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O SEDYMENTACJI ŚRODKOWEGO EOCENU SERII MAGURSKIEJ W POLSKICH KARPATACH ZACHODNICH

(Tabl. VI—XI, 18 fig.)

Sedimentation of the Middle Eocene of the Magura Series, Polish western Carpathians

(Pl. VI—XI, 18 Figs.)

STRESZCZENIE

Metody badań poprzednio stosowane przez N. B. Wassojewicza i A. B. Wisteliusa zostały przyjęte w niniejszym studium sedymentologicznym skał fliszowych znanych z prac M. Książkiewicza.

Badania autora nad sedymentacją osadów środkowego eocenu serii magurskiej (piaskowców pasierbieckiego, warstw hieroglifowych i piaskowca magurskiego) dotyczyły głównie następujących problemów: 1) istnienia periodyczności w procesie depozycji osadów fliszowych, 2) wyróżnienia na podstawie struktur wewnętrznych poszczególnych subelementów w obrębie ławic, 3) obecności i charakteru struktur międzyrytmowych, 4) rozmieszczenia śladów pochodzenia organicznego, 5) zastosowania małych otwornic jako wskaźników warunków hydrodynamicznych. Poza interpretacją obserwowanych zjawisk w oparciu o literaturę geologiczną i oceanograficzną zastosowano w pracy metody matematyczne do badania szeregów czasowych.

Obszar objęty badaniami terenowymi przedstawia fig. 1. Stosunki facjalne i kierunki transportu materiału klastycznego przedstawione na fig. 2 są znane z prac Książkiewicza (1948, 1958, 1960, 1966; patrz także Geroch et al., 1967, i Bieda et al. 1967). Sedymentacja tych trzech formacji, jak również w mniejszym stopniu innych formacji tego samego wieku jest tu opracowana z zamiarem określenia mechanizmu kierunków transportu i warunków środowisk depozycji.

W oparciu o kryteria stosowane przez Wassojewicza (1948) autor na podstawie ogólnych cech petrograficznych wyróżnia w badanych osadach fliszowych dwa elementy. Jako element I określane są: zlepieniec lub piaskowiec lub też mułowiec; jako element II: łupek piaszczysty, łupek marglisty lub margiel. W obrębie elementów na podstawie

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struktur wewnętrznych wyróżniane są ponadto subelementy. Ze względu na to, że w badanych osadach istnieje rytmiczne powtarzanie się zarówno elementów, jak i istniejących w ich obrębie subelementów, autor dla określenia zespołu złożonego z elementu I i nadległego elementu II stosuje nazwę rytmu. Natomiast termin ławica używany jest przez autora w znaczeniu ogólnym dla określenia bądź całego rytmu, bądź też poszczególnych elementów. Miąższość ławic podawana jest zgodnie z klasyfikacją Ingrama (1954).

Według terminologii Gilberta (w Williams et al., 1954) elementy I piaskowca magurskiego, warstw hieroglifowych, piaskowca pasierbieckiego i warstw beloweskich mogą być uznane za szarogłazy z różnorodnymi proporcjami tła (ziarna o średnicy mniejszej niż 0,02 mm), w piaskowcach osieleckich natomiast występują piaskowce kwarcowe. Cechy petrograficzne piaskowców z badanych formacji podane są w postaci trójkątnego diagramu (kwarc — fragmenty skał i łyszczyki — skalenie) na fig. 3A i B. Stosunkowo duża ilość polikrystalicznego kwarcu, świeżych skaleni, łyszczyków i fragmentów skał (głównie produktów regionalnego metamorfizmu) w elementach I od średnich do bardzo grubych kategorii miąższości należących do piaskowca magurskiego, pasierbieckiego i osieleckiego pozwala sądzić, iż materiał tych formacji podlegał krótkotrwałemu transportowi, a następnie był szybko deponowany. Można zatem wnosić, że obszar depozycji znajdował się blisko obszaru źródłowego. Warstwy hieroglifowe i beloweskie, z drugiej strony, wykazują brak niestabilnych składników i były prawdopodobnie osadzane stosunkowo daleko od obszaru źródłowego. W każdej z opisywanych formacji (warstw), a szczególnie w piaskowcu pasierbieckim obserwuje się detrytyczne fragmenty skał pochodzące z tej samej formacji; fragmenty te zostały wyerodowane zarówno z elementów I jak i II.

Na warstwy beloweskie i hieroglifowe jak również zespoły ławic w piaskowcu magurskim, pasierbieckim i osieleckim głównie składają się bardzo cienkie i cienkoławicowe elementy (zob. tabl. VI, fig. 1). Uzupełniające się elementy tych kategorii miąższości ławic zwykle wykazują proste uwarstwienie frakcjonalne (proste rytmy) nałożone na pionowo następujące po sobie subelementy. Elementy II wyższych kategorii miąższości ławic występują stosunkowo rzadko w wszystkich badanych formacjach. Głównie występują one jako margle, margle ilaste i łupki margliste.

Średnio-, grubo- i bardzo gruboławicowe elementy I występuje powszechnie w piaskowcu magurskim, pasierbieckim i osieleckim (zob. tabl. VI, fig. 2; tabl. VII, fig. 1), gdzie tworzą większą część złożonych rytmów z wielokrotnym uwarstwieniem frakcjonalnym. Tego rodzaju złożone rytmy mogą odzwierciedlać albo przyspieszenie procesu sedymentacji, albo erozję wcześniej osadzonego rytmu przed lub w czasie osadzania następującej warstwy (patrz fig. 4).

Szczegółowe obserwacje i pomiary rytmów oraz kolejności subelementów zostały przeprowadzone w kilkunastu większych odsłonięciach. Ze względu na znaczne deformacje tektoniczne w badanym obszarze powiązanie danych uzsykanych w poszczególnych odsłonięciach nie jest możliwe.

W pojedynczych rytmach boczne zmiany w miąższości elementów (fig. 5) dają się zauważyć jako:

1. Falisty charakter powierzchni kontaktowych między uzupełniającymi się elementami (I i II) w rytmach bardzo cienkich, cienkich i średnich klas miąższości ławic należących do wszystkich formacji.
2. Rzadko występujące, izolowane soczewki drobnoziarnistego pia-

skowca w łupkach znalezione w niektórych przekrojach warstw hieroglifowych.

3. Wypełnione osadem frakcji piaszczystej rozmycia w łupkach, które mogą obcinać niżejległe rytmy. Dają się one zauważyć w zespołach cienkich i średniogrubych ławic warstw hieroglifowych i piaskowca magurskiego.

4. Rozmycia utworzone na stropach elementów I w piaskowcu pasierbieckim, wypełnione cienkimi naprzemianległymi ławicami piaskowców i łupków.

Pomimo, że pojedyncze pomiary w kolejności rytmów miąższości zauważone w odsłonięciach osadów fliszowych nie są ilościowymi funkcjami czasu, kolejne wartości mogą tworzyć naturalne grupy odznaczające się systematycznym zróżnicowaniem, które może, lecz nie musi być zależne od czasu. Kolejne wartości miąższości ławic dla profilów w piaskowcu magurskim i warstw hieroglifowych (zob. rozkłady miąższości elementów I i II w fig. 6 i 7) zostały przedstawione jako nie wygładzone szeregi czasowe o $\log_{10} (u_1, u_2, u_3, \ldots, u_{N-1}, u_N)$ jako rzędne, a numery rytmów $1, 2, 3, \ldots, N-1, N$ jako odcięte, przy czym u = miąższości elementów lub rytmów i N = ogólna suma kolejności rytmów. Czasowe kierunki zmienności sedymentacji (Wistelius, 1961 b), dla N-20 terminów były badane według wzoru 21-terminu Spencera:

$$u'_0 = \frac{1}{350} [60u_0 + 57(u_{-1} + u_{+1}) + 47(u_{-2} + u_{+2}) \\ + 33(u_{-3} + u_{+3}) + 18(u_{-4} + u_{+4}) \\ + 6(u_{-5} + u_{+5}) - 2(u_{-6} + u_{+6}) \\ - 5(u_{-7} + u_{+7}) - 5(u_{-8} + u_{+8}) \\ - 3(u_{-9} + u_{+9}) - (u_{-10} + u_{+10})].$$

Autor podjął też próbę określenia względnie małej periodyczności w terminach *n*-4 w oparciu o podany przez Shepparda wzór 5-terminu:

$$u'_0 = \frac{1}{35} [17u_0 + 12(u_{-1} + u_{+1}) - 3(u_{-2} + u_{+2})].$$

Pochodne tych wzorów są podane przez Whitakera i Robinsona (1929). Oba wzory były szeroko stosowane przez Wisteliusa w celu uwypuklenia czasowych kierunków zmienności sedymentacji (patrz Wistelius, 1961 a, 1961 b). W niniejszej pracy wykresy z wygładzonymi ekstremami zostały obliczone za pomocą programu t 5/68 opracowanego dla maszyny UMC-1 (Jelonek i Simpson, 1968).

Z 3000 rytmów (czyli z 9000 nie wygładzonych wartości i 18 000 wygładzonych wartości) badanych w szeregach czasowych kolejność rytmów w piaskowcu magurskim w kamieniołomie w Osielcu (tabl. VI, fig 2; fig. 8—10) i w warstwach hieroglifowych odsłoniętych w brzegu potoku w Zawoi-Wilcznej (tabl. VI, fig. 1; fig. 11—13) została uznana za najbardziej reprezentatywną dla dokładnego opisu (patrz także tabela 1). Logarytmicznie normalny rozkład liczebności miąższości ławic dla I i II typu elementów tych profilów jest uwidoczniony na fig. 6 i 7. Jasno zdefiniowane kierunki zmienności widoczne w nie wygładzonych szeregach czasowych dla I typu elementów i rytmów piaskowca magurskiego (fig. 8A, C) są zaznaczone w wygładzonych ekstremach szeregów czasowych (fig. 9A, C; 10A, C). Cienkoławicowe zespoły rytmów składające się przeważnie z prostych rytmów drobnoziarnistych piaskowców i mułowców przechodzących w łupki dają się zauważyć w szeregach czasowych jako zgrupowane oscylacje (Nederlof 1959, str. 653—660) o minimalnych odchyleniach.

Oscylacje te są rozdzielone seriami fluktuacji, w których bardzo gruboławicowe elementy I (i rytmy) leżą między przedstawicielami grubych i średnich kategorii miąższości. Te grubsze kategorie miąższości zawierają stosunkowo dużo rytmów złożonych z elementów I w postaci średnioziarnistych piaskowców. Ławice, które dają te fluktuacje, oddzielone są przez bardzo cienkoławicowe, i czasami średnioławicowe elementy I. Szeregi czasowe dla elementów II (fig. 8B, 9B, 10B) wykazują małą zmienność z przeważającymi cienkoławicowymi i bardzo cienkoławicowymi elementami. Fluktuacje w tychże odpowiadają fluktuacjom z elementów I (por. fig. 8, 9, 10).

W profilu odsłonięcia warstw hieroglifowych w Wilcznej czasowe kierunki zmienności sedymentacji prostych rytmów (tabl. VI, fig. 1; fig. 11—13) dają się określić seriami zgrupowanych oscylacji o zróżnicowanej skali zmienności. Otrzymano zgodność między szeregami czasowymi dla elementów I i II. Zgrupowane oscylacje charakterystyczne dla warstw hieroglifowych, a także zauważone w piaskowcu magurskim wskazują na słabą periodyczność w procesie osadzania. Regularna naprzemianległość zgrupowanych oscylacji i serii fluktuacji w piaskowcu magurskim wskazuje na silnie periodyczne, ilościowe zmiany sedymentacji. Periodyczność ta może być rezultatem bądź periodyczności ruchów tektonicznych w obszarze źródłowym, bądź periodycznych zmian klimatu albo też obu tych czynników jednocześnie. Brak materiału porównawczego uniemożliwia jednak ostateczne rozstrzygnięcie tego problemu.

Zjawiska odzwierciedlające deformacje ławic podczas sedymentacji występują w badanych formacjach względnie rzadko, a głównie jako osuwiska pojedynczych ławic (na przykład, patrz tabl. VII, fig. 2) i intruzje piaszczyste.

Rytmy badanych formacji odznaczają się ograniczoną skalą w typie struktur wewnętrznych (zob. tabl. VIII, a także Simpson, w druku). Często kilka odmiennych struktur nazywanych w pracy subelementami występuje razem na różnych poziomach tego samego rytmu. W prostych rytmach te subelementy występują od dołu ku górze w kolejności podanej przez Nesteroffa (1961), Boumę (1962, 1964) i Ballance'a (1964): uwarstwienie frakcjonalne (A), piaszczyste poziomo usytuowane warstewki (B), uwarstwienie przekątne (C), mułowe poziomo usytuowane warstewki (D), łupek bez struktur (E). W złożonych rytmach kolejność ta jest także zachowana, chociaż może zachodzić pionowe powtórzenie struktur. W pracy tej, jako osobny subelement zostało wprowadzone uwarstwienie konwolutne (C'). Każda kolejność, w której składniki powtarzają się periodycznie, może być opisana w postaci macierzy, której współrzędne są prawdopodobieństwami przejść kolejnych składników. 729 przejść pomiędzy subelementami liczone w pionowym przekroju warstw hieroglifowych w Zawoi-Wilcznej dały macierz porównawczą, na podstawie której macierz prawdopodobieństw przejść została obliczona za pomocą programu T 7/68 (Jelonek i Simpson, 1968). Ten sam program został zastosowany celem obliczenia stanu równowagi (zob. znaczenie kolejnych potęg w fig. 14), w którym wiersze macierzy uzyskują tę samą wartość. Obliczenia wykazały sześćdziesiątą potęgę. Następnie posługując się programem T 12/68 ustalono syntetyczną, pionową, kolejność subelementów (Jelonek i Simpson, l.c.). Pierwszy stan (subelement) został wybrany w sposób przypadkowy i pionowa miąższość tego subelementu została również wzięta w sposób przypadkowy z rozkładu liczebności miąższości dla tego stanu. Następnie zgodnie z prawdopodobieństwami przejść w wierszu odpowiadającym pierwotnemu stanowi w macierzy prawdopodobieństw przejść, został wybrany drugi stan. Ten sam proces obliczenia zastosowany został dla 498 przejść dalszych. Część tej syntetycznej kolejności podana jest w fig. 15.

Trzy syntetyczne przekroje utworzone prze tę samą macierz prawdopodobieństw przejść porównano z podstawowym przekrojem warstw hieroglifowych w następujący sposób: dla każdego przekroju obliczano macierz prawdopodobieństw przejść na podstawie macierzy porównawczej opartej na przejściach mierzonych co 10 cm. Potęgi stanów równowagi obliczone dla tych macierzy prawdopodobieństw przejść oraz prawdopodobieństwa w równowadze są porównywalne. To z kolei pozwala przypuszczać, że istnieje zależność między danymi subelementami a bezpośrednio przed nimi występującymi strukturami, analogiczna do zależności opisanej w badaniach eksperymentalnych dotyczących transportu osadów (na przykład, patrz Simons i Richardson, 1963). Jak się przyjmuje, proste rytmy we fliszu prawdopodobnie zostały zdeponowane przez pojedyncze prądy o zmniejszającej się szybkości. Dla zbadania tego problemu utworzono sześcioskładnikową, syntetyczną kolejność subelementów posługując się przypadkowo dobranymi numerami otrzymanymi w kolejnych rzutach kostką. Sześć tych subelementów A—E nosiło numery 1—6. Pojedyncze występowania są jednostkami miąższości. Procenty syntetycznych rytmów o różnych uwarstwieniach w ten sposób uzyskanych są podane w tabeli 2. Proste rytmy zawierające 2 lub 3 subelementy dały w wyniku 27,72% całości. Nie uzyskano prostych rytmów zawierających więcej niż 3 subelementy z powodu ograniczonej ilości prób. Można zatem stwierdzić, że jest nieprawdopodobne, aby profile zawierające wyłącznie lub nawet w większości proste rytmy mogły być utworzone przez kolejne niezależne próby. Stochastyczny model występowania subelementów jest bardziej zgodny z faktami obserwowanymi w naturze aniżeli model uzyskany na podstawie niezależnych prób.

Najczęściej występującym typem struktur międzyrytmowych znajdywanym w warstwach beloweskich i hieroglifowych jest lineacja w postaci płytkich, podłużnych zagłębień, które występują na powierzchniach międzyrytmowych. Jamki wirowe i ślady wleczenia są stosunkowo częste. Przedmioty znalezione w dolnym biegu śladów wleczenia są zwęglonymi fragmentami roślin, okruchami łupków, otoczakami oraz ziarnami gruboziarnistego piasku (zob. tabl. IX, fig. 1) i nawet skorupkami bentonicznych otwornic (patrz Simpson 1969 a). Na spągach średnio-, grubo- i bardzo gruboławicowych elementów I piaskowca pasierbieckiego i osieleckiego występuje mniejsza rozmaitość struktur międzyrytmowych. Powierzchnie międzyrytmowe są często płaskie, z wyjątkiem ostro zarysowanych śladów wleczenia lub izolowanych jamek wirowych. W stosunkowo grubych zespołach ławic piaskowca magurskiego daje się zauważyć znaczne zróżnicowanie typów struktur międzyrytmowych. Ślady wleczenia są najczęściej występującymi strukturami. Poza międzyrytmowymi strukturami znajdowanymi w innych formacjach często występują hieroglify pierzaste i wzory grzbietów o pośrednio sześciościennej i podłużnej konfiguracji.

Kierunki transportu materiału klastycznego na podstawie struktur i międzyrytmowych i wewnętrznych podane są na fig. 16—18.

Zespoły śladów organicznych znalezione w fluktuacjach składających się z złożonych warstw w piaskowcu magurskim odpowiadają ichnofacji z *Zoophycos* Seilachera (1958) scharakteryzowanej przez fodinichnia. Na podstawie śladów organicznych warstwy hieroglifowe i beloweskie należą do względnie głębokowodnej facji z *Nereites*, w której przeważają wędrujące paschichnia. Przejściowe ichofacje reprezentowane są przez mieszane zespoły śladów organicznych występujących w najwyższych warstwach hieroglifowych, odsłoniętych S od Stryszawy i w warstwach magurskich, w których *Zoophycos* występuje wraz z wędrującymi i odgałęziającymi się formami. Niektóre ślady organiczne z badanych formacji przedstawione są w tabl. IX, fig. 2—6, tabl. X, tabl. XI, fig. 1—5.

Duże otwornice są stosunkowo częste w średnio-, grubo- i bardzo gruboławicowych elementach I piaskowców pasierbieckich i osieleckich. Również występują tam kolce jeżowców i okruchy skorupek małżów. W cienkoławicowych utworach tych samych formacji oraz w innych formacjach badanych duże skamieniałości są rzadkie. Odciski jeżowca (tabl. XI, fig. 4, 5) i kilku meduz (Simpson, 1969 b) zostały znalezione w warstwach hieroglifowych.

Skorupki otwornic występujących w elementach I często są rozpuszczone na kontaktach z ziarnami klastycznymi (tabl. XI, fig. 6) lub częściowo przekrystalizowane.

Pelagiczne otwornice są rzadkie w badanych formacjach. Ograniczone są one do stosunkowo rzadkich średnio-, grubo-, i bardzo gruboławicowych elementów II, występujących w warstwach hieroglifowych i piaskowcu magurskim w postaci ciemnych, marglistych łupków (Jednorowska i Simpson w druku). Spokojne warunki depozycji pelagicznej powinny objawiać się w formie jednolitego pionowego rozmieszczenia skorupek pelagicznych w ławicach łupków. Niejednolite pionowe rozmieszczenie skorupek otwornic, szczególnie pelagicznych wskazuje na działalność prądów dennych (a nie prądów zawiesinowych), która miała miejsce podczas deponowania stosunkowo gruboławicowych elementów II. Prądy te musiały być sporadyczne, skoro pozwoliły na stopniową akumulację materiału przez pelagiczną sedymentację.

W zespołach cienkich ławic, głównie w warstwach hieroglifowych, autor obserwował występowanie skorupek małych otwornic rozmieszczonych na powierzchniach międzyrytmowych (Simpson, 1969 a). Występowanie ich interpretowane jest jako efekt pionowych przeważnie przemieszczeń skorupek, które pozostają w związku z erozją.

Najważniejsze wnioski, które wynikają z przeprowadzonych badań autora, są następujące:

1. Dno ilaste było erodowane przez ten sam prąd, który deponował następnie osady rytmu.
2. Kolejne subelementy danego prostego rytmu są rezultatem depozycji jednego prądu.
3. Mechanizm depozycji odzwierciedla periodyczne zmiany w dostawie materiału z obszaru źródłowego.
4. Warunki wymienione w punktach 1, 2 i 3 wyjaśnić można najlepiej, przyjmując działanie prądów zawiesinowych.
5. W badanych osadach efekty depozycji pelagicznej i depozycji przy udziale prądów dennych (a nie prądów zawiesinowych) są przeważnie ograniczone do stosunkowo gruboławicowych łupków marglistych i margli.
6. Cechy petrograficzne, struktury będące rezultatem prądów oraz ślady organiczne sugerują, że piaskowiec magurski deponowany był stosunkowo blisko obszaru źródłowego, podczas gdy warstwy hieroglifowe i warstwy beloweskie tworzyły się w większej odległości od tego obszaru.

Piaskowiec pasierbiecki oraz piaskowiec osielecki są prawdopodobnie osadami podmorskich stożków, które powstawały blisko obszaru źródłowego.

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Abstract: Methods of investigation previously employed by N. B. Vassoyevich and by A. B. Vistelius are adopted in an integrated sedimentological study of flysch rocks, known from the work of M. Książkiewicz.

Comparison of time trends of sedimentation, defined by time series of layer thickness values, reveals striking differences between flysch formations, referable to differing distances of the depositional area from the edge of the basin and hence, to differing sensitivities to tectonic or climatic change, operative in the source area. Computer simulation of deposition, based on a stochastic model, supports the case for sedimentation of each individual simple bed from a single moving suspension. An independent-event model, used for comparison, is inapplicable to either proximal or distal flysch sedimentation as a whole, though such a model is to a limited extent mimicked in proximal sequences, largely made up of composite beds.

These conclusions are substantiated and supplemented by limited petrographic study and by more detailed considerations of the geometries of internal sedimentary structures, as revealed by radiography, associations of interfacial structures and gross assemblages of trace fossils. Organic clasts, particularly the tests of benthonic and pelagic Foraminifera, used as tracers within individual beds, provide additional information, relating to erosion of the substratum by moving suspensions, pelagic sedimentation and also the action of bottom currents, not of turbidity-current type.

INTRODUCTION

Locality

The Magura series form the uppermost of several tectonic units developed in the Flysch Zone of the Polish Carpathians as a result of Miocene folding (Zuber, 1918; for general accounts see J. Nowak, 1927; Świdziński, 1948; Książkiewicz, 1956). The stratigraphy of the Magura series and structural and stratigraphical relationships between this nappe and other tectonic units are discussed in more detailed reviews by Bieda et al., (1967) and Geroch et al., (1967). For the present account, sedimentary features of three Eocene formations (Pasierbiec Sandstone, Hieroglyphic Beds, lowermost Magura Sandstone), belonging to the Magure flysch of the western Polish Carpathians, were studied in an area, limited in the SW by the Polish-Czechoslovakian territorial boundary, between the villages Koszarawa and Lipnica Wielka, and in the N and NE by the Skawa River, between Sucha and Jordanów (Fig. 1). Throughout the entire area, a cover of superficial deposits is developed and exposures are mostly confined to ephemeral stream-sections, located on the slopes of the Jałowieckie and Babiogórskie ranges, and to a small number of road-cuttings and quarries.

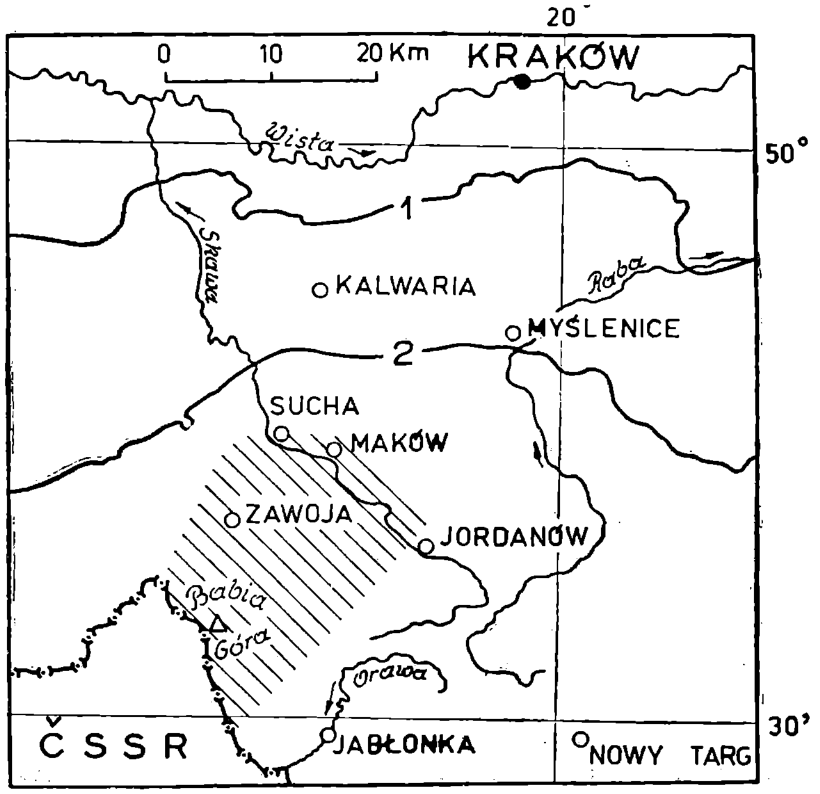

Fig. 1. Położenie terenu objętego badaniami w obszarze Karpat Zachodnich. 1 — północny brzeg Karpat fliszowych; 2 — północny brzeg jednostki magurskiej

Fig. 1. Location of study area in Western Polish Carpathians. 1 — northern Carpathian boundary; 2 — northern boundary of Magura unit

Geological setting and stratigraphy

Though some observations of a general nature were made in the area a century ago by Paul (1968) and later by Tietze (1888), Szajnocha (1902) and J. Nowak (1937), only in the years immediately preceding the Second World War were detailed investigations carried out. These results were published together with more recent research on a 1 : 200 000 sheet, which dealt with the geology of the entire western Polish Carpathians (see Sokołowski, 1958, for a compilation of the mapping carried out by Beres, Klimaszewski and Książkiewicz in the Zawoja-Maków Podhalański area). Present-day knowledge of the structural and facies relationships between different formations of flysch type exposed in the area comes mainly from the investigations of Książkiewicz (1948, 1958, 1960, 1966; also in Geroch et al., 1967, and in Bieda et al., 1967). Moreover, a system of zones, based upon assemblages of large Foraminifera, established by Bieda (1946, 1959, 1966; also in Bieda and Książkiewicz, 1958; Bieda et al., 1963; and Bieda et al., 1967), together with age determinations of small Foraminifera (Blaicher, 1961; Jednorowska, 1966, and in Geroch et al., 1967), provide a firm basis for the stratigraphic scheme presently being developed in the area under discussion and throughout the Magura series. The short summary immediately following is based upon the work of Książkiewicz.

North of the area studied, the northern boundary of the Magura series trends WSW—ENE; axes of main folds, which are frequently recumbent, run WSW—ENE within the area, while surface traces of most of the principal faults extend SSE—NNW (Książkiewicz, 1966, Fig. 4, facing p. 32). In the area under consideration, the Magura series comprises sedimentary rocks ranging in age from Senonian to Eo-Oligocene and characterized by:

1. sequences, mappable as formations, on the basis of the predominance of certain distinctive lithologies;
2. a lateral arrangement of these formations into definite facies belts;
3. the diachronous nature of certain formations of widespread distribution and the coeval character of lithologically dissimilar formations, restricted to particular facies belts.

Three formations are found throughout the whole area: the Inoceramian Beds (Senonian-Palaeocene), comprising calcareous and micaceous, fine- and medium-grained sandstones, alternating with clayey and marly shales, the Variegated Shales (Lower Ypresian-Lutetian), red and sometimes green shales with intercalations of fine-grained, glauconitic sandstones; the Magura Sandstone (Upper Lutetian-Priabonian), consisting of mainly medium-grained sandstones of varying thickness, separated by thin shale layers. Maximum thicknesses of these formations are in the order of 300 m., 300 m. and 2000 m. respectively; the boundaries of the latter are diachronous and become progressively older within the limits given in a N—S direction. Sub-facies distinguished within the outcrop-belt of the Magura Sandstone are: a glauconitic sub-facies in the northern part of the area, a muscovitic sub-facies in the southern part, an arkosic sub-facies, occurring locally in the S, and a shaly sub-facies (Infra-Magura Shales), limited to the central part of the area.

