Acta Mineralogica-Petrographica, Szeged, XXII/2, 241—265, 1976

A COMPARISON OF THE SEDIMENTARY STRUCTURES OF SOME UPPER-PANNONIAN INTRABASINAL AND MARGINAL SEDIMENTARY SEQUENCES

M. Szónoky

INTRODUCTION

The Pannonian formations represent the largest volume of sedimentary rocks within the geologic record of Hungary. The water- and hydrocarbon resources of these layers have been revealed by a number of exploratory wells drilled in a rather uneven areal distribution. The paleontological stratigraphical hydro- and petroleum-geological characteristics of these formations have been discussed in a number of fairly valuable studies. In spite of this fact there are significant differences from place to place in the level and amount of knowledge concerning these formations. We are still heavily lacking — for instance — some information connected with the characteristics of the intrabasinal and marginal sediments and with the variation of the margines of the Pannonian sedimentary basin. The detailed discussion of these shortcomings is beyond the scope of this study. Although the difficulties in delineating the sediments infilling the Pannonian Basin horizontally and vertically explain a number of things, the reluctance in doing the method of comparing the different facies is considered as one of the sources of the existing shortcomings. This is why the author's intention is to distinct two — one intrabasinal and one marginal — Upper-Pannonian sequences which could be correlated in time and to analyse them as thoroughly as possible by demonstrating the analogies and distinct features in their lithological and litho-faciological development.

The samples of the so called marginal facies were taken in water exploring boreholes with continuous core sampling in Keresztespuszta (boreholes Keresztespuszta—1, 2, 3; abbrev.: Kp—1, 2, 3) and Tortyogó (boreholes Tortyogó—4; abbrev.: To—U/4), all situated south of the Permian-Mesozoic mass of the western part of the Mecsek-Mountain (S.-Hungary). The core samples representing the intrabasinal development were recovered from 26 and 2 hydrocarbon exploring boreholes with a rather scattered core sampling in the Algyő and Szeged area (Southern Part of the Great Hungarian Plain) respectively. These samples have been qualitatively described by the author within the framework a service contract between the Geological and Paleontological Department of the József Attila University of Sciences (Szeged) and the National Oil and Gas Trust of Hungary.

In addition to registering the fabric as well as internal and external forms of the sedimentary structures the comparative studies of the author have based on facies analyses considering macro- and microfossils equally. After drawing the paleo-geographical conclusions from the methods mentioned above stratigraphical details and historico-geological relationships of the areas involved have also been outlined, detailed discussion of which is beyond the scope of our recent study.

The paleogeographical setting of the samples representing the intrabasinal and marginal facies is shown in the *Fig. 1.*

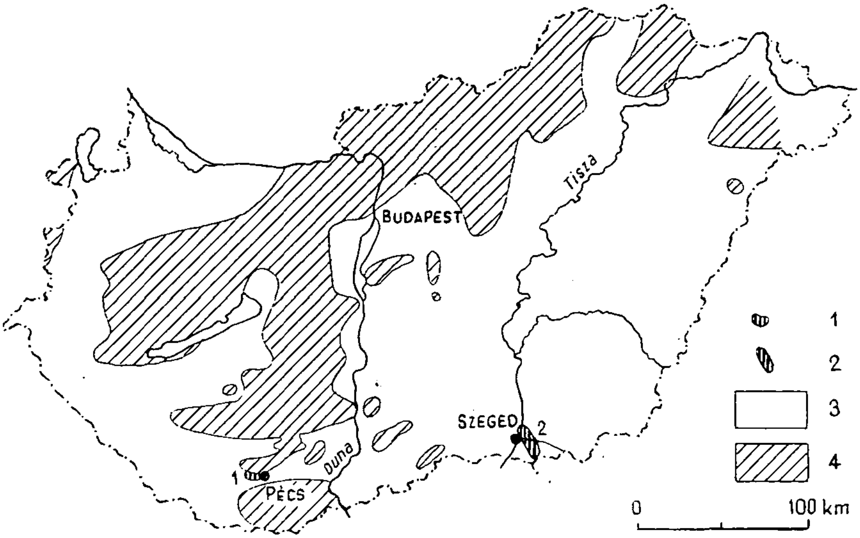

Fig. 1. The paleogeographical setting of the areas Keresztespuszta and Algyő-Szeged at the border of the Lower-Upper-Pannonian. [After KŐRÖSSY, L., 1971]. 1. Area of Keresztespuszta; *2.* Algyő- Szeged area; *3.* open water table; *4.* Islands.

I. THE MARGIN OF THE SEDIMENTARY BASIN: THE GEOLOGICAL SETTING OF THE AREA KERESZTESPUSZTA-TORTYOGÓ (SOUTH-HUNGARY)

A basin with a W—E strike is shown in the "Structural Map of the Pre-Tertiary Basement of Southern-Transdanubia" [1964], in the southern foreground of the western part of the Mecsek Mountain. The basin is bordered by the Permian—Mesozoic anticline of the western part of the Mecsek Mts. from the North, and by the crystalline anticline of the Görcsöny—Gyód area revealed by boreholes only. The area studied here (Keresztespuszta—Tortyogó) is on the northern slope of this basin.

During the Upper-Pannonian the whole mass of the Mecsek Mts. emerged forming a middle-mountain, while the contrasted movement of the depression situated in the southwestern foreground during the Pannonian has developed a depositional basin for the sediments eroded from the mountains. This relatively high rate of subsidence of the area studied decreased to zero by the end of the middle section of the Upper-Pannonian, so that the upper part of the Upper-Pannonian could not be formed here at all. The setting of this "chanell" connecting large basin-units in Transdanubia and in the Great Hungarian Plain may have been a very significant parameter as for the fauna of the area involved *(Fig. 1)*. The well-agitated meso-, myo- and oligohalyn waters flowing from the East may have also created favourable conditions for the evalution of the Pannonian faunal assembladges.

The boreholes studied stopped in Upper-Permian, Upper-Triassic fractured sandstone, slaty siltstone, dolomitic marl, intersected heavily by faults and upthrusts, as a conseuquence of the immediate vicinity of a tectonic zone. The boreholes Kp—1 and 2 have reached the basement in a more elevated structural position, the boreholes

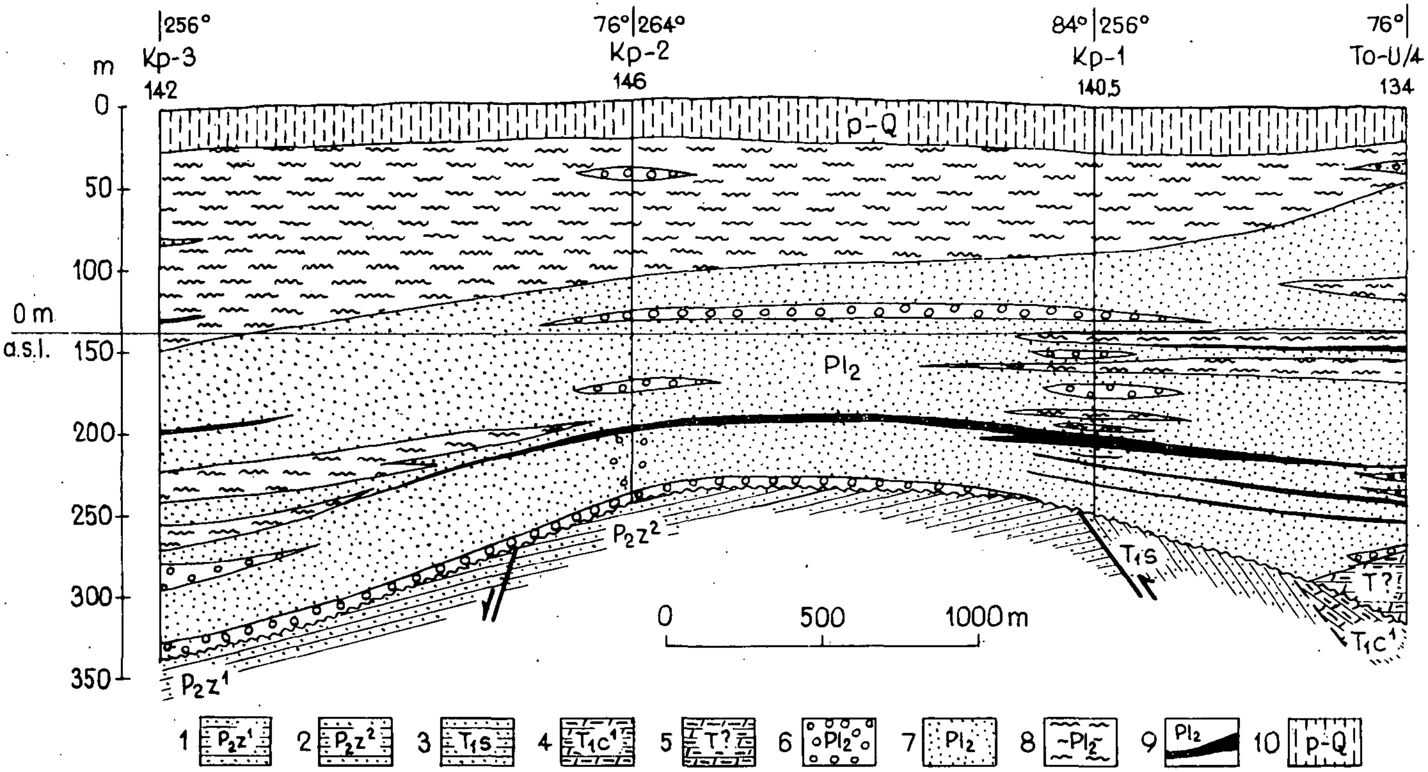

Fig. 2. Geological profile between the boreholes Keresztespuszta—3 and Tortyogó—U/4. *1—2.* Upper-Permian beds; *3.* Seisian beds; *4.* Campilian beds; *5.* Triassic (?) dolomitic marl; *6.* Upper-Pannonian conglomerate; *7.* Upper-Pannonian sand; *8.* Upper-Pannonian silt; *9.* Upper-Pannonian lignite; *10.* Pleistocene loess.

