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FEATURES OF SEDIMENTARY ROCKS POSSIBLY DUE TO INTERNAL WAVES

(8 Figs.)

Fale wewnętrzne a sedymentacja

(8 fig.)

Abstract. It seems possible that internal waves may be a cause of ripple marks, graded bedding, mega-ripples, swash marks, deposition of layers of clastics, and that the associated backwash currents may leave marks similar to those left by other currents.

INTRODUCTION

The object of the present paper is to suggest that the internal waves are one of the possible causes of some common features of sedimentary rocks.

The general questions concerning the energy, dimensions and origin of the internal waves as relevant to geological processes were discussed previously (Gąsiorowski, 1972; 1974).

The experiments made were qualitative. The fluids were water and kerosene. Waves were induced at their boundary by the movement of a floating object, by a stream of air, or by a paddle. The sediments were sand of various grades, small pebbles, brick powder, loess, wood sawdust, plant grains, plant detritus.

DIRECT INFLUENCE OF INTERNAL WAVES ON UNCONSOLIDATED DEPOSITS

Ripplemarks

Symmetrical ripplemarks found at great depths (e.g. Ter-Chien Huang and Goodell, 1970) have been accounted for by some authors by internal waves. Internal waves ripplemarks are easily obtained in experiments.

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Under certain conditions, internal waves are perpendicular to the external waves. The theory of the phenomenon is expressed by P h i l l i p s (1966, p. 173). In the experiments, such waves may be obtained by tapping near the bottom of a rectangular tank.

It would follow that the direction of the symmetrical ripplemarks does not by itself indicate the course of the shoreline (Fig. 1). This effect might be common in shallow density layered saline basins.

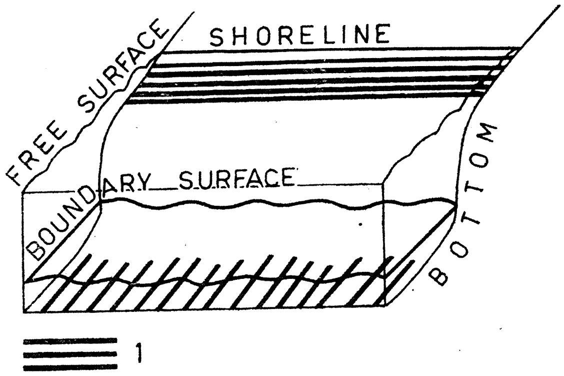

Fig. 1. Perpendicular sets of external and internal waves ripplemarks (1) in neighbouring areas

Fig. 1. Ripplemarki fal zewnętrznych i wewnętrznych (1) prostopadłe w sąsiednich obszarach

Sorting and Stratification

The internal waves may stir up an unconsolidated sediment, just as the external waves may do. Unless the sediments were entirely homogenous, different settling velocities during re-deposition would result in some type of stratification.

If the sediment were a mixture of two elements with widely different physical properties, e. g. sand and brick powder, these elements will become separated to form two layers (Fig. 2). If it was a mixture of two or more elements gradually passing one into another, graded bedding should appear.

If the internal waves stirred up only the upper part of an unconsolidated sediment, the undisturbed part would be overlain by the redeposited part. If the internal waves were able to stir up only some of the elements, the other elements would be washed around and tend to accumulate at the level where the stirring reached (Figs. 3, 4).

DEPOSITION FROM INTERNAL WAVES

We shall consider a layer of turbid water or of brine at whose upper boundary develop internal waves.

Adiabatic cooling would occur in the crests of the waves, generally tending to make easier crystallization. Whether this phenomenon is significant depends on the height of the waves.