Four facies zones, arranged transversely with respect to the principal tectonic trend, are distinguishable on the basis of limitations in the areal distribution of certain formations intervening in vertical sequence between those of more widespread occurrence (see Fig. 2). In the N of the area (marginal zone), the Variegated Shales are separated vertically from the Inoceramian Beds by about 300 m. of coarse-grained sandstones alternating with subordinate shales (Lower Ypresian Ciężkowice Sandstone); further S, there is direct contact between these two formations. In the marginal and N-central zones, up to around 300 m. of fine- and medium-grained sandstones, alternating with subordinate shales (Lower Priabonian Sub-Magura Beds), are found immediately below the Magura Sandstone. In the marginal zone, these rest upon Variegated Shales; in the N-central zone, upon the Hieroglyphic Beds (Upper Lutetian), which are fine-grained sandstones alternating with shales. Coarse-grained sandstones, conglomeratic sandstones and conglomerates alternating with subordinate shales form lenses between the Variegated Shales and Sub-Magura Beds or Magura Sandstone in the marginal zone, and between the Hieroglyphic Beds and Sub-Magura Beds or Magura Sandstone in the N-central zone. These coarse-grained rocks are of Upper Lutetian age and are known as the Upper Pasierbiec Sandstone. Similar coarse-grained rocks form a continuous body, up to 300 m. in thickness, between the Variegated Shales and the Hieroglyphic Beds in the N-central zone, and lenses at the base of the Hieroglyphic Beds in the S-central zone. These latter occurrences are termed Lower Pasierbiec Sandstone. S and SE of Babia Góra (inner zone), the Hieroglyphic Beds and Pasierbiec Sandstone do not occur and on the Variegated Shales rest the Beloweza Beds (Upper Ypresian), themselves overlain by the Łącko Marls

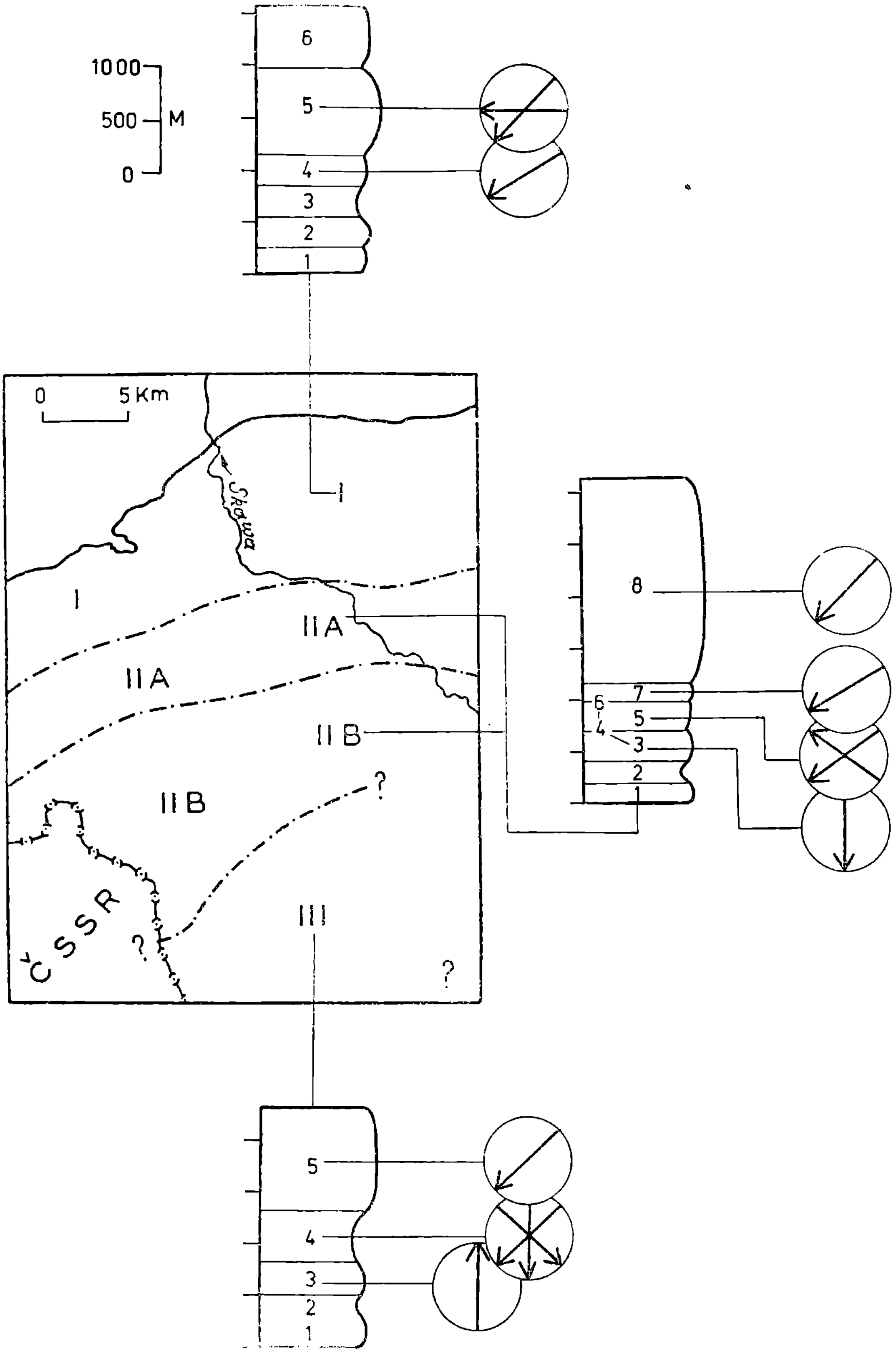

Fig. 2. Strefy facjalne w badanym obszarze (według Książkiewicza, 1958a, 1963, 1966; patrz także Bieda et al., 1967). I — strefa marginalna: 1 — warstwy inoceramowe; 2 — piaskowiec ciężkowicki; 3 — pstre łupki; 4 — warstwy podmagurskie; 5 — piaskowiec magurski; 6 — warstwy nadmagurskie; II — strefa centralna (A — część północna; B — część południowa): 1 — warstwy inoceramowe, 2 — pstre łupki; 3, 4, 6 — piaskowiec pasierbiecki; 5 — warstwy hieroglifowe; 7 — warstwy

(Lower Lutetian), which are succeeded vertically by the Magura Sandstone. The Beloweza Beds (100—300 m.) are similar in gross petrology to the Hieroglyphic Beds, while the Łącko Marls are hard, grey marls alternating with fine-grained, glauconitic sandstones. The designation Osielec Sandstone applies to calcareous, fine-grained sandstones with abundant glauconite and alternating with shales; these are seen as isolated layers and as mappable sequences, associated with or replacing the Pasierbiec Sandstone in the N- and S-central zones.

Sujkowski (1938) and Książkiewicz (1947) deduced the operation of currents in the deposition of the Carpathian flysch sandstones, from observations of rippled tops of sandstones and cross-laminae in sandstones respectively. The field observations of Migliorini (1944, 1950) in the Italian Macigno and experimental work by Kuenen (1948) on turbidity currents led to the joint publication (Kuenen and Migliorini, 1950) in which deposition from moving suspensions of sediment in water was held to account for the formation of sandstones exhibiting an upward reduction in grain size. This notion was soon to be acknowledged as that most suited to explain the origin of flysch beds in the Polish Carpathians (Książkiewicz, 1952, pp. 422—430). Directions of current movement deduced from the orientations of structures on the lower surfaces of sandstones in the area under consideration, corrected for tectonic tilting, were given by Książkiewicz (1958, 1963, 1966) and are summarized in Fig. 2.

Aims

Mapped on a regional scale as formations, the Pasierbiec Sandstone, Hieroglyphic Beds and Magura Sandstone present conspicuous differences in three-dimensional geometry (see Książkiewicz, 1966, Fig. 2, facing p. 10; also Geroch et al., 1967, Fig. 37, facing p. 254). Moreover, though the lithological and structural properties of each formation satisfy the requirements intrinsic to the facies term „flysch" (see Sujkowski, 1957; Dżułyński and Smith, 1964), pronounced differences exist between the three in terms of these very attributes. Thus the sedimentology of these formations and, to a lesser extent, that of their lateral age equivalents is here elaborated, with a view to determining more closely the mechanisms of transportation and depositional environments.

podmagurskie; 8 — piaskowiec magurski; III — strefa wewnętrzna: 1 — warstwy inoceramowe; 2 — pstre łupki; 3 — warstwy belowezkie; 4 — margle łąckie; 5 — piaskowiec magurski. Główne kierunki transportu materiału klastycznego oznaczone strzałkami

Fig. 2. Facies zones in study area (see Książkiewicz, 1958a, 1963, 1966; also in Bieda et al., 1967). I — marginal zone: 1 — Inoceramian Beds; 2 — Ciężkowice Sandstone; 3 — Variegated Shales; 4 — Sub-Magura Beds; 5 — Magura Sandstone; 6 — Supra-Magura Beds; II — central zone (A — N-central; B — S-central): 1 — Inoceramian Beds; 2 — Variegated Shales; 3, 4, 6 — Pasierbiec Sandstone; 5 — Hieroglyphic Beds; 7 — Sub-Magura Beds; 8 — Magura Sandstone; III — inner zone: 1 — Inoceramian Beds; 2 — Variegated Shales; 3 — Beloweza Beds; 4 — Łącko Marls; 5 — Magura Sandstone. Main transport directions of sediment indicated by means of arrows

Some basic definitions

In terms of gross petrology, a given flysch sequence exhibits a strikingly regular, vertical repetition of sandstone-shale couplets. While the boundary between a given sandstone and the shale upon it rests is a definite interface, the transition between the sandstone and the immediately overlying shale may be one of a variety of types, ranging from gradational to sharp in definition. The sandstone-shale couplet bounded by two successive, like interfaces is the smallest rhythmic unit of components, repeated in vertical sequence and distinguishable on the basis of either differences in texture and composition or predominance of particular sedimentary structures, and is here termed bed or rhythm. After Vassoyevich (1948, p. 56 et seq.), flysch beds can be divided into vertically arranged elements, based upon lithology. In the present study, it was convenient to recognize type-I (conglomerate, sandstone, siltstone) and type-II (silty shale, argillaceous shale, marly shale, marl) elements. Further subdivision of beds and elements of beds into sub-elements can also be made (Vassoyevich, 1948); here, the criteria employed for this purpose are internal sedimentary structures. Beds and elements are here collectively termed layers. The scheme of thickness classes devised by McKee and Weir (1953), in the amended form published by Ingram (1954), is used in the present account to describe beds, elements and sub-elements alike.

LITHOFACIES DESCRIPTIONS

General

Hand-specimen appearances of the rocks of the formations studied were described by Książkiewicz (1958, 1966), while Wieser (1963, 1966) gave a somewhat more detailed outline of their petrographic characteristics. In the present account, the petrography of type-I elements belonging to these formations is briefly considered as an aid to determination of the lithologic composition and location of source areas.

Type-I elements

Because of variable and generally poor exposure throughout the area studied, sampling was based upon practical field considerations rather than upon more desirable statistical methods. Quantification of petrographic data for flysch sediments is complicated by compositional changes within a bed or element, concomitant with a common vertical diminution of grain size (see discussion by Kamieński et al., 1967; Unrug, 1968). Therefore the number of samples taken from a single bed depended upon bed thickness (at least one sample every 20—30 cm), as well as on petrographic variation visible in hand-specimen.

As pointed out by Dott (1964), existing terminology for arenaceous rocks is complex and not completely adequate for descriptive purposes. Here the nomenclature of Gilbert (in Williams et al., 1954) is employed. Thus in type-I elements of the Magura Sandstone, Hieroglyphic Beds, Pasierbiec Sandstone and Beloweza Beds, types of wacke with varying proportions of matrix (grains of diameter less than 0,02 mm) predominate, while in the Osielec Sandstone, quartz arenites are found (see also Wieser, 1963, 1966). The petrography of the formations studied is summarized in Table 2 and given in terms of three components (quartz — rock fragments — micas — total feldspar) in Fig. 3 A and B. In terms of provenance, the following facts are significant:

1. In the thin-layered type-I elements of all formations studied, monocrystalline quartz (monoquartz) predominates as sub-angular and angular grains. Monoquartz grains partially recrystallized and with margins corroded by calcareous cement are also common in these layers. Polycrystalline quartz (polyquartz) is usually rare or absent. Type-I elements of the medium, thick and very thick classes, however, may contain in the order of 30% polyquartz. Thus the Magura Sandstone, Pasierbiec Sandstone and Osielec Sandstone contain relatively high proportions of polyquartz in addition to monoquartz, while Hieroglyphic Beds and Beloweza Beds usually contain only monoquartz.

2. In the Hieroglyphic Beds and Beloweza Beds, feldspars are relatively scarce, occurring as sub-angular and angular grains determined as being within the oligoclase and albite ranges. These grains frequently are altered. On the other hand, the Magura Sandstone contains abundant (up to 25%) feldspar, most commonly in the albite and oligoclase ranges, with microperthite and orthoclase also present. The same range in feldspar composition is known from the Osielec Sandstone and Pasierbiec Sandstone. In these three last-mentioned formations, only orthoclase shows any extensive alteration. Sodic feldspars are in most cases fresh.

3. Rock fragments are scarce or absent in the relatively thin-layered successions of the formations studied. Chert, organic limestones, phyllites, gneiss and granite are represented, in the Hieroglyphic Beds and Beloweza Beds. Rare occurrences of well rounded siltstone pebbles with a thin carbonaceous coating are known from thin type-I elements of the Hieroglyphic Beds and pellets of shale are also sometimes found. At the top of the Hieroglyphic Beds, in the stream Jaworzyna, a coarse-grained sandstone of Pasierbiec Sandstone type contains fragments of fine-grained, cross-laminated sandstone identical to the sandstones of the Hieroglyphic Beds. The laminae show no sign of distortion, thus indicating a relatively advanced degree of compaction at the time of erosion. Reworked fragments of sandstone are rare in the Polish Carpathian flysch and only one such instance has been previously recorded (Książkiewicz, 1961b, p. 25). In the Pasierbiec Sandstone, reworked fragments of shale and marl are fairly common, frequently attaining cobble size. Shale fragments are of common occurrence in the Magura Sandstone. In the Pasierbiec Sandstone, a considerable range in rocks types is represented, including chert, organic limestone, schists, phyllites, gneiss, and granite. The Magura Sandstone also contains relatively high proportions (up to 24%) of rock fragments, similar in composition to those of the Pasierbiec Sandstone.

4. Micas, seen predominantly as muscovite with subordinate biotite, rarely exceed 8% of the rock in type-I elements belonging to the thin-layered successions. Low values of the same order also characterize the Pasierbiec Sandstone. In the Magura Sandstone, however, high proportions of up to 15% mica may be seen.

5. Cement and matrix may together make up as much as 30% of the rock in type-I elements of the Hieroglyphic Beds. Cement is usually in excess of matrix and is composed of abundant microcrystalline calcite

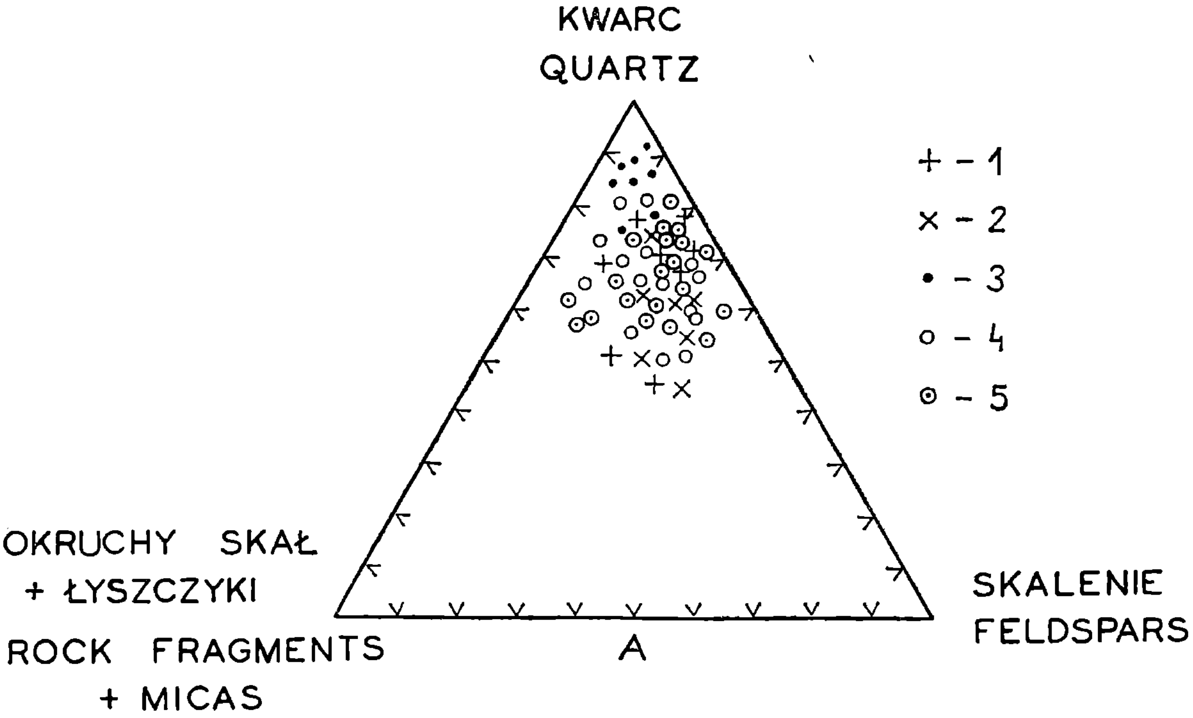

Fig. 3 A. Skład petrograficzny badanych osadów. 1 — piaskowiec pasierbiecki; 2 — warstwy belowezkie; 3 — piaskowiec osielecki; 4 — warstwy hieroglifowe; 5 — piaskowiec magurski

Fig. 3 A. Petrography of formations studied. 1 — Pasierbiec Sandstone; 2 — Beloweza Beds; 3 — Osielec Sandstone; 4 — Hieroglyphic Beds; 5 — Magura Sandstone

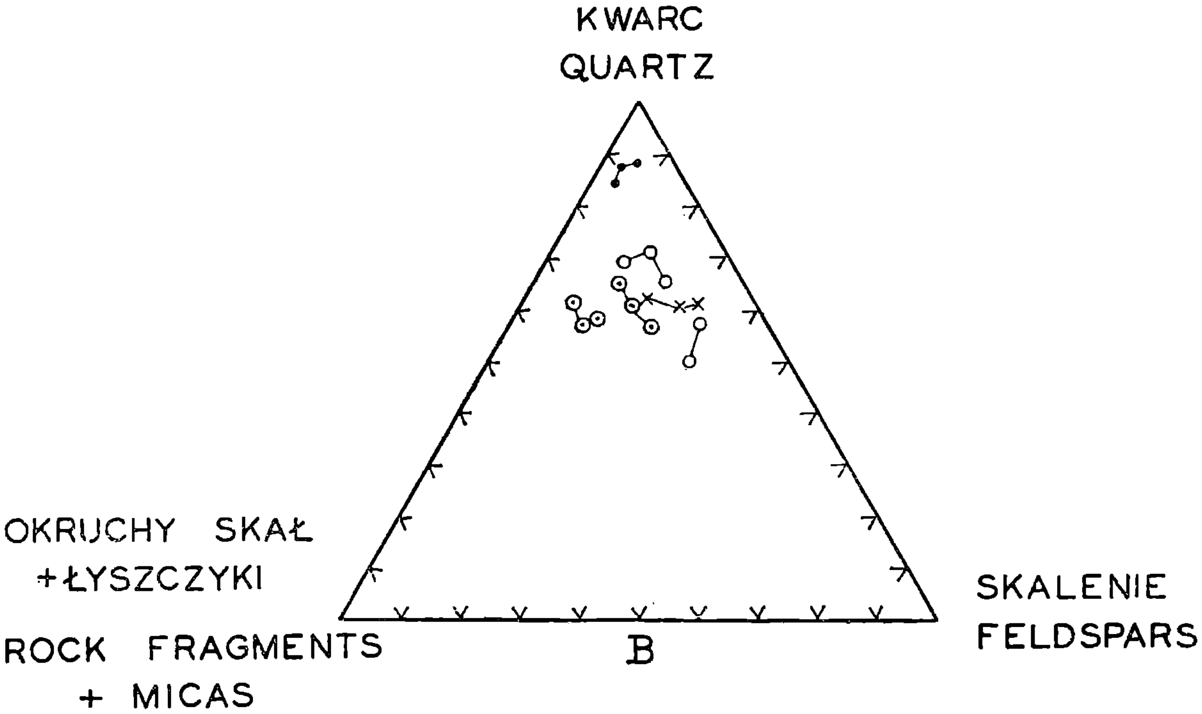

Fig. 3 B. Przykłady zmienności składu petrograficznego w poszczególnych ławicach. Objaśnienia jak w Fig. 3 A

Fig. 3 B. Examples of petrographic change in particular beds. Explanation as in Fig. 3 A and less commonly occurring recrystallized quartz. Matrix material is made up of clay minerals, granular quartz, finely comminuted plant debris and glauconite, listed in the most common order of abundance. In the Magura Sandstone, the proportion of matrix plus cement is generally lower (in the order of 20%) and the components are similar in type, though locally glauconite is important as a matrix mineral. In the Osielec Sandstone, glauconite may constitute up to 20% of the rock.

6. Large Foraminifera from a shallow-water environment are common in type-I elements of the Pasierbiec Sandstone and also in the Osielec Sandstone. Other commonly occurring organic remains are *Lithothamnium* and small Foraminifera. Pelagic Foraminifera occurring in type-I elements of thin-layered successions provide clear evidence of bottom erosion.

Material of the type-I elements belonging to the Magura Sandstone, Osielec Sandstone and Pasierbiec Sandstone was clearly subjected to only short-lived transport, followed by comparatively rapid deposition and burial. These deposits are proximal. These deductions follow from the occurrence of unstable clasts in an unaltered form. The Hieroglyphic Beds and Beloweza Beds, on the other hand, constitute distal deposits, with finer grain size and scarcity of unstable clasts. In all cases, mass movement of material is suggested by the presence of eroded fragments of sediment of similar age mixed with terrigenous sediment.

Type-II elements

Differential thermal analysis and X-ray analysis of shales[1] reveal the presence of abundant quartz and illite, with lower proportions of chlorite, hydromuscovite, orthoclase, oligoclase and calcite. In one case, abundant lepidocrocite was found (Wieser and Simpson, in press). These elements contain angular and sub-angular quartz grains and most probably represent the final stages of mass movement, when the finest grained material settled from suspensions (see Radomski, 1960, p. 124). Relatively scarce, thick and very thick marly shales found in the Hieroglyphic Beds and Magura Sandstone contain numerous rounded and well rounded quartz grains, often in excess of angular or sub-angular grains. The occurrence of abundant, rounded and well rounded grains in these type-II elements, together with pelagic Foraminifera, suggests that pelagic deposition played an important role in their formation (compare with Radomski, 1958; 1960). Scarce type-II elements made up largely of microcrystalline calcite (micrites of Folk, 1959) also occur in all formations studied.

LAYER PROPERTIES

General

The three-dimensional, internal and external geometries of successive beds to a large extent reflect organization of clastic particles by currents. Hydrodynamic conditions of flow when deposition was predominant are

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[1] The author thanks Prof. Dr T. Wieser, of the Geological Institute Kraków, for his interpretation of these results.

recorded as internal structures. Interfacial structures (Dżułyński and Simpson, 1966b), on the other hand, evidence varying degrees of particle entrainment from the upper surface of sediment already deposited. This entrainment may have taken place prior to or during transportation of sediment constituting the next bed in vertical sequence (Książkiewicz, 1952, p. 419; 1961b; Dżułyński and Radomski, 1955). It is thus paradoxical that the paths of depositional currents employed in palaeogeographic reconstructions of flysch basins are frequently deduced from the attitudes of erosional, interfacial structures (Craig and Walton, 1962, p. 118). Clearly the directional properties of internal and interfacial structures should be evaluated separately.

Layer thickness

Stratification, defined by lateral persistence of vertical lithologic change, is the most conspicuous feature of sedimentary rocks and yet one which has received scant attention in sedimentological studies (Weller, 1960, p. 354). In general terms, lithologic change implies change in conditions of deposition. Rhythmic layering of the type making up flysch sequences clearly evidences repetition of this latter change. The episodic nature of the greater part of flysch sedimentation was recognized by Sujkowski (1938, pp. 44—46) and is best explained by the turbidity current theory of Kuenen and Migliorini (1950) and by notions developed from this (see Dżułyński et al., 1959, p. 1114).

Vertical grading of clastic grains in flysch beds reflects a gradual change from predominant deposition of sand to predominant deposition of mud. It should be noted that, although a number of different internal sedimentary structures may be present within a flysch bed, the vertical change in grain size may take place through these (Książkiewicz, 1952), giving an impression of superimposition. Grading may thus be „superposed"[1] (Crowell et al., 1966, p. 18) or may occur as a separate structure in the absence of laminae; this latter type of occurrence is considered separately in a later section. Simple grading (Książkiewicz, 1947, 1952) is a progressive, upward diminution in the proportion of relatively coarse grains between two successive interfaces. Simple grading may be continuous, with successively smaller size grades predominating upwards, or discontinuous, with one or more size grades absent from the range (Książkiewicz, 1952; Kuenen, 1952, 1953). Clearly a relatively sharp contact between complementary type-I and II elements will be found where grading is discontinuous, while continuous grading will be accompanied by a gradational passage.

In the formations considered, beds in the very thin, thin and medium thickness classes are characterized by simple grading. The maximum and modal grain sizes of type-I elements are in the fine-sand and silt ranges and vertical separation of grain sizes is poor. Thus grading of the type-I elements is frequently delayed (Walton, 1956), or largely confined to the vicinity of the contact between complementary elements. Simple grading with good separation tends to be best developed in beds of thin

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[1] In the present account, reference is made to this phenomenon as imprinted grading.

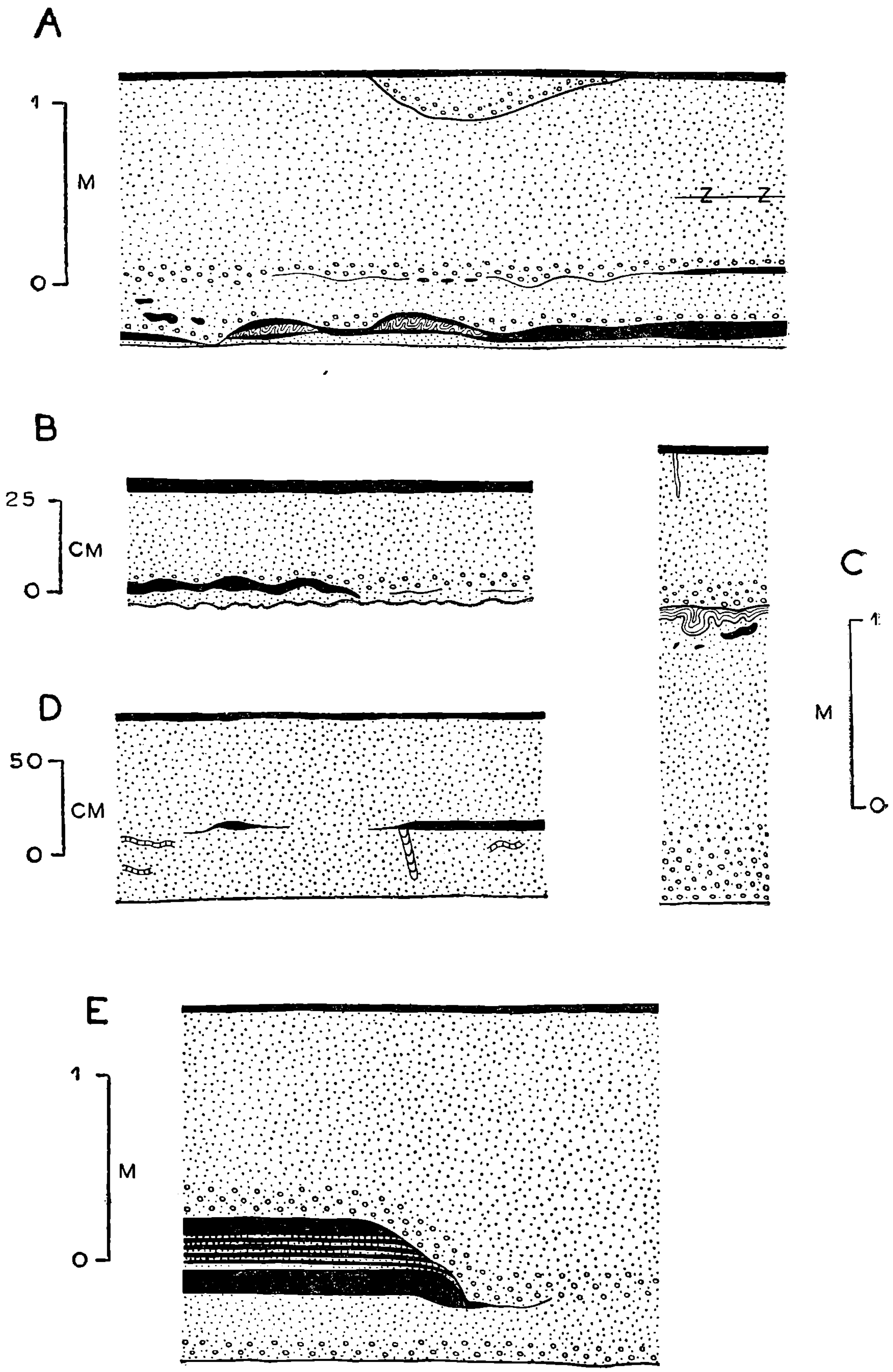

Fig. 4. Types of composite bed. Explanation in text. A, C. D. E — Magura Sandstone, magurski, kamieniołom w Osielcu; B — warstwy hieroglifowe, Zawoja-Wilczna

Fig. 4. Types of composite bed Explanation in text. A, C, D, E — Magura Sandstone, Osielec quarry; B — Hieroglyphic Beds, Zawoja-Wilczna

to medium thickness. The foregoing remarks are particularly applicable to virtually the entire succession of Hieroglyphic Beds, in which thick and very thick beds are rare (see Pl. VI, Fig. 1). Beds belonging to the higher thickness classes frequently display a vertical repetition of grading in the type-I element, a phenomenon only rarely present in the lower thickness classes. Repeated grading of clastic particles was described by Książkiewicz (1947, 1952) and termed multiple. The term composite bed, used by other authors (for example, Książkiewicz, 1952; but see also Dżułyński and Ślączka, 1958) to denote the occurrence of different internal structures in a single bed, is here restricted to beds displaying multiple grading. Multiple grading is rare in the Hieroglyphic Beds, but of common occurrence in both the Pasierbiec Sandstone and the Magura Sandstone (see Fig. 4). It may originate in two different ways:

1) A composite bed may reflect acceleration in the rate of sedimentation, in that sediment was deposited from a moving suspension prior to the completion of the preceding depositional episode (see Dżułyński and Ślączka, 1958; Walton, 1967, p. 315). This is a plausible explanation for multiple grading, in which different size grades predominate in particular horizontal laminae, as in numerous thick and very thick type-I elements belonging to the Pasierbiec Sandstone and Osielec Sandstone respectively.