Kp—3 and To—U/4 have done it in a lower one. The Upper-Pannonian sediments are of clastic origin, deposition of which started by a loose, friable conglomerate in the boreholes Kp—2, 3, by a pebbly sand in the borehole Kp—1, and by a tuffaceous sand in the borehole To—U/4 *(Fig. 2)*. The sequence is composed of sand, locally calcareous sandstone layers with a southward dipping of 3—10° (Plate I, *Fig. 1*; Plate IV, *Fig. 3*). The grain size of the particles are varying but the overwhelming majority of them belongs to the realm of the coarse and medium size classes. The nearshore sequence evidencing for a rapid infilling is interrupted by repeated pebbly interbeddings of ancient piedmont deltas composed of clastic material produced by abrasion and by creeks with steep slopes and discharging into the basin.

Thus the piedmont lacustrine sedimentation is characterized by an overall occurrence of pebbly intercalations from permanent and periodical water flows as well as from torrential creeks. A loose, very poorly sorted conglomerate with a thickness of several meters has been deposited by this flows and creeks (Plate IV, *Figs. 1—2*). The intensive transporting activity of the torrential creeks is evidenced by these pebbly facies interfingering deeply into the nearshore zone. The lignite seams indicating a periodical appearance of swampy conditions occur in a well-defined stratigraphical horizon, in the lower part of the Upper-Pannonian. Thin silt lenses pinching out laterally are intercalated into the sandy mass of the same interval (SZEDERKÉNYI, T., BARANYAI, I., RÓNAKI, L. 1968].

The Pleistocene is represented by loess with a thickness of 20—30 m and containing *Succineae* remnants characteristic of humid areas.

Sedimentary structures of the marginal sequence

Sedimentary structures of the marginal areas to the sedimentary basin involved are summarized after BALOGH, K. [1971] in the *Table 1.* Within the group of the internal structures, a new form, the so-called “whirl-structures”, has been distinguished. Its formation could be explained by the vicinity of the coastline, by the relatively high rate of sedimentation as well as by the turbulent character of the flowing water or mud (=turbidity currents). The sediment deposited in such way is mostly poorly sorted. Being composed grains of different sizes this sediment may have been stirred up periodically by bottom currents even after the deposition.

Due to the rate of the sedimentation and to the close vicinity of the shoreline, the internal-, external- and deformation structures seem to be less frequent in the areas of marginal development as compared to those in the intrabasinal facies.

The nearshore sediments of the marginal areas are characterized by horizontally-laminated bedding, whirl-structures, cross-bedding, ripple-bedding and composite bedding as well as by submarine slumpstructures and/or sediment flows.

Internal structures

a) Horizontal lamination and microlamination evidence for the deposition of the sediment in a nonagitated environment and on equipotential surfaces perpendicular to the gravity. In the Tortyogó-part of the margin of the basin a relatively rapid sedimentation has taken place during the Upper-Pannonian, thus the structures involved could be formed mainly in the upper part of the cycle only, in the periods of less rapid sedimentation (Plate I, *Figs. 1—2*). Similar forms are characteristic of the different stages of the swamp formation, thus the microlamination is frequent in the lignite seams and in the carboniferous shales accompanying them. The horizontal lamination can be studied also in several outcrops nearby the Mecsek-Mts. (e. g.: Hird, Danitz-puszta)

b) The whirl-structures could be identified mainly by poor sorting and by the presence of coarser-finer interbeddings forming irregular-shaped „clouds" in it. Fossil-fragments and shells transported by the turbidity current have also been deposited and buried. These fossil remnants are connected with coarser-finer rocks intervals depending upon their size (Plate I, *Fig. 6;* Plate II, *Fig. 1*); or in other places the coarser particle have washed together forming load structures of defined outlines (Plate I, *Fig. 3*).

The characteristic feature giving the name of this structure is most striking in the case of microscopic photographs, because the whirling effect has been preserved and recorded by the orientation of micas (Plate I, *Fig. 4*; Plate II, *Fig. 2*). Both the overlying and underlying beds of the *Congeria rhomboidea* lumachelle described from the sample recovered from a depth of 249 m in the borehole Kp—3 are characterized by the presence of whirling structures. The dual occurrence of these two phenomena (i. e. lumachelle + whirling structures) evidences a permanent agitation of water. Quartz grains of 1—2 mm in diameter and *Mollusc*-shells of the same size have been buried in the silt (Plate II, *Figs. 3—4*; Plate I, *Fig. 5*; Plate III, *Fig. 1*). Syngenetic and postdepositional (*i. e.* due to the loading effect of the overburden) shell-fracturing could be easily distinguished here (Plate II, *Figs. 5—6*).

The author is of the opinion that the whirl-structures have formed in the nearshore part of the marginal areas, where both the bottom currents caused by discharging fresh-water flows and waves could be active and could remobilize the sediment had already deposited. This structure occure in the lower and upper part of the Upper-Pannonian equally, though is more characteristic of the fine sand--silt environments. Naturally, in sediments coarser than fine sand this structure could not be detected at all.

c) Cross-bedding has not been observed in the core samples studied by the author, because the structures formed in the deltas of the ancient creeks have been easily destroyed by the abrasion. Delta-like formations, cross-lamination have been reported by Wein, Gy. [1952], while evaluating the core samples recovered from the boreholes of the local water-plant in Tortyogó. It is an interesting reference, because these structures due to the loose texture of the sand stones could hardly be observed in core samples, although it is an widespread phenomenon in the outcrops of the Southern and Eastern parts of the Mecsek Mts. (e. g.: sand quarry of Pécsvárad).

d) The ripple-bedding may develop as a consequence of the pendulum-like motion of the nearshore water. The amplitude, the length and the setting of the ripples is a function of the energy of the moving water. Such structures could be formed here in the less agitated sandy, nearshore zones of the upper part of the Upper-Pannonian series only.

A symmetrical ripple bedding characteristic of marginal, shallow water formations and extending as long as 5—6 m or so in the sand quarry of Hird has been reported and documented by photos as well by Kleb, B. [1973].

e) Composite bedding. A periodical flare up in the activity of currents is recorded by fine sand and coarse silt intercalations, lenses observed in the otherwise well sorted, non-bedded clayey silts. The parallel and non-parallel lamination and the noncontinuous lenticular bedding are general. The more complicated forms of the composite bedding — *i. e.:* continuous lenticular bedding and flaser bedding — are the characteristic features of the intrabasinal facies. It is assumed that in the more distant and deeper environments of the marginal areas even these, more complicated forms could occur but in our samples have not been detected yet.

In the Tortyogó-part of the basin too, the parallel and non-parallel lenticular bedding have been observed in sediments of the periods with less vigorous water-agitation only (Plate III, *Fig. 2*).

External structures

Bioglyphs or biogenic marks have been found in one sample among those studied by the author. On a bedding plane of the fine silt core from a depth of 126 m in the borehole Kp—3, crawling trails and grazing trails (burrows) of mobile mud-eating worms could be observed (Plate III, *Figs. 3—4*). In the sediments of the less vigorously agitated environments of the marginal developments of the Upper-Pannonian in the Middle-Mountain these burrows are so frequently encountered locally (*e. g.:* near lignite seams) that they could be utilised for correlating different horizons [Jámbor, Á., Korpás-Hódi, M. 1971].

Tool marks have not been found in the samples studied but in the more remote areas their occurrence could be reasonably postulated because — due to the vicinity of a steep shoreline — different "tools" (boughs, fossils, rock-debris) could get into the deeper part of the basin, where their marks could be easily buried. The formation of the tool marks could be promoted by strong currents, by the far-reaching effects of the waters discharging into the Lake and by the wave-activity of the Lake.

Deformation structures

a) Load structures could be formed at the contact of silt and sand layers of the still plastic underlying beds. Load pouches have been rarely found in the samples from the boreholes in the foredeep of the western part of the Mecsek Mts. only. This fact is due to the relative coarse-grained development of the whole sequence (Plate III, *Fig. 5*).

b) Marks referring to sediment flow, subaqueous slumps have been identified in the sample from a depth of 132,5 m in the borehole Kp—3 (Plate III, *Fig. 6*). More consolidated, fine silt and clay shreds, scales had been intercalated into the coarse silt of these structures. The subaqueous slumping and stirring as well as re-deposition are processes of polygenetic nature [Balogh, K., 1973]. Currents amplified by subaqueous slumping and, in our case, the far reaching vigorous currents of water-flows discharging in a vary rapid rate into the Lake from the coastal areas might play important role in forming these marks. Though the bottom of the Lake were covered by a rather shallow water at the time of the deposition of this sediment, the vicinity of the shoreline and a small change in the bottom-morphology may have triggered off the slumping of the sediments. It is also kept in mind, that the emerge of the Mecsek-"Island" was being under way. The more clayey silt-shreds, scales have their own internal structure. This phenomenon could be formed also in a lake-bottom covered by plants as a result of currents within the free water masses.