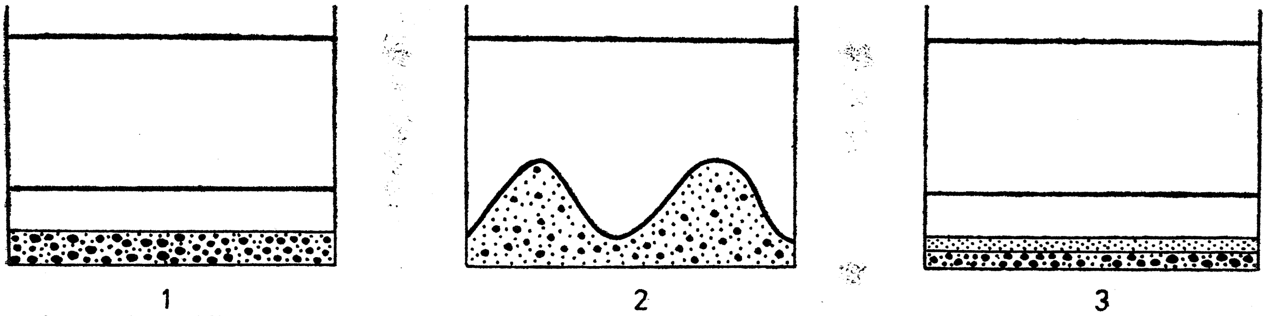

Fig. 2. Stratification obtained by stirring up by internal waves followed by redeposition. The sediment was originally a mixture of very fine grained sand and brick powder or wood sawdust previously soaked in water

Fig. 2. Warstwowanie otrzymane wskutek wzburzenia osadu przez fale wewnętrzne a następnie powtórne osadzenie. Pierwotnym osadem była mieszanina bardzo drobnoziarnistego piasku i pyłu ceglanego lub trocin nasiąkniętych wodą

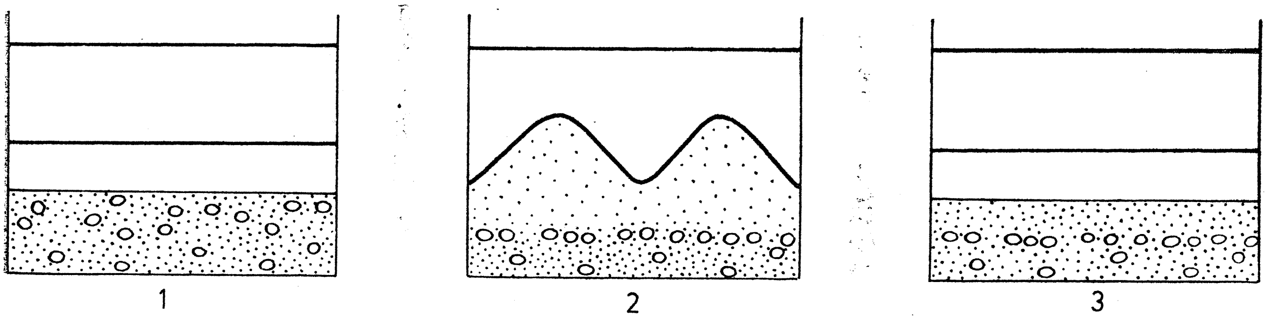

Fig. 3. Stratification obtained by differential stirring up by internal waves of the upper part of an unconsolidated sediment followed by redeposition. The sediment was originally brick powder or wood sawdust previously soaked in water containing small quartz pebbles

Fig. 3. Warstwowanie otrzymane wskutek wybiórczego wzburzenia przez fale wewnętrzne górnej części nie zestalonego osadu, a następnie powtórne osadzenie. Pierwotnym osadem był pył ceglany lub trociny nasiąknięte wodą zawierające małe otoczaki kwarcowe