2) A composite bed may indicate erosion of a previously deposited graded bed, prior to or during the emplacement of the next layer, (see Dżułyński and Ślączka, 1958; Walker, 1966, pp. 96, 97). This erosion was extremely uneven. It is clearly evidenced where the different graded parts of a multiple-graded type-I element are separated by intermittent horizontal partings, which may be followed laterally to concentrations of shale pebbles, to continuous layers of shale and, more rarely, to short sequences of relatively thin beds (Fig. 4). Sometimes trace fossils, particularly of *Zoophycos* type, occur on the surfaces of these partings. Where the partings die out, the different graded parts of the element are welded together, frequently along an irregular surface, marked only by an abrupt, vertical change in grain size (see also Książkiewicz, 1952, Fig. 9, p. 420). In other cases, the parts welded together are non-graded (see Koszarski, 1956, p. 395) and with similar grain size distributions. In these latter instances, but for the presence of intermittent partings and shale layers, the composite nature of the bed would be indiscernible. Composite beds of this type are sometimes found in the Hieroglyphic Beds and are extremely common in the Magura Sandstone (Fig. 4). It is likely that thick and very thick, non-graded type-I elements belonging to the Pasierbiec Sandstone and Magura Sandstone respectively arise in this way. Several instances are known from the Magura Sandstone of sand-filled washouts, up to several metres in width and sometimes in the order of 1—2 metres in depth, occupying the upper parts of type-I elements (Fig. 4). These are discernible from abrupt, vertical changes in grain size and are usually asymmetrical in cross-section, with the steepest wall upcurrent.

Lateral changes in layer thickness

Single beds and complexes are not traceable beyond the limits of individual exposures, owing to the folded nature of the successions and the restriction of exposures largely to stream section. Within the limits of a given exposure, beds may be followed laterally for only relatively short distances, in the order of 10 m. at the most, and seldom exhibit any pronounced variation in thickness. The following lateral changes in thickness of elements may be observed:

1) Undulations in the contacts between complementary sandstone and shale elements are sometimes seen in beds of the very thin, thin and medium classes belonging to all formations considered. These beds are characteristically cross-laminated throughout the type-I elements, which display rippled tops. Frequently type-I elements with undulatory upper surfaces have irregular soles with closely packed flute markings of marked relief, a condition which gives rise to considerable, small-scale variation in thickness. This last-mentioned phenomenon is particularly well developed in the Hieroglyphic Beds (Fig. 5; compare with Fig. 2 of Ślączka and Unrug, 1966, p. 158).

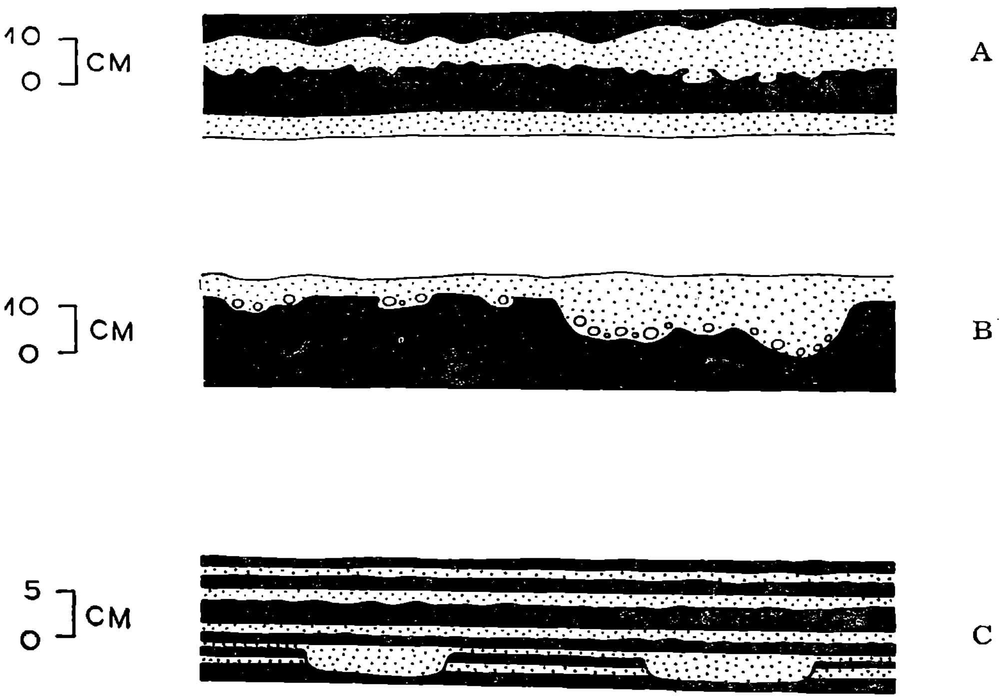

Fig. 5. Nieregularna miąższość ławic. A — warstwy hieroglifowe, potok Mosorny, Zawoja; B — piaskowiec pasierbiecki, Cicha; C — warstwy hieroglifowe, Zawoja-Jaworzyna

Fig. 5. Lateral variation in layer thickness. A — Hieroglyphic Beds, stream Mosorny, Zawoja; B — Pasierbiec Sandstone, Cicha; C — Hieroglyphic Beds, Zawoja-Jaworzyna

2) Extremely rare, flattened lenticles of fine-grained sandstone, elongated in the plane of the bedding and enclosed by shale (see the „lenticular beds" described by Unrug, 1959, Fig. 8, p. 208), were found in the succession of Hieroglyphic Beds exposed in the stream Końskie. On the relatively flat, upper surfaces of the lenses, organic trails of the type *Paleobullia* occur, while on the convex, lower surface, parallel to lenses of these extends a trail referable to postdepositional *Scolicia*. The lenses display no internal structure. They are thought to represent isolated sand ripples, formed on a mud surface (see Hsu, 1964, Fig. 2, p. 381) and

probably deformed by loading before being burrowed by sediment-eating organisms. If the lenses do represent deformed ripples, it is likely that these latter were formed, when turbidite sands were reworked by bottom currents not of turbidity-current type.

3) Sand-filled washouts in shale are seen as gently rounded depressions of the interface, in the order of 1—2 m. in width. They are frequently symmetrical in sections normal to the current direction, determined from sole markings of the same bed, and asymmetrical parallel to the current direction with the steep wall upcurrent. Depth varies, but is usually at least 2—3 times the normal thickness of the type-I element, of which the washouts form a part. Washouts of this type are rare in the formations considered. They are largely confined to complexes made up of beds of thin and medium thicknesses in the Hieroglyphic Beds and Magura Sandstone (Fig. 5), where they usually truncate several beds occurring lower in the sequence. In the Magura Sandstone, washouts frequently contain coarser material than other parts of the same type-I element and this displays simple grading. Furthermore, flute moulds may be seen on the walls of the washouts, while on the relatively flat bottoms, a variety of tool-formed structures occur. The most common of these latter structures are narrow groove moulds with coarse sand grains at their down-current ends. Thus clearly the current transporting the sand also was instrumental in shaping the washout. In the Hieroglyphic Beds, washouts are filled with fine-grained sandstone, which in each case does not differ markedly from that of the rest of the type-I element. The element as a whole is made up of cross-laminae and frequently the filling material of the washout is also arranged in this way. In some cases, the laminae filling the washout are convoluted, while those belonging to the rest of the type-I element are undeformed. In such a case, it is possible that the predominantly vertical movements which evidently gave rise to convolution of the laminae also caused, or at least emphasized the localized increase in thickness of the type-I element (compare with Unrug, 1959, p. 206).

4) Where the infilling of an intrastratal washout, formed at the top of a type-I element, differs markedly from the element in petrographic character, the lateral variation in thickness of the eroded element is conspicuous. Such an instance is known from the Pasierbiec Sandstone exposed in the stream Końskie, where a type-I element with a maximum thickness of 42 cm. has been eroded down to 1 cm. above the interface, over a distance of 2 m. normal to the current direction. The channel is filled with thin, alternating elements of fine-grained sandstone and shale, which terminate at the walls. The type-I elements of the infilling material are lenticular in section. Here is an instance, in which the infilling of a washout clearly records several episodes of deposition following the scouring of the washout by a current, which apparently deposited no sediment. This last-mentioned current was probably not a turbidity current. It should be added, however, that the type-I element with the scoured upper surface is coarse-grained and composite, itself resulting from several episodes of deposition.

Vertical variation in layer thickness

Though single measurements in a sequence of bed thicknesses recorded at a flysch exposure are not numerical functions of time[1], successive values may still form natural groups characterized by a systematic variation, which latter may or may not be time-dependent. Thus formal time-series analysis (see, for example, Kendal, 1948) may be applied to data of this type. The utility of data presented as a time series is as follows:

1) Even where the random component of variation predominates, an unsmoothed time series is nevertheless a useful, graphical summary of petrologic variation in an exposure (see the non-analytical approach of Sujkowski, 1938, pp. 40, 41 and Figs. 11—14; Dangeard et al., 1961, Fig. 2, p. 253; Książkiewicz, 1961, Fig. 1, p. 30).

2) A time series may be used as a test for periodicity on various scales, relative to the length of the series. Several attempts have been made to demonstrate a rhythmic component in flysch sequences, using unsmoothed (Sujkowski, 1938, 1957, p. 549) and smoothed (Nederlof, 1959, Graphs 1 and 2, p. 652; Dean and Anderson, 1967, Fig. 3, p. 63; Walker, 1967, Fig. 3, p. 27) time series, but without success. Vassoyevich (1948, 1951, 1954) has described rhythmicity in flysch on the basis of elements of beds, with the bed as the smallest rhythmic component. Similar analytical procedures were employed by Durkovic (1960), Grubić and Komatina (1962—3) and Khrischev (1967).

3) A smoothed time series may reveal a trend, or regular component of variation, large in scale relative to the length of the series. Periodicity of this type would correspond in scale to that inferable from usages of the terms „megacyclothem" (Moore, 1936, p. 29), „megarhythm" (Książkiewicz, 1960, p. 22), „time trend of sedimentation" (Vistelius, 1961b) and „macrorhythm" (Khrischev, 1967, p. 218). These terms are not synonyms, but define large-scale trends of various magnitudes. The term used by Vistelius (1961b) lends itself to general application and is adopted in the present account.

Successive layer thickness values for sequences in Magura Sandstone and Hieroglyphic Beds were plotted as unsmoothed time series, with $\log_{10}(u_1, u_2, u_3, \ldots, u_{N-1}, u_N)$ as ordinate and bed numbers 1, 2, 3, . . ., $N-1$, N as abscissa, where $u =$ thickness of element or bed and $N =$ total number of beds in the sequence. Time trends of sedimentation were investigated for N-20 terms, using Spencer's 21-term formula:

$$\begin{aligned} u'_0 = \frac{1}{350}[60u_0 &+ 57(u_{-1}+u_{+1}) + 47(u_{-2}+u_{+2}) \\ &+ 33(u_{-3}+u_{+3}) + 18(u_{-4}+u_{+4}) \\ &+ 6(u_{-5}+u_{+5}) - 2(u_{-6}+u_{+6}) \\ &- 5(u_{-7}+u_{+7}) - 5(u_{-8}+u_{+8}) \\ &- 3(u_{-9}+u_{+9}) - (u_{-10}+u_{+10})]. \end{aligned}$$

Tests were made for relatively small-scale periodicity in N-4 terms, using Sheppard's 5-term formula:

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[1] As stated by Miller and Kahn (1962, p. 346), „a time series is a sequence of observations ordered with respect to time". Clearly there is ordering through time of beds in vertical sequence, although the time intervals between instants of flysch deposition cannot be measured.

$$u_0' = \frac{1}{35}\,[17\,u_0 + 12\,(u_{-1} + u_{+1}) - 3\,(u_{-2} + u_{+2})].$$

The derivation of these formulae is given by Whittaker and Robinson (1929). Both formulae have been extensively used by Vistelius to accentuate time trends of sedimentation (see Vistelius, 1961a, 1961b, for summary accounts). The same smoothing formulae were also used by Fox and Brown (1965) in a comparison of fossil distribution and thin-section data, representing observations made at equally spaced vertical intervals in a limestone section. In the present study, smoothed curves were computed by means of the program t5/68, written for the UMC-1 computer (Jelonek and Simpson, 1968).

Out of the 3000 beds examined in times series, the succession in Magura Sandstone exposed in the quarry at Osielec and the cliff exposure of Hieroglyphic Beds at Zawoja-Wilczna are chosen as being representative, for purposes of detailed description (see also Table 1). Thickness distributions for type-I and type-II elements of these sequences are shown in Figs. 6 and 7 respectively. For the Magura Sandstone exposed in the quarry at Osielec (Plate VI, Fig. 2), the arithmetic-mean thickness of type-I elements is 32,11 cm., with a standard deviation of ±67,31 cm., while type-II elements give an average thickness of 3,84 cm and a standard deviation of ±4,44 cm. For beds, the arithmetic-mean thickness is 35,96 cm. and the standard deviation ±67,78 cm. The range in thickness for type-I elements (1 to 560 cm.) is considerably greater than that of type-II elements (1 to 45 cm.); beds show a thickness range of 2 to 572 cm. The Pearson correlation coefficient between thicknesses of type-I and type-II elements of the same bed is 0,07 for 603 beds. In the Wilczna section of Hieroglyphic Beds, arithmetic-mean thicknesses for type-I elements (6,47 cm.; standard deviation ±7,98 cm.) and beds (11,13 cm.; standard deviation ±10,11 cm.) respectively are lower, while that for type-II elements is greater (4,66 cm.; standard deviation ±4,81 cm.). The thickness ranges are 1 to 92 cm. for type-I elements, 1 to 82 cm. for type-II elements and 2 to 100 cm. for beds. A value of 0,20 for Pearson's correlation coefficient indicates weak positive correlation between thicknesses of type-I and -II elements for 340 beds.

A clearly defined trend is seen in the unsmoothed time series for type-I elements and beds of the Magura Sandstone (Fig. 8, A and C respectively). Very thin and thin type-I elements form complexes, from which the coarser thicksess classes are largely excluded. The latter occur in groups delimited by thin and very thin elements. Thus between units 52 and 145, no very thick type-I elements occur and only 7,44% of the units belong to the medium and thick classes. Likewise, between units 329 and 443, the very thick class is not represented and 9,65% of the units belong to the medium and thick classes. Because medium and thick type-I elements tend to occur near the margins of the complexes of thin and very thin beds, the choice of bounding units for the complexes is to a large degree arbitrary. Rarely type-I elements of the medium and thick classes form single fluctuations within the thin-layered complexes. A thin-layered complex beginning with unit 601 is not recorded in full on Figs. 8—10, owing to poor exposure of the top of the section. Type-I elements belonging to the thin-layered complexes are fine-grained sandstones and siltstones, with simple, vertical grading of particles.

Between the thin-layered complexes, type-I elements of all thickness classes occur. Thus from unit 146 to unit 328, 46,76% of type-I elements

Tabela (Table) 1

lokalizacja reference no.	ilość ławic no of beds	piaskowce sandstones 1	piaskowce sandstones 2	łupki shales 1	łupki shales 2	piaskowiec + łupek sandstone + shale 1	piaskowiec + łupek sandstone + shale 2	korelacja correlation
OS/KA/1—603	603	32,1140	67,3123	3,8356	4,4391	35,9593	67,7787	0,0734
OS/SP/1—20	70	29,4421	47,6758	6,1136	6,9908	35,5565	48,3816	0,0292
71—253	189	37,4949	74,6672	6,0945	8,5533	43,5927	75,5270	0,0441
SK/SK/1—215	215	15,3177	27,2629	2,5263	1,7033	17,8480	27,6865	0,2209
ZA/MO/1—129	129	26,9216	47,5678	4,1470	4,9465	31,0688	48,3392	0,1052
130—213	83	24,2160	73,7407	3,3482	3,8298	27,5659	74,2636	0,1112
214—262	48	29,7915	38,2961	3,4164	3,2843	33,2083	38,4014	0,0107
SK/SŁ/1—50	50	21,4196	33,3434	34,1196	41,0689	55,5396	67,9578	0,6645
ZA/WI/1—340	340	6,4685	7,9827	4,6617	4,8130	11,1348	10,1133	0,2016
ZA/KO/1H1—220	220	2,6253	1,1894	2,8567	1,5508	5,4847	2,0809	0,1456
ST/RO/1—205	205	3,2497	2,6808	2,2162	1,2162	5,4615	3,4185	0,4553
ZA/KO/1—51	51	11,5678	19,7541	2,6662	2,1024	14,2350	20,8259	0,4707

Objaśnienie:, Explanation:

OS/KO — Kamieniołom w Osielcu, piaskowiec magurski;
Osielec Quarry, Magura Sandstone
OS/SP — Kamieniołom spółdzielczy w Osielcu, piaskowiec magurski;
Osielec cooperative-quarry, Magura Sandstone
SK/SK — Odsłonięcie w brzegu Skawicy, Skawica, piaskowiec magurski;
Exposure in Skawica River, Skawica, Magura Sandstone
ZA/MO — Przekop drogi, Zawoja-Mosorne, piaskowiec magurski;
Road-cutting, Zawoja-Mosorne, Magura Sandstone
SK/SŁ — Odsłonięcie w potoku, Skawica-Sołtysia, łupki śródmagurskie;
Exposure in stream, Skawica-Sołtysia, Intra-Magura Shales
ZA/WI — Odsłonięcie w potoku, Zawoja-Wilczna, warstwy hieroglifowe;
Exposure in stream, Zawoja-Wilczna, Hieroglyphic Beds
ZA/KO/H — Odsłonięcie w potoku, Zawoja-Końskie, warstwy hieroglifowe;
Exposure in stream, Zawoja-Końskie, Hieroglyphic Beds
ST/RO — Odsłonięcie w potoku, Stryszawa-Roztoki, warstwy hieroglifowe;
Exposure in stream, Stryszawa-Roztoki Hieroglyphic Beds
ZA/KO — Odsłonięcie w potoku, Zawoja-Końskie, warstwy podmagurskie;
Exposure in stream, Zawoja-Końskie, Sub-Magura-Beds

1 — średnia arytmet. miąższości ławic; arythm. mean thickness
2 — odchylenie standardowe miąższości ławic; standard deviation

Tabela (Table) 2

RYTMY UWARSTWIENIA UTWORZONE PRZEZ 1021 KOLEJNYCH, NIEZALEŻNYCH PRÓB

BEDDING TYPES GENERATED BY 1021 CONSECUTIVE INDEPENDENT TRIALS

proste rytmy simple beds		złożone rytmy composite beds	
2-składnikowe 2-component	3-składnikowe 3-component	2-krotne 2-fold	3-krotne 3-fold
23,34%	4,38%	27,74%	44,52%

Tabela 2 do str. 213.
Table 2 for p. 253.

are thin or very thin, 42,31% are medium or thick and 10,93% are very thick. Also, between units 439 and 600, very thin and thin type-I elements make up 40,74%, medium and thick elements 44,43% and very thick elements 14,63%. The elements of the medium and coarser thickness

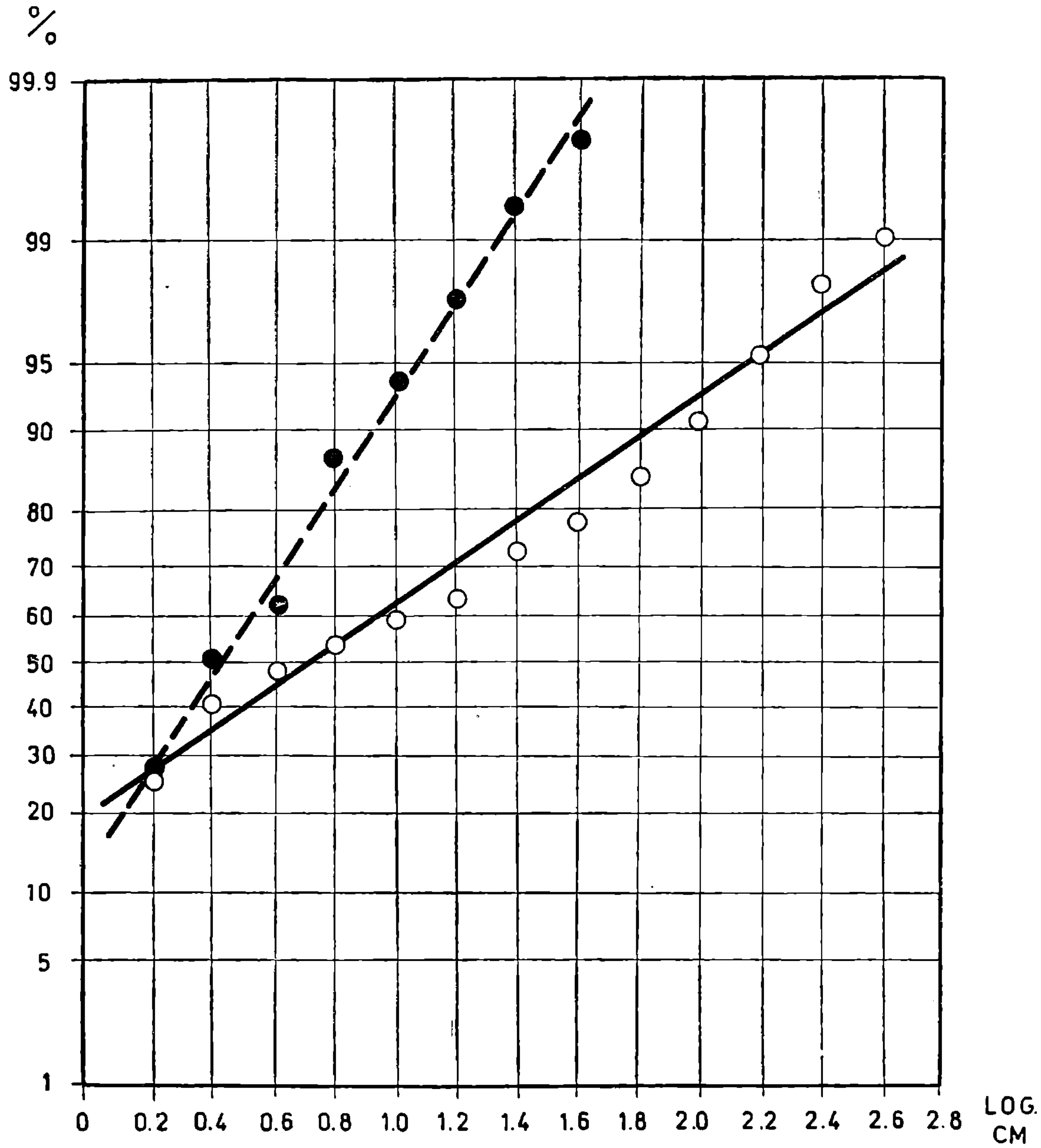

Fig. 6. Rozkład miąższości elementów piaskowca magurskiego w układzie logarytmicznym. Kółka białe oznaczają elementy I; kółka czarne, elementy II

Fig. 6. Log frequency distribution of element thicknesses for Magura Sandstone. Unfilled circles for type-I elements; filled circles for type-II elements

classes are medium-grained sandstones, frequently displaying multiple grading. Very thick type-I elements occur in complexes, in which they are flanked by groups of thick or medium elements. These complexes are bounded by thin and very thin or sometimes medium type-I elements. They each comprise 20 to 30 units and are seen on smoothed time series (Fig. 9 A, Fig. 10 A) as well defined fluctuations.

The unsmoothed time series for type-II elements (Figs. 8 B) shows little variability, with thin and very thin elements predominant. Only 6,63% of elements occur in the medium thickness class and coarser classes are absent. The time series is relatively uniform. Fluctuations in the smoothed curves (Fig. 9 B, Fig. 10 B) correspond with similar characteristics in the type-I curves for the thin-layered complexes only. Moreover, in these latter complexes, thickness values of type-II elements are usually greater than or equal to those of the corresponding type-I elements. The unsmoothed and smoothed time series for beds are similar to the curves for type-I elements.

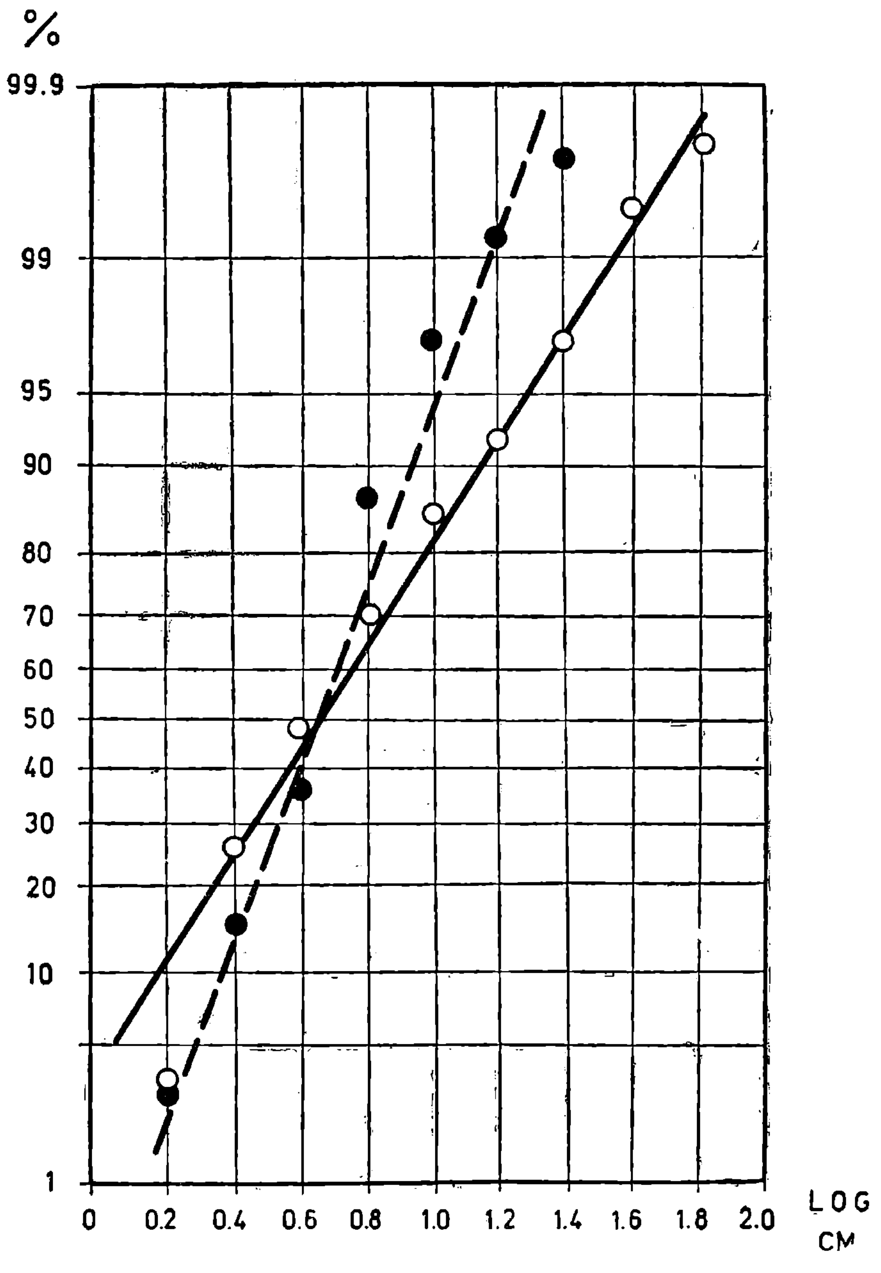

Fig. 7. Rozkład miąższości elementów warstw hieroglifowych w układzie logarytmicznym. Objaśnienia jak w fig. 6

Fig. 7. Log frequency distribution of element thicknesses for Hieroglyphic Beds. Explanation as for Fig. 6

Fluctuations were described from time series of type-I elements in Upper Carboniferous flysch by Nederlof (1959, pp. 653—660). Wood and Smith (1959, pp. 177, 178) recorded complexes belonging to the Aberystwyth Grits, in which either thick or thin beds may predominate. The same authors also described complexes, each beginning abruptly with a thick bed, which is followed by progressively thinner beds. Kelling (1961, p. 57) mentioned Ordovician „rhythms”, each comprising a very thick type-I element, succeeded by 4 or 5 type-I elements of the medium or thick classes, separated by thin shale partings. He also described thin-layered, fine-grained greywackes as complexes intercalated in a sequence of medium- and thick-layered alternations of coarse-grained greywacke and mudstone (Kelling, 1961, p. 59). Significant vertical changes in element thickness have been noted by Scott (1966, Table II, p. 86) in Cretaceous flysch. These different types of fluctuations are comparable to the two basic types, which make up the time trend of sedimentation in the Magura Sandstone exposure at Osielec.

In the Wilczna section of Hieroglyphic Beds (Plate VI, Fig. 1) the time trend of sedimentation is less obvious than in the preceding case. Medium- and thick-layered type-I elements together make up 19,12% of the total, while for type-II elements, this value is reduced to 4,12%. In the time series for type-I elements (Fig. 11 A), very thin elements tend to occur together in groups of up to 5 units, as seen between units 101 and 104 and between units 107 and 109, for example. These latter elements are sandy siltstones, similar to the „interturbidite lithologies” of Ballance (1961, p. 468). The elements described by Ballance (1961) show ripple-drift cross-lamination however, while those in the Hieroglyphic Beds are usually made up of horizontal laminae. No trends are seen in the unsmoothed time series for type-I and -II elements. However, both sets of smoothed time series (Fig. 12 A and B; Fig. 13 A and B) for type-I and type-II elements show good agreement as to the positions of minor fluctuations. An underlying time trend of sedimentation is most clearly seen in the smoothed time series for bed thicknesses (Fig. 12 C; Fig. 13 C) as a definite grouping of the most pronounced oscillations from the beginning of the section to unit 49, from unit 120 to unit 189 and between units 239 and 290. Units 50 to 119 and 184 to 235, on the other hand, are characterized by lower variability.

Thus time trends of sedimentation are defined by grouped oscillations and fluctuations in the Magura Sandstone at Osielec, while in the Wilczna section of Hieroglyphic Beds, only grouped oscillations are represented. The time series for the Osielec section possess characteristics observed in exposures of Magura Sandstone in the quarry near Bystra and in the roadside cutting at Zawoja-Mosorne. The last-mentioned sections are very much smaller and are interrupted by gaps in exposure, but thin-layered complexes as fluctuations comprising grouped oscillations, separated by predominantly medium- and thick-layered fluctuations are seen on unsmoothed and smoothed time series. Time series for Hieroglyphic Beds exposed in the streams Końskie, Mosorne, Jaworzyna and Roztoki give time trends of sedimentation similar in type to that obtained for the Wilczna section. A commonly observed phenomenon is the grouping of pronounced oscillations where thick and very thick, medium- or coarse-grained sandstones are associated with thin and very thin shales and scarce medium-, thick- and very thick-layered marls (see also Książkiewicz, 1966, p. 46).