II. THE INTERNAL PART OF THE BASIN: GEOLOGICAL SETTING OF THE ALGYŐ-SZEGED AREA

The NW—SE striking elevated blocks of the Algyő and Szeged areas are parts of a buried ridge which could be followed in the southern part of the Great Hungarian Plain. This ridge has Carboniferous (?) and Triassic beds overlying the Paleozoic crystalline basement. The blocks of the Pre-Tertiary basement — islands of different areal extent — separated the different part-basins encircled by them.

The block of Szeged has already been inundated during the Middle-Miocene transgression and formed a submarine ridge only during the Lower-Pannonian. In contrary, the crystalline block of Algyő — excepting its western flank — still existed as an island area even at the beginning of the Lower-Pannonian [BALOGH, K., 1973].

Above the blocks being in a structurally higher position as compared to their environ, the compaction of the thick Pliocene sedimentary series has formed a number of hydrocarbon-bearing growth-anticlines showing a gradually decreasing dip upwards *(Fig. 3)*.

The eastern, Algyő-block is composed of metamorphic rocks entirely. In contrary, in Szeged, the basement of the Tertiary basin consists of Carboniferous (?) breccia, Lower-Triassic quartzose sandstone and Middle-Triassic brecciated dolomite all of them overlying the metamorphic rocks being in a deeper structural position by as much as several hundred meters as compared to the same metamorphic basement in Algyő. The coarse-grained abrasion conglomerate of the transgressive Tortonian sea inundating the former island after a considerable period of erosion could be followed up in the western flank of the Algyő-structure only. In Szeged, however, the much more finer, sandy, marly sediments overlying this coarse conglomerate series occur too, referring to a gradual moving off the shoreline.

A Lower-Pannonian basal conglomerate has deposited mostly in the margins of the metamorphic ridges of Algyő still in an elevated position at that time. The several m thick sandstone, dark marl and limy marl series overlying the conglomerate evidences for the rapid subsidence of the former island. This transgressive sequence is composed of clayey marl—marl beds, more upward sandstone layers and finally sandstone-clayey marl layers [KŐRÖSSY, L., 1971].

The Lower-Pannonian basal conglomerate is missing in Szeged, the sedimentation of this substage starts with the deposition of a marl-limy marl series here.

The mean thickness of the Lower-Pannonian in Algyő is as much as 600 m and amounts to 1000 m in the flanks. In Szeged-trough the limy—marl horizon is relatively thin showing a thickness of several ten meters — the mean thickness of the Lower-Pannonian varies between 600—900 m.

The Upper-Pannonian sedimentation forms the regressive phase of the Pannonian cycle. This may be due to the Rhodanian phase of the Alpine orogeny.

The shallow lacustrine Upper-Pannonian sequence consists of a variation of rhythms composed of sandstone-clayey marl, lignite. In addition, periods of more and less rapid sedimentation change each other.

The total thickness of the Upper-Pannonian in Algyő amounts to 1200—1500 m. This series consists of a variation of sand, sandstones and clayey-marl as well as lignite ribbons with a thickness of several decimeter, and silt. In Szeged, the Upper-Pannonian could be found in depth interval of 600—1950 m b. s. l.

The fluviatile Upper-Pliocene generally in a depth of 300—750 m b. s. l. consists of the variation of clay and sand.

The Upper-Pliocene beds are overlain by a Pleistocene-Holocene series of aeolian—fluviatile origin [T. KOVÁCS, G., 1973; VÖLGYI, L., SUBA, S., BALLA, K., CSALAGOVITS, I., 1970].

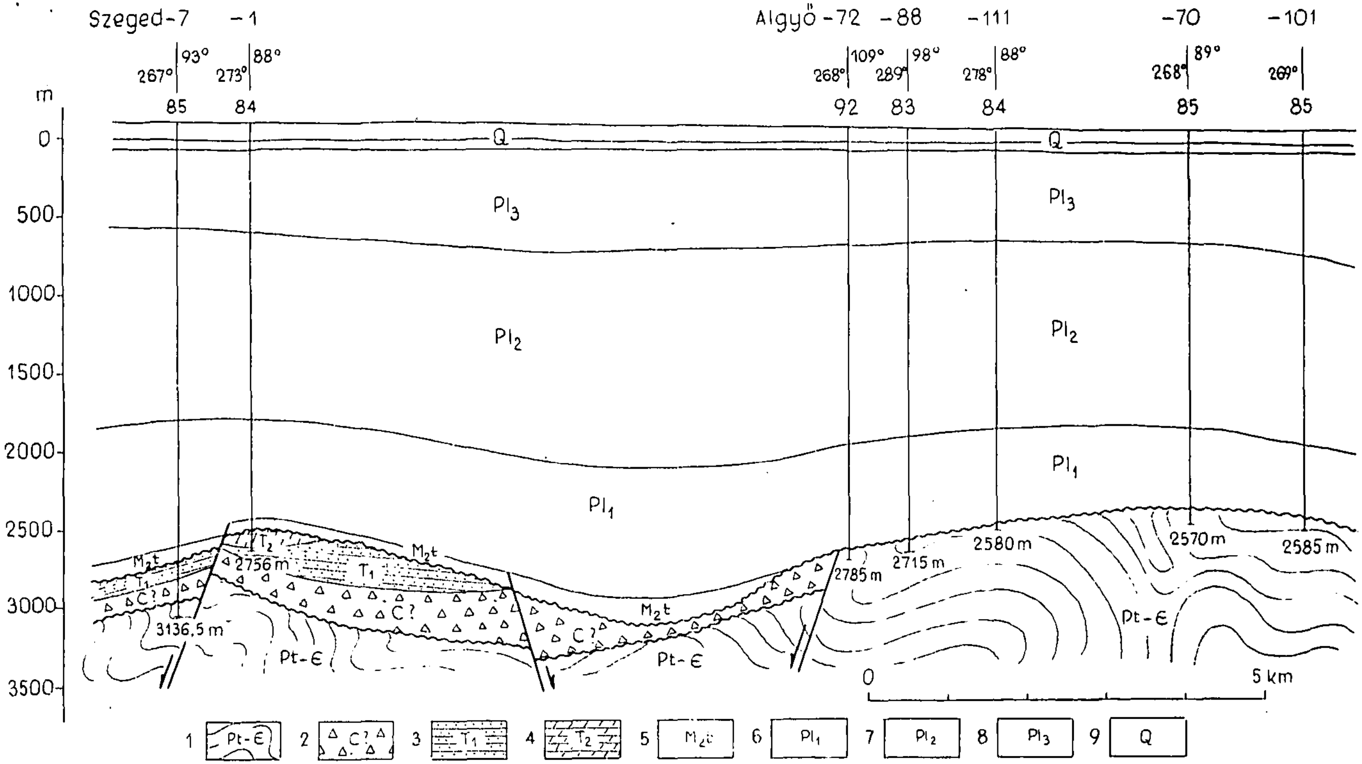

Fig. 3. Geological profile between the boreholes Szeged—7 and Algyő—101 [After T. Kovács, G., 1973]. *1.* Precambrian and Early-Paleozoic metamorphic rocks. *2.* Carboniferous (?) breccia; *3.* Lower-Triassic sandstone; *4.* Middle-Triassic dolomite; *5.* Miocene; *6.* Lower-Pannonian; *7.* Upper-Pannonian; *8.* Upper-Pliocene; *9.* Holocene-Pleistocene.

TABLE 1

Frequency of occurrence of the sedimentary structures of the marginal and intrabasinal Upper-Pannonian sediments

	I. Internal structures						II. External structures		III. Deformational structures				
	Horizontally parallel lamination, microlamination	Graded bedding	Whirl structures	Cross bedding	Ripple bedding	Composite bedding [lenticular bedding, composite ripple bedding]	Bioglyphs	Mechanoglyphs	Load structures	Growth fault	Sand injections	Convolution	Sediment flow, subaqueous slumping
Marginal development	Frequent in the coal-bearing clays accompanying the lignite beds in the upper part of the Upper-Pannonian cycle	—	Characteristic	Frequent in the outcrops of the eastern and southeastern part of the Mecsek foreground	Occurs	Occurs	Occurs	—	Rare	—	—	—	Occurs
Intrabasinal development	Characteristic	Frequent	Very scarce	Frequent	Frequent	Charactheristic	Frequent	Occurs	Characteristic	Occurs	Very scarce	Frequent	Frequent

The sedimentary structures of the intrabasinal sequence

The intrabasinal Upper-Pannonian sequence is much more aboundant in sedimentary structures as compared to the marginal facies *(Table 1)*. External, internal and deformational structures can be found equally, excepting the whirl structures known in the marginal areas only.

