TECTONIC CONTROL OF SEDIMENTATION IN THE UPPER PANNONIAN SECTION OF A BOREHOLE AT MACS, GREAT HUNGARIAN PLAIN, HUNGARY

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INTRODUCTION

The Upper Pliocene (Levantine) sequence is absent at many places below the Pleistocene fluviatile and eolian formation of the Great Hungarian Plain, so that the Pleistocene is immediately underlain by the Pannonian stage representing the earlier Pliocene.

In the Great Plain basin the upper boundary of the Upper Pannonian sequence is at very different depths (0 to 800 m). On the edges of the basin, however, the Upper Pannonian is represented even at 400 m height a.s.l. or more. Considering the average 100-m elevation a.s.l. of the Great Hungarian Plain, this would mean

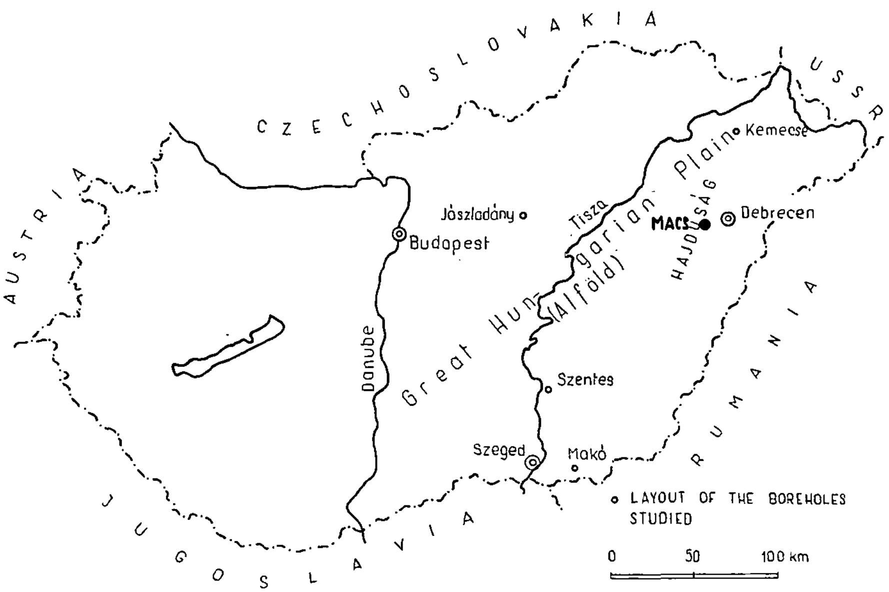


Fig. 1. Layout

some 1100 m of difference in elevation as a maximum caused by heavy post-Pannonian tectonic movement.

In the north part of the Great Plain, the Hajdúság, there is a structurally higher-perched Pannonian table-land; hence, the Hajdúság is an area, where the upper surface of the Pannonian sequence lies close to the present-day surface [M. ERDÉLYI, 1962; B. MOLNÁR, 1966] *(Fig. 1)*. Several investigators of the Hajduság's geology have realized that it differs in character from the surrounding area [GY. ÉBÉNYI—E. R. SCHMIDT, 1931, 1938, 1939; K. FERENCZ, 1956; I. FERENCZI, 1939—1940; L. KŐRÖSSY, 1956; I. DOBOS, 1953; A. RÓNAI, 1955; J. SÜMEGHY, 1944; P. SZÓFOGADÓ, 1958; J. URBANCSEK, 1953]. As regards the Pleistocene sedimentary sequence, this difference is known as a result of the exhaustive study of the Pleistocene member of the Macs borehole [M. ERDÉLYI, 1962; B. MOLNÁR, 1966] *(Fig. 1—2)*. The nearly 50-m-thick Pleistocene sequence here has proven eolian, in contrast with the fluviatile filling of the surrounding area. Within the sequence, ten (*Fig. 2.* I—X.) phases of loess deposition, a minimum of six phases of soil genesis, and five interlayers of wind-blown sand can be distinguished (see simplified profile in *Fig. 2*). The eolian sequence could be deposited thank to the high-perched position of the Hajdúság against its background in Pleistocene time, a reason why fluvial accumulation was impossible here and only eolian sediment was deposited.

Core-drilled by the staff of the Hungarian Geological Institute between 1958 and 1959, the borehole at Macs traversed, beside the above-mentioned Pleistocene eolian sequence, an additional 453 m of Upper Pannonian sediment [M. ERDÉLYI, 1962]. The interesting geological setting of the Hajdúság within the Great Plain basin required — and the reliability of the drill-core material enabled — the Pannonian sequence to be also examined in detail.

The megascopic description of the material could already reveal that the Upper Pannonian here had been deposited in a shallow lake — mainly marshy environment [M. ERDÉLYI, 1962]. Accordingly, the Upper Pannonian lake was, in what is now the Hajdúság, generally shallower than in the rest of the basin. Thus, it can be supposed that the contemporaneous tectonic deformation of the area is readily reflected by the sedimentary sequence deposited that time.

Therefore, the purpose of the present investigation is to gain — by studying the Upper Pannonian sediments of the Macs borehole sunk in the Hajdúság — an understanding of the relationship between tectonic movement and sedimentation in the north part of the Great Plain.

The lithologic log of the Macs borehole of 501 m bottom hole depth (where the Upper Pannonian is represented by the interval of 48 to 501 m) and a considerable part of the analyses (grouped as A, B, C, and D in four parts) are shown in *Figs. 2—5*. In each figure, on the left side of the log, the elevation a.s.l. and the depths of drilling have been indicated. Additional explanation has been given in the legend *(Fig. 6)*.

SEDIMENTOLOGICAL REVIEW OF THE MACS BOREHOLE

Granulometric composition and its statistic evaluation

The lithologic log, recorded macroscopically, and then analysed for grain size composition, of the borehole is illustrated by *Figs. 2—5*. In the graphic representation, the finer-grained and darker sediments have been more densely, the coarser and lighter ones less densely hachured.