Poor exposures of the Osielec and Pasierbiec Sandstones do not permit investigation by means of time series. However, in both cases, alternations of relatively thin- and thick-layered complexes are seen. In the relatively thin-layered complexes, fine-grained sandstones of the very thin, thin and rarely medium thickness classes alternate with shales of similar thickness. The relatively thick-layered complexes comprise medium-, thick- and very thick-layered sandstones and conglomerates, separated by thin shales and occasional thick or very thick marls. Vertical variation of layer thickness in the Beloweza Beds resembles that in the Hieroglyphic Beds, as far as can be seen from scarce exposures. In the Łącko Marls, relatively thin-layered complexes are succeeded by complexes characterized by variability in layer thickness, with medium- to very thick-layered marls and sandstones as well as very thin-, thin- and medium-layered elements.

Origin of time trends of sedimentation in flysch sequences

Any attempt to account for the grouped oscillations and fluctuations here described must be highly speculative, in the light of present knowledge. Nevertheless, as pointed out by Sloss (1962), conceptual stratigraphic models provide a valuable means of evaluating processes and responses in the development of sedimentary sequences. Sloss (1962, Fig. 11, p. 1056) proposed a „turbidite model", in which rate of subsidence, T, of a sedimentary basin exceeds quantity Q of sediment supplied to a peripheral piedmont deposit. With continued basin subsidence and piedmont deposition, the angle of repose for the clastic wedge is exceeded and mass movement basinward takes place. Q, R, M (compositional and textural factor) and D (dispersal factor) define the external geometry of a sedimentary body, so that

$$\text{shape} = f(Q, R, D, M)$$

However, the assumption of constant M by Sloss (1962) is inadmissible. Furthermore, the inherited nature of grain properties in flysch, as well as the possibility of multisource supply of material, indicates a fair degree of independence between composition and texture (see Dott, 1964, p. 71). D depends upon weights assigned to both erosion and deposition by turbidity currents and bottom currents respectively and to pelagic deposition; this is elsewhere discussed at length on the basis of sedimentary structures and faunal evidence.

Fluctuations in sedimentary time series might arise out of variations of Q with time. The clastic wedge built up at the basin margin might be a river delta (Kuenen, 1957b) and periodic variations in supply, which might be seasonal or due to long-term climatic changes, could then give rise to fluctuations in thickness for deposits laid down by turbidity currents. An alternative explanation might rely primarily upon periodic changes in R. Evidence has been assembled by Hallam (1963) for a progressive increase in relief of the Earth's surface since the Cretaceous, effected by intermittent epeirogenic movements, eustatic changes of sea level and progressive oceanic subsidence. Pulsatory, vertical movements, particularly of the last-mentioned type, might give rise to the thick-layered fluctuations in the Magura Sandstone. Intervals of stabilization of sea-level would favour the outward building of the clastic wedge (see the R-variable model of P. Allen, 1964, p. 290), during which the thin-layered complexes might accumulate. Grouped oscillations showing relatively high variation might reflect tectonic movements.

Deformed beds

Deformation resulting from lateral displacement is rarely seen in the formations studied. Scarce, one-bed slumps (Książkiewicz, 1958, pp. 139—146) are confined to medium, thick and very thick beds of the Magura Sandstone. These are sometimes only seen as curved, concave-up partings in type-I elements, marking the lower boundary of the displaced, upper part of the layer (see Książkiewicz, 1958b, Fig. 14, p. 141). Type-I elements of medium thickness, particularly those occurring near the margins of fluctuations in bed thickness, are sometimes bent into single, flat-lying folds with parallel limbs. Similar features have been described and figured by Wood and Smith (1959, p. 172 and Plate VIII, Fig. 3), who termed the phenomenon prolapsed bedding. More rarely, folded lumps of laminated sandstone, with apparent long axes in the order of 30 to 40 cm. in length, are found embedded in a sandy matrix (see also Książkiewicz, 1958b, Fig. 13, p. 140 and Fig. 22, p. 145). In the example from the Intra-Magura Shales figured (Plate VII, Fig. 2), the sole of the one-bed slump is sharp, with groove moulds.

Lateral-displacement structures have been previously interpreted as being due to sliding of beds downslope and the direction of closure of folds has been taken to indicate direction of dip of palaeoslope (see, for example, Wood and Smith, 1959; Murphy and Schlanger, 1962; Scott, 1966). Prentice (see p. 192 in discussion of Wood and Smith, 1959), however, suggested that structures of this type might result from bottom disturbances caused by the emplacement of a turbidity current, even in absence of a slope. This has recently been confirmed experimentally in an important contribution by Dżułyński and Radomski (1967; see especially Photo 1). Thus lateral-displacement structures may, but need not necessarily indicate palaeoslope and should accordingly be interpreted with caution. Vertical displacement of material from beds is seen as sandstone dikes and sills, passing through both type-I and -II elements. These are confined to a small number of occurrences in shaly, thin-layered complexes of the Magura Sandstone. Examples may be seen in the Intra-Magura Shales at Skawica-Sołtysia and in the Magura Sandstone proper at Zawoja-Policzne.

INTERNAL SEDIMENTARY STRUCTURES

General

Flysch beds are characterized by a limited range in type of internal structure. Several different structures commonly occur together, occupying different levels of the same bed. Bailey (1930) deduced absence of current action during the formation of graded bedding and concluded that this arrangement of grains and cross-lamination are mutually exclusive phenomena, characterizing entirely different facies types. However, Vassoyevich (1932), Signiorini (1936) and Sujkowski (1938), working independently in different flysch successions, described occurrences of graded bedding and associated structures indicative of current action, such as rippled tops of type-I elements. Signiorini (1936) also gave a fixed, vertical order of appearance for internal structures, with grading followed by sandy laminae, which may be horizontal throughout or in part convoluted. Multiple grading of clastic particles and also sets of inclined laminae, sometimes convoluted, were reported by Książkiewicz (1947) from type-I elements belonging to several flysch formations of the western Polish Carpathians. Cross-lamination in the lower parts of sandstones, succeeded towards the top by horizontal lamination, and also forming central zones in otherwise horizontally laminated sandstones were described (Książkiewicz, loc. cit.). Convoluted laminae („warstwowanie spływowe"), vertically succeeding graded bedding and cross-laminae respectively and sometimes followed by horizontal laminae, were observed by the same author (Książkiewicz, 1949). An intrastratal sequence, comprising grading, followed by horizontal laminae, in turn succeeded upwards by cross-laminae was given by Vassoyevich (1948, Fig. 6, p. 92). Książkiewicz (1952) described various types of „single" (loc. cit., Fig. 1, p. 403) and multiple (loc. cit., Fig. 2, p. 406) graded bedding, as well as relationships between grading, horizontal lamination and cross-lamination (loc. cit., Fig. 5, p. 410 and Fig. 6, p. 412), from field observations in the Carpathian flysch. Later workers (for example, Kuenen, 1953, 1957; Radomski, 1958; Birkenmajer, 1959; Dżułyński and Ślączka, 1959; Unrug, 1959; Wood and Smith, 1959; Bassett and Walton, 1960) described intrastratal sequences from different flysch formations. In most cases, a preferred vertical order was either specified or implied.

Nesteroff (1961) established an „ideal type sequence" of internal structures for terrigenous turbidites collected in cores from a number of modern abyssal plains. This sequence, beginning at the base of a bed is: grading, horizontal laminae, cross-laminae, horizontal laminae, structureless pelite (see Nesteroff, 1961, Plate I, p. 267 and Fig. 3 A, p. 268). One or more of these bedding types may be absent (Nesteroff, 1961, Fig. 3 B—D, p. 268) from the sequence in a given bed. Similar intrastratal sequences were independently described by Bouma (1962, pp. 48—57) from Eocene flysch of the Alpes Maritimes and by Ballance (1964, p. 468, also Fig. 2, p. 469) from the Miocene of New Zealand. Both Bouma (1962) and Ballance (1964) report the occurrence of convoluted laminae in the cross-laminated sub-element. A bed consisting of the composite sequence (in the meaning of Duf and Walton, 1962) of internal structures[1] was recovered from a channel in the outer fan of La Jolla submarine canyon, off California (Bouma, 1964, Fig. 3, p. 378). Thus the occurrence in deep-sea turbidites and flysch beds of this composite sequence and incomplete sequences displaying a preferred, vertical arrangement of structures strongly supports the idea of a common depositional mechanism for these deposits.

For all formations considered in the present account, laminae may often be distinguished in type-I elements of thin and medium layer thickness, particularly where partings parallel to laminae are defined by concentrations of like components, such as mica flakes, plant fragments and glauconite grains. Partings of this type are scarce and intermittent in thick and very thick type-I elements belonging to the Magura Sandstone and Pasierbiec Sandstone. In many cases, the presence of horizontal laminae, cross-laminae and convoluted laminae may be detected at the

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[1] Bouma's term „turbidite facies model" for this composite sequence (Bouma, 1964) is inappropriate in terms of scale and is certainly not supported by anything in the report by Potter (1959) to which he refers.

exposure within beds exhibiting imprinted grading, but details of their geometry and contact relations remain obscure. These latter attributes were examined by means of sawed vertical surfaces, treated with balsam and viewed under the binocular microscope, as well as acetate peels taken from these. Radiographs were made [1] of thin slabs 0,2—0,5 cm. in thickness, cut at right angles to the bedding; procedure employed and a discussion of some of the results are given by Simpson (in press).

Description of internal structures

In beds displaying simple, superposed grading, sub-elements characterized by the predominance of particular internal structures are arranged in the vertical order given by Nesteroff (1961), Bouma (1962, 1964) and Ballance (1964). Where beds exhibit multiple, imprinted grading, this order is also frequently preserved, though vertical repetition of structures may occur.

Graded sub-element (A)

Vertical grading of grain sizes is usually simple, with moderate to poor separation of size grades, while other internal structures are either poorly developed or absent. When this sub-element is present within a bed characterized by simple, superposed grading, it always occurs at the base of the type-I element. Where separation is poor, the non-graded condition is sometimes seen (see Walker, 1965, p. 6). The degree of separation within the element may vary for different size grades. For instance, some coarse- and medium-grained sandstones belonging to the Pasierbiec Sandstone display an abrupt separation of pebble-sized clasts at the interface, while the sand-sized grades of the same sub-element show poor vertical separation. This is also true for certain type-I elements of the Hieroglyphic Beds exposed S of Wieprzec, in which grains of pebble and coarse-sand sizes occur only at the interface. The same phenomenon has been reported from Recent deep-sea turbidites by Conolly and von der Borch (1967). In some coarse-grained sandstones of the Magura Sandstone, the greatest concentrations of coarse grains occur at the relatively flat interfaces, though the same size grade is in each case distributed in reduced proportions fairly evenly throughout the type-I element. Groove moulds with the coarse grains at their downcurrent ends and current crescents scoured around the clasts are of common occurrence at interfaces in the Magura Sandstone, where these layers of coarse grains are found. Another instance of abrupt separation of the coarsest size grade is seen, where current transported pebbles and grains of coarse-sand size have become trapped in depressions of the mud surface as in flute marks occurring in the Magura Sandstone. In this latter case, the coarse grains are closely packed and usually exhibit imbrication, with a downcurrent dip.

In several cases, radiographs revealed the presence of crude, intermittent laminae in the graded sub-element. These show up as flattened, dark lenses on positive prints of radiographs and occur in instances where the transition from the graded sub-element to the one above is gradational

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[1] All radiographs were made by A. Makarewicz, under the supervision of Dr. M. Sterecka, at the Laboratory of Radiography, DOKP Medical Clinic, Kraków, for which the author acknowledges his indebtedness.

(Pl. VIII, Fig. 1). This gradational transition is seen as a progressive, vertical increase in the number of laminae, the lateral continuity of which also tends to increase upwards. The intermittent laminae are in the form of lenses and asymmetric ripple-like bodies, composed of comparatively high proportions of coarse grains, and in other cases as more continuous, relatively fine-grained laminae, which frequently unite laterally (see also Książkiewicz, 1952, Fig. 4, p. 409; Birkenmajer, 1956, Pl. I, Figs. 2 and 13; Koszarski, 1956, Fig. 1a, p. 394; Unrug, 1959, p. 214; Crowell et al., 1966, p. 18). Instances are also known in which laminae die out again upwards, to be replaced by coarser grained sediment, without internal structure, save for a poor separation of grain sizes, thus giving a type of inverted grading (Książkiewicz, 1952, p. 405).

Non-graded type-I elements may show regular and irregular arrangements of grains (Koszarski, 1956, p. 395). In the former case, there is uniform distribution of grades vertically, while in the latter, localized concentrates of either relatively coarse or relatively fine material are irregularly distributed. Prints of radiographs of some medium-layered, non-graded sandstones of irregular type, belonging to the Pasierbiec Sandstone, reveal a mottled structure (Moore and Scruton, 1957), clearly referable to the burrowing activity of organisms.

In the very thin, thin and medium classes of bed thickness for the formations studied, the graded sub-element is rare and usually makes up the entire type-I element of a thin or very thin bed. The sub-element is most common in thick and very thick beds, particularly in the Magura Sandstone, where it is often repeated vertically within composite beds.

Lower sub-element of horizontal laminae (B)

A sub-element characterized by the predominance of horizontal laminae of fine or medium sand may occur above the graded sub-element, or may itself form the basal part of the bed. The laminae are frequently defined by the regular alternation of light and dark coloured layers, which differ in composition in that the darker layer contains a higher proportion of clay, mica flakes and comminuted plant debris (Książkiewicz, 1952, p. 408; Unrug, p. 213; Webby, 1959, Fig. 11, p. 471; Bouma, 1962, p. 63; Kuenen, 1966, p. 528).

Laminae may appear to be arranged vertically in a number of different patterns (Książkiewicz, 1952, pp. 407—411; Birkenmajer, 1959, Plate I, p. 131), most of which have been based on variation in vertical distance between successive dark layers. Radiographs of the so-called „gradational bedding" (see Birkenmajer, 1959, p. 28) in fine-grained sandstones belonging to the Łącko Marls show that the thickest, light-coloured layers (1—2 cm.) are themselves made up of laminae up to 0,2 mm. in thickness. The compositional differences within successive laminae making up these apparently structureless layers are so slight as to be invisible to the naked eye. Of considerable interest is the fact that laminae of a single sub-element are vertically arranged in groups comprising laminae of similar composition.

As pointed out by Kuenen (1966, p. 530), the horizontal laminae of flysch sandstones frequently wedge out laterally. This is usually seen as the lateral union of two or more dark layers. This is also a characteristic feature for horizontal laminae in sandstones of channel and flood-plain deposits (Hamblin, 1964, Fig. 4, p. 188). Rare sets of tangential

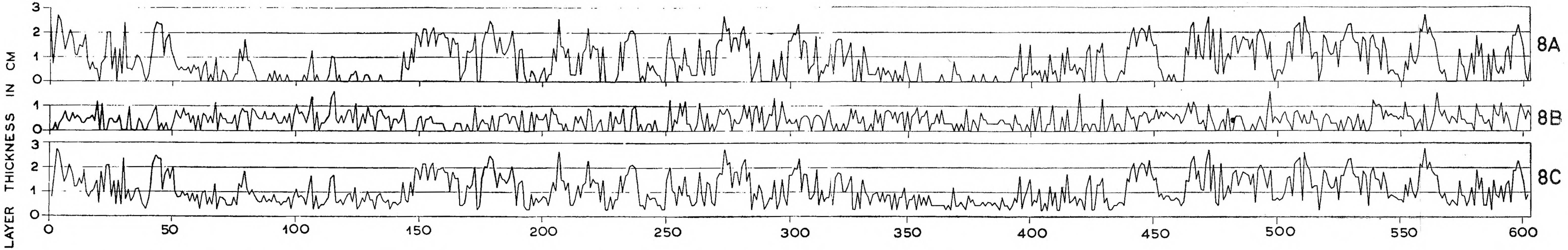

Fig. 8. Nie wygładzone szeregi czasowe miąższości elementów I (A), elementów II (B) i rytmów (C) dla piaskowca magurskiego odsłoniętego w kamieniołomie w Osielcu

Fig. 8. Unsmoothed time series for thicknesses of type-I elements (A), type-II elements (B) and beds (C) for the Magura Sandstone, exposed in the quarry at Osielec

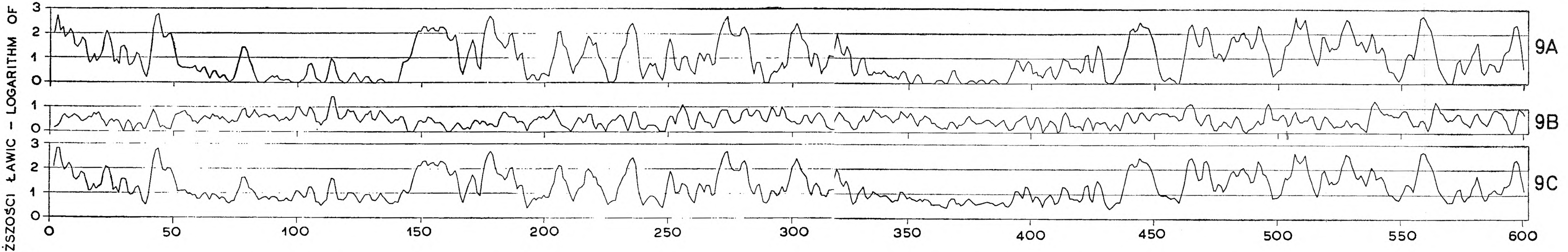

Fig. 9. Wygładzone szeregi czasowe w oparciu o wzór Shepparda. Na podstawie danych miąższości ławic przedstawionych w fig. 8

Fig. 9. Smoothed time series obtained using Sheppard's formula. On basis of layer thicknesses given in Fig. 8

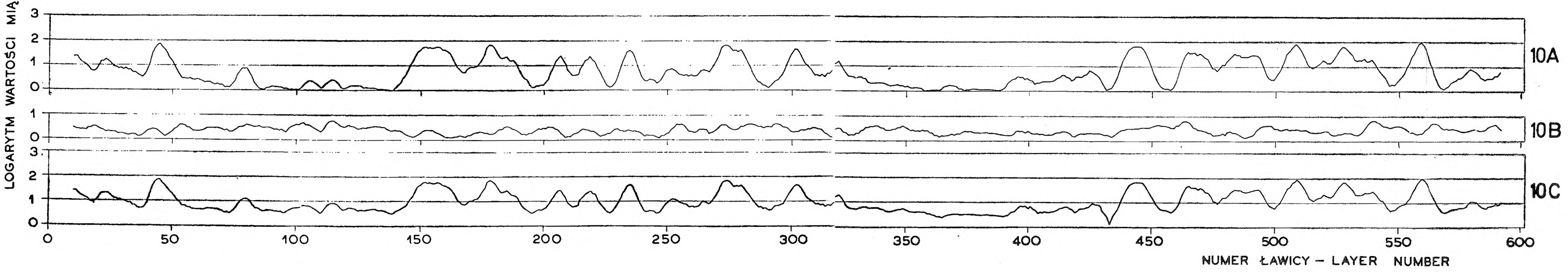

Fig. 10. Wygładzone szeregi czasowe w oparciu o wzór Spencera. Na podstawie danych miąższości ławic przedstawionych w fig. 8

Fig. 10. Smoothed time series obtained using Spencer's formula. On basis of layer thicknesses given in Fig. 8

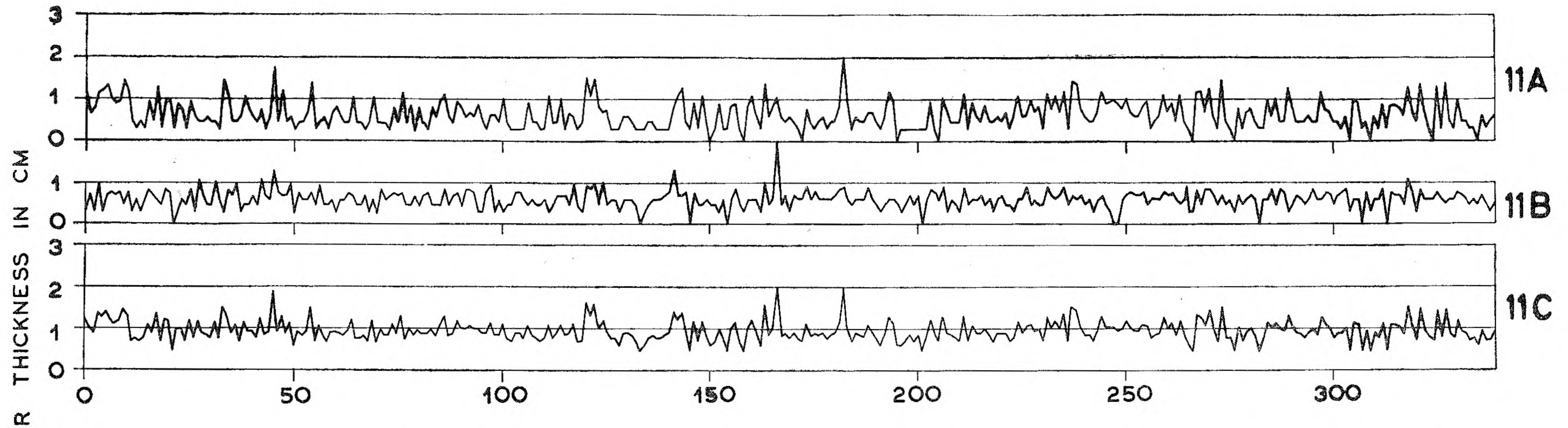

Fig. 11. Nie wygładzone szeregi czasowe miąższości elementów I (A), elementów II (B) i rytmów (C) dla warstw hieroglifowych, Zawoja-Wilczna

Fig. 11. Unsmoothed time series for thicknesses of type-I elements (A), type-II elements (B) and beds (C) for the Hieroglyphic Beds, Zawoja-Wilczna

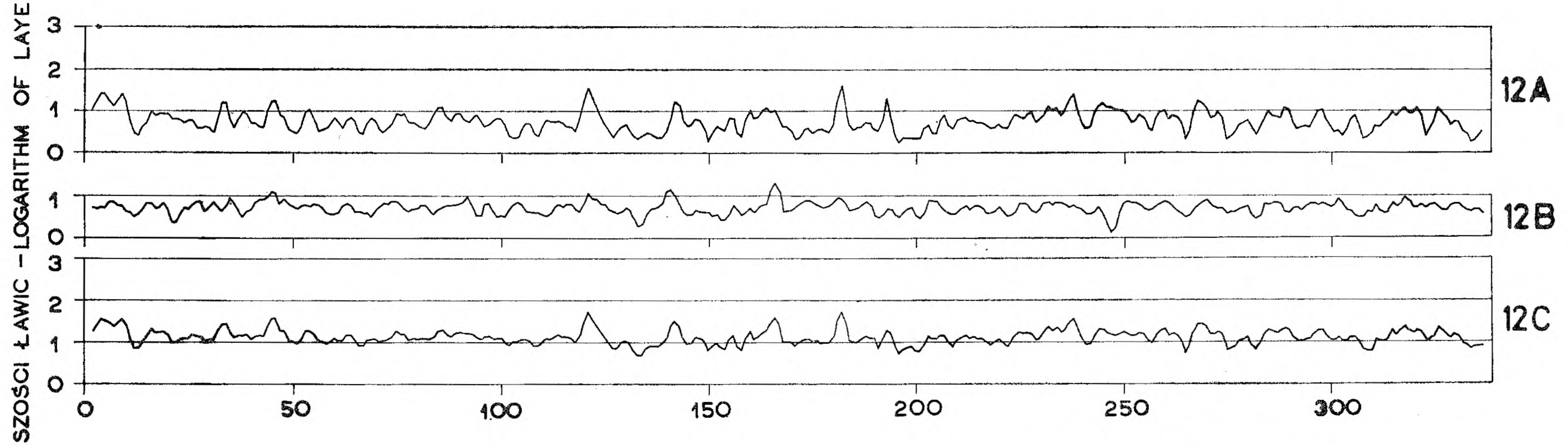

Fig. 12. Wygładzone szeregi czasowe w oparciu o wzór Shepparda. Na podstawie danych miąższości ławic przedstawionych w fig. 11

Fig. 12. Smoothed time series obtained using Sheppard's formula. On basis of layer thicknesses given in Fig. 11

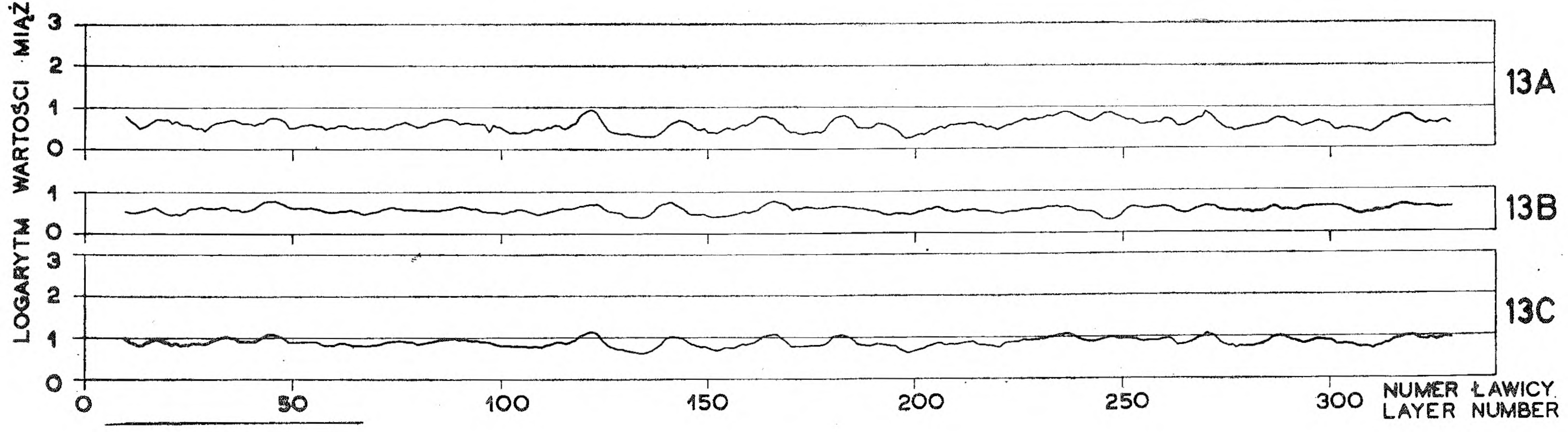

Fig. 13. Wygładzone szeregi czasowe w oparciu o wzór Spencera. Na podstawie danych miąższości ławic przedstawionych w fig. 11

Fig. 13. Smoothed time series obtained using Spencer's formula. On basis of layer thicknesses given in Fig. 11

foresets, with an inclination of up to 20° and resting upon an undulatory surface, have been found in B sub-elements occurring in the Hieroglyphic Beds (see, for instance, Pl. VIII, Fig. 2). The print of a radiograph revealing such an occurrence does not show any internal structure between the undulatory base of the layer of foresets and the dark horizontal layer immediately below. However, this may be a consequence of uniformity in grain size and the undulations may represent small ripples. The foresets occupy layers up to 0,4 cm. in thickness. Small current ripples have been reported from lower sub-elements of horizontal laminae in the Schlieren and Wäggital flysch formations, Switzerland (Hubert, 1967).

Where the lower sub-element of horizontal laminae occurs at the base of a bed particularly in the Hieroglyphic Beds, material filling irregularities of the interface, such as scoured-out trails and flute marks, is arranged in trough cross-laminae. In cross-section, these latter are roughly parallel to the sides of the depression which they fill, flattening out vertically to be replaced by horizontal laminae or truncated by horizontal laminae. Laterally sets of trough cross-laminae may either wedge out or become horizontal.

In plan view, sandy, horizontal laminae sometimes display either the linear arrangement of shallow grooves and low ridges termed parting lineation (Crowell, 1955; see also Pl. VIII, Fig. 3) or preferred orientation of coalified wood fragments. Lineations of both types show only slight directional variation vertically within a given sub-element B, coinciding as a rule with the lineations defined by interfacial structures or the direction of maximum dip of cross-laminae for the same bed.

Type-I elements of all thickness classes in the formations studied may contain this sub-element. In very thin to medium type-I elements, the lower sub-element of horizontal laminae may predominate, even to the exclusion of other sub-elements. In the thick and very thick type-I elements of the Magura Sandstone, this sub-element is frequently repeated at different levels throughout composite beds, while in the Pasierbiec Sandstone and Osielec Sandstone, the entire element may exhibit horizontal lamination with imprinted grading.

Sub-element of cross-laminae (C)

Cross-lamination is very common in type-I elements of flysch beds (Książkiewicz, 1947, 1952) and is widely distributed throughout the formations investigated. The laminae of this sub-element are similar to those of the lower sub-element of horizontal laminae, in that they are delineated by relatively dark-coloured layers, which contain high proportions of matrix material. Cross-laminae of „ripple-drift" type (Sorby, 1908) usually predominate. These are characterized by rhythmic lateral repetition of lee-side laminae in climbing sets, which reflect the simultaneous forward and upward movements of migrating ripples. The stoss-side laminae may be partially or completely eroded away, thus giving rise to irregular bounding surfaces between sets. Both ripple-drift cross-laminae with stoss-side laminae eroded away (see McBride, 1962, Fig. 9, p. 51; Walker, 1963, Figs. 2 and 3, pp. 181, 182) and with stoss-side laminae preserved (see Walker, 1963, Figs. 6 and 7, pp. 185, 186) are known from the formations studied, particularly the Hieroglyphic Beds. Though in a given bed these types are mutually exclusive, they are frequently found in different beds of the same exposure. The genetic link between cross-laminae of this type and the forward movement of ripples is borne out by scarce occurrences of crescentic ripples (lunate ripples of J. R. L. Allen, 1963) on the tops of type-I elements cross-laminated throughout, which are found in the Hieroglyphic Beds exposed in the stream Końskie, Zawoja-Gołynia (see also Dżułyński and Ślączka, 1958, Fig. 11, p. 225). Plan views of ripples are rare, but this relationship is assumed to be one of general significance (J. R. L. Allen, 1960, p. 195; Walker, 1963, p. 174).