The description and analysis of sedimentary structures of 144 Upper-Pannonian samples is a result of a work lasting for years [Balogh, K. *et al.*, 1968, 1969, 1972]. The core samples represent the lower part of the Upper-Pannonian; they have been recovered from the intervals of 1840—2080 m and 1600—1770 m in Algyő and Szeged respectively; i. e. they comprise the most intensively explored, 150—250 m thick interval of the sandstone—siltstone series.

Internal structures

After the relatively balanced sedimentation of the Lower-Pannonian started a period of variable shallow-lacustrine sedimentation. The characteristics of the sediment accumulation in the different part-basins with a different rate of subsidence were controlled by the energy and turbulency conditions of the currents dominating there.

a) Series of layers varying in thickness of several mm-s to several cm-s or so and characterized by horizontal or slightly rippled, parallel lamination, microlamination are marked mostly by differences in the grain size composition, by the simple sorting of the beds, by the orientation of mica-scales as well as by differences in colour caused by the organic substances of floral origin in it (Plate IV, *Figs. 4—5*; Plate V, *Fig. 2*). The carboniferous, microlaminated clay and silt found locally, has deposited in a depth interval of the shallow lake characterized by the total absence of the waves (Plate IV, *Fig. 4*), where the sedimentation was a periodical phenomenon only. In the case of the carboniferous slate an autochtonous swamp existing in a well-defined period only should be postulated.

Thin beds mostly form a series of small rhythms with a continuous transition between the rhythmunits (Plate V, *Fig. 1*). The horizontal-parallel lamination has also been observed as one of the elements of the composite bedding intercalated into sand ripples and silt layers (Plate IV, *Fig. 7*; Plate VI, *Figs. 3, 6*). Well-sorted, fine grained sandstones with a network of thin coal seams (ribbons) in a horizontal rippled-parallel position are extremely frequently encountered (Plate VI, *Fig. 4*).

b) Graded bedding. In the silt and fine sand layers simple sorting has been observed so far, which refers to the gradual decrease in the energy level of the turbidity current. In the case of fine-grained sediments the graded bedding accompanied by fine horizontal lamination forms a composite bedding, the finely laminated part of which settles down from the least dense suspension of the turbidity current [Balogh, K., 1971; Plate V, *Fig. 1*]. By moving offshore the graded bedding becomes more completed.

c) Cross bedding. Cross bedded sand ripples of the shallow sublittoral zone with an amplitude of 1—4 cm or so, and with a maximum length of 10—15 cm are frequently found in the saples studied. Their small scale refers to the low energy level of the bottom current tracting them. Different erosion phases of the sand ripples climbing on the bottom could be observed (Plate IV, *Fig. 6*). The erosion was triggered off by an abrupt change in the direction or velocity of the current. The set of the cross bedded sand ripples are mostly composed of beds with varying orientation (Plate IV, *Fig. 7*). The fine beds of the sand ripples are characterized by a sorting value reflecting the changes in the current velocity as well as by an accumulation of the clay-silt and mica scales (Plate VI, *Figs. 1—2*). The dip of the beds amounts to 8—10—25°.

d) Ripple bedding. If the partially eroded sand ripple are separated by clay flasers (Plate IV, *Fig. 8*) a ripple bedding develops.

e) The composite bedding is formed by addition of two or more bedding forms. Its development is due to currents of different energy level and orientation. A variation of horizontally and crosslaminated beds is a phenomenon of fairly frequent occurrence (Plate IV, *Fig. 7*; Plate VI, *Fig. 3*).

Both forms of the lenticular bedding — the discontinuous and continuous one — could be observed equally (Plate IV, *Fig. 6*).

A part of sand lenses in silt beds could be considered as remnants of subsided sand ripples.

In the silts seemingly almost entirely homogenous, coarser and finer interbeddings, lenses of several mm to cm or so in size respectively are frequent (Plate VI, *Fig. 5*).

External structures

On the bedding planes of clayey silts or fine sandstones bioglyphs of meandering form are frequent. This sections prepared from samples perpendicular to the bedding show traces of some burrowing, mud-eating and mud-dwelling organisms clearly. Locally, these burrows of 1—10 mm in size show a massive appearance upon or within a beding plane. The microlaminated sediments mostly with large volume of organic substances and with non-agitated environments assured an ideal condition for benthonic organisms (Plate VII, *Figs. 1, 3*). In microphotographs, they occur as well-bedded fillings or — in fine grained sediments — as cylindric or trough-shaped fillings with definite outlines and composed of coarser grains (Plate VII, *Figs. 2, 4*).

Massive accumulation of well-preserved *Mollusca*-macrofauna could be only rarely observed in the sediments of the inner parts of the basin. Even some parts of the calcareous shell of *Limnocardium schmidti* [M. HÖRN.], *Congeria czjzeki* M. HÖRN. *Dreissena sp.* are preserved on the stones recovered from the interval 1960—1961 m below the surface in the borehole Algyő—454. The orientation of the fossils here refer to a rapid burial and drift; thus their traces are of rather indistinct appearance (Plate VIII, *Fig. 5*).

The mechanoglyphs are represented by gullies and channels on the surface of silts and sand ripples. These evidence for an increase in energy level and re-suspension as well as further transportation of the sediments had already been deposited (Plate VI, *Fig. 4*). This phenomenon accounts also for the eroded sand ripples of samples with composite bedding (Plate IV, *Fig. 6*).

Deformation structures

a) The load structures are extremely characteristic of the finer sediments of the intrabasinal Lower and Upper-Pannonian. Their presence shows that — due to the differentiated load — some part of the coarser sand bed or sand ripple deposited upon the surface of the still plastic fine mud may have been submerged into it. This submerge may has been promoted by some shocking effects (earthquakes or microseismic activity of local extend).

As a result of mud-deformation, downwards load pockets and load sacks, upwards and beside the former forms flames-tructures of silty substance were formed. Their are of several mm to several cm or so in size (Plate VII, *Fig. 5*), and are almost present in any bedding plane of samples composed of silt and sand interbedding. In microscope, the sharp contact of the two sediments of different grain size are always striking (Plate VII, *Fig. 6*).

b) The sedimentary faults are considered as shearing planes penecontemporaneous to the sedimentation. They are more frequent in the Lower-Pannonian, but less frequent in the silts and fine sands of the Upper-Pannonian. They show a displacement of some mm or cm or so, without any continuation upwards or downwards (Plate VIII, *Fig. 1*).

c) Sand injections. They developed as a result of liquefaction in the sediments in a form of sandstone or silt injections with a size of 1—2 mm or so.

d) Convolution. This is a phenomenon of frequent occurrence in the sequence composed of silt and sandstone interbedding in the lower part of the Upper-Pannonian. This structure may have been developed by the crest-deformation of the submerged sand ripples or by liquefaction triggered off by chocking effect of earthquake waves. An impressive example of sand ripples submerging into silt is shown in the *Fig. 2* of Plate VIII. The structures had been formed earlier sometimes might be subjected to dragging effect too.

e) Slumping and sediment flow take place if — due to a sudden impulse — the loose sediment deposited on the uneven slope of the bottom starts to move. This phenomenon show a widespread occurrence in the Upper-Pannonian as a result of the frequent crust movements. Chaotic folded structures of silt and fine sand due to mud movement are shown in the *Fig. 3* of the Plate VIII. In microscope, the sediment of different grain size folded mutually into each other are separated by a sharp contact; sometimes even the fade traces of their primary bedding can be perceived (Plate VIII, *Fig. 4*).

The silt scales, "pancakes" and pebbles in sandstone are also in connection with the water movement after the slumping. New and new pieces were torn up and transported further by the currents from the more consolidated silt shreds which had been torn up earlier due to the slumping. These shreds (or if they are slightly rounded: pebbles) preserve their inner structure. Their size is several mm to cm or so (Plate VIII, *Fig. 6*).

III. COMPARISON OF THE SEDIMENTOLOGY AND HISTORY OF THE MARGINAL AND INTRABASINAL SEQUENCES STUDIED

The Pannonian Lake reached its largest areal extension during the Upper-Pannonian. The water table of the Lake getting more and more fresh has fallen into different parts. Thus, by the lapse of time a continuous decrease in the distance from the shores can be considered. While the development of the Early-Neogene intrabasinal and marginal sediments had been substantially different due to the shoreline pattern, to the extension and slope conditions of the drainage area and to the relief of the bottom of the sedimentary basin, during the Upper-Pannonian—when nearshore conditions were dominant both in Transdanubia and in the Great Hungarian Plain — the faciesspectrum became much more simple: a nearshore environment and a neritic zone could be distinguished on the basis of biofacies.

Due to the lack of any comprehensive study, the paleogeography of the Mecsek Mts. and the Upper-Pannonian in Algyő—Szeged could be inserted as small mosaics only in the evolutional sequence of the Pannonian. By comparing the different sets of layers the following facts could be stated:

1. The lithological differences in the series involved are connected with the development of their sedimentary basin different in time and space. The Upper-Pannonian in the foredeep of the Western Mecsek Mts. inundated the basement complex, meanwhile in the Szeged—Algyő area the sedimentation had been in progress since the Miocene or Lower-Pannonian, respectively. Due to the crust movements at the border of the Lower/Upper-Pannonian infilling of the sedimentary basin started with coarser sediments. The sediments of the two areas involved are differing in their grain size, sorting, rounding and mineral composition.