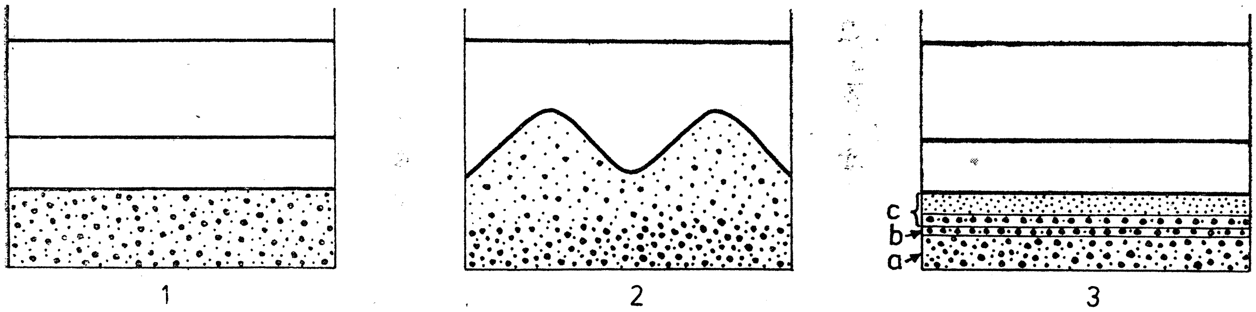

Fig. 4. Stratification obtained by stirring up by internal waves of the upper part of an unconsolidated sediment followed by redeposition. The original sediment was a mixture of very fine sand and of brick powder or wood sawdust previously soaked in water. a — not stirred up; b — partly stirred up; c — stirred up and redeposited

Fig. 4. Warstwowanie otrzymane wskutek wzburzenia przez fale wewnętrzne górnej części nie zestalonego osadu, a następnie powtórne osadzenie. Pierwotnym osadem była mieszanina bardzo drobnoziarnistego piasku z pyłem ceglanym lub trocinami nasiąkniętymi wodą. a — osad nie wzburzony; b — częściowo wzburzony; c — wzburzony i powtórnie osadzony

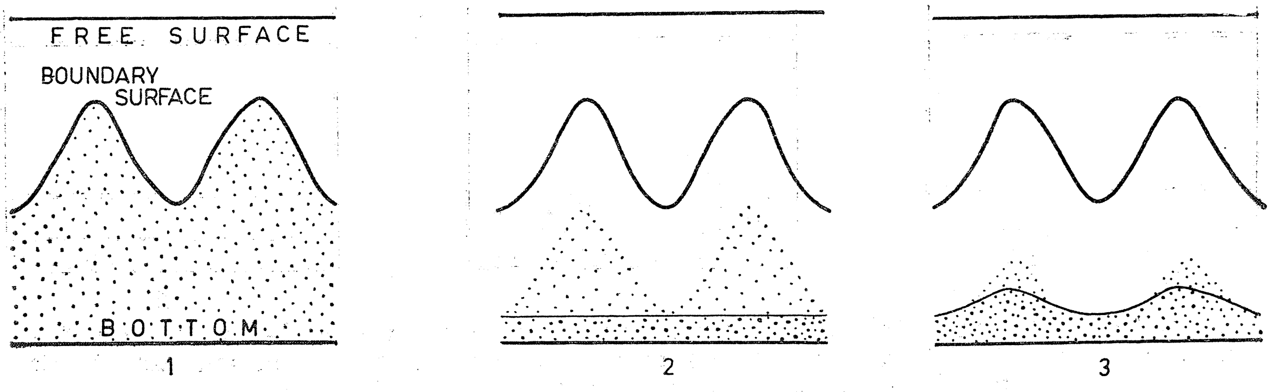

Fig. 5. Deposition of mega-ripples from standing internal waves
Fig. 5. Osadzenie mega-ripples ze stojących fal wewnętrznych

Mega-ripples

Standing internal waves may form in certain conditions (Defant, 1960) and last for a few days (e.g. Munk, 1941). The amount of the suspended material under the crests exceeding that under the troughs, the sediments settled may have an undulated upper surface (Fig. 5). If the settling of the sediment would not greatly influence the density of the turbid water — e. g. only the coarsest grade present in small amounts were settled — the shape of the waves should not be very much changed.

We did not succeed to obtain such forms in our experiments, due to the difficulties of maintaining standing internal waves for a sufficiently long time.

Swash Marks

Swash marks left by internal breakers are easily obtained in experiments. Internal swash marks composed of organic detritus were described by Gąsiorowski (1972, Fig. 2); those composed of inorganic fragments are analogous. The internal waves commonly much exceeding in size the external ones, the natural internal swash marks might be correspondingly greater.