In sections parallel to the direction of flow, cross-laminae dip down-current at angles of up to 15°, while the bounding surfaces between sets or stoss-side laminae, where present, dip up-current at lower angles (2—12°). Commonly, from the base of the type-I element upwards, bounding surfaces between sets dip up-current a progressively higher angle. Concomitant with this, upward increases in both ripple wave-length and amplitude are observed. These facts are in disagreement with the findings of Walker (1963, p. 177), who considered an upward decrease in amplitude to be characteristic for ripple-drift cross-lamination in turbidites. The lowermost bounding surface between sets is frequently almost horizontal, as are corresponding surfaces near to the top of the type-I element. Normal to the direction of flow, troughs with curved (concave-up), lower bounding surfaces and, more rarely, horizontal laminae are seen. The latter are seen in very thin and thin, type-I elements, consisting usually of sandy siltstone, fine grained sandstone or pebbly, coarse-grained sandstone; they may have been formed by transverse ripples (Dżułyński and Walton, 1965, p. 176).

Trough cross-lamination is occasionally found together with ripple-drift lamination within single sub-elements of cross-laminae, particularly at the base of the sub-element. This is seen in cross-section as a series of overlapping, rounded troughs, each with the lower bounding surface concave-uppermost. Each trough is filled with a set of cross-laminae, which may display either concordant or discordant angular relations in vertical sections parallel to the direction of flow. The laminae may be delineated in sections by dark, matrix-rich layers, as is usually the case in the Hieroglyphic Beds and other formations with relatively fine-grained type-I elements. In coarse-grained type-I elements of the Pasierbiec Sandstone, striking changes in grain size take place from one cross-lamina to the next. Furthermore, in the Pasierbiec Sandstone, where this type of cross-lamination frequently occurs to the exclusion of the ripple-drift type, cosets and even sets of cross-laminae may display a conspicuous lithological heterogeneity. This latter feature is frequently seen as an abrupt vertical transition from cross-laminae of pebbly, coarse-grained sandstone to cross-laminae of fine-grained sandstone with rare, large Foraminifera lying flat in the plane of the lamination (Pl. VIII, Fig. 4). The fine-grained laminae usually show discordant angular relations and their angle of inclination decreases upwards. Distinction may be made between trough cross-laminae, limited to erosional depressions not associated with ripples, and concordant laminae, filling and extending beyond roughly symmetrical troughs between ripples. The latter type of trough infilling occurs at the top of sets of ripple-drift cross-laminae.

Fine-grained laminae of this sub-element may exhibit deformation, varying from a mere warping of cross-laminae to a general convolution, usually confined to one or more definite sets. In the latter case, the convoluted sets are restricted to the central parts of the sub-element or appear at the top (see Bouma, 1962, p. 63).

Cross-laminae are present in most type-I elements of thin or medium thickness in all formations, and frequently make up the greater part or even the whole of the vertical thickness of type-I elements within this range. In thick and very thick type-I elements of the Magura Sandstone, cross-laminae are known from scarce curved partings close to the tops of the elements and from upper-surface occurrences of rib-and-furrow structure (Stokes, 1953; Dżułyński and Ślączka, 1958). The likelihood of widespread vertical distribution of cross-laminae within type-I elements of the higher size classes is suggested by occurrences of rib-and-furrow structure on the soles of the latter and by radiographs showing faint traces of the bounding surfaces between sets.

Sub-element of convoluted laminae (C′)

Where convoluted laminae were observed in a given bed throughout a fairly constant vertical thickness, constituting a significant proportion of the entire type-I element, these were assigned to a separate sub-element. Frequently, though intensity of convolution may vary vertically, convoluted laminae are arranged in a pattern of deformation seen throughout a given vertical section trough the sub-element. The original cross-laminated or parallel-laminated nature of the convoluted laminae is often seen. In fine-grained sandstones, convoluted laminae are delineated as are the undeformed laminae of the lower sub-elements. In medium-grained sandstone of thick, type-I elements, such as those of the Magura Sandstone, a single folded lamina rich in plant remains may evidence convolution affecting the entire element. Coarse sandstones and conglomerates do not usually exhibit convolution. Convoluted laminae are best developed in type-I elements of the thin grade.

Convolutions are seen in vertical cross-section as a series of relatively broad, rounded downfolds, separated by narrow, often sharp-crested upfolds (Signiorini, 1936). At the top of the sub-element, the most intense deformation usually occurs (Książkiewicz, 1949, p. 497). Plan view of convoluted laminae is rarely seen, since convolution frequently occurs in beds displaying continuous grading, with gradational contacts between elements. The plan views most commonly seen in beds of the coarser thickness grades belonging to the Magura Sandstone consist of small-scale domes and eye-folds, fairly regularly spaced on the eroded upper surface of the type-I element. More rarely seen are symmetrical, sub-parallel ridges and sharp-pointed cones, as described by Dżułyński (1963, p. 107) and Dżułyński and Smith (1963).

Upper sub-element of horizontal laminae (D)

Laminae here are delineated as in the lower sub-element of horizontal laminae, the main difference being that in the upper sub-element, the clay-rich parts of laminae predominate (see also Wood and Smith, 1959, p. 170; Walker, 1965, p. 19). Also as in the lower sub-element, laminae frequently wedge out laterally, both singly and in groups. As stated by Bouma (1962, p. 49) and Walker (1965, p. 3), this sub-element is frequently invisible, as a result of tectonic deformation or weathering. In the Carpathian flysch, compaction was probably important in obscuring this sub-element.

Shale sub-element (E)

Because the upper sub-element of horizontal laminae (D) may continue across the transition between elements to include the lower part of the type-II element, particularly in beds with indistinct contacts between elements, it is convenient to consider a shale sub-element forming the upper part of each bed. This sub-element is without internal structure of inorganic origin, save for an upward decrease in grain size. This latter condition is clearly seen in outcrops of Magura Sandstone, where the uppermost 1 or 2 cm. of shale in a bed is finely comminuted and possesses an oily lustre, as a result of tectonic movement along the plane of the interface.

Transitions between sub-elements

Bouma (1962, p. 49) described transitions between sub-elements in the Peira Cava Sandstones as being abrupt, gradual or indistinct. He later (Bouma, 1965, Figs. 16, 17; 1965, pp. 299 and 317) reported the occurrence of an erosional contact between cross-laminae and horizontal laminae in part of a sandstone element retrieved from the canyon axis of La Jolla Fan Valley. This phenomena he contrasted with the „transitional" or presumably non-erosional contacts between these sub-elements in flysch sandstones. In the Eocene of the Magura nappe, however, erosional contacts with small-scale, scour-and-fill structures (Shrock, 1948. pp. 230—238) between sub-elements are fairly common. Furthermore, it should be noted that a sharply defined, though flat contact may result from erosion. The following remarks are for the most part confined to observations of the Hieroglyphic Beds, since transitions between sub-elements in type-I elements of the Pasierbiec Sandstone and Magura Sandstone are as a rule seen only where a conspicuous vertical change in grain size takes place.

Where a graded sub-element rests upon pelite, the contact E—A is a sharp interface, which frequently displays irregularities attributable to the scouring action of currents or to the burrowing activities of organisms (see, for example, Sujkowski, 1938; Książkiewicz, 1952; Kuenen, 1957). These interfacial structures are considered in greater detail elsewhere in this account. Suffice is here to say that frequently entrainment of particles from the entire mud surface may be deduced. This is equally true for instances of other sub-elements resting on pelite.

The transition A—B is usually gradational, particularly where lens-like bodies of sand become increasingly common upwards in the graded sub-element. However the lens-like segregations of particular grain sizes reported here are highly suggestive of some process involving partial reworking of material already deposited. Where sharp A—B contacts are seen, these usually mark abrupt vertical changes in grain size. A—C contacts are not normally seen, and are confined to instances where erosion has locally removed part of the lower sub-element of horizontal laminae (Pl. VIII, Fig. 5). Contacts between grading and convolution of laminae are extremely rare and are gradational. Also very rare are contacts of the type A—D; those seen are irregular and clearly erosional. A—E transitions are relatively uncommon and are gradational.

B—C transitions are mostly sharp and regular throughout the width of an exposure. However, irregular contacts of this type, characterized by intrastratal washouts filled with trough cross-laminae, are by no means uncommon (Simpson, in press, see also Vassoyevich, 1948, Fig. 6, p. 92; Unrug, 1959, Plate XXI, Fig. 1). These washouts are often situated above similar structures located at the E—B transition (interface). Transitions B—C′ and C—C′ are usually gradational, in that deformation of horizontal laminae and cross-laminae progressively increases in intensity upwards. On the other hand, transitions E—C′ and C′—D are always sharp and invariably erosional (see also Książkiewicz, 1949, Fig. 4, p. 499; Dżułyński and Walton, 1965, Fig. 119, p. 180). The transition D—E is always gradational, but it should be noted that erosion is sometimes evidenced by rare occurrences of elongate flute marks in silty shale at or close to this contact.

Thus of the 36 transitions between sub-elements theoretically possible, only 20 are admissible for a sequence of simple beds and most of these may show evidence of erosion. Clearly in composite beds, the number of probabilities increases through repetition of sub-elements.

Internal structures of micrites

The internal structure of the relatively scarce micrite layers is barely visible in hand specimen. However, radiographic prints and thin sections reveal a predominance of horizontal (Simpson, in press, Jednorowska and Simpson, in press) laminae, defined by varying proportions of clastic grains. Thin and very thin micrite layers are made up almost entirely of horizontal laminae. Some of the lowermost laminae may be convoluted, in which case the folds are symmetrical in vertical cross section with amplitude 0,5 to 1,0 mm. and are often truncated by overlying horizontal laminae. On the other hand, thick and very thick type-II elements of micritic type are characterized by a systematic vertical change in internal structure. Multiple grading of sand-size grains is seen as concentrations of these into laminae and very thin layers in the lower parts of such elements. These relatively coarse-grained layers may themselves be made up of thinner laminae and their lower surfaces are erosional. A basal, sandy lamina with poor vertical separation of grain sizes is succeeded by horizontal, micritic laminae. The latter exhibit features analogous to those of type-I elements, in that they die out laterally and are bipartite, with clastic grains largely confined to the lower parts. These are replaced upwards by inclined laminae, similar in type but dipping at up to 20°. Inclined laminae presumably reflect dunes of indeterminate wave length. The uppermost inclined laminae are characterized by lateral pinching and swelling. This condition becomes prevalent as the angle of dip decreases upwards and laminae are replaced by isolated lenses. The uppermost micrite displays scarce, argillaceous laminae, which are up to 0,5 mm. in thickness.

Hydrodynamic interpretation of internal sedimentary structures

The terminology of Varnes (1958; see also Morton and Streitz, 1967, pp. 124, 126) for movement types of landslides might be extended to include modes of underwater mass movement:

1. Falls result from the free falling of material, regardless of size.
2. Slides reflect movement along one or more shear or slip surfaces,

which may form the boundaries of distinct segments within the affected mass.

3. Flows are displaced masses, in which deformation takes place on the scale of the individual grain and discrete slip surfaces do not occur. Depending on water content, contacts between grains arise mainly through rafting of particles by their neighbours lower in the flow, or through impact.

4. Density or turbidity currents are moving suspensions of sediment in water, in which contacts between grains arise mainly as a result of collisions.

Experiments on turbidity currents carried out by Kuenen (in Kuenen and Migliorini, 1950) yielded graded deposits analogous to those found vertically repeated both in exposures of flysch and flysch-like strata and in cores of Recent deep-sea sediments. It was concluded that such sequences are largely made up of turbidite layers. Furthermore, experiments A-V and B-III described by Kuenen and Migliorini (1950, pp. 105, 106, 108) and experimental work by Kuenen and Menard (1952) supported a turbidity-current or flow origin for poorly graded and non-graded beds also found in these types of sequence. The coarsest sediment undergoing transportation is assumed to occupy the most rapidly moving, head part of a turbidity current, replaced both laterally rearwards and vertically upwards by progressively finer material (Kuenen and Migliorini, 1950; Kuenen, 1956, pp. 136, 137; 1957, Fig. 19, p. 253). Where a decrease in slope occurs, deposition of the coarsest material takes place under conditions of waning velocity to give deposits with lateral and vertical grading. Moderately sorted, non-graded beds may be attributed to sedimentation from a turbidity current with uniform granulometric composition in the head part (Kuenen and Menard, 1952, pp. 93—95), constantly fed perhaps from a flow source, while unsorted graded beds are deposited directly from a flow (Kuenen and Menard, 1952, p. 95). Types of mass movement with characteristics gradational between those of turbidity currents and flows are known (Kuenen, 1956) and deposits formed in this way have been termed fluxoturbidites (Dżułyński et al., 1959, p. 1114; Unrug, 1963; undaturbidites of Rizzini and Passega, 1963, pp. 71, 72).

Though the traditional explanation for the origin of graded beds and non-graded beds associated with them is still basically sound, important amendments derive from theoretical and experimental studies. These concern the separation of sediment size grades during transportation and the generation of bottom forms[1], preserved as internal sedimentary structures.

Attention was drawn by Gilbert (1914; see also Bagnold, 1956) to the existence at the base of a turbulent, sediment-bearing current of a dense „saltation zone”, from which turbulent eddies are excluded by the dispersive pressure generated by collisions between grains. This phenomenon, as developed in turbidity currents, has been termed „fluidized sediment mass” (Hsu, 1959) and „traction carpet” (Dżułyński and Sanders, 1962); in this account, the latter term is adopted. The relatively coarse-grained, basel layer may contain up to 53% grains by

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[1] In this account, bottom form is used as synonym for the term bed form, frequently encountered in experimental studies (for example, Simons et al., 1965).

volume (Bagnold, 1956). Thus, as grains are added from above to a traction carpet of this composition, others are concomitantly deposited on the bottom. Clearly in such cases, vertical grading in the deposited layer will reflect vertical grading in the moving traction carpet. Also the traction carpet constitutes a part of the turbidity current, moving in response to drag by the turbulent part of the current and with increases in drag by the turbulent part of the current and with increases in momentum gained from added grains (see Dżułyński and Sanders, 1962, p. 88; Kuenen, 1966, pp. 543, 544). Sanders (1965, pp. 211 et seq.) now sees the development of a flowing grain layer taking place independently, without an accompanying turbulent suspension.

A uniform concentration of grains vertically throughout a current may arise where the tangential attraction of gravity applied to transported grains exceeds the energy required to keep them in suspension, thus giving an avalanching effect (Bagnold, 1962, 1963; Inman, 1963). This condition of autosuspension is determined by the angle of the bottom slope and with a decrease in this angle, autosuspension will cease and deposition will commence, with the decrease in velocity of the current. Rapid deposition accompanying a large decrease in velocity would give rise to a non-graded bed. Obviously, depending on the rate of decrease in slope, a variety of internal structures may be formed, including well developed, simple grading and laminae (see Walker, 1965, pp. 11, 12). Thus although Sanders (1965) claims that these different types of inertia flow may be recognized in sedimentary deposits, in practice the most that can be done is to suggest a number of alternative possibilities.

In the Magura Sandstone, the widespread occurrence of medium to very thick, type-I elements of medium grain size, characterized by poor sorting suggests deposition from dense sand-laden currents, which in most cases did not form a traction carpet. It is possible either that deposition occurred suddenly, on cessation of autosuspension conditions, or that the current was poorly differentiated, owing to a tendency for the main body of the current to move faster than the head (D. T. Hopkins, 1964, fide Dżułyński and Walton, 1965, p. 173; Middleton, 1965). In either case, it is clear that an early stage of current movement is represented and the deposits are proximal. Similar reasoning may be applied to the non-graded conglomerates and conglomeratic sandstones of the Pasierbiec Sandstone, though these latter were probably deposited from sediment flows and not from turbidity currents.

Gilbert (1914, pp. 32, 33) and Brush (1959) showed experimentally that, where water flows with increasing velocity over a sand layer, early forming ripples are replaced at higher velocities by a plane bottom. More recently, controlled flume experiments (Simons and Richardson, 1961, 1962a, 1962b; Simons et al., 1965) gave with increasing discharge a sequence of bottom forms, appearing in the fixed order: rippples, dunes, transition, plane bottom, standing waves and antidunes. In sedimentary rocks, the most common manifestation of bottom forms is as vertical sections through internal structures and, on the basis of experiments, vertical sequences of structures in simple beds have been taken to indicate progressive decreases in velocity upwards (for example, Bouma, 1962, p. 97; McBride and Kimberly, 1963, p. 1852). Simons and Richardson (1961, p. 91) suggested that bottom form be used to define the flow regime prevalent during deposition of sediments. Flow regime classification of sum total movement in alluvial channels is based on the form of bottom configuration, mode of particle transport, process of energy dissipation and phase relations between bottom and water surface (Simons et al., 1961; p. VI; Simons et al., 1965, Table 1, p. 36). Thus deduction of flow regime from sedimentary structures avoids placing undue emphasis upon single factors (Harms and Fahnestock, 1965, pp. 108, 109).

The succession of bottom forms produced in experiments by Simons and Richardson (1961) is closely comparable to the sequence of internal structures in simple beds of the formations studied and a flow regime interpretation of these deposits may be attempted (see Harms and Fahnestock, 1965; Walker, 1965, Table 4, p. 22). Thus in general terms, the graded sub-element (A) and the lower sub-element of horizontal laminae (B) are assigned to an upper flow regime of low flow resistance and large capacity for sediment transportation, while those structures higher in the sequence belong to the lower flow regime, in which these latter conditions are reversed. As pointed out by Harms and Fahnestock (1965, p. 109), absence of upper-regime structures, as in the Hieroglyphic Beds and Beloweza Beds, may indicate that the depositing current never attained the upper flow regime. Another explanation, however, might be that the current passed through the upper regime with deposition of relatively coarse material in the proximal part of the basin, to give only lower-regime bottom configurations in the finer-grained sediments deposited distally (compare with the hypothetical depositional cone of Bouma, 1962, Fig. 25-A, p. 99).

According to Simons et al. (1965, p. 37), the upper flow regime is characterized by downcurrent rolling of grains „in sheets a few diameters thick". A recent re-appraisal of a movie, made of early experiments on turbidity currents (Kuenen, 1966, pp. 543, 544), revealed a graded layer in motion at the base of each current. Thus deposition of the graded sub-element according to the modified traditional view is clearly possible under upper-regime conditions. An obvious comparison may be made between the lower sub-element of horizontal laminae and the plane-bottom configuration of flume experiments. J. R. L. Allen (1964, p. 105) showed that parting lineation parallel to the direction of current movement is an equilibrium bottom form in the upper flow regime. Książkiewicz (1952, p. 426, 427) attributed the formation of horizontal laminae in turbidites to the operation of numerous, weak and dilute suspensions, emplaced in rapid succession as secondary currents. Unrug (1959, pp. 211—217) provided an extension of this view when he suggested that incomplete mixing in the tail of a turbidity current causes differentiation into separate suspensions, which settle to form laminae. A similar idea was put forward by Wood and Smith (1959, p. 183). Such an origin has experimental support (Kuenen, 1951, p. 21) and would effectively explain deposition of the clay-rich, bipartite laminae of the upper sub-element of horizontal laminae. It cannot, however, be applied to the coarser-grained laminae of the lower sub-element, presumed to form in the lower part of the upper flow regime. Neither laminar flow at the base of a turbidity current (Glaessner, 1958, p. 6; Hsu, 1959) nor pulsations in velocity (Lombard, 1963; Sanders, 1960) are adequate in explaining the formation of bipartite laminae in the lower sub-element. For the present author, the notion of „like seeking like", put forward by Kuenen (1965, 1966) on the basis of his own experiments and the work of Moss (1962, 1963), seems to be reconcilable with the experimental observations of Simons et al. (1965) to account for unipartite, horizontal laminae, such as those found in B sub-elements of the Magura Sandstone and relatively rare medium-grained sandstones of the Hieroglyphic Beds. Pebbly and coarse-sandstone laminae of the Pasierbiec Sandstone appear to reflect a similar depositional mechanism, but since type-I elements several metres in thickness may be made up of laminae of this type, it is likely that sediment flows of the type described by Dill (1964) were operative.

Crude, intermittent laminae and ripples occasionally found in graded sub-elements in the Hieroglyphic Beds are probably referable to the transition between flow regimes, in which intermediate bottom configurations are obtained.

Ripple cross-laminae of sub-element C, common to all thin-layered sequences, represent a stable bottom form of the lower flow regime (Simons and Richardson, 1961). A detailed account of particle movement during ripple migration is given by Reineck (1961, pp. 52—55). Ripples arise as a bottom configuration in response to shear applied by a current to a cohesionless sand bottom. Excess shear is dissipated, when vortices form about horizontal axes in the ripple troughs and grains are rolled up the stoss slopes, to avalanche on to the lee sides of ripples. The geometry of cross-laminae, resulting from ripple migration is a function of ripple velocity and rate of deposition from suspension (Reineck, 1961, p. 56; J. R. L. Allen, 1963, p. 220; Walker, 1963, p. 176). Ripples developed in sand deposited from a turbidity current climb, when continuous fall-out of particles (Sanders, 1963; Walker, 1963) from a traction carpet takes place under conditions of low applied shear, with deposition in excess of erosion by trough vortices. This dependence of internal geometry upon rate of sediment supply is well illustrated by the experiments of McKee (1965).

It seems that convoluted laminae may arise in a number of different ways, each involving the application of a differential-pressure system to cohesive, unlithified laminae:

1. Downward movement of ripple troughs, concomitantly filled with cross-laminae (Kuenen, 1953). The mechanism is initiated by current flow over a rippled surface, which gives suction at crests and increased pressure at troughs of ripples. Propagation is by current flow and deposition into the sinking troughs.

2. Downward displacement of ripple crests, piled one upon the other (Kuenen, 1953; Dżułyński and Kotlarczyk, 1962; Dżułyński and Ślączka, 1965). Initiation is by uneven loading of the substratum consequent upon ripple formation and the system is maintained by the continued generation of ripples.

3. Upward displacement of horizontal laminae in response, to the shearing action of that part of the turbidity current flowing over the bottom (Sanders, 1960). Here initiation is by current shear and propagation as in (1).

4. The differential-pressure system is intrinsic to turbidity currents passing over plastic laminae (Holland, 1959; Dżułyński and Smith, 1963). Initiation and propagation are by the impingement of vortices upon a cohesive, laminated substratum.

5. The differential-pressure system is one of inverse density stratification (Dżułyński, 1966), consisting of a dense current passing over a less dense, laminated substratum. Initiation is the attainment of a con-

dition of density disequilibrium and propagation is by incomplete convective motion.

6. Inverse density stratification in the laminated sediment alone provides a differential-pressure sytem (Bogacz et al., 1968). Initiation occurs when a relatively weak trigger force releases the potential energy of the system and propagation is a function of the dilatant behaviour of the laminae.

In the formations studied, conditions 1 and 3 are those most likely to have been fulfilled, the former being particularly applicable to convoluted laminae observed in the Hieroglyphic Beds and Beloweza Beds. Condition 3 best accounts for convoluted laminae observed in the Magura Sandstone. Piling of ripple crests (2) to give a characteristic nodular appearance is restricted to a few occurrences in the Hieroglyphic Beds. Likewise cones and ridges referable to condition 5 are extremely rare.

Simulation experiment

Any continuous sequence, in which components are periodically repeated, may be described by a matrix, the co-ordinates of which are probabilities of transition from one component to another. If the thickness distribution of the components are known, then a synthetic sequence may be generated by means of random-process theory. The experimentally derived sequence may then be compared with the observed sequence.

Vistelius (1949, 1952) was the first to describe and analyse measured stratigraphic sections using a transition matrix, obtained from counts of contacts between different lithologies for sedimentary sequences in the Caucasian flysch and Middle Pliocene of Azerbijan. Independently, De Raaf et al. (1964, p. 43 and Fig. 22, p. 41) constructed a „facies relationship diagram”, based on the number of contacts between different lithologies in the Abbotsham Formation, while Allègre (1964) proposed the use of similar diagrams, together with transition probability matrices, to describe stratigrapic sections. Later, Vistelius and Faas (1965a, b) employed random-process theory in a study of a turbidite sequence in the southern Urals, while Vistelius and Feigelson (1965) established a Markovian model and with the aid of this, analysed transitions between turbidite lithologies. Carr et al. (1966) generated a synthetic section comprising sandstone, shale and limestone components, using a transition probability matrix derived from a measured section of the Mississippian Chester Series. Not only petrographic attributes of a sedimentary succession may be expressed in the form of a transition probability matrix. In an important contribution by Harbaugh (1966), a comprehensive model with Markovian elements simulates sediment dispersal, facies development and faunal migration in a subsiding sedimentary basin. Sequences of internal sedimentary structures were employed by Potter and Blakely (1967), who synthesized a fluvial sand body, characterized by five bedding types (cross-bedding, massive beds, parting lineation, ripple mark, mudstone) and by changes in grain size and permeability.

Procedures in the construction of transition probability matrices and in the simulation of sedimentary sequences using them are given by Carr et al., (1966), Griffiths (1966), Vistelius (1966, pp. 39—82) and Krumbein (1967) and are here only briefly outlined, together with several simplifying assumptions with regard to flysch sedimentation:

1. Depositional events giving rise to simple beds in vertical sequence reflect consecutive trials, which may be time-dependent only in so far as they may separately be dependent upon trials forming some other, time-dependent system.

2. Successive phases of a single depositional event gave rise to the limited number of sub-elements, which tend to appear in a fixed, vertical order in a simple bed. This is only partly true, in so far as a shale sub-element may in part result from pelagic deposition (Radomski, 1958).

3. The reduction in vertical thickness of a given sub-element by erosion was slight by comparison with the original thickness.

4. The tendency shown by sub-elements of a simple bed to occur in a fixed order between successive interfaces is maintained, regardless of the number of sub-elements present. The sub-elements of a simple bed may be taken to represent consecutive trials, each of which depends on the outcome of the one preceding, but is independent of the outcomes of all former trials. Thus a vertical sequence of sub-elements forms a Markov chain of the first order.

5. The transition probabilities of consecutive states making up such a system may be investigated by arranging them in the form of a square, stochastic matrix, with non-negative co-ordinates and row sums of 1.

729 transitions between sub-elements, counted in the continuous, vertical section in Hieroglyphic Beds shown in Plate VI, Fig. 1, gave the transition probability matrix:

$$\left\| \begin{array}{cccccc} 0{,}0000 & 0{,}0435 & 0{,}0000 & 0{,}0000 & 0{,}0000 & 0{,}9565 \\ 0{,}0000 & 0{,}0000 & 0{,}4571 & 0{,}4286 & 0{,}0000 & 0{,}1143 \\ 0{,}0000 & 0{,}0000 & 0{,}0000 & 0{,}0872 & 0{,}0051 & 0{,}9077 \\ 0{,}0000 & 0{,}0000 & 0{,}0000 & 0{,}0000 & 0{,}0227 & 0{,}9773 \\ 0{,}0000 & 0{,}0000 & 0{,}0000 & 0{,}0000 & 0{,}0000 & 1{,}0000 \\ 0{,}0678 & 0{,}1003 & 0{,}5339 & 0{,}0324 & 0{,}2655 & 0{,}0000 \end{array} \right\| = \pi_1 .$$

Clearly this is a useful descriptive device. For instance, it is easily seen that with cross-laminae taken as initial state, transitions of types C-A, C-B and C-C are impossible (zero probability), while the probabilities of C-C′ and C-D being seen are slight (0,0872 and 0,0051 respectively). The probability of shale following cross-laminae, on the other hand, is very high (0,9077). States may be predicted beyond the vertical limits of a measured section (see Griffiths, 1966). The probabilities of a particular state appearing in successive simple beds are determined by raising the initial transition probability matrix to the appropriate successive powers. For example, Fig. 14 shows derivation of transition probabilities for state C after two steps of vertical repetition of the sequence of states. If each of the six states were treated in a similar manner, the second power of π_1,

$$\left\| \begin{array}{cccccc} 0{,}0649 & 0{,}0959 & 0{,}5306 & 0{,}0497 & 0{,}2539 & 0{,}0050 \\ 0{,}0078 & 0{,}0115 & 0{,}0610 & 0{,}0436 & 0{,}0424 & 0{,}8338 \\ 0{,}0616 & 0{,}0910 & 0{,}4846 & 0{,}0295 & 0.2430 & 0{,}0903 \\ 0{,}0663 & 0{,}0980 & 0{,}5218 & 0{,}0317 & 0{,}2595 & 0{,}0227 \\ 0{,}0678 & 0{,}1003 & 0{,}5339 & 0{,}0324 & 0{,}2655 & 0{,}0000 \\ 0{,}0000 & 0{,}0029 & 0{,}0458 & 0{,}0895 & 0{,}0035 & 0{,}8582 \end{array} \right\| ,$$

would be obtained. As pointed out by Griffiths (1966, p. 6), successively higher powers of a transition probability matrix for a regular Markov

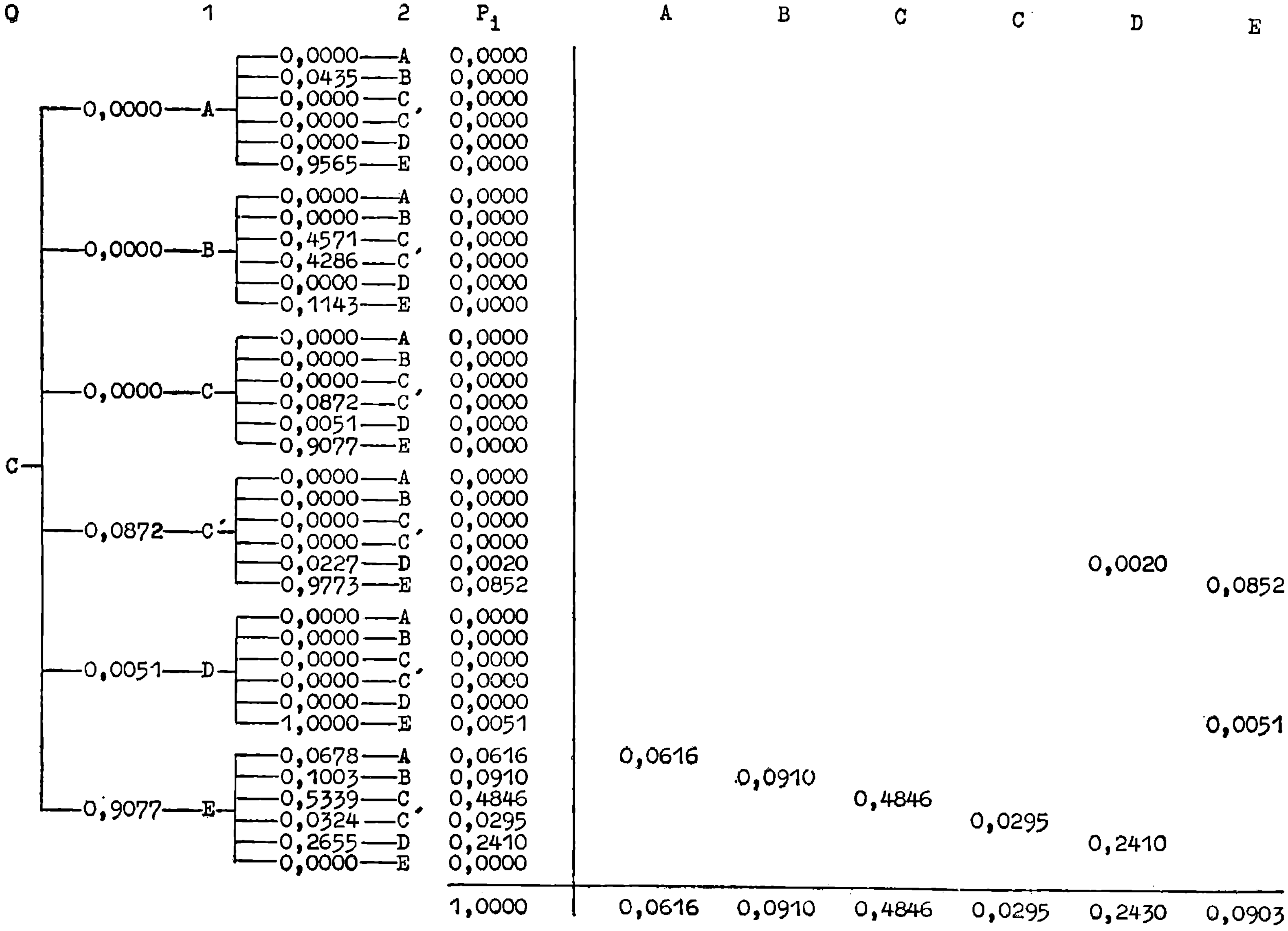

Fig. 14. Znaczenie kolejnych potęg macierzy prawdopodobieństw przejść. Dwa kolejne rzędy w macierzy prawdopodobieństw przejść (potęgi 1 i 2) dla stanu C podane jako przykład

Fig. 14. Significance of successive powers of transition probability matrix. Two successive powers (1 and 2) for the row of state C in the transition probability matrix taken as an example

chain approach a matrix, in which each row is a fixed probability vector with positive co-ordinaes. Thus at the 60th power, π_1 yielded the following matrix:

$$\begin{Vmatrix} 0{,}0315 & 0{,}0480 & 0{,}2702 & 0{,}0592 & 0{,}1262 & 0{,}4649 \\ 0{,}0315 & 0{,}0480 & 0{,}2702 & 0{,}0592 & 0{,}1262 & 0{,}4649 \\ 0{,}0315 & 0{,}0480 & 0{,}2702 & 0{,}0592 & 0{,}1262 & 0{,}4649 \\ 0{,}0315 & 0{,}0480 & 0{,}2702 & 0{,}0592 & 0{,}1262 & 0{,}4649 \\ 0{,}0315 & 0{,}0480 & 0{,}2702 & 0{,}0592 & 0{,}1262 & 0{,}4649 \\ 0{,}0315 & 0{,}0480 & 0{,}2702 & 0{,}0592 & 0{,}1262 & 0{,}4649 \end{Vmatrix} .$$

This matrix did not change at the 61st and successively higher powers. Thus the stochastic model employed describes a Markov chain, which is termed regular and ergodic, since any state may be reached from any other state in a finite number of steps. The initial transition probability matrix was derived from a tally matrix by means of computer program t7/68. which then calculated the values of successive powers, until the equilibrium state was reached. t7/68 was written for the Polish UMC-1 computer and is described by Jelonek and Simpson (1968).