While the sedimentary sequence in the Mecsek foreground keeps to be coarse grained during the whole Upper-Pannonian cycle (pebble, coarse and medium sand, sandstone) and the sediments becomes finer at the end of the infilling in some swampy periods only, the neritic sequence is, however, characterized by the dominance of finer sediments during all the cycle. The rocks of the Algyő area are well sorted, the sediments of the nearshore sequence, however, are marked by their poor sorting.

The $CaCO_3$ content of these two areas are highly different. The sedimentary sequence of the foredeep is almost totally carbonate-free — excepting the psefitic rocks and some more carbonaceous sandstone banks. The carbonate content of the intrabasinal set is relatively high, independently of the grain size.

The Upper-Pannonian of the Mecsek foredeep being very close to the shoreline forms a regressive half-cycle extending from a coarse conglomerate to the fine silt-clay.

The intrabasinal Upper-Pannonian sequence, however, could be devided into several smaller cycles as it was revealed by MOLNÁR, B. [1965] at first for the upper part of this sequence. The hydrocarbon exploring boreholes in Algyő—Szeged, however, recovered core samples from the lowest part of the Upper-Pannonian only. Several regressive halfrhythms have been reported from these samples by MUCSI, M., RÉVÉSZ, I. [1968, 1975] and by MUCSI, M. [1973].

2. The sedimentary structures of the intrabasinal and marginal sequences are summarized in the *Table 1.*

Due to the vicinity of the sleep coast, to the more rapid rate of sedimentation, to the coarser grain size, the marginal development is much less aboundant in internal, external and deformation structures as compared to the intrabasinal one. The formations here are characterized by horizontal-parallel lamination, whirl-structures, the more simple forms of the cross bedding, ripple bedding and composite bedding. The whirl-structures are the special features of the nearshore sedimentation and are considered as results of turbidity currents and of vigorously agitated water.

The sedimentary structures of the intrabasinal sequence of layers, however, are more different in forms and they are more frequently encountered as compared to those in the sediments on the steep coast. The finer grain size and the more considerable distance from the shoreline were favourable factors for the formation of internal structures. This shallow lacustrine set of less agitated water is dominated by the different forms of the horizontal-parallel lamination, graded bedding, cross-bedding and composite bedding.

The fine-grained sediments of the ancient lakebottom have recorded a considerable number of trace fossils and marks of deformation processes in micro- and macrosize. Due to the low energy level of the bottom currents and to the considerable distance from the shoreline, whirl structures can be found in this region very scarcely.

The flowing and waving activity of the shallow lake have developed small scale forms — cm to dm in order of magnitude — only in the fine mud of the bottom.

SUMMARY

1. The sediments of the steep coast in the SW-Mecsek Mts. are poorly sorted and mostly non-bedded due to the rapid sedimentation and re-deposition. The horizontal bedding as well as the whirl-structures characteristic of the well-agitated water and the composite bedding appear by moving offshore only. The intrabasinal environment near Szeged is dominated by horizontal-parallel lamination, cross- and graded bedding. The surficial or deformation structures are most frequent here as well.

2. The so-called "whirl-structure" characteristic of the marginal sediments only has been distinguished here as a new form within the group of the internal structures.

3. The sediments of the intrabasinal Upper-Pannonian series in Algyő—Szeged refer to a sediment accumulation in a more balanced condition: the grain size of the sediments deposited here varies between clay and fine sand. The fossil plant remnants and the fine and medium size pebbles accompanying silt have deposited in the foreset part of a large delta being formed in an open lake and showing a considerable variation of sedimentary structures.

4. The Keresztespuszta-Tortyogó area of steep coast environment have been in a „channel" connecting the big sedimentary basins in Transdanubia and in the Great Hungarian Plane and being in the direction of the faunal migration as well.

The Algyő—Szeged area, however, belonged to the larger Neogene basin with large areas of open water in the Southern Part of the Great Hungarian plain.

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DR, MIKLÓS SZÓNOKY
Institute of Geology and
Paleontology
Attila József University
H—6722 Szeged, Egyetem u. 2—6
Hungary

EXPLANATION OF PLATES

PLATE I

Sedimentary structures of the marginal sediments:

Fig. 1. Horizontal, parallel micro-laminae of fine sand. The beds are marked by limonite acçumulation. — Polished surface section. — Borehole Keresztespuszta—3, 187,2 m

Fig. 2. A 0,2—5 mm thick limonitic ribbon in fine sand bearing silt with a postdepositional and perhaps postdiagenetical connection to the more clayey bed. — Borehole Keresztespuszta—3, 57,8 m — 1 N — 22x.

Fig. 3. Whirl structures formed by rounded sandy silt clay and Mollusca-shell debris with an irregular diagonal section in silt. — Polished surface section. — Borehole Keresztespuszta—3, 138,5 m

Fig. 4. Whirl-structures in coarse silt. The oval form of the structures is shown by the orientation of micas. — Borehole Keresztespuszta—3, 53,0 m — 1 N — 22x

Fig. 5. A lumachelle composed of shell fragments of young individuals of *Gastropoda, Congeria* and *Limnocardium* in fine sand bearing silt with whirl-structure. — Borehole Keresztespuszta—3, 249,0 m/3 — 1 N— 22 x

Fig. 6. Silt showing whirl-structure and containing shell fragments of *Limnocardium* and *Congeria.* — Polished surface section. — Borehole Keresztespuszta—3, 249,0 m/4

PLATE II

Sedimentary structures of the marginal sediments:

Fig. 1. Lenticular and whirling silt having *Limnocardium* and *Congeria* shell fragments. — Polished surface section. — Borehole Keresztespuszta—3, 260,0 m/2

Fig. 2. Whirl structures in clayey silt. — Borehole Keresztespuszta—3, 70,2 m — 1 N — 22x

Fig. 3. Lumachelle of *Congeria* shells in fine sand bearing silt. — Borehole Keresztespuszta—3, 249,0 m

Fig. 4. A lumachelle of *Congeria rhomboidea* M. HÖRN. with inprint of *Pteradacna pterophora* BRUS. marked by the arrow. — Borehole Keresztespuszta—3, 249,0 m/2

Figs. 5—6. Fractured *Congeria* and *Limnocardium* shells washed together and intercalated into a fine sand bearing silt with a whirl structure. — While the shell-fracturing in the *Fig. 6* are of postdiagenetic character and caused by the load of the overburden, the fracturing in the *Fig.5* are of contemporaneous to the deposition. — Borehole Keresztespuszta—3, 249,0 m/3 — 1N — 22x

PLATE III

Sedimentary structures of the marginal sediments:

Fig. 1. Whirl structure in a fine sand bearing silt. The thin *Mollusca*-shell sustained the coarser grains as a watch-glass. — Borehole Keresztespuszta—3, 249,0 m/3 — 1 N — 22x

Fig. 2. Parallel, non-continuous lenticular bedding in silt. — Polished surface section. — Borehole Keresztespuszta—3, 270,0 m

Figs. 3—4. Silt filled worm burrows with rounded diagonal section and irregularly shaped longitudinal extension. — Borehole Keresztespuszta—3, 126,0 m

Fig. 5. Load pocket at a sandstone-silt contact. — Borehole Keresztespuszta—3, 42,7 m — 1 N — 22x

Fig. 6. A sample composed of sediment components of various grain size and formed by a subaqueous slumping. — Polished surface section. — Borehole Keresztespuszta—3, 132,5 m

PLATE IV

Figs. 1—3. Sedimentary structures of the marginal sediments:
Figs. 4—8. Sedimentary structures of the marginal sediments:

Fig. 1. Non-sorted loose conglomerate cemented by medium grained sandstone. — Sediment of a torrential creek. — Borehole Keresztespuszta—3, 286,0 m

Fig. 2. The texture of a loose conglomerate consisting of quartzite debris mainly. — Sediment of a torrential creek. — Borehole Keresztespuszta—3, 285,0 m — +N — 22x

Fig. 3. Fine sandstones consisting of sharp-edged quartz and quartzite grains cemented by calcareous material. The sandstone has a pebble of 2 mm in diameter too. — Borehole Keresztespuszta—3, 196,8 m — 1 N — 22x

Fig. 4. An interbedding of horizontal micro-laminae of clay and silt. — The majority of the laminae are simply sorted, their finishing element is clay or carboniferous silt. — Borehole Szeged—11/18: 1615,20—1615,31 m

Fig. 5. Fine sand showing a horizontal parallel microlamination. — Polished sufrace section. — Borehole Algyő—231; 1/5: 1911,42—1911,50 m

Fig. 6. An interbedding of cross-bedded sand ripples and silt showing composite [continuous lenticular] bedding. — The sand ripples have been eroded in some places. — Borheole Algyő—211;1/3: 1886,90—1887,03 m

Fig. 7. An interbedding of cross bedded sand ripples and silt showing horizontal parallel and parallel ripple bedding. — Polished surface section. — Borehole Algyő—231; 1/9: 1915,50—1915,70 m

Fig. 8. An interbedding of carboniferous silt and non-parallel, ripplied, microlaminated and cross-bedded sandstone. — Borehole Szeged—1; 1/8: 1605,08—1605,26 m

PLATE V

Sedimentary structures of intrabasinal sediments:

Fig. 1. A series of small rhythms consisting of coarse silts and fine sandstone showing simple sorting. — 5 small rhythms could be observed in the photographs. — Borehole Algyő—247; 1/9: 1956,19—1956,35 m — 1 N — 22x

Fig. 2. The series of photographs showing the stratification pattern of a horizontally laminated silt. — The clayey fine silt is overlain by a coarse silt with fine sand. The upper part consists of interbedding of silt beds with coal ribbons. — Borehole Szeged—1; 1/16: 1614,60—1614,65 m —1 N — 15x

PLATE VI

Sedimentary structures of intrabasinal sediments:

Fig. 1. Lamellae with a dip of 8—10° of a cross-bedded sand ripple pinching out gradually. — The final part of each is aboundant in clay and mica. — Borehole Algyő—231; 1/9: 1915,50—1915,70 m — 1 N — 12x

Fig. 2. Horizontally microlaminated fine-grained sandstone overlain by a cross-bedded sand ripple. — There is an unconformity of 25° at the contact of the two beds, whick is illustrated by the orientation of the mica scales. — Borehole Algyő—241; 6/3: 2023,11—2023,30 m — 1 N — 22x

Fig. 3. A sample of composite bedding consisting of interbedding of horizontally and cross laminated set of beds. — The microlamination is shown by carbonized fossil plant debris accumulated in form of ribbons with a thickness of 0,1—5 mm or so. — Borehole Algyő—241; 6/3: 2023,11—2023,30 m.