Experimental internal tides or seiches also left swash marks, differing from those left by internal breakers by being more regular (Fig. 6).

Layers

Internal tides and seiches may deposit the suspended material they contain over the whole area flooded, covering it with a continuous layer of sediment. If the suspended material was not homogenous, graded bedding might develop. Lateral changes of sediment thickness might appear (Fig. 7).

The internal seiches may last very much longer than the internal tides — up to several days (H u t c h i n s o n, 1957), and therefore deposition from the internal seiches might be more important than from the internal tides.

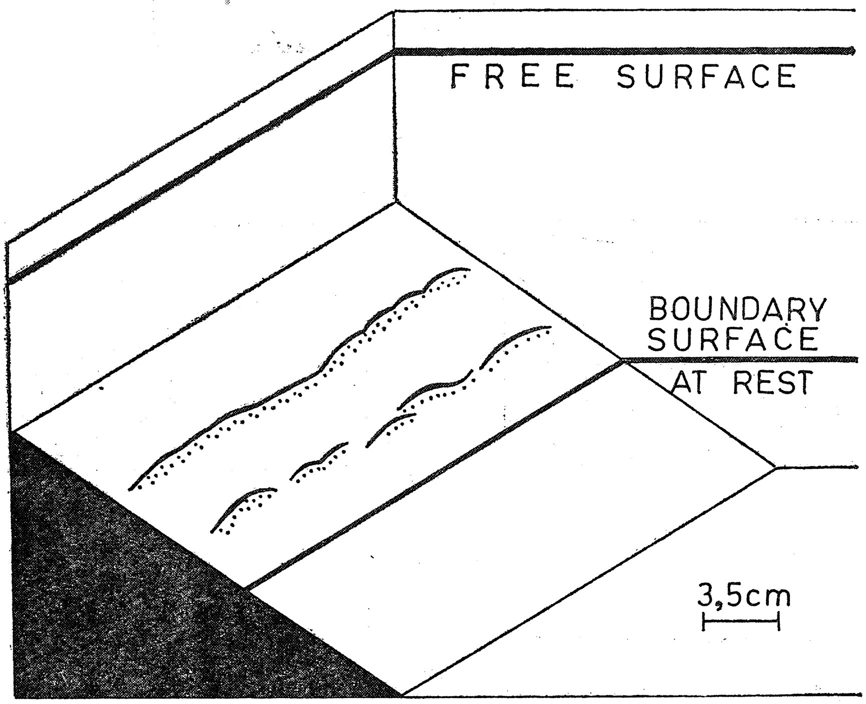

Fig. 6. Swash marks of plant detritus left by an internal tide (higher) and by internal breakers (lower)

Fig. 6. Swash marks z detritusu roślinnego pozostawione przez przypływ wewnętrzny (wyżej) i przez wewnętrzne grzywacze (niżej)

In the case of brines containing crystals, the material deposited may be dissolved when the tide or seiche recedes, and pseudomorphoses of evaporite minerals may appear in areas where chemical deposition is otherwise impossible.

Crystallization of Evaporite Minerals

S l o s s (1969, p. 785) thought that if a layer of brine reached the free surface due to an internal seiche, "hopper crystallization would occur at the exposed surface of the saturated water and bottom crystallization would pervade the entire basin below the pycnocline".

EROSIONAL FEATURES FORMED IN UNCONSOLIDATED SEDIMENTS

Stirring up of sediment by internal waves or tides may be followed by deposition in another area, thus diminishing the amount of the sediment in the original area (Fig. 7).

