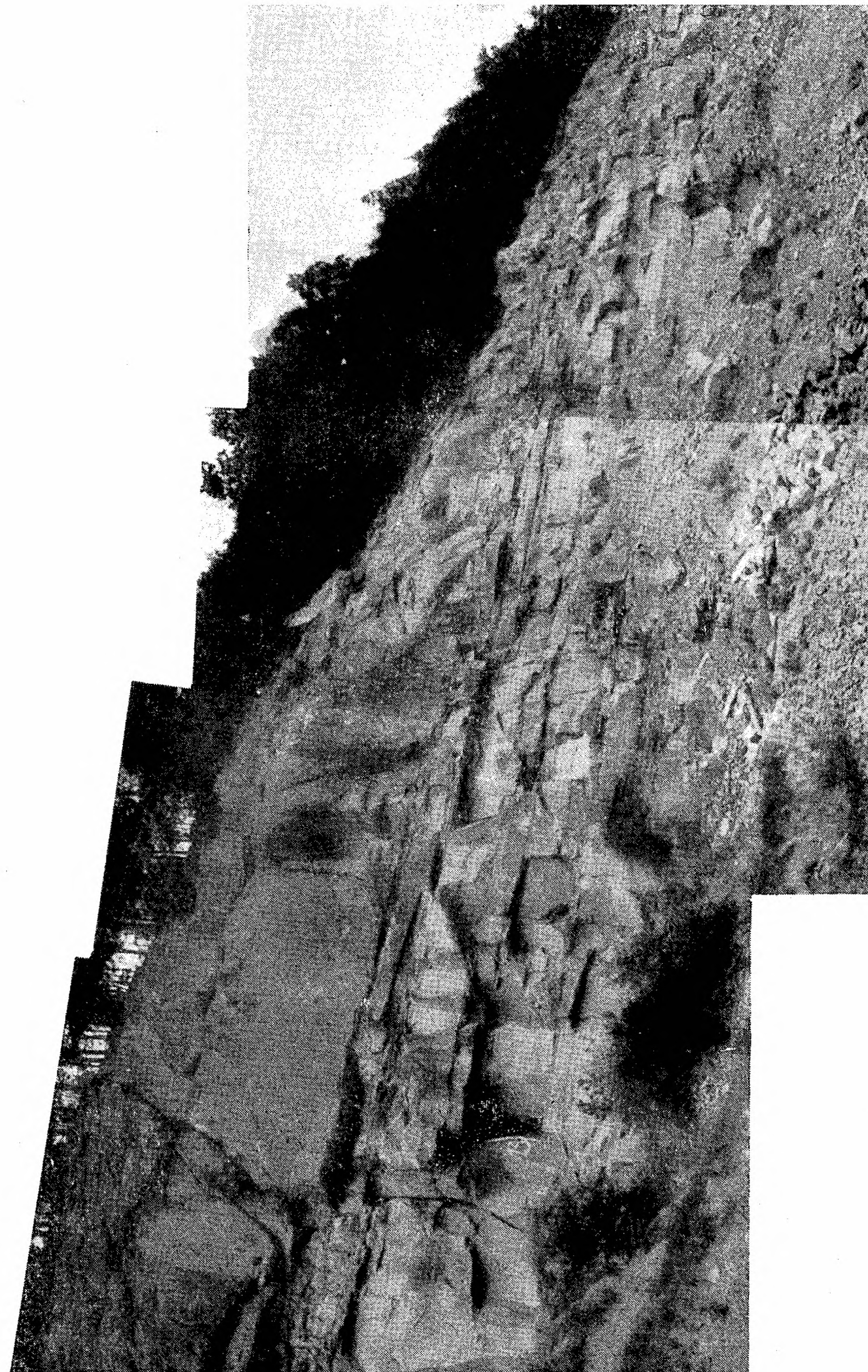

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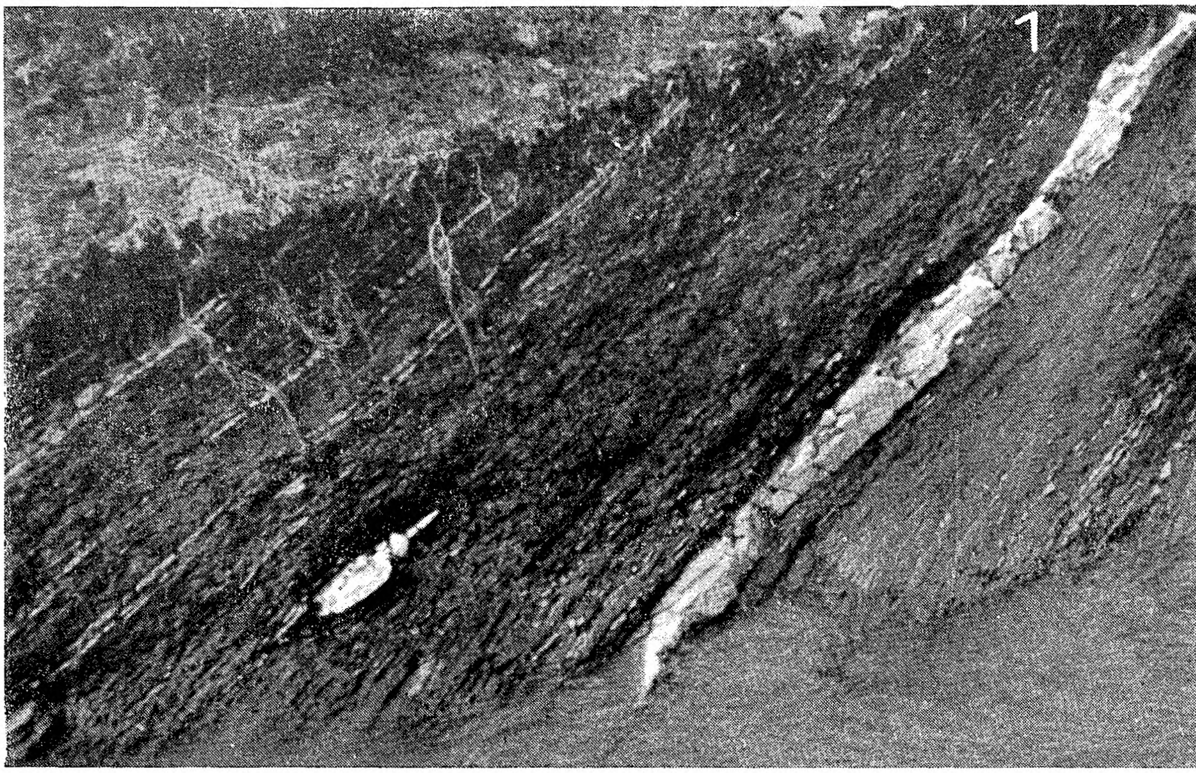