Fig. 4. The contact of a non-bedded sandstone with pebbles of fine sandstone and fine sand having a network of coal-bearing ribbons and lenses. — The coal-bearing sandstone shows continuous ripple bedding with a slightly eroded interface. — Borehole Algyő—216; 1/10—1/11: 1926,74—1926,85 m

Fig. 5. 2,5 mm long lense parallel to the bedding plane in a horizontally micro-laminated silt. — Borehole Szeged—9; 4/16: 1765,00—1765,10 — 1 N — 22x

Fig. 6. Interbedding of horizontal parallel microlaminae of sandstone and silt. — The slightly ripple looking surface of the thicker sand beds refers their sand ripple nature. — Borehole Algyő—247; 1/9: 1956,19—1956,35 m

PLATE VII

Sedimentary structures of intrabasinal sediments:

Fig. 1. Well-sorted micro-laminated, rippled-microlaminated coarse and fine silt with bioturbations. — There is an oblique outwash plane in the middle of the sample. — Borehole Szeged—1; 1/12: 1611,64—1611,82 m

Fig. 2. Worm-burrow filled by coarse silt in a parallelly microlaminated coal-bearing silt. — Borehole Szeged—1; 1/16: 1614,60—1614,65 m — 1 N — 22x

Fig. 3. Well-sorted fine silt and sandstone with bioturbation. — Polished surface section. — Borehole Szeged—1; 1/12: 1611,18—1611, 30m

Fig. 4. Trail of a burrowing filled by fine sand, on the bedding plane of a claystone. — Borehole Algyő—242; 2/3: 1967,93—1968,17 m — 1 N — 22x

Fig. 5. Convolute load pouch subsided into silt and accompanied by a silt flame structures. — Borehole Algyő—241; 5/4: 1992,5 m

Fig. 6. Load pocket at a contact of clay and silt showing parallel microlamination. — Borehole Szeged—1; 1/16: 1614,60—1614,65 m — 1 N — 22x

PLATE VIII

Sedimentary structures of intrabasinal sediments:

Fig. 1. A 0,4—0,9 mm thick fine sandstone lamina thrown by a small sedimentary fault in silty clay. — Borehole Szeged—1; 1/14: 1612,92—1613,02 m — 1 N — 22x

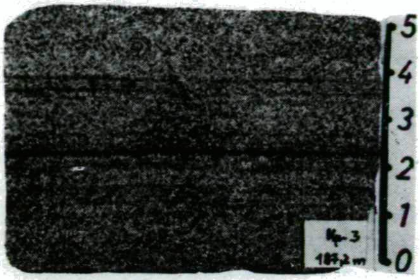
Fig. 2. Convolute sand ripples subsided into silt. — Borehole Algyő—242; 2/2: 1965 m

Fig. 3. Trace of mud movement in fine sand bearing silt. — Borehole Algyő—241; 7/2: 2059,34—2059,60 m

Fig. 4. A part of fine sandstone lamina curved and folded into silt by mud movement. — Borehole Algyő—247; 1/5: 1945,16—1945,45 m — 1 N — 22x

Fig. 5. A massive occurrence of *Limnocardium schmidti* [M. Hörn.], and *Congeria cžjžeki* M. Hörn. in fine sandstone. — Borehole Algyő—454; 2: 1960,0—1961,0 m

Fig. 6. Clay lense torn up by mud movement in silt. — Borehole Algyő—241; 7/2: 2059,34—2059,60 m — 1 N — 22x



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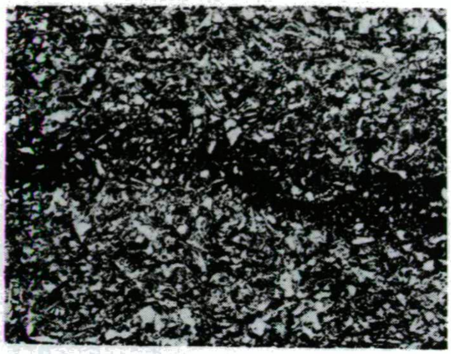

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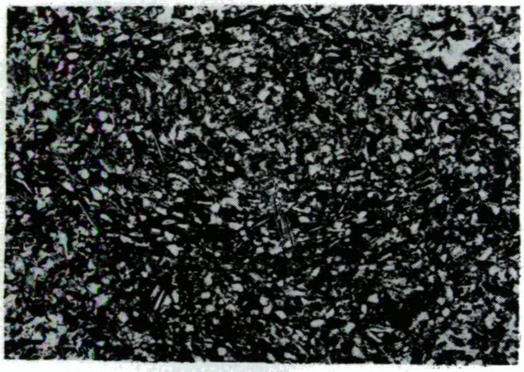

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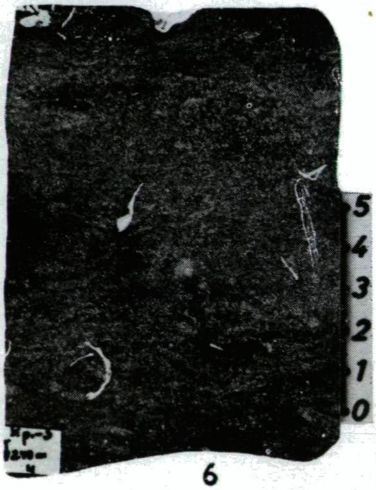

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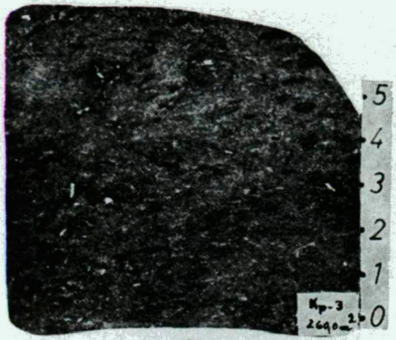

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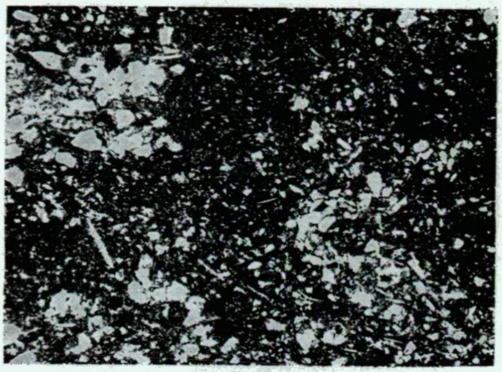

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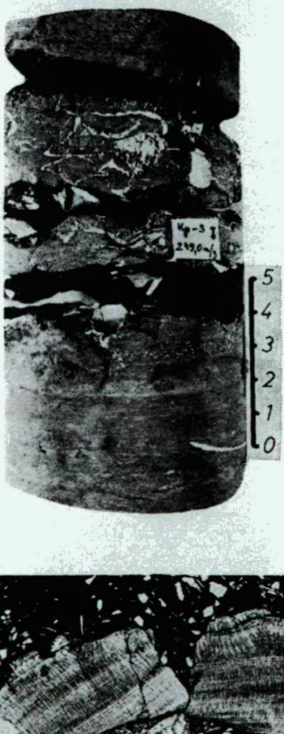

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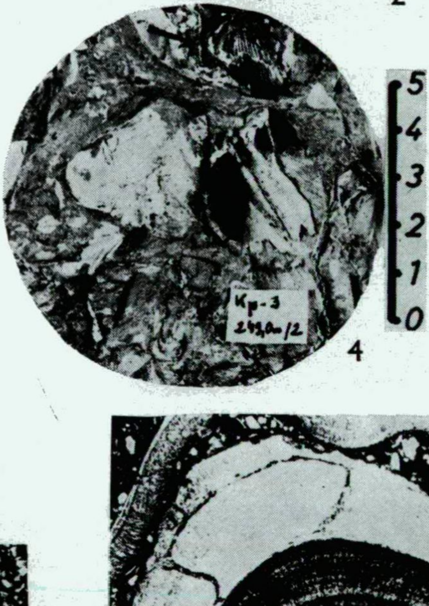