A synthetic, vertical sequence of sub-elements was generated using program t12/68 (Jelonek and Simpson, 1968). The method employed is similar to that of Potter and Blakely (1967). An initial state was chosen randomly and the vertical thickness for that sub-element was randomly taken from the corresponding thickness distribution. Then, in accordance with the transition probabilities of the row, corresponding to the initial state in the transition probability matrix, the second state was selected. A thickness value was taken randomly from the thickness distribution for the second state. This process was repeated for 500 transitions. Part of a synthetic sequence thus generated is shown in Fig. 15.

Three synthetic sections generated by the same transition probability matrix were compared with the fundamental section of Hieroglyphic Beds in the following way. For each section, a transition probability matrix was computed from a tally matrix based on transitions measured at fixed vertical intervals of 10 cm. Equilibrium states computed from each transition probability matrix were compared.

The transition probability matrix for transitions at 10 cm. intervals in the Hieroglyphic Beds section is

$$\begin{Vmatrix} 0{,}0000 & 0{,}0000 & 0{,}0000 & 1{,}0000 & 0{,}0000 & 0{,}0000 \\ 0{,}0000 & 0{,}3846 & 0{,}1923 & 0{,}2692 & 0{,}0000 & 0{,}1538 \\ 0{,}0000 & 0{,}0794 & 0{,}2222 & 0{,}0794 & 0{,}0635 & 0{,}5556 \\ 0{,}0000 & 0{,}0400 & 0{,}1200 & 0{,}2000 & 0{,}0000 & 0{,}6400 \\ 0{,}0000 & 0{,}1667 & 0{,}4167 & 0{,}0833 & 0{,}0000 & 0{,}3333 \\ 0{,}0088 & 0{,}0789 & 0{,}3246 & 0{,}0526 & 0{,}0702 & 0{,}4649 \end{Vmatrix} = \pi_2,$$

which gave the following fixed probabilities at the 8th power: 0,0041, 0,1137, 0,2642, 0,1052, 0,0493 and 0,4635.

Three synthetic sections yielded the transition probability matrices

$$\begin{Vmatrix} 0{,}1000 & 0{,}3000 & 0{,}3000 & 0{,}0000 & 0{,}0000 & 0{,}3000 \\ 0{,}0000 & 0{,}2273 & 0{,}0909 & 0{,}4545 & 0{,}0455 & 0{,}1818 \\ 0{,}0429 & 0{,}0714 & 0{,}3714 & 0{,}4857 & 0{,}0714 & 0{,}3571 \\ 0{,}0263 & 0{,}0263 & 0{,}3421 & 0{,}1316 & 0{,}1579 & 0{,}3158 \\ 0{,}0000 & 0{,}1765 & 0{,}2353 & 0{,}0000 & 0{,}0000 & 0{,}5882 \\ 0{,}0455 & 0{,}0568 & 0{,}2727 & 0{,}1591 & 0{,}0909 & 0{,}3750 \end{Vmatrix} = \pi_3,$$

$$\begin{Vmatrix} 0{,}0000 & 0{,}0000 & 0{,}2500 & 0{,}0000 & 0{,}2500 & 0{,}5000 \\ 0{,}0000 & 0{,}2000 & 0{,}2400 & 0{,}3200 & 0{,}0400 & 0{,}2000 \\ 0{,}0270 & 0{,}0676 & 0{,}3108 & 0{,}0811 & 0{,}0811 & 0{,}4324 \\ 0{,}0217 & 0{,}0000 & 0{,}1522 & 0{,}4130 & 0{,}1087 & 0{,}3043 \\ 0{,}0000 & 0{,}2500 & 0{,}4500 & 0{,}0000 & 0{,}0000 & 0{,}3000 \\ 0{,}0105 & 0{,}1053 & 0{,}3053 & 0{,}1158 & 0{,}0737 & 0{,}3895 \end{Vmatrix} = \pi_4$$

and

$$\begin{Vmatrix} 0{,}0000 & 0{,}5000 & 0{,}2500 & 0{,}0000 & 0{,}0000 & 0{,}2500 \\ 0{,}0250 & 0{,}3750 & 0{,}1000 & 0{,}3000 & 0{,}0500 & 0{,}1500 \\ 0{,}0000 & 0{,}0149 & 0{,}3582 & 0{,}1940 & 0{,}1045 & 0{,}3284 \\ 0{,}0200 & 0{,}0400 & 0{,}1000 & 0{,}2200 & 0{,}1000 & 0{,}5200 \\ 0{,}0000 & 0{,}1905 & 0{,}1905 & 0{,}0476 & 0{,}0476 & 0{,}5238 \\ 0{,}0222 & 0{,}1667 & 0{,}2889 & 0{,}1556 & 0{,}0778 & 0{,}2889 \end{Vmatrix} = \pi_5$$

a		b		c
C	3	C	3	C
E	2	E	3	A
C	2	A	3	A
E	4	E	2	E
C	9	C	15	C
E	7	E	4	C
C	3	D	3	E
E	5	E	2	B
B	5	C	2	C
C	14	E	5	E
E	4	C	4	E
A	2	E	7	C
E	3	B	6	B
B	1	C	7	C
C	3	E	4	A
C	6	C	2	A
E	7	E	2	E
B	2	C	15	B
C	5	E	2	D
C	3	C	13	B
E	6	E	2	D
D	2	D	2	D
E	1	E	2	C
C	3	D	2	E
E	2	E	3	C
C	6	A	2	A
E	4	E	2	C
D	2	B	8	C
E	3	C	8	C
C	9	E	2	E
				B
				E
				B
				C
				A
				E
				D

Fig. 15. Porównanie rzeczywistych i syntetycznych kolejności subelementów: a — rzeczywista kolejność w warstwach hieroglifowych, Zawoja-Wilczna; b — syntetyczna kolejność na podstawie modelu stochastycznego; c — syntetyczna kolejność na podstawie niezależnych prób

Fig. 15. Real and synthetic sequences of sub-elements compared: a — real sequence from Hieroglyphic Beds, Zawoja-Wilczna; b — synthetic sequence based on stochastic model; c — synthetic sequence based on independent-event model

respectively. π_3 and π_5 both gave an equilibrium state at the 8th power, with fixed probabilities of 0,0362, 0,0906, 0,2930, 0,1420, 0,0800 and 0,3582 for the former and 0,0151, 0,0957, 0,2856, 0,1635, 0,0754 and 0,3646 for the latter. π_4 yielded the fixed probabilities 0,0149, 0,1445, 0,2341, 0,1864, 0,0806 and 0,3395 at the 10th power.

Thus the powers at which equilibrium states are reached, as well as the probabilities at equilibrium are comparable. Therefore, the Markovian model chosen to describe the vertical sequence of sub-elements in the Hieroglyphic Beds is to a large extent appropriate. This, in turn, indicates dependence of a given sub-element upon antecedent structures, analogous to that recorded in flume studies of sediment transport (for example, Simons and Richardson, 1963). It follows that simple beds in flysch sequences were probably deposited from single currents of decreasing velocity.

Sources of probable error, leading to some deviation from Markovian behaviour, are:

1.) the inclusion of a separate sub-element of convoluted laminae, which is unavoidable, since in many cases the latter obscure details of primary laminae, deformed after deposition;

2.) failure to recognize the upper sub-element of horizontal laminae in some instances.

Zeller (1964) synthesized two- and three-component, stratigraphic sequences by means of random numbers, thickness depending on the number of successive times a particular number was selected. He concluded that a section comprising randomly selected lithologies may show characteristics of a „truly cyclic sequence” (Zeller, 1964, p. 635) and that much of cyclicity exists only in the mind of the geologist. However, for simple beds in flysch sequences, each interface marks the earliest structural record of an individual episode, thus obviating the operational necessity for arbitrary decisions as to the choice of reference transitions. A six-component, synthetic sequence of sub-elements was generated, using random numbers obtained from successive rolls of a die. The six sub-elements, A to E, were represented by the numbers 1 to 6. Therefore, transitions in which shale is followed by any other sub-element are interfaces. Single occurrences are units of thickness. Percentages of simple- and composite-bed types thus generated are given in Table 2. Simple beds comprising two and three sub-elements together account for only 27,72% of the total. Simple beds comprising more than three sub-elements were not generated, though this fact undoubtedly reflects the limited number of trials. It is, therefore, highly improbable that successions comprising exclusively, or given predominantly, simple beds could be formed by consecutive, independent trials, where a trial is the phase of current activity, operative in the formation of a single sub-element.

In a transition probability matrix constructed from a series of consecutive, independent trials, however, the trials are no longer wholly independent (see Krumbein, 1967, p. 8). The transition probability matrix derived from the independent-trial sequence of sub-elements was:

$$\left\| \begin{matrix} 0{,}1938 & 0{,}2063 & 0{,}1250 & 0{,}1625 & 0{,}1563 & 0{,}1563 \\ 0{,}1598 & 0{,}1953 & 0{,}1716 & 0{,}1716 & 0{,}1657 & 0{,}1361 \\ 0{,}1012 & 0{,}1667 & 0{,}1726 & 0{,}1667 & 0{,}1726 & 0{,}2202 \\ 0{,}1919 & 0{,}1860 & 0{,}1686 & 0{,}1628 & 0{,}1628 & 0{,}1279 \\ 0{,}1824 & 0{,}1647 & 0{,}1824 & 0{,}1882 & 0{,}1529 & 0{,}1294 \\ 0{,}1296 & 0{,}1605 & 0{,}1790 & 0{,}1667 & 0{,}2160 & 0{,}1481 \end{matrix} \right\| = \pi_6$$

At the 5th power, the equilibrium state was reached:

$$\left\| \begin{matrix} 0{,}1601 & 0{,}1802 & 0{,}1668 & 0{,}1699 & 0{,}1704 & 0{,}1527 \\ 0{,}1601 & 0{,}1802 & 0{,}1668 & 0{,}1699 & 0{,}1704 & 0{,}1527 \\ 0{,}1601 & 0{,}1802 & 0{,}1668 & 0{,}1699 & 0{,}1704 & 0{,}1527 \\ 0{,}1601 & 0{,}1802 & 0{,}1668 & 0{,}1699 & 0{,}1704 & 0{,}1527 \\ 0{,}1601 & 0{,}1802 & 0{,}1668 & 0{,}1699 & 0{,}1704 & 0{,}1527 \\ 0{,}1601 & 0{,}1802 & 0{,}1668 & 0{,}1699 & 0{,}1704 & 0{,}1527 \end{matrix} \right\| \cdot$$

It will be noted that the co-ordinates of π_6 all have real, positive values, varying in the narrow range 0,1012 to 0,2202. Furthermore, the co-ordinates of the equilibrium state are closer to the theoretical value of 0,1667 than are those obtained by Krumbein (1967) for a smaller sample of trials. This is in accordance with Krumbein's statement that the finite sample controls equilibrium-state properties.

This Markovian model of a non-Markovian system is useful in illustrating differences between simple beds and composite beds of various types (regardless of whether or not a Markov process is present) and also in providing the basis for discussion of a potential, probabilistic model of flysch sedimentation. Clearly the independent-event, transition probability matrix has real co-ordinates for transitions unlikely to be found in nature, such as D-D and E-E. However, transitions reflecting reversals in the vertical order of appearance of sub-elements for simple beds, such as D-A and C′-B, though of a low order of probability, should have real values in sequences of composite beds. Thus independent-event sequences may be mimicked to varying degrees in proximal deposits, while basinwards, decreased proportions of composite beds will give rise to lowered probabilities and in some cases zero values for transitions indicating inversions of the order of sub-elements for simple beds. Further basinwards, probabilities of the latter transitions decrease to zero, as in the Hieroglyphic Beds of the Magura Series in most exposures. Then a progressive lowering in probability takes place for transitions involving the graded sub-element and the lower sub-element of horizontal laminae; these, particularly the former, may be reduced to zero. Concomitant with this reduction is an increase in probability for transitions involving the sub-element of cross-laminae.

The idealized scheme outlined above is, of course, little more than a qualitative, probabilistic extension of the concepts represented in Bouma's hypothetical cone of deposition (Bouma, 1962, Fig. 25A, p. 99; see also M. N. Dimitrijević et al., 1967, Fig. 1, p. 9), supported by qualitative observations in the Magura Sandstone and limited quantitative study of the Hieroglyphic Beds. Complicating factors likely to occur in nature are sediment supply from more than one source, progressive basinward increase in the importance of pelagic deposition and the variable influence of marine bottom currents.

INTERFACIAL STRUCTURES

General

Interfacial structures are commonly seen as the sole markings (Kuenen, 1957) of type-I elements, which are the infillings or moulds (Craig and Walton, 1962; P. E. Cloud in Dżułyński and Sanders, 1962) of marks made on a mud surface (Sanders, 1956).

That these structures are mostly the products of current activity was deduced on the basis of morphology and from the fact they frequently define a prominent lineation in the plane of the interface (see, for example, Sujkowski, 1938; Rich, 1950). Dżułyński and Sanders (1962) employed a useful of subdivision of interfacial structures:

1) Scour marks, characterized by entrainment of bottom sediments;

2) Tool marks, reflecting the impingement of current-borne objects upon the mud bottom;

3) Deformation marks, which record the plastic response of surface muds to stresses applied by a current.

It should be noted that transitional types of structures occur (Dżułyński and Simpson, 1966a, b).

Distribution of interfacial structures

In the Beloweza Beds, Hieroglyphic Beds and relatively thin-layered complexes of other formations studied, the most common type of interfacial structure is an often indistinct lineation defined by shallow, elongate scours, occurring throughout the whole interface. This structure is termed scour lineation. Current-modified, organic trails provide areas of locally intensified scouring on soles showing scour lineation. In the relatively thin-layered sequences, flute marks may occur as solitary, usually trianguloid scours at otherwise flat interfaces or as closely spaced, compound moulds, giving highly irregular interfaces with flame structures (see Walton, 1956). The latter type of fluted interface is rare and usually comprises elongate-symmetrical flute moulds as figured by Radomski (1958, Pl. 39, Fig. 1). Frequently interfaces of the last-mentioned type display longitudinal trains of overlapping flute moulds in zig-zag patterns representing progressively deeper scouring in a downcurrent direction. This type of scoured interface may also display flute moulds with corkscrew welts at their upcurrent ends (see Dżułyński and Walton, 1965, Fig. 26, p. 41).

Flute moulds clearly reflect differential scouring action of a turbulent fluid, moving over a mud bottom (see review by Dżułyński and Walton, 1965, pp. 47—55). The propagation of flute marks was explained by D. T. Hopkins (in Dżułyński and Walton, 1965, pp. 47, 52, 53) and J. R. L. Allen (1968) as being due to erosion attendant upon flow expansion downcurrent of a negative step. However this may only take place after the formation of an initial depression of the mud surface. This latter might arise as a result of tool impingement (Dżułyński and Simpson, 1966a, b) or by preferential scouring of inhomogeneities in the bottom muds by vertical vortices. Vertical vortices are clearly evidenced by some flute moulds of corkscrew type.

The tool marks most frequently occurring in these thin-layered successions are groove moulds, usually seen as counterparts of straight scratches of the mud surface, in the order of several millimetres in width. Somewhat less common are flat-bottomed groove moulds, several centimetres in width and of similar depth. These broader grooves are often compound, in that they are themselves marked by minor striations running parallel to the margins. It is worthy of note that neither ruffled grooves of type described by Walton (1955) and ten Haaf (1959) nor chevron marks (Dunbar and Rodgers, 1957) are normally found in relatively fine-grained sequences. Impact marks (Radomski, 1958, p. 362, 403) are comparatively rare in these beds. Scarce brush and prod marks sometimes occur at relatively flat interfaces in the Hieroglyphic Beds. Exceptionally, the interface is extremely irregular, owing to the concentration of numerous, closely spaced brush and prod marks, accompanied by groove moulds with carbonized plant fragments at their downcurrent ends. There is little doubt that the transported plant fragments acted as tools in such cases, since they are exceptionally abundant in the type-I element above the interface, often densely packed in horizontal laminae. Other clasts responsible for the formation of tool marks in thin-layered sequences are pebbles and grains of coarse-sand size (Pl. IX, Fig. 1), benthonic Foraminifera and shale fragments. Coarse sand grains and scarce pebbles are found at the downcurrent ends of groove moulds in the Hieroglyphic Beds, S of Wieprzec. The tests of benthonic Foraminifera, both tubular and many-chambered in type, are seen at the downcurrent ends of numerous microscopic grooves, at interfaces in successions of Hieroglyphic Beds, particularly in the stream Jaworzyna (see Simpson, 1969 a). The role of shale fragments as tools is suggested by occurences in the Hieroglyphic Beds of scarce current crescents, of maximum width up to 1 cm. only, formed around small pellets of shale.

In the thin-layered sequences under discussion, deformation marks are extremely rare. Chaotically arranged wrinkles of the interface have been found in the Hieroglyphic Beds at Stryszawa—Roztoki. Isolated, load-casted ripples are sometimes found as low mounds of rounded outline (see Dżułyński and Walton, 1965, Fig. 99, p. 147) on the soles of thin, cross-laminated type-I elements, also in the Hieroglyphic Beds.

On the soles of medium, thick- and very thick-layered type-l elements of the Pasierbiec Sandstone and Osielec Sandstone, an even more limited range of interfacial structures is seen. Interfaces of these sequences are commonly flat, save for sharply defined, compound groove moulds or isolated, compound flute moulds. Groove moulds are usually several centimetres in width and may terminate abruptly in a downcurrent direction. Flute moulds of these beds are frequently trianguloid with areas of relatively flat sole between them. Compound flute moulds are of zig-zag type, displaying downcurrent deepening and corkscrew morphologies also occur. Relatively large-size flute moulds with an overall corkscrew shape have been termed vortex moulds[1] (M. N. Dimitrijević, 1962/63; M. N. Dimitrijević et al., 1967, pp. 17, 18). These are found in the Pasierbiec Sandstone near Cicha, giving rise to highly irregular interfaces (see Fig. 5B), where conglomeratic, coarse-grained sandstones rest upon thick marly shales. The morphologies of the structures at Cicha suggest the erosive action of vertical vortices, but it should be noted that in all cases clasts of pebble and even cobble sizes form part of the infilling material. Thus it is likely that the scouring action of the generating current was supplemented by the abrasive action of current-borne tools. An early stage in the formation of these structures is represented by current crescents filled with coarse sand and formed around large pebbles at interfaces in the Pasierbiec Sandstone at Osielec, for example.

In the relatively thick-layered complexes of the Magura Sandstone, considerable variety in type of interfacial structure is exhibited. Flute moulds are usually of trianguloid type and may occur as isolated, some-

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[1] Described as vortex casts by M. N. Dimitrijević (1962/63), but changed here for consistency in nomenclature.

times compound scours at otherwise flat interfaces or may be closely grouped to give irregular interfaces. Compound groove moulds, in the order of 10 cm. or more in width, and single grooves are the most commonly seen structures on the interfaces of these thicker-layered beds. Grooves of both types are usually continuous over the visible interface, though compound grooves sometimes end abruptly. Current crescents are formed around coalified wood fragments and lumps of shale. Though all types of impact marks occur, these are relatively rare and mainly restricted in occurrence to type-I elements of medium thickness.

Of the formations studied, only in the Magura Sandstone are deformation marks of widespread occurrence. Ridge patterns intermediate in type between hexagonal and longitudinal configurations (see Dżułyński and Simpson, 1966a, b; „squamiform markings" of ten Haaf, 1959, p. 46, 47) are common where interfaces are overlain by medium- and thick type-I elements. Dżułyński and Simpson (1966, p. 209) considered these structures to arise where a component of forward motion modifies hexagonal configurations of ridges formed by partial convection, resulting from the emplacement of a heavy suspension upon a cohesive mud bottom. Frondescent markings (ten Haaf, 1959; feather-like markings of Książkiewicz, 1958) are well developed in the thicker-layered complexes of the Magura Sandstone. These may attain large dimensions of 20 to 30 cm. maximum width. According to Dżułyński and Walton (1963, pp. 291—295), these structures result from the penetration of the mud surface by sinking, longitudinal filaments of suspension during flow.

Associations of interfacial structures

In the formations studied, the composition of an assemblage of interfacial structures is characteristic for a given type-I element throughout the exposure. Also within the limits of the exposure, both general morphology and scale remain fairly constant for a particular type of marking (compare with ten Haaf, 1959, p. 27; McBride, 1962, p. 57) at a given interface, regardless of the presence of other types of interfacial structure. Clearly each association reflects an equilibrium bottom configuration, stable under changing flow conditions in the time lag between structure formation and deposition.

Assemblages of closely packed flute moulds occur in the absence of tool markings in the formations considered. In relatively thick-layered sequences, tool markings also tend to be absent from interfaces with isolated flute moulds. Mixed assemblages of flute and groove moulds occur more frequently in the relatively thin-layered sequences of all formations studied. In such cases, it is sometimes possible to determine the order of formation of the two different types of structure. A number of instances were observed in the Hieroglyphic Beds of isolated flutes, early formed with respect to fine grooves cut into both the flat interface and the base of the scour. Another example of tool marks postdating scours, also from the Hieroglyphic Beds, is provided by closely packed impact marks and grooves with plant fragments at their downcurrent ends, concentrated in the troughs of elongate scour marks. Tool marks associated with scour lineation in relatively thin layered sequences usually possess sharply defined margins, suggesting that they were formed later than the phase of scouring.

Deformation marks frequently occur in absence of other structures. However, ridge patterns may both antedate and postdate tool markings, which latter usually take the form of broad groove moulds. Frondescent markings occur either alone or at interfaces of beds with groove moulds.

Directional properties of interfacial and internal structures compared

The different types of structure making up a given assemblage of interfacial structures usually indicate a common sense of current movement. This holds true for all formations studied and suggests that in each case all structures were formed by a single current. The only commonly observed exception is provided by crossing sets of groove moulds, which diverge at angles of up to 40°. As shown by Dżułyński and Simpson (1966b, Fig. 4, p. 200), however, interfering sets of groove marks may be formed by a single current.

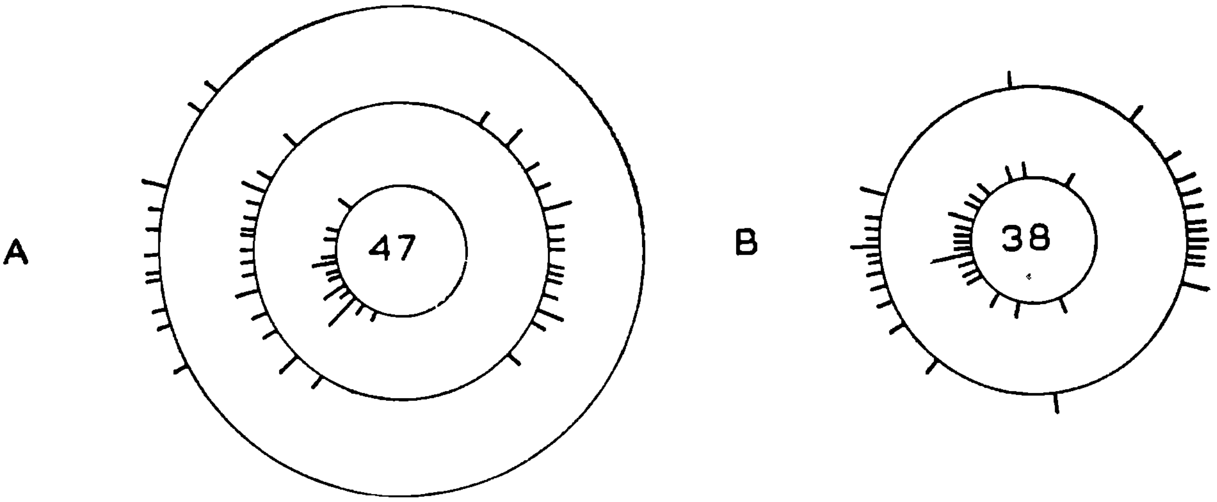

Fig. 16. Kierunki transportu materiału klastycznego w piaskowcu magurskim. Strefa centralna. Zawoja. A — struktury na spągach rytmów; jamki wirowe oznaczone na kole wewnętrznym, ślady wleczenia na kole środkowym, hieroglify pierzaste i wzory grzbietów na kole zewnętrznym; B — uwarstwienie przekątne na kole wewnętrznym, lineacja widoczna na powierzchni warstewek i fragmenty drewna zaznaczone na kole zewnętrznym. Cyfry w środku rysunku oznaczają ilość obserwacji

Fig. 16. Current directions in the Magura Sandstone. Central zone, Zawoja. A — interfacial structures; flute marks on inner circle, groove marks on middle circle, frondescent marks and ridge patterns on outer circle; B — cross-laminae on inner circle, parting lineation and orientation of plant fragments on outer circle. Numbers indicate total observations

Considerations of the senses of current movement obtained from readings of orientation of internal and interfacial structures respectively (Fig. 16, 17 and 18) lead to the following conclusions:

1) For each formation considered, good agreement is obtained for current directions read from different types of interfacial structures. These directions correspond to those given by Książkiewicz (1958, Fig. 6, p. 781, Fig. 7, p. 79; 1963; 1966).

2) Close agreement is seen between senses of movement given by both plant-fragment orientation and parting lineation as compared with those obtained from interfacial structures. This is seen in the Hieroglyphic Beds and Magura Sandstone.

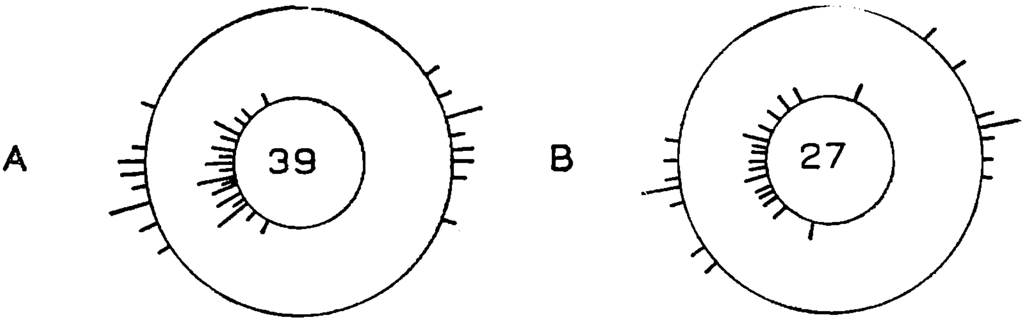

Fig. 17. Kierunki transportu materiału klastycznego warstw hieroglifowych. Strefa centralna, Zawoja-Końskie. Objaśnienia jak w fig. 16

Fig. 17. Current directions in Hieroglyphic Beds, Central zone, Zawoja-Końskie. Explanation as for Fig. 16

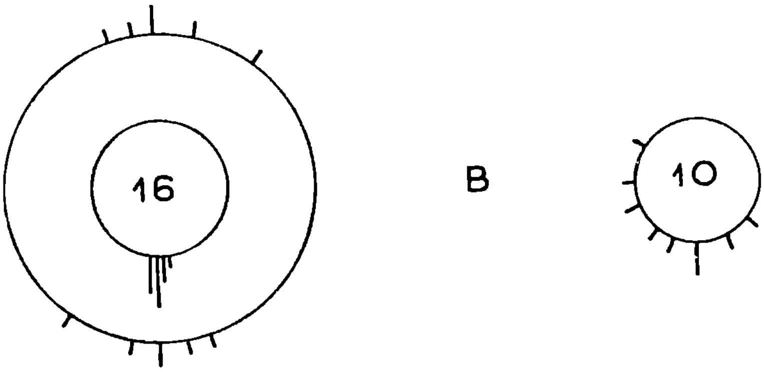

Fig. 18. Kierunki transportu materiału klastycznego piaskowca pasierbieckiego. Strefa centralna, Zawoja. Objaśnienia jak w fig. 16

Fig. 18. Current directions in Pasierbiec Sandstone, central zone, Zawoja. Explanation as for Fig. 16

3) Modal current directions deriving from readings of maximum inclination of cross-laminae are in good agreement with those for interfacial structures. For each formation considered, however, readings from cross-laminae display a wider dispersion than do those of interfacial structures.