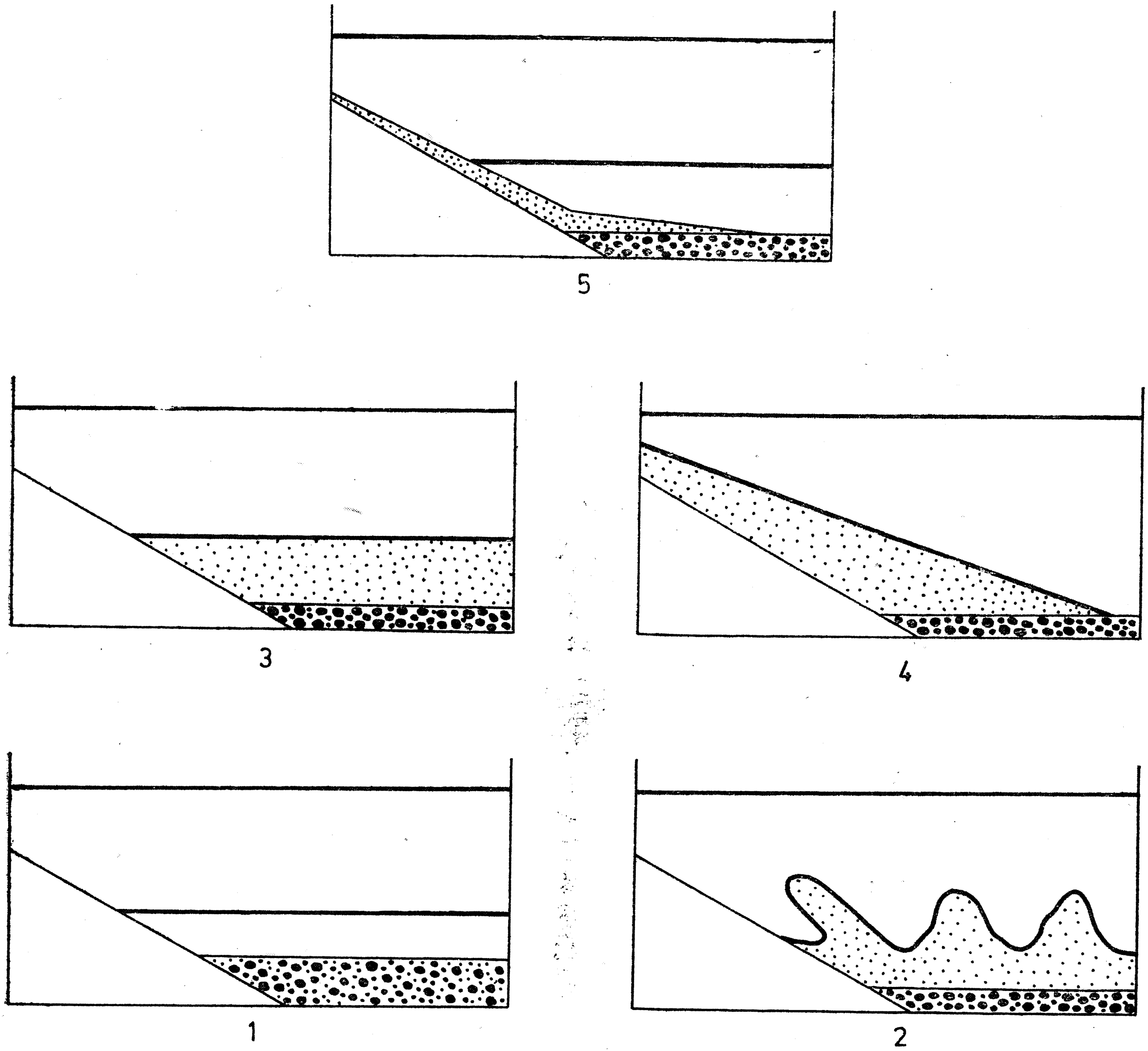

Fig. 7. Distribution of sediments obtained by differential stirring up by internal waves of an unconsolidated sediment followed by redeposition from an internal tide. Deposition during stages 2 and 3 is omitted. The original sediment was a mixture of medium grained sand and brick powder or wood sawdust previously soaked in water

Fig. 7. Rozmieszczenie osadów otrzymane wskutek wybiórczego wzburzenia przez fale wewnętrzne nie zestalonego osadu, a następnie powtórne osadzenie z wewnętrznego przypływu. Pierwotnym osadem była mieszanina średnioziarnistego piasku z pyłem ceglanym lub z trocinami nasiąkniętymi wodą

It is possible that various backwash currents on a sloping bottom associated with internal breakers, tides or seiches if strong enough may leave marks undistinguishable from those left by other currents.