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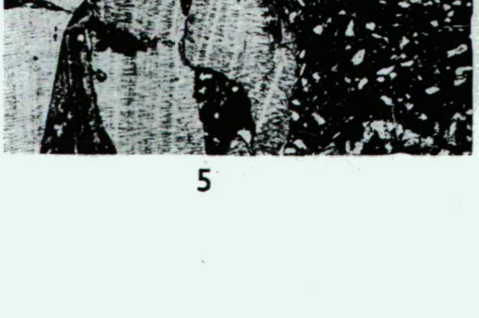

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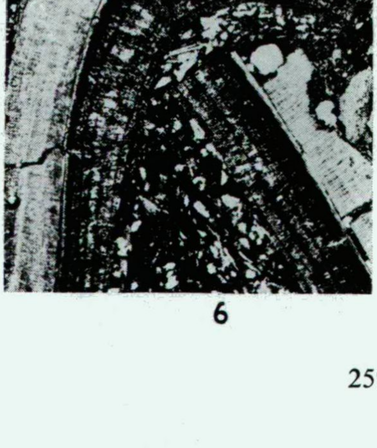

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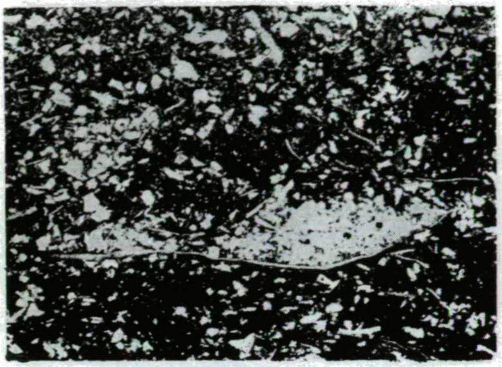
PLATE III



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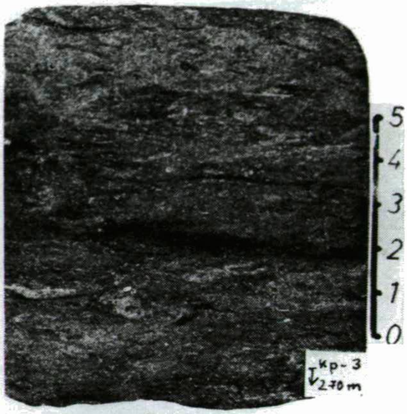

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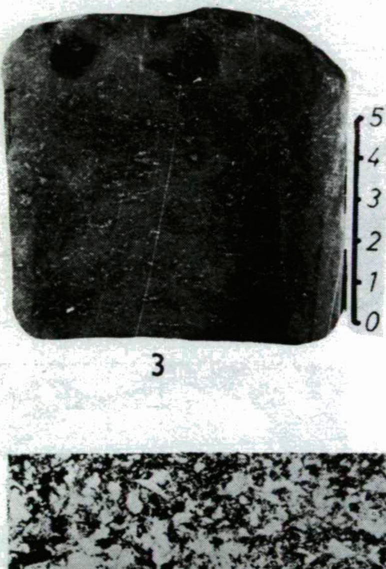

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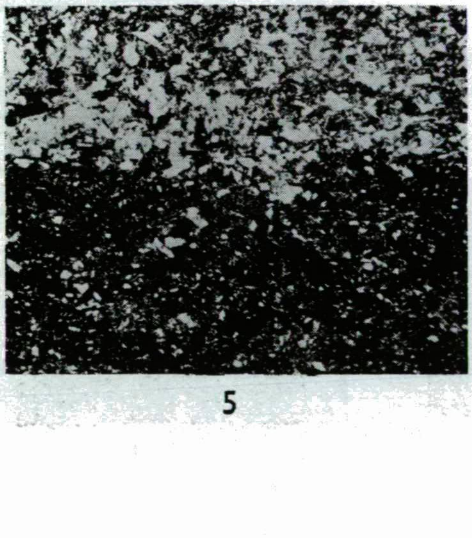

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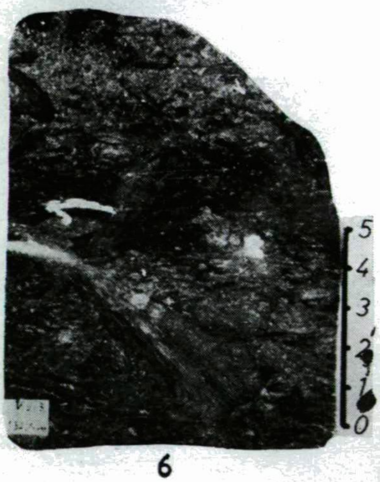

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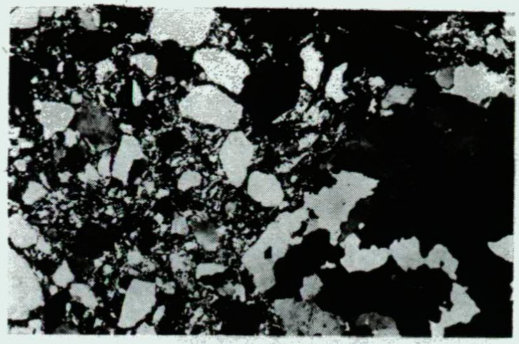

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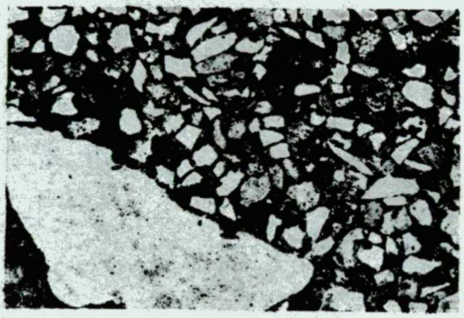

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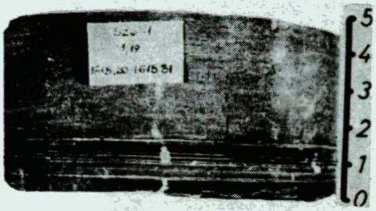
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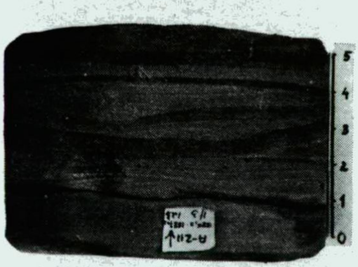
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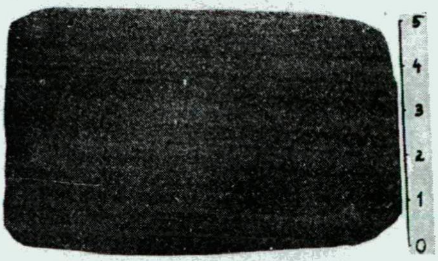
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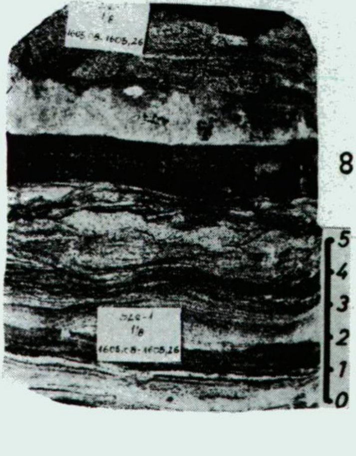
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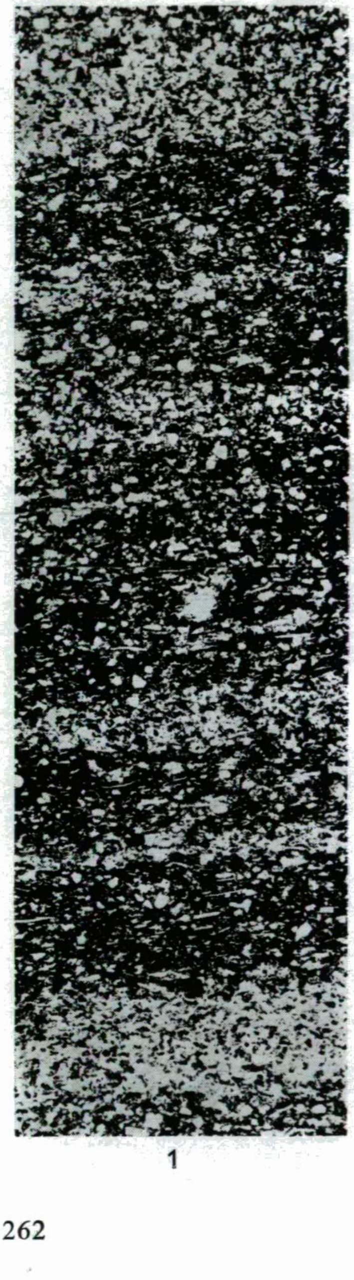
PLATE V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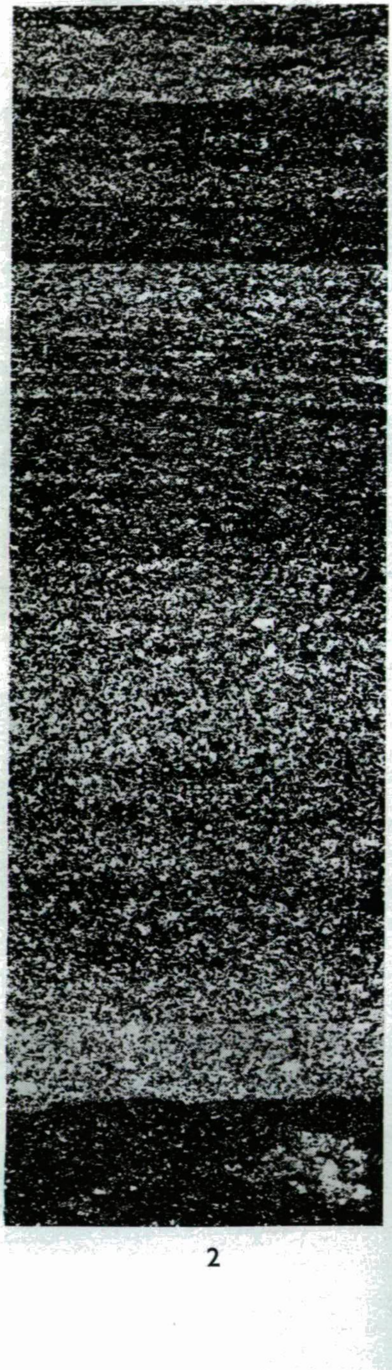
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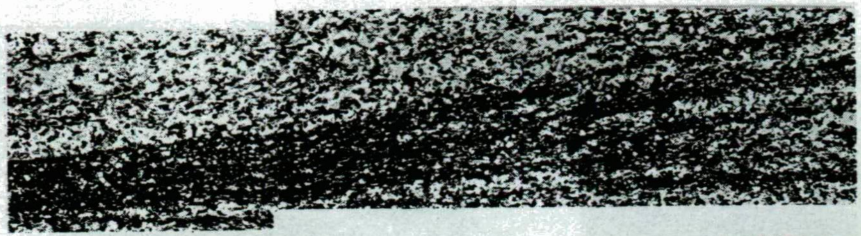