TRACE FOSSILS

General

Trails and burrows preserved in sedimentary sequences have been termed trace fossils (S. Simpson, 1957). In flysch successions, trace fossils record the life activities of soft-bodied inverbrates (Książkiewicz, 1961a, pp. 15, 16) and constitute the sole evidence for the existence of the latter, which are only rarely preserved as body fossils. Furthermore, they provide the only irrefutable evidence of autochthonous life in depositional basins receiving flysch sediments.

In recent years, studies of trace fossils from the Polish Carpathian flysch have published by W. Nowak (1956, 1959) and Książkiewicz

(1960, 1961). Some trace fossils found in the Eocene formations considered here have been figured and listed by Książkiewicz (1958a, 1963, 1966). Ichnogenera discussed in the present account are given according to the characteristics listed by Häntzschel (1962, 1965).

Preservation of trace fossils

The descriptive terminology employed here is that of Seilacher (1964, Fig. 1, p. 297). In Carpathian exposures, the trace-fossil composition of a given bed remains relatively constant laterally and is usually confined to a few ichnogenera only. The formation of trace fossils of the assemblage characteristic for a given bed may sometimes be dated in relative terms, with respect to depositional events. The categories predepositional, syndepositional and postdepositional, applied to sedimentary structures of all types by Książkiewicz (1952, pp. 417, 418) and Vassoyevich (1953), are adopted here.

1) Predepositional traces are formed in mud, prior to the deposition of the next bed in vertical succession (Książkiewicz, 1952, p. 417; 1960, p. 739; Kuenen, 1957, pp. 233, 234; Seilacher 1962). They are preserved as positive hyporeliefs on the soles of type-I elements. Traces of this type are considered to arise when bottom muds are eroded to expose internal burrows and buried trails, which are at some later time filled with sand (see Seilacher, 1962, p. 232). Clearly the problem of the unknown length of time interval between erosion and infilling, discussed for current-formed scour structures, is also applicable to many predepositional traces (see Pl. IX, Figs. 2—6). Indeed, traces of this type frequently display various stages of modification by scouring, forming a continuous, lateral passage on the same bedding surface. Bilobed and unilobed semireliefs of *Scolicia* de Quatrefages and *Belorhaphe* Fuchs, common in the Hieroglyphic Beds, are frequently preserved in this way (Pl. IX Figs. 2—4). Occasionally, well developed flute moulds are localized along scoured trails of *Scolicia* type (Pl. IX, Fig. 2). The attitude of the exhumed trail with respect to the principal current direction evidently determines to a large extent the degree of scouring, since any orientation in which one wall of a trail forms a „transverse" step (D. T. Hopkins in Dżułyński and Walton, 1965; J. R. L. Allen, 1968) will favour the generation of eddy systems. Even where a trail has suffered a minimum of erosion, its predepositional nature may frequently be recognized from the type or organization of the infilling material. Thus in fine-and medium-grained sandstones of the Pasierbiec Sandstone, predepositional trails are filled with coarse sand and pebbles, as well as fragments of lamellibranch shells and echinoid spines (see also Książkiewicz, 1960, p. 739 and Plate II, Fig. 8). *Scolicia* and *Spirophycus* Häntzschel, in the Hieroglyphic Beds and Sub-Magura Beds, commonly have a fine-grained infilling of cross-laminae usually of trough type (Pl. IX, Fig. 5).

2) Syndepositional traces are represented by a single group, comprising bilobed distensions of the soles of type-I elements (Pl. X, Fig. 1). Along the longitudinal axis of the trace, one side slopes gently, while the opposite, more strongly bilobed side forms a sharp re-entrant with the flat sole. A longitudinal band of granulated appearance, up to 2 cm. in width, may coincide with the median furrow. The re-entrant side of the trace points upcurrent, where the current direction may be obtained

from the maximum dip of cross-laminae in the same bed[1]. This current-controlled preferred orientation clearly arises, when an animal burrows in mud to avoid being swept away by a current. Upcurrent undercutting of the mud bottom would afford maximum protection for the animal against the scouring action of the current. The laminated internal structure of the trace and complete destruction of sandy cross-laminae in an inclined band above the trace are clearly organic in origin and mark the escape activities of the buried animal after deposition was completed. Traces of this type are fairly common in the Hieroglyphic Beds and are also known from the Sub-Magura Beds. Preferred orientation (rheotaxis) has been described by Seilacher (1953, 1955) for *Cruziana* d'Orbigny, *Isopodichnus* Bornemann, *Rusophycus* Hall and *Sagittichnus* Seilacher. Reference will be made to the trace described above under the name n.f. aff. *Sagittichnus.*

3) Postdepositional traces include all internal burrows. These generally differ somewhat in composition and texture from the rest of the element in which they occur and to varying degrees deform internal structures of inorganic origin. Within some flattened, formerly cylindrical burrows in shales of the Magura Sandstone, plant fragments or mica flakes may be concentrated. Burrowing is clearly facilitated where textural discontinuities occur in beds. Thus in type-I elements, relatively scarce, flattened tubes of *Palaeophycus* Hall[2] are found on parting surfaces between horizontal laminae, while in type-II elements, fairly abundant, delicate patterns of meanders, networks, spirals and branching forms are found. It should be added that certain forms, such as *Scolicia* and *Rhabdoglyphus* Vassoyevich in the Hieroglyphic Beds and *Zoophycos* Massalongo in the Magura Sandstone, are usually at the contacts between elements as semireliefs on the upper surfaces of type-I elements. The most pronounced textural discontinuities in a sequence of beds are at the interfaces and it is here that postdepositional burrows frequently occur (Götzinger and Becker, 1932; Seilacher, 1954; Kuenen, 1957; Książkiewicz, 1960). In the Pasierbiec Sandstone and Beloweza Beds, *Palaeophycus* is frequently seen as a positive semirelief, both on the upper and lower surfaces of type-I elements. In vertical cross-section, however, the same trace is a full relief (Pl. X, Fig. 2). The more delicate burrows, such as those which forms networks and meanders at interfaces, are often of small diameter in comparison with the grains which fill them and are rarely seen as reliefs in this position. However, a postdepositional character may be deduced where, in a single system of burrows, semireliefs at the interface pass laterally into full reliefs in shale (see for example, Wood and Smith, 1959, p. 167). Another criterion is the encrustation of current-formed structures (Simpson, 1967) or current-scoured predepositional traces. However, it should be noted that cross-cutting relationships between interfacial structures and traces of organic origin (for example, Pl. IX, Fig. 6) are frequently ambiguous.

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[1] The author is grateful to Prof. Dr H. Świdziński, of the Academy of Mining and Metallurgy Kraków, and the Polish Academy of Sciences, for the suggestion that this trace might exhibit a preferred orientation.

[2] In the present account, all branching or single, cylindrical burrows without other distinctive features, are referred to as *Palaeophycus*.

Trace fossils and layer thickness

The larger predepositional traces, for example, *Scolicia* of *Subphyllochorda* type, show little dependence upon layer thickness in their distribution. They are usually preserved on the soles of fine-grained sandstones of the thin to medium thickness classes and are rare in medium- and coarse-grained sandstones. This is undoubtedly due to the increased eroding power of currents transporting relatively coarse debris. For the same reason, delicate meandering and branched forms occurring at interfaces are largely restricted to thin and very thin type-I elements of fine-grained sandstone. Likewise, in the Hieroglyphic Beds, syndepositional n.f. aff. *Sagittichnus* was not found on the soles of type-I elements thicker than 8 cm. Postdepositional *Scolicia,* as a sole semirelief, is confined to fine--grained type-I elements 8 cm. or less in thickness. *Zoophycos* principally occurs on the upper surface of medium- and thick-layered type-I elements of medium grain size in the Magura Sandstone. In the uppermost Hieroglyphic Beds exposed in the stream Roztoki, S of Stryszawa, however, *Zoophycos* occurs on the upper surfaces of thin and very thin elements of fine-grained sandstone.

Vertical, sand-filled tubes up to 0,8 cm. in diameter, may extend throughout medium- and thick-layered type-I elements of the Magura Sandstone (see also Książkiewicz, 1961a, p. 16). Unrug (1963, p. 72) surmised that similar burrows in the Istebna Beds may arise purely out of the feeding activities of animals, without any escape activity (ten Haaf, 1959, p. 58). This appears to be borne out by finds of feeding burrows extending to similar distances below the bottom in the sediments of the SW Pacific, (Bezrukov and Romankevich, 1960).

The existence of a limited range of thicknesses for type-I elements with certain postdepositional traces as sole structures has been taken to confirm the instantaneous nature of deposition from turbidity currents (Seilacher, 1962, pp. 229—232). Postdepositional traces usually found at the tops of type-I elements may sometimes be used to prove the composite nature of relatively thick type-I elements. In the Magura Sandstone, vertical and near-vertical, single tubes, as well as U-tubes similar to those of *Corophioides* Smith, are in some cases restricted in occurrence to immediately below faint, horizontal partings, irregularly spaced vertically throughout very thick type-I elements. *Zoophycos* is also sometimes found on partings of this type. Each parting records erosion of the top of a bed, after a time interval following deposition, during which burrowing took place. Thus trace fossils may be used to detect single sedimentary episodes, where these have been obscured by erosion.

Trace-fossil assemblages

The following are the trace-fossil characteristics of the formations considered (see also Książkiewicz, 1958a, 1966), considered in terms of the ethological classification of Seilacher (1953):

1) The richest gross assemblages of trace fossils occur in the Beloweza Beds, where delicate pascichnia (meandering and branching trails), such as *Paleodictyon* Meneghini, *Belorhaphe, Cosmorhaphe* Fuchs, *Helicolithus* Azpeitia and *Helminthoida* Schafhäutl, are found together with larger, predepositional burrows of *Scolicia* (c.f. *Subphyllochorda*) and *Spirophycus* types. These latter probably represent repich-

nia (locomotion trails). Many ichnogenera may occur together in the same bed and at the same interface.

2) Tubular, postdepositional burrows are common in the Pasierbiec Sandstone and Osielec Sandstone, particularly in the thin-layered complexes. Scare pascichnia such as *Belorhaphe* and predepositional *Scolicia* are also found.

3) In the Hieroglyphic Beds, single layers tend to be characterized by particular trace fossils, or groups of trace fossils, often to the exclusion of other forms, save for postdepositional, linear burrows of widespread distribution. Thus postdepositional *Scolicia* frequently occurs alone on soles as closely packed semireliefs. Syndepositional n.f. aff. *Sagittichnus* the only representative of cubichnia (resting traces) in the formations considered, is usually found at flat interfaces, otherwise devoid of trace fossils. Rare instances have been observed of postdepositional *Scolicia* extending for short distances from n.f. aff. *Sagittichnus* along the interface. Some assemblages comprise almost exclusively spiral, branching or meandering pascichnia of a single ichnogenus, such as *Spirorhaphe* Fuchs (Pl. X, Fig. 3), *Paleodictyon* of irregular type (in the sense of Seilacher, 1962) and *Protopalaeodictyon* Książkiewicz. In other cases, current-scoured, predepositional *Scolicia* or *Spirophycus* predominate at interfaces. Fodinichnia (at the same time shelters and feed burrows) are represented by *Zoophycos,* which is only found in the uppermost Hieroglyphic Beds, where *Rhabdoglyphus* and *Scolicia* also occur on the upper surfaces of type-I elements.

4) The Łącko Marls are characterized by rare pascichnia and more common, tubular burrows occurring at interfaces, while towards the tops of marl layers, *Chondrites* Sternberg is usually found.

5) Scarce *Zoophycos* and n.f. aff. *Sagittichnus* as well as meandering pascichnia, such as *Paleomeandron* Peruzzi (Pl. X, Fig. 4), occur in the Sub-Magura Beds. Scoured, predepositional burrows are fairly common.

6) Fodinichnia represented mainly by *Zoophycos* predominate in the thick-layered complexes of the Magura Sandstone (Pl. XI, Figs. 2, 3); which constitute fluctuations in time series of bed thicknesses. In these beds, predepositional burrows are scarce. Pascichnia, among which *Paleomeandron* is the most common, and repichnia are found on the soles of thin and very thin layers delimiting fluctuations. *Lorenzinia* Gabelli (Pl. XI, Fig. 1), interpreted here as a predepositional feeding trace, is found with the latter. In the thin-layered, shaly complexes of the Magura Sandstone, scarce pascichnia and scoured, predepositional tubes occur.

Ichnofacies distribution

Studies of burrows in ancient and Recent sediments have shown that burrows of similar morphology may result from similarity in behavioural response of taxonomically unrelated animals to a given environment (Seilacher, 1953). Seilacher (1958) has published trace-fossil spectra (Spurenspektren), in which types of traces predominating in different depositional environments are shown. These demonstrated the existence of five main associations of trace fossils or ichnofacies (Seilacher, 1967, pp. 414, 415), representing different bathymetries on a relative scale. Of these, only the two ichnofacies of greatest inferred depth are relevant to the Carpathian Eocene: the *Zoophycos* ichnofacies and the deeper-water *Nereites* ichnofacies. The former is characterized by fodinichnia; the latter by meandering pascichnia (Seilacher, 1964, Table 1, pp. 310, 311).

An obvious comparison may be drawn between the trace-fossil assemblages of the thick-layered fluctuations in the Magura Sandstone and Seilacher's *Zoophycos* ichnofacies. The greater part of the Hieroglyphic Beds and, more particularly, the Beloweza Beds would correspond to the *Nereites* facies. Thus, on the basis of trace fossils alone, it seems that the Hieroglyphic Beds in the southern part of the area and the Beloweza Beds were laid down in deeper water than were the thicker-layered Magura Sandstone. This might be more convincing if transitional ichnofacies could be demonstrated. These are probably the mixed assemblages of the uppermost Hieroglyphic Beds exposed S. of Stryszawa and the Sub-Magura, Beds, in which *Zoophycos* occurs together with meandering and branching forms.

The Magura Sandstone assemblages with meandering pascichnia, which are found in the thin and very thin beds, delimiting thick-layered fluctuations may reflect periodic deepening of the basin. The thin-layered complexes separating groups of fluctuations, with their characteristic, impoverished assemblages of trace fossils, show no predominance of any forms which might be taken to indicate increase or decrease in depth of deposition. Absence of *Zoophycos* and vertical burrows perhaps reflects periods of relative stability in the basin. Likewise, the occurrence of pascichnia and absence of fodinichnia in the Pasierbiec Sandstone and Osielec Sandstone suggest that both were deposited at greater depths than was the Magura Sandstone.

BIOFACIES DESCRIPTIONS

General

Conclusive evidence of resedimentation has been provided by studies of organic remains in flysch and in Recent, deep-sea sediments. Migliorini (1944) described occurrences of Eocene small Foraminifera in sandstone elements of beds with shales containing Oligocene microfossils. This apparent paradox can only be explained by invoking erosion and resedimentation of the Eocene forms in Oligocene time (Migliorini, 1944; Kuenen and Migliorini, 1950). Książkiewicz (1947, pp. 148, 149) considered the association of large Foraminifera with conglomeratic layers in the Carpathian flysch and the sorting of these tests together with clastic particles to indicate transportation by „violent currents". Transportation of shallow-water fossils to a relatively deep-water environment by turbidity currents was deduced by Książkiewicz (1952, pp. 432—435) for occurrences of large and small Foraminifera, lamellibranchs, algae and corals in coarse-grained sandstones and conglomerates, which alternate in vertical sequence with shales containing predominantly agglutinated, small Foraminifera. Strong support for these deductions came from contemporary discoveries of shallow-water, benthonic Foraminifera in the deep-sea sands of the North Atlantic (Ericson et al., 1951, 1952), the Gulf of Mexico (Phleger, 1951a) and the San Diego Trough, off California (Phleger, 1951b). Thus in flysch sequences and deep-sea sediments alike, faunal assemblages of type-I elements (allochthonous) are considered to indicate mass movement downslope of animal remains and clastic grains as turbidity currents, which eroded bottom muds containing relatively deep-water organisms, while the fauna of type-II elements are thought to be largely autochthonous (see also Natland and Kuenen, 1951; Phleger, 1960, pp. 90—99).

In this chapter, fauna is considered in relation to depositional features and organic clasts are used as tracers to provide answers to two main questions, which arise from uncertainty as to the rôle of ocean currents in the formation of flysch deposits:

1. Do truly autochthonous faunal assemblages occur in flysch sequences?
2. Where are the pelagic deposits in flysch?

Large Foraminifera

Coarse-grained, type-I elements of all formations studied frequently contain relatively high percentages (up to 6%) of macrofossils, represented by fragmented lamellibranch shells, algal networks, echinoid spines and large Foraminifera. Of these, the last-mentioned group is the most common. As pointed out by Książkiewicz (1947), large Foraminifera are sorted in the same way as the inorganic clastic components of the element. Thus in the conglomerates and coarse-grained sandstones of the Pasierbiec and Osielec Sandstones and more rarely in the Magura Sandstone, large Foraminifera tend to be distributed fairly evenly throughout non-graded type-I elements and are graded vertically according to size in graded type-I elements. This is equally true for beds of Pasierbiec-, Osielec- and Magura-type, found as interlayers in other formations. In multiple-graded elements with horizontal laminae, large Foraminifera are concentrated in particular laminae occurring at different levels throughout the elements. In such instances, imbrication of tests is sometimes seen, with diameters dipping downcurrent at angles of up to 12°. Exceptionally well preserved, large Foraminifera and echinoid spines are found in and around shale fragments of cobble size within some coarse-grained, type-I elements. These shale fragments were evidently eroded from the bottom by the currents transporting the coarse material and were probably carried as armoured mud balls (Bell, 1940) with large Foraminifera and grains of pebble grade forming the „armour". In one coarse-grained sandstone belonging to the Pasierbiec Sandstone, exposed in the stream Końskie, shale fragments contain Palaeocene, small Foraminifera, while large Foraminifera of the same element give an Upper Eocene age [1].

In formations comprising mainly medium and fine-grained, sandstones as type-I elements, large Foraminifera are rare and confined to the coarser-grained, lowermost parts of beds. In such cases, coarse grains and large Foraminifera are concentrated together in depressions of the interface, as in the Łącko Marls at Dworek Moniaków, Zubrzyca Górna.

Occurrences of large Foraminifera in type-II elements are extremely rare. Where this is seen, as in the 20 cm. of pebbly mudstone overlying a type-I element of Pasierbiec Sandstone type near the top of the Hiero-

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glyphic Beds in the stream Jaworzyna, deposition may be considered to have taken place from viscous suspension (Sanders, 1965, pp. 213, 214). Both small Foraminifera in the type-II element and large Foraminifera in the type-I and -II elements indicate an Upper Eocene age.

Plant fragments

These are locally abundant, particularly in the Hieroglyphic Beds and Magura Sandstone, occurring as coalified, lath-shaped particles. Plant fragments, usually not more than 2 cm. in length, are found concentrated in the upper parts of bipartite, horizontal laminae within thin- and medium-layered type-I elements and also at the interfaces of such elements. Where the rock may be split along surfaces of plant-rich laminae, elongate fragments are seen to show a preferred orientation, roughly parallel to the current direction given by the dip of cross-laminae or by sole markings for the same type-I element. Preferred orientation of plant fragments is also seen at interfaces, where they are often accompanied by current crescents, groove marks and impact marks.

Plant-rich cross-laminae of ripple-drift type were observed at the base of a type-I element belonging to the Pasierbiec Sandstone, exposed near Cicha. Plant fragments are concentrated on the lee slopes of ripples. The eroded stoss slopes decrease in dip upwards, to become horizontal. The cross-laminae are truncated by a horizontal layer of plant debris, 1,5 mm. thick, which is succeeded vertically by horizontal laminae containing only relatively scarce, carbonaceous fragments. It is therefore evident that a high proportion of plant fragments in suspended sediment transported in the lower flow regime appears to have a damping effect on ripple propagation and horizontal laminae are formed.

Occurrences of plant debris in Recent deep-sea sediments have been taken to indicate fluviatile sources for material deposited from turbidity currents (Heezen, 1959, p. 151; Nesteroff and Heezen, 1960; Ericson et al., 1961, p. 246).

Counterparts

Fragmented shelly remains, such as lamellibranch valves and echinoid spines, may be locally abundant in coarse-grained sandstones and conglomerates of the Pasierbiec Sandstone, but are not found in either the Hieroglyphic Beds or the Magura Sandstone. It is, therefore, of interest to note two occurrences of macrofossils as counterparts in the Hieroglyphic Beds.

The counterpart of the test of an irregular echinoid (Plate XI, Figs. 4, 5) was found as a positive structure on the sole of a 5-cm. sandstone, exposed near the top of the Hieroglyphic Beds in the stream Jaworzyna, Zawoja-Policzne. Detail from the greater part of the upper, external surface of the test is preserved. Imprints of the three anteriorly directed ambulacral areas are well preserved, while on the other hand, most of the apical system and the posteriorly directed ambulacrae and interambulacrae are concealed by sand which entered the test. Details of pores and sutures are well preserved and the termination of ambulacrae with their replacement by a single suture can be seen. The echinoid is probably referable to the genus *Echinanthus*. The test is oriented with its long axis parallel to the direction followed by the sand-depositing current, which latter was determined from flute moulds and cross-lamination: the anterior margin points downcurrent. Current-scouring around the test is indicated by the presence of a prominent current crescent, which forms the upcurrent boundary of the trace. The sandy infilling of this mark contains redeposited small Foraminifera of the genera *Sphaerammina* and *Trochamminoides*. It is deduced that the echinoid was carried by the sand-bearing current, which after deposition, rotated it into a position of stability and scoured the mud bottom at the upcurrent side. The Foraminifera were either concentrated *in situ* by removal of the bottom mud during scouring or were transported along with the sand until they became trapped in the scour depression, formed around the echinoid test.

Ten Haaf (1959, p. 54) described similar traces of echinoids from abundant occurrences in the Pliocene Flysch of the Apennines, but believed them to be autochthonous. Only two other occurrences in Polish flysch are known to the present author:

1. Forms identified as *Echinanthus* found as body fossils in shales belonging to the Lower Krosno Beds of Roztoki Dolne, eastern Polish Carpathians (Ślączka, 1963, p. 184).
2. A specimen found as a body fossil on a sandstone sole in the Senonian flysch of Pieniny (Książkiewicz and Mitura, 1964, p. 267; Książkiewicz, personal communication, 1966).

The extreme rarity of echinoids in the Carpathians and Pieniny itself suggests that they were not indigenous to the environment of deposition of flysch beds.

Circular impressions on the upper surface of a fine-grained sandstone layer, belonging to the Hieroglyphic Beds exposed at Stryszawa-Roztoki, have been interpreted by the present author (Simpson, 1969b) as being the counterparts of medusae, deposited from suspension, along with the silt-size fraction.

Small Foraminifera

Analyses of samples taken at different levels within single turbidite beds show that the uppermost sediment of type-II elements may contain indigenous benthonic Foraminifera, sometimes with planktonic forms admixed, while the remainder of the bed is characterized by reworked contemporary and fossil forms (Natland and Kuenen, 1951; Książkiewicz, 1952, pp. 433—435; 1961, pp. 10—15; Hanzliková, 1953; Grossheim and Borisyenko, 1953; Natland, 1963, Fig. 2, p. 949 and Fig. 3, p. 951; Vella, 1963a; Ingle, 1967, Fig. 15, p. 248; Pflaumann, 1967, Fig. 2, p. 205). A progressive, downslope increase in proportion of displaced species in beds was confirmed by Bandy (1961) in the Gulf of California.

1. In the formations studied, foraminiferal assemblages for particular type-II elements of the lower thickness grades were seen to comprise almost exclusively arenaceous benthonic forms (see characteristic assemblages given by Bieda et al., 1967). As pointed out by Książkiewicz (1961a, p. 14), successive layers are frequently characterized by the predominance of entirely different genera. Calcareous planktonic Foraminifera are characteristically absent from type-II elements of the lower thickness grades, but occur occasionally in type-I elements, together with reworked arenaceous forms and sometimes large Foraminifera.

A similar distribution of planktonic forms was described, for instance, by Ingle (1967, p. 249) from the Pliocene Pico Formation, off California, where a graded sub-element was found to contain 11% planktonic Foraminifera, though these were absent altogether from the type-II element of the same bed. It seems, therefore, that pelagic sediment is frequently eroded away completely by sand-bearing currents (see also Nesteroff and Heezen, 1963). Foraminifera occurring in type-I elements frequently display penetration of the test wall by clastic grains, or even by other tests, with which they are in contact, and also varying degrees of recrystallization (see Pl. XI, Fig. 6). Thus the cement of such elements may often be at least in part derived from organic tests (compare with Gaweł, 1950).

2. Occurrences of benthonic Foraminifera at the interfaces between beds of the formations studied have been described and interpreted by Simpson (1969a). These interfacial assemblages of Foraminifera are seen often as concentrations of tests on the soles of thin-layered, type-I elements of fine-grained sandstone, which latter are usually made up entirely of cross-laminae. These same sandstone soles are either relatively flat or display depressions of the interface, which evidence current entrainment of bottom muds. In some cases, lateral transport of Foraminifera tests is clearly evidenced by occurrences at the downcurrent ends of tool marks, while in others, only rotation of elongate tests into preferred orientation in the plane of the interface may be deduced. In many instances, however, it may be assumed with a high degree of certainty that lateral movement of tests was minimal, especially where a.) relatively long tubular and branching tests are preserved at the interface and b.) forms predominating or occurring to the exclusion of others at the interface predominate also in the upper part of the directly underlying shale. All instances cited above are figured and described in detail by Simpson (1969a). Clearly these latter, *in situ* or approximately in situ occurrences evidence colonization of the mud surface during intervals of non-deposition or pelagic deposition under relatively tranquil conditions, between phases of sand influx.

3. Planktonic Foraminifera, together with Radiolaria, calcareous and arenaceous benthonic Foraminifera, fish teeth and ostracode valves, comprise the impoverished microfauna of medium-, thick- and very thick--layered, type-II elements, occurring sporadically throughout the Hieroglyphic Beds and localized in the Intra-Magura Shales of the Magura Sandstone (Jednorowska and Simpson, in press). The rocks are dark, marly or argillaceous shales. Considerations of lithological type and of the relatively great thicknesses attained (generally up to 3 m.) suggest that the turbidity current theory is inadequate to explain their origin. The fine grain size of the sediments and the very occurrence of tests belonging to pelagic for forms suggest the possibility of an origin for these layers by pelagic sedimentation. Such an origin, however, would presumably be reflected in some degree of uniformity in the vertical distribution of pelagic tests within a given type-II element. In fact, the vertical distribution of Foraminifera tests, both of planktonic and benthonic forms, as seen in samples taken in a continuous, vertical series, is extremely irregular. It is therefore likely that the relatively thick shale layers reflect pelagic deposition of fine-grained sediment and organic remains, but with perhaps intermittent reworking of the deposits by bottom currents, not of turbidity-current type. These conclusions are strongly supported by

the occurrence in the shales of rounded and well rounded quartz grains of the medium and fine sand grades, probably of aeolian origin (compare with Radomski, 1958). Furthermore, sand-size quartz grains may be concentrated in layers in the order of 1—2 cm. thickness at various levels in the shales, reflecting different phases of current activity.

DISCUSSION

On the basis of observations in the Middle Eocene of the western Polish Carpathians, it has so far been confirmed that flysch successions arise out of the interplay of three main modes of sediment supply:

1. Episodic mass movement downslope of all size grades, principally as suspensions;
2. Currents not of turbidity-current type, here termed bottom currents, which may be either agents of reworking or of primary deposition;
3. Pelagic deposition of pelitic material.

Internal sedimentary structures of micrite layers occurring in the formations described are taken to reflect deposition from bottom currents. The relatively scarce, thick-layered marly shales found particularly in the Hieroglyphic Beds and Magura Sandstone, on the basis of irregular vertical distribution of pelagic Foraminifera, are considered to evidence pelagic deposition followed by reworking by bottom currents.

The existence of a time lag between the formation of an association of interfacial structures and the deposition of the type-I element overlying the interface presents the possibility that currents of different types were separately operative. For instance, Klein (1964) suggested that flute marks were eroded on a mud bottom by bottom currents and were later filled with sand deposited from non-eroding turbidity currents. That the mud bottom was eroded by the same currents, from which individual flysch beds of the formations studied were deposited, is suggested by the following lines of evidence taken together:

1. There is a rough positive correlation between thickness of type-I elements and the dimensions of flute or groove moulds on the soles of these (see also Książkiewicz, 1952).
2. A positive correlation exists between maximum grain size of type-I elements and the dimensions of flute or groove moulds on their soles.
3. Plant-fragment orientation, parting lineation and grain orientation in sub-element B give senses of movement in good agreement with lineations defined by structures on the interface immediately below.
4. The direction of maximum dip of cross-laminae in sub-element C corresponds to that given by the lineation defined by interfacial structures.
5. The capacity of sediment-bearing currents to erode is borne out by occurrences of redeposited fragments of shales, marl and sandstone, similar in age to the type-I elements in which they are found.
6. Assemblages of all types of interfacial markings, in each case eroded and filled by the same moving suspension, have been produced experimentally (Dżułyński and Walton, 1963; Dżułyński and Simpson, 1966 a, b).