Possibly, such backwash currents may become turbid on their way downslope.

INTERNAL WAVES IN UNCONSOLIDATED SEDIMENTS

No unambiguous results were obtained in the experiments. The movements which developed seemed to have resembled waves, but it was not ascertained whether the resemblance was significant.

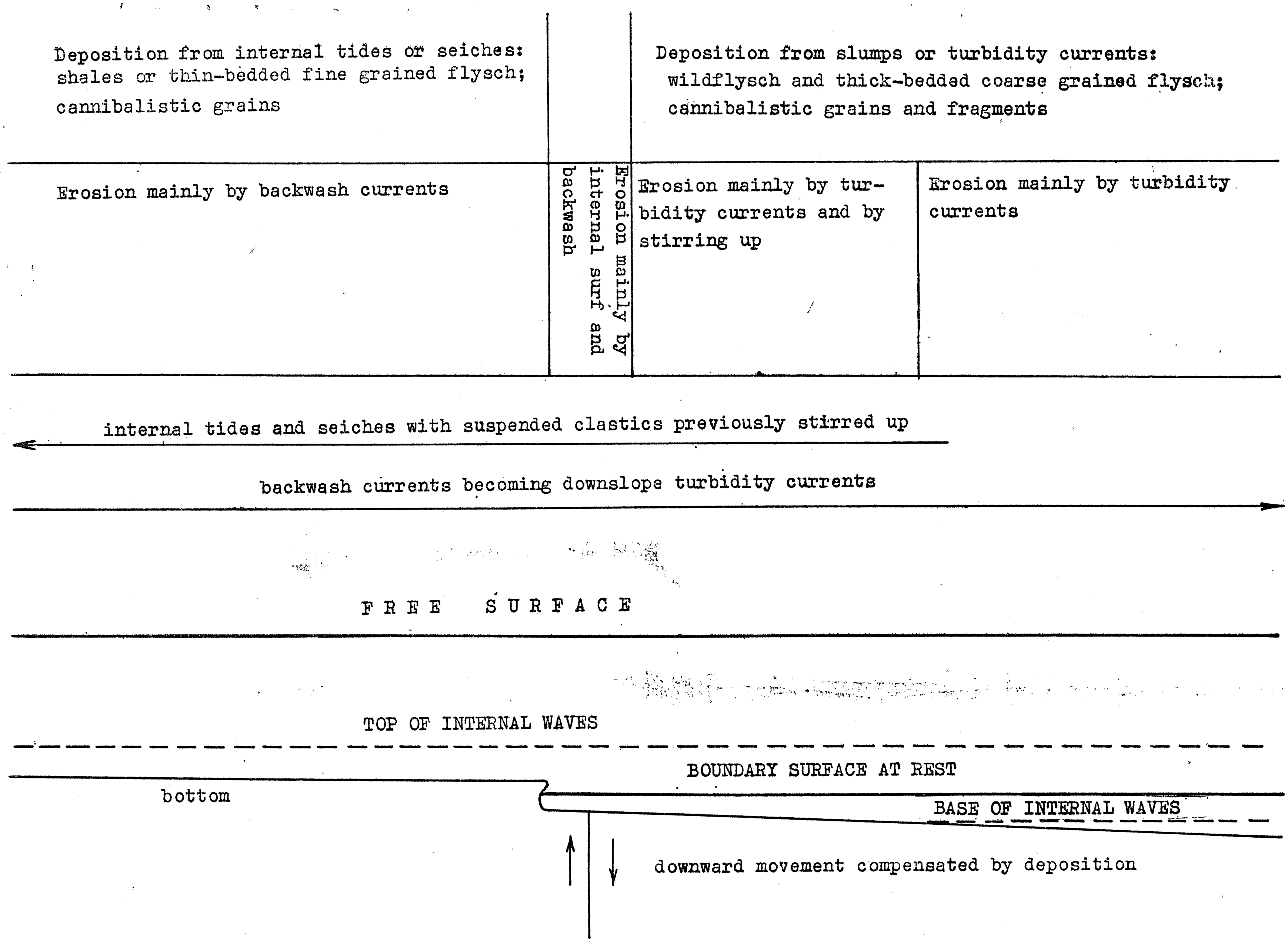

Fig. 8. Model of a flysch basin with clastics derived by erosion by internal waves of a small cliff in an active fault zone