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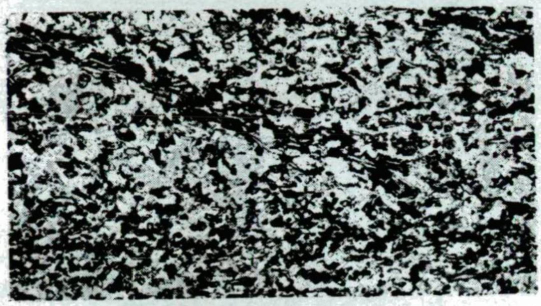

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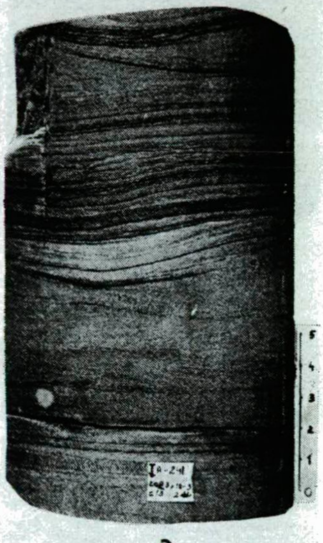

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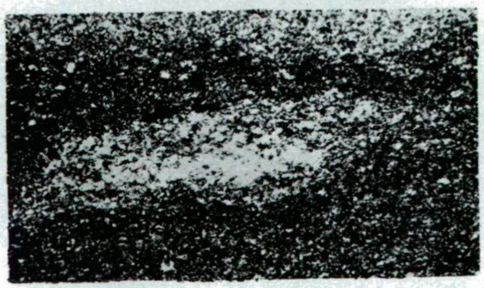

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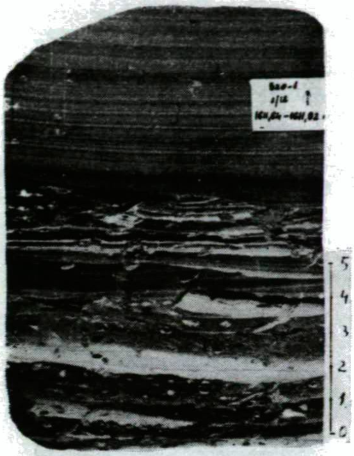

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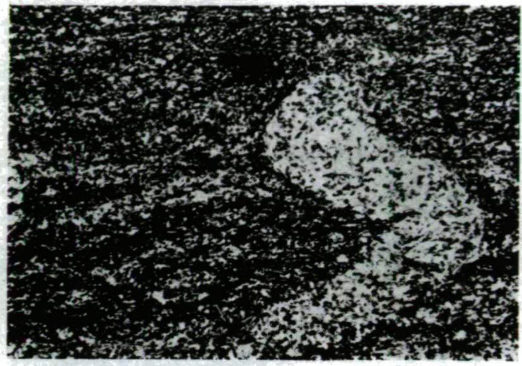

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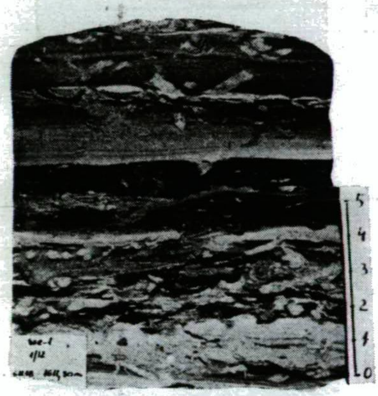

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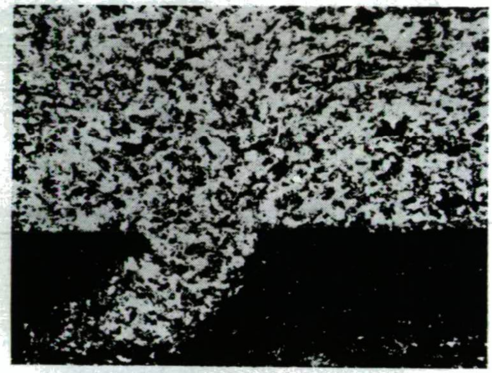

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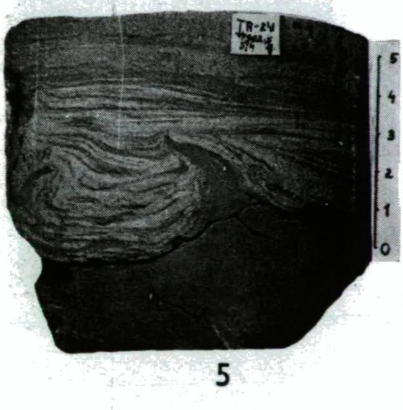

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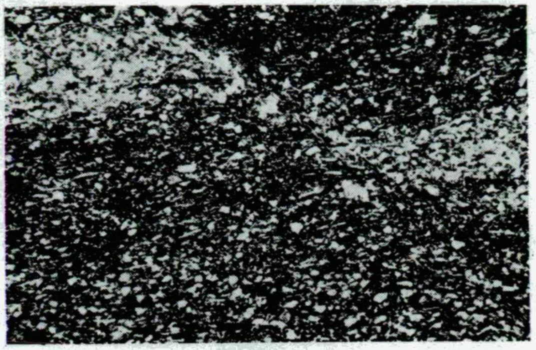
PLATE VIII



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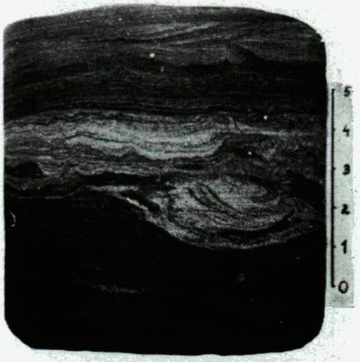

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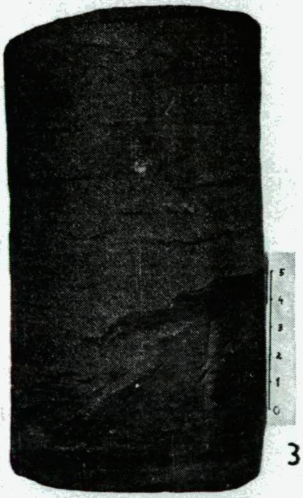

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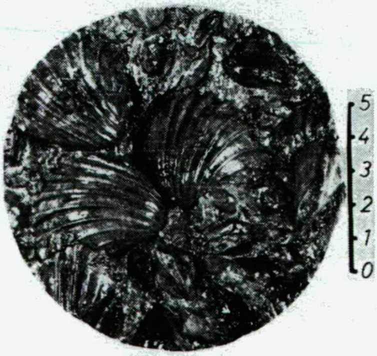

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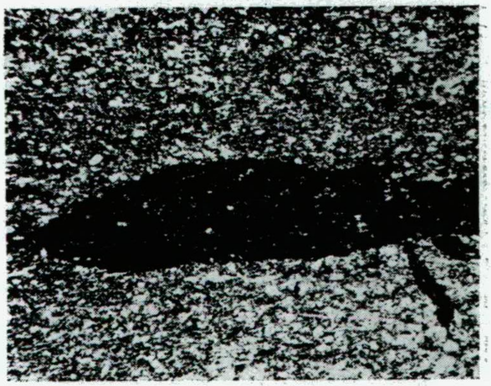

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