The reworking of type-I elements by bottom currents to give horizontally laminated or cross-laminated deposits has been envisaged by Craig and Walton (1962), Kelling (1962, 1964) and Hsu (1964). This is theoretically possible, as shown by Klein (1966) and Hubert (1964), who extrapolated grain sizes, which might be eroded by bottom currents travelling at up to 60 cm. sec.$^{-1}$ (see, for example, Darbyshire, 1964), from the erosion curves given by Hjulstrom (1935, Fig. 27, p. 325) and Sundborg (1956, Fig. 13, p. 177). However, the following facts point to deposition of the successive sub-elements of a given simple bed from a single current:

1. A positive correlation exists between maximum grain size and thickness of type-I elements of simple beds.
2. Simple beds display a positive correlation between number of sub-elements A-E and bed thickness.
3. The approximation to Markov behaviour of vertical sequences of sub-elements is analogous to the dependence upon antecedent bottom configurations displayed by successive bottom forms, generated with increasing current velocity in controlled flume experiments. Reworking by bottom currents would presumably give rise to frequent vertical repetitions of sub-elements and inversions of vertical succession particularly common to independent-event processes.

Thus one single current may generate a given association of interfacial structures, as well as the bed above the interface. The choice between turbidity currents and bottom currents at this point is complicated by the fact that many of the least tentative explanations of the presumed hydrodynamic properties of turbidity currents employ reasoning based upon knowledge of water currents. The most convincing evidence of resedimentation by turbidity currents is faunal. No other mechanism satisfactorily accounts for occurrences of shallow-water organisms together with benthonic and pelagic Foraminifera in type-I elements, alternating with type-II elements containing benthonic and occasionally pelagic Foraminifera, as seen in all formations studied.

Time trends of sedimentation based upon vertical variation in layer thickness for the formations studied can be interpreted in terms of:

1. periodicity in differential movement of source and depositional basin,
2. periodicity of supply dependent essentially upon climatic factors,
3. conditions 1 and 2 combined.

A depositional mechanism sensitive to periodicity in such progressive changes is the one most probably operative in the deposition of the flysch sequences studied. Clearly mass movement of unconsolidated sediment, initiated by slope failure in the source area, would provide a „simultaneous" record of all conditions.

Non-graded and poorly graded type-I elements of the higher thickness classes, occurring in all formations studied, reflect deposition from sediment flows. Thus originate medium to very thick, non-graded type-I elements of the Pasierbiec Sandstone and Magura Sandstone. The non-graded condition may be explained by rapid deposition upon cessation of autosuspension or by differential flow arising out of poor mixing. In either case, a near-source location is suggested. The proximal nature of these deposits is confirmed by the presence of relatively high proportions of polyquartz, feldspar and rock fragments. The Pasierbiec Sandstone exhibits a downcurrent (southerly) decrease in grain size and has been interpreted as a submarine-fan deposit by Dżułyński et al., (1959). The source of clastic material was the metamorphic outer part of the Silesian cordillera, which formed the northern border of the Magura trough (Książkiewicz, 1958c). As pointed out by Dżułyński et al., (1959, p. 1108), coarse-grained type-I elements containing shallow-water, organic remains, were probably derived from coastal deposits. It is likely that the conglomerates and coarse sandstones with large Foraminifera and in most cases devoid of plant material, belonging to the Pasierbiec Sandstone, were transported to the head of a submarine canyon by longshore drifting of material (compare with Menard, 1960). From there, the coarse-grained material moved either in bulk or by continuous flow of grains down to the canyon mouth and beyond, to spread outwards as a fan (see Menard, 1960, footnote to p. 1273). The Magura Sandstone, on the other hand, was transported mainly from the E and NE, slightly oblique to the axis of the Magura trough. Here a delta source is extremely likely, since carbonized wood fragments are common and the remains of shallow-water organisms are rare. The presence of common feldspar, together with fragments of igneous rocks presumably both derived from the core of the Silesian cordillera, in addition to metamorphics as encountered in the Pasierbiec Sandstone, provides strong support for the concept of fluvial supply.

The relatively thin-layered successions, made up of simple beds, reflect repeated deposition from turbidity currents. The Hieroglyphic Beds display current directions from the E and NE. Their monotony in composition, grain size and current direction, displayed throughout the area, suggests constant supply by turbidity currents from a source on the margin of the Silesian cordillera. Reduced proportions of polyquartz, the presence of sericitized feldspars, scarcity of rocks fragments and fine grain size of type-I elements are indicative of distal deposition. The Beloweza Beds were deposited by turbidity currents travelling from the S and SE and likewise form a distal facies. In the latter case, the source area was probably a southern cordillera (Dżułyński et al., Fig. 8, p. 1105).

On the basis of gross trace-fossil assemblages, it has been independently shown that the Magura Sandstone was probably deposited at a shallower depth than were either the Hieroglyphic Beds or Beloweza Beds. It has also been suggested that varying degrees of tectonic instability in the depositional basin are reflected in these gross assemblages, as seen in the Magura Sandstone. Furthermore, the Sub-Magura Beds and the uppermost Hieroglyphic Beds in the W part of the area represent intermediate depths. These relative bathymetries, based upon observations of trace fossils, are in accord with sedimentological properties of the formations studied. Considerations of areal dimensions and bottom slope led Książkiewicz (1961, p. 6) to the conclusion that the average depth of the Carpathian flysch basin did not greatly exceed 1000 m. Depths of occurrence for Foraminifera species known from the Carpathian flysch and found in Recent sediments of the Pacific Ocean (Saidova, 1964; see discussion by Koszarski and Żytko, 1965) suggest that greater depths of over 3000 m. are at least possible. Clearly there is no absolute index of bathymetry for flysch sequences and only the relative depths given are valid for the Eocene formations considered.

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OBJAŚNIENIA TABLIC
EXPLANATION OF PLATES

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Tablica — Plate VII

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Fig. 1. Magura Sandstone. Skawica—Maryniakowo
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Fig. 2. Postdepozycyjne ślady organiczne w przekroju. Zdjęcie rentgenowskie przekroju pionowego. Piaskowiec pasierbiecki. Zawoja—Końskie

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Fig. 3. *Spirorhaphe* Fuchs. Spąg piaskowca. Warstwy hieroglifowe. Zawoja—Jaworzyna

Fig. 3. *Spirorhaphe* Fuchs. Sandstone sole. Hieroglyphic Beds. Zawoja—Jaworzyna

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Fig. 5. *Rhabdoglyphus* Vassoyevich. Spąg piaskowca. Warstwy hieroglifowe. Stryszawa—Roztoki

Fig. 5. *Rhabdoglyphus* Vassoyevich. Sandstone sole. Hieroglyphic Beds. Stryszawa—Roztoki

Fig. 6. Postdepozycyjny ślad organiczny typu *Scolicia*. Spąg piaskowca. Warstwy hieroglifowe. Zawoja—Końskie

Fig. 6. Postdepositional trail of *Scolicia* type. Sandstone sole. Hieroglyphic Beds. Zawoja—Końskie

Tablica — Plate XI

Fig. 1. *Lorenzinia* Gabelli. Spąg piaskowca. Piaskowiec magurski. Kamieniołom w Osielcu

Fig. 1. *Lorenzinia* Gabelli. Sandstone sole. Magura Sandstone. Osielec quarry

Fig. 2. *Zoophycos* Massalongo. Piaskowiec magurski. Osielec

Fig. 2. *Zoophycos* Massalongo. Magura Sandstone. Osielec

Fig. 3. *Zoophycos* Massalongo. Magura Sandstone. Zawoja—Mosorne

Fig. 3. *Zoophycos* Massalongo. Magura Sandstone. Zawoja—Mosorne

Fig. 4. Odcisk jeżowca na spągu ławicy piaskowca. Warstwy hieroglifowe. Zawoja—Jaworzyna

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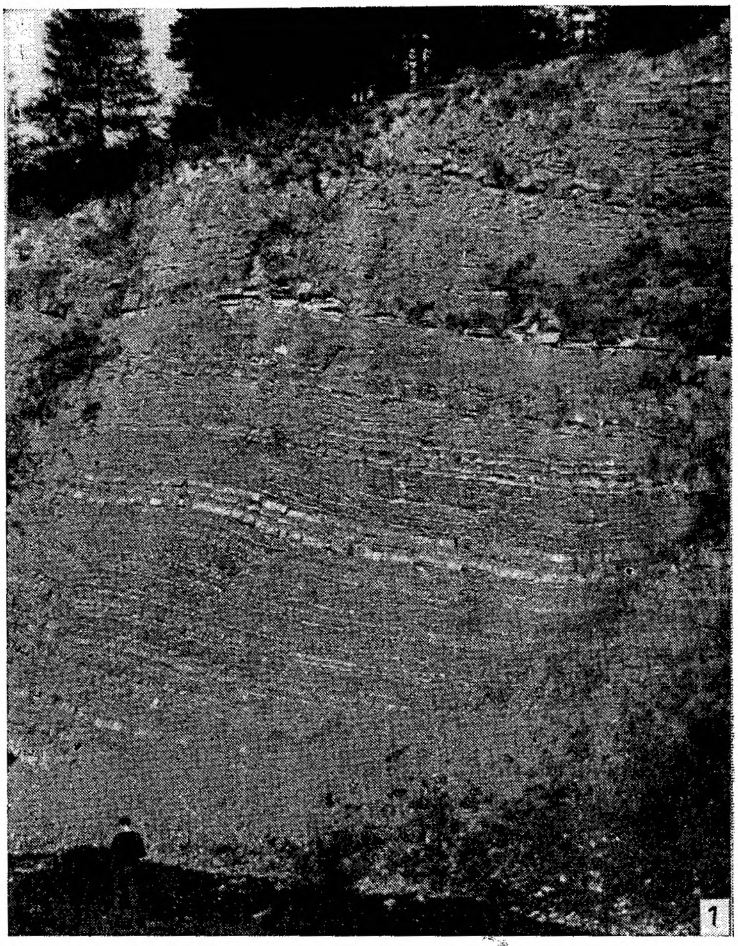
Fig. 6. Test of small Foraminifera with solution of wall evidenced at contacts with quartz grains. Hieroglyphic Beds. Zawoja—Jaworzyna



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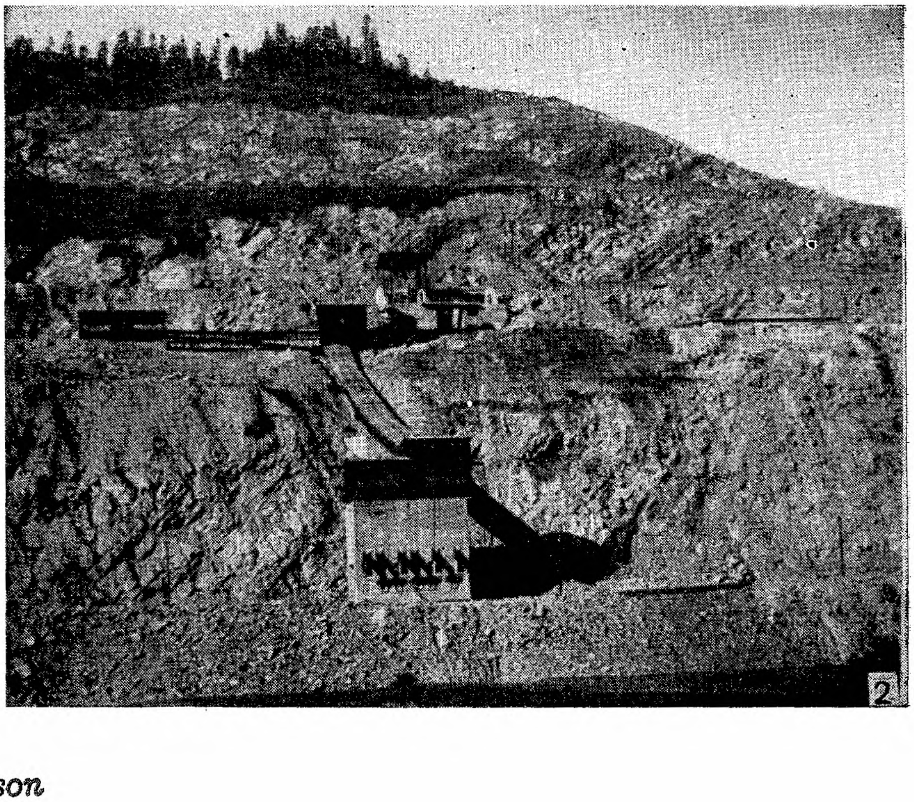

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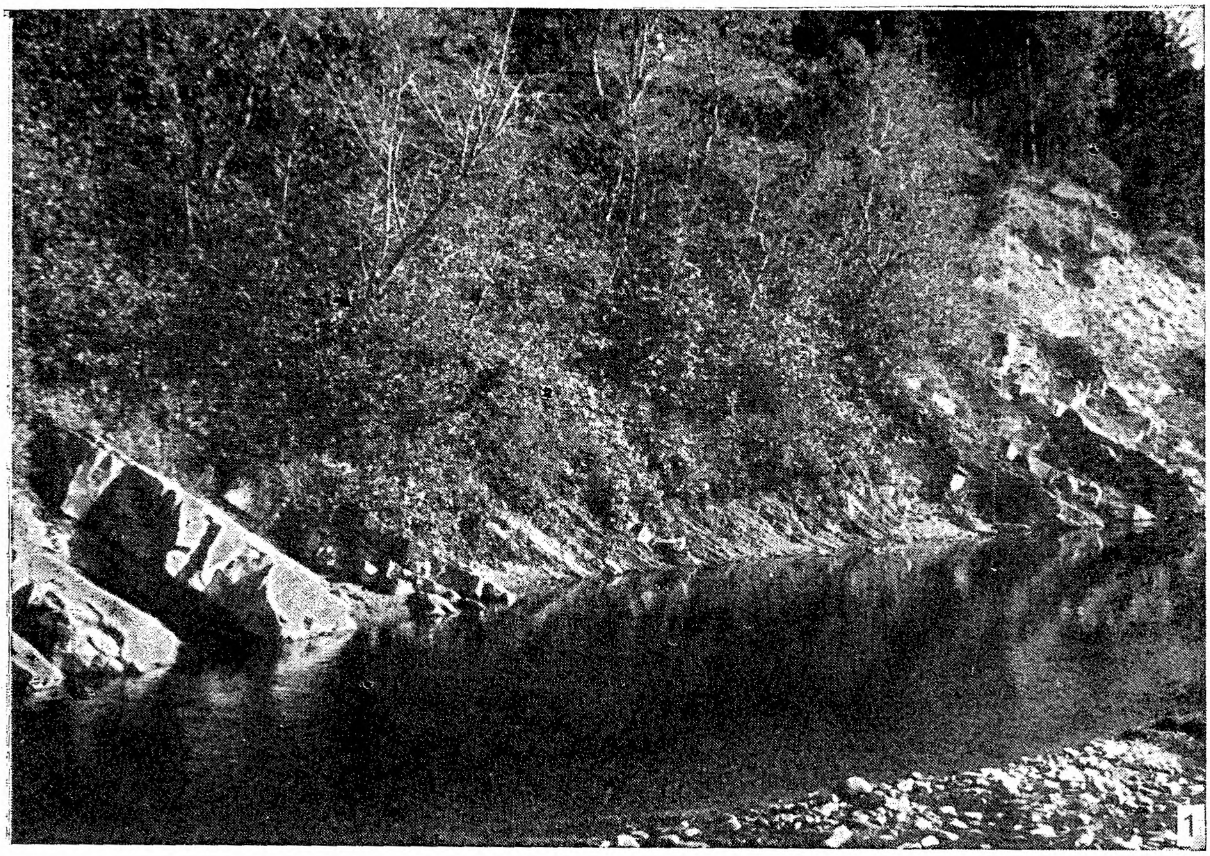

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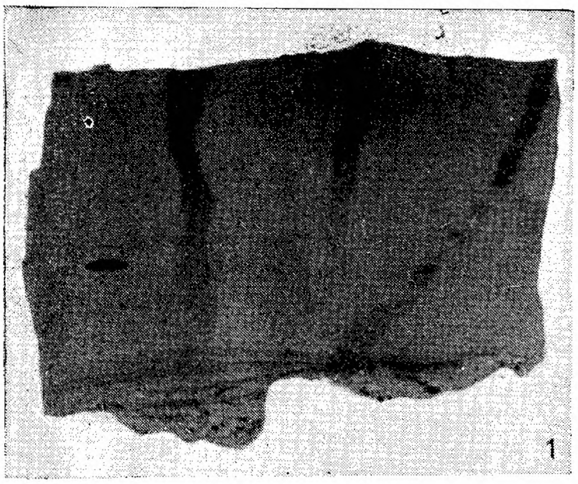

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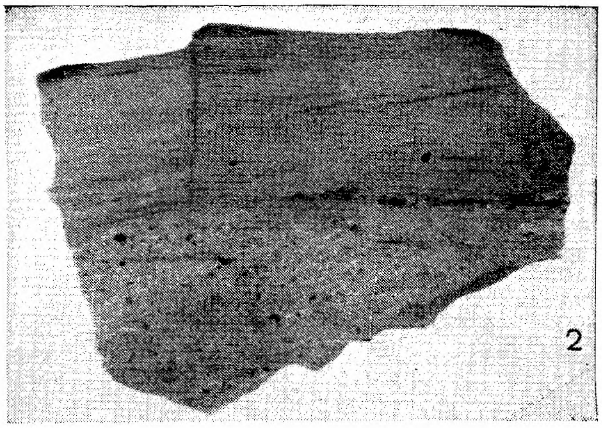

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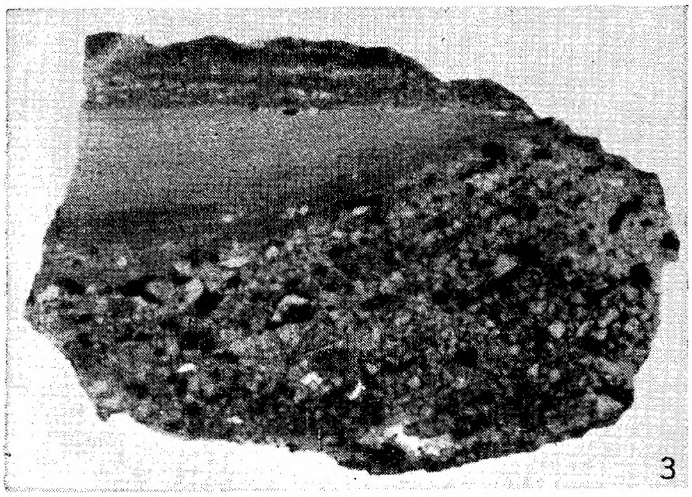

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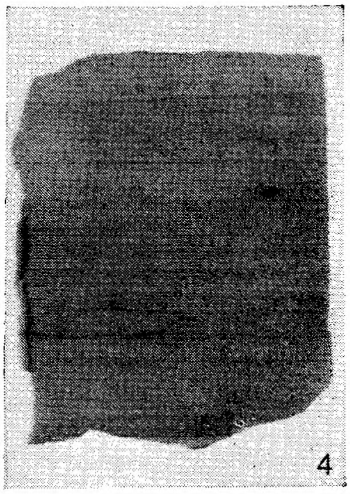

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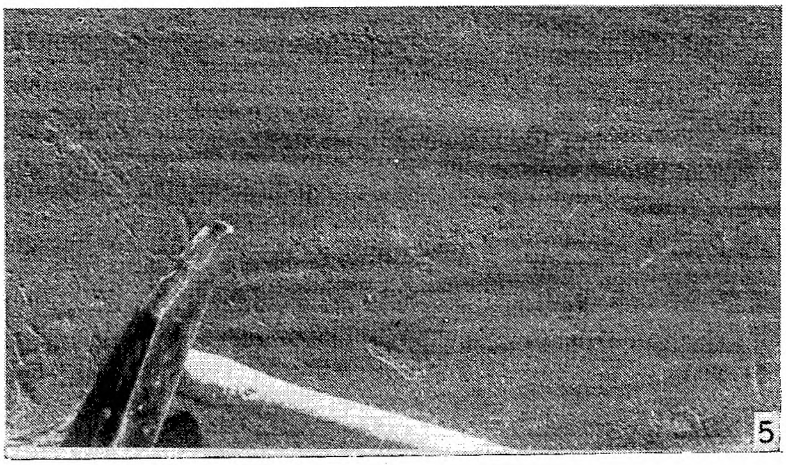

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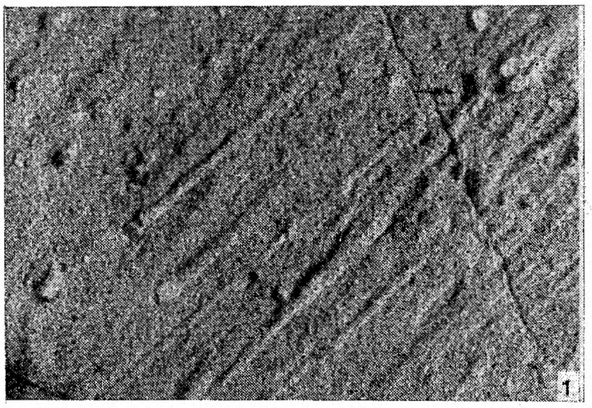

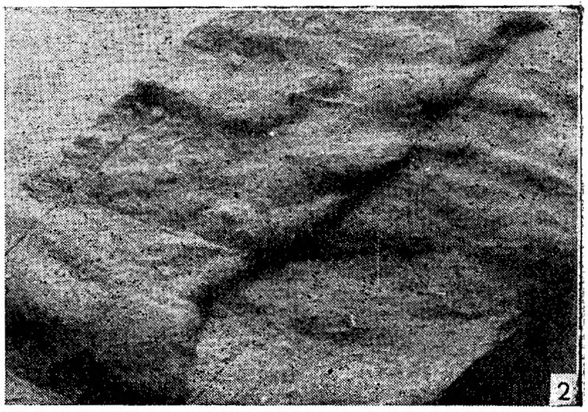

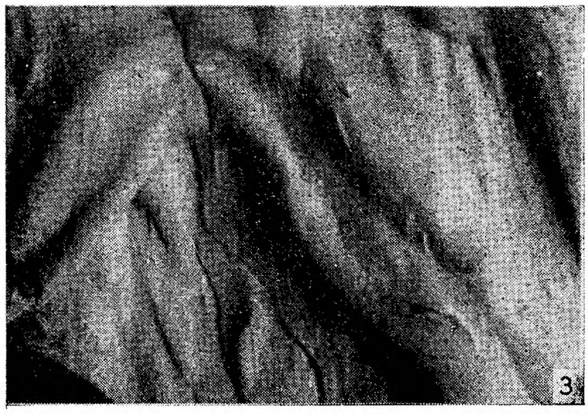

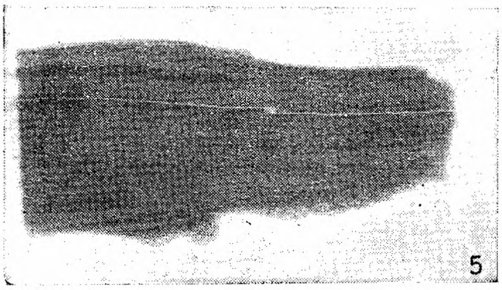

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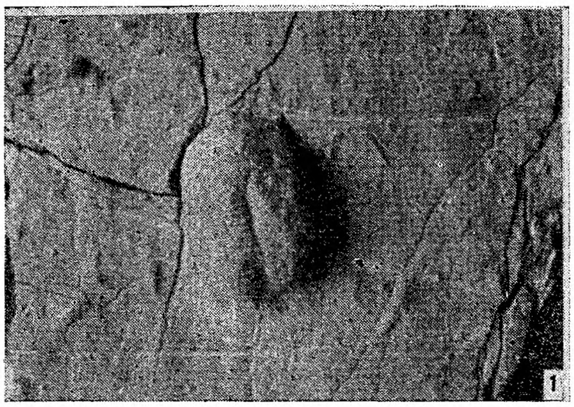
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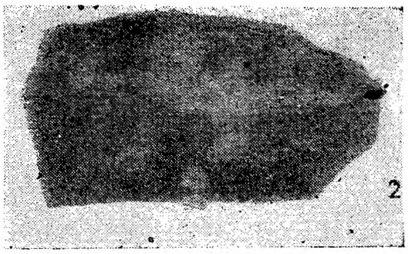
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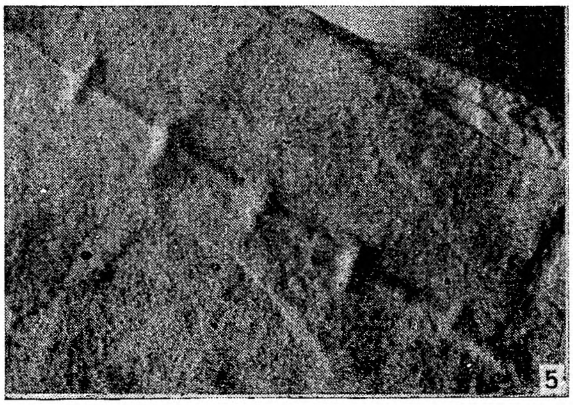
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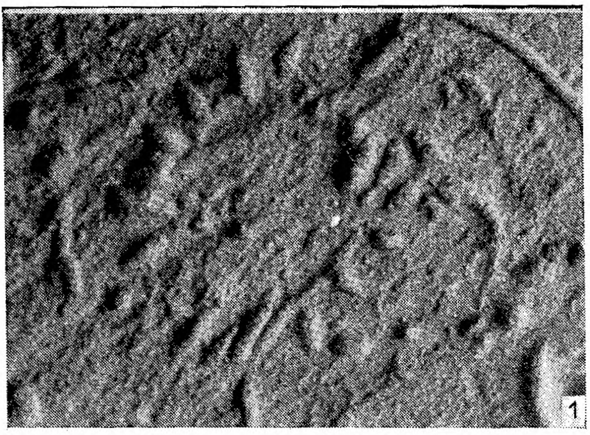
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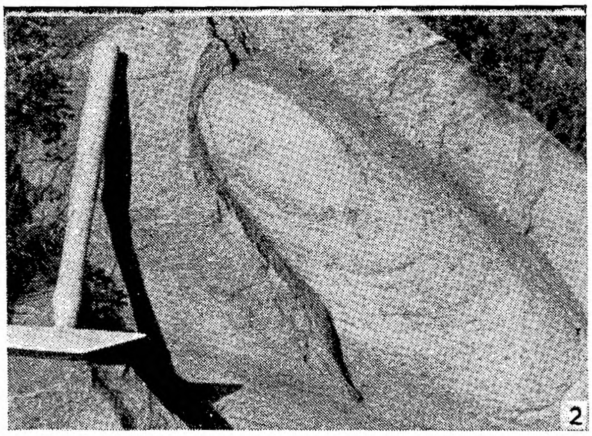
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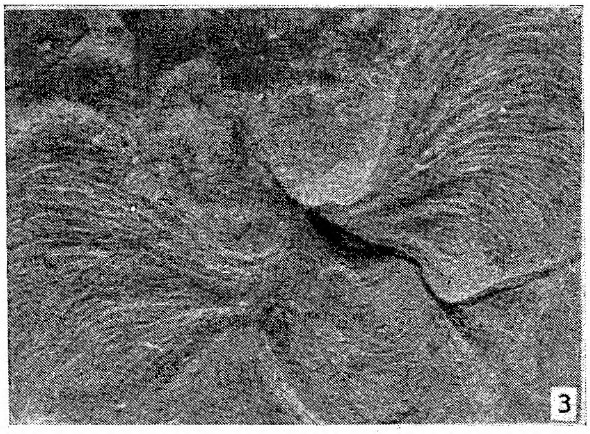
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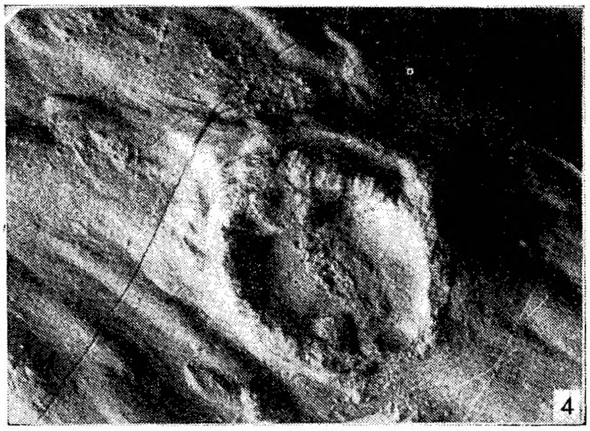
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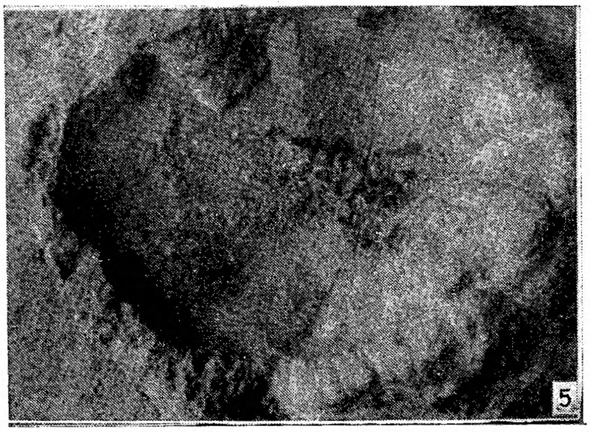
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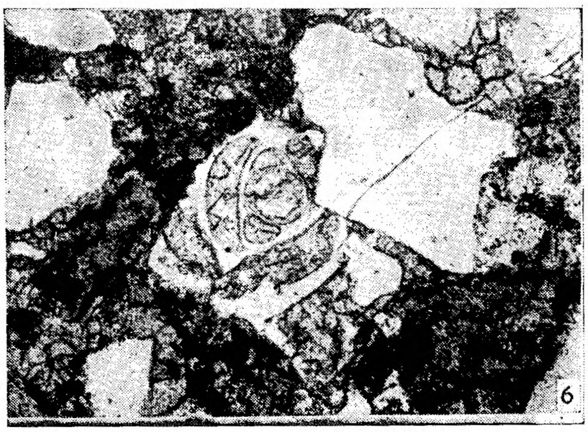
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