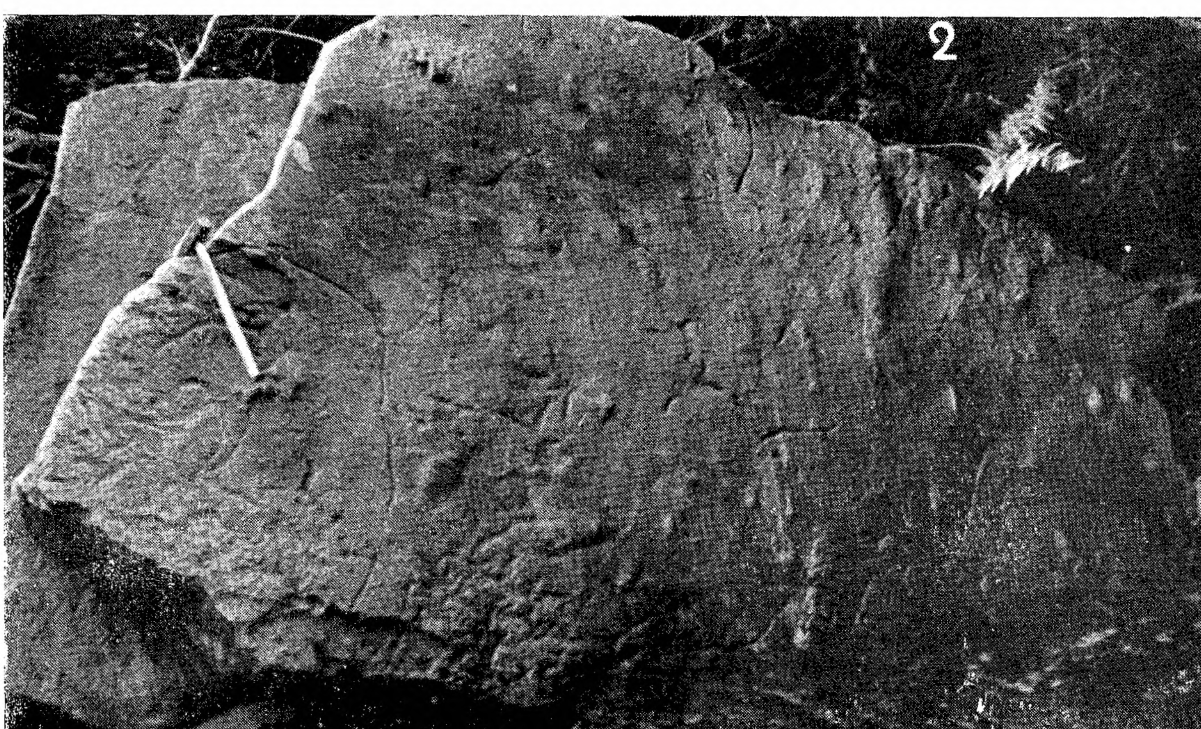

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