Fig. 8. Model zbiornika fliszowego, materiał klastyczny pochodzi z erozji przez fale wewnętrzne małego klifu w strefie czynnego uskoku

However, it seems possible that structures such as described by Anketell, Cegła and Dżułyński (1970) are due to interfering internal waves.

These structures were formed due to the energy stored in a reversed density system. Possibly, in a normal density system analogous structures would develop if the energy were external, derived e.g. from earthquakes.

It might be significant that the nodular structures obtained by Anketell, Cegła and Dżułyński (o.c., Fig. 4E) are similar to the pattern of the cellular standing internal waves (Defant, 1960, Fig. 219).

It would be also interesting to know whether tides or seiches may develop in unconsolidated sediments.

These subjects need further investigations.

POSSIBLE GEOLOGICAL SIGNIFICANCE

We shall assume that the energy of the natural internal waves is adequate to form the features described above. We shall assume also that erosion by internal waves may be important. Both assumptions are by no means certain (cf. Gąsiorowski, 1974).

Leaving aside the obvious implications of our assumptions, we shall present only a case of a flysch complex of an entirely underwater origin, deposited on a gently sloping bottom, the clastics being derived from a small cliff in the zone of an active fault (Fig. 8). The pattern might fit the case of a thin generally fine grained flysch series adjoining a thicker and coarser grained series, e.g. Subsilesian and Silesian series of the Carpathians.

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STRESZCZENIE

Fale wewnętrzne mogą wytworzyć ripplemarki. W pewnych warunkach fale wewnętrzne są prostopadłe do fal zewnętrznych, wtedy i ripplemarki fal zewnętrznych i wewnętrznych będą do siebie prostopadłe (fig. 1). Jeśli fale wewnętrzne wzburzą nie skonsolidowany osad tak, że znajdzie się on w zawiesinie, to przy powtórnym osadzaniu wskutek różnych szybkości opadania powstanie warstwowanie, w pewnych przypadkach warstwowanie frakcjonalne (fig. 2—4).

Osadzanie substancji znajdujących się w zawiesinie w stojących falach wewnętrznych może doprowadzić do powstania mega-ripples (fig. 5). Wewnętrzne grzywacze, przypływy lub seiches mogą pozostawić swash marks (fig. 6). Osadzanie substancji znajdujących się w zawiesinie w wewnętrznych falach przypływowych a szczególnie wielodniowych seiches może doprowadzić do powstania ciągłej warstwy na większym obszarze (fig. 7). Podobnie, wewnętrzny przypływ lub seiche solanki może pozostawić kryształy ewaporytów w obszarach, gdzie wytrącanie chemiczne nie jest możliwe.

Według Slossa (1969), jeśli warstwa solanki wskutek wewnętrznej seiche osiągnie wolną powierzchnię, to może dojść do wytrącania się ewaporytów.

Prądy powrotne związane z wewnętrznymi grzywaczami, przepływami lub seiches mogą pozostawiać w nie skonsolidowanym osadzie podobne ślady jak inne prądy.

Jest możliwe, że fale wewnętrzne mogą występować nie tylko w wodzie, ale także w płynnych osadach wpływając na ich strukturę. Ta sprawa wymaga dalszych badań.

Nie wiadomo, czy energia fal wewnętrznych występujących w naturze jest lub była kiedyś wystarczająca do wywołania zjawisk wymienionych wyżej (cf. Gąsiorowski, 1973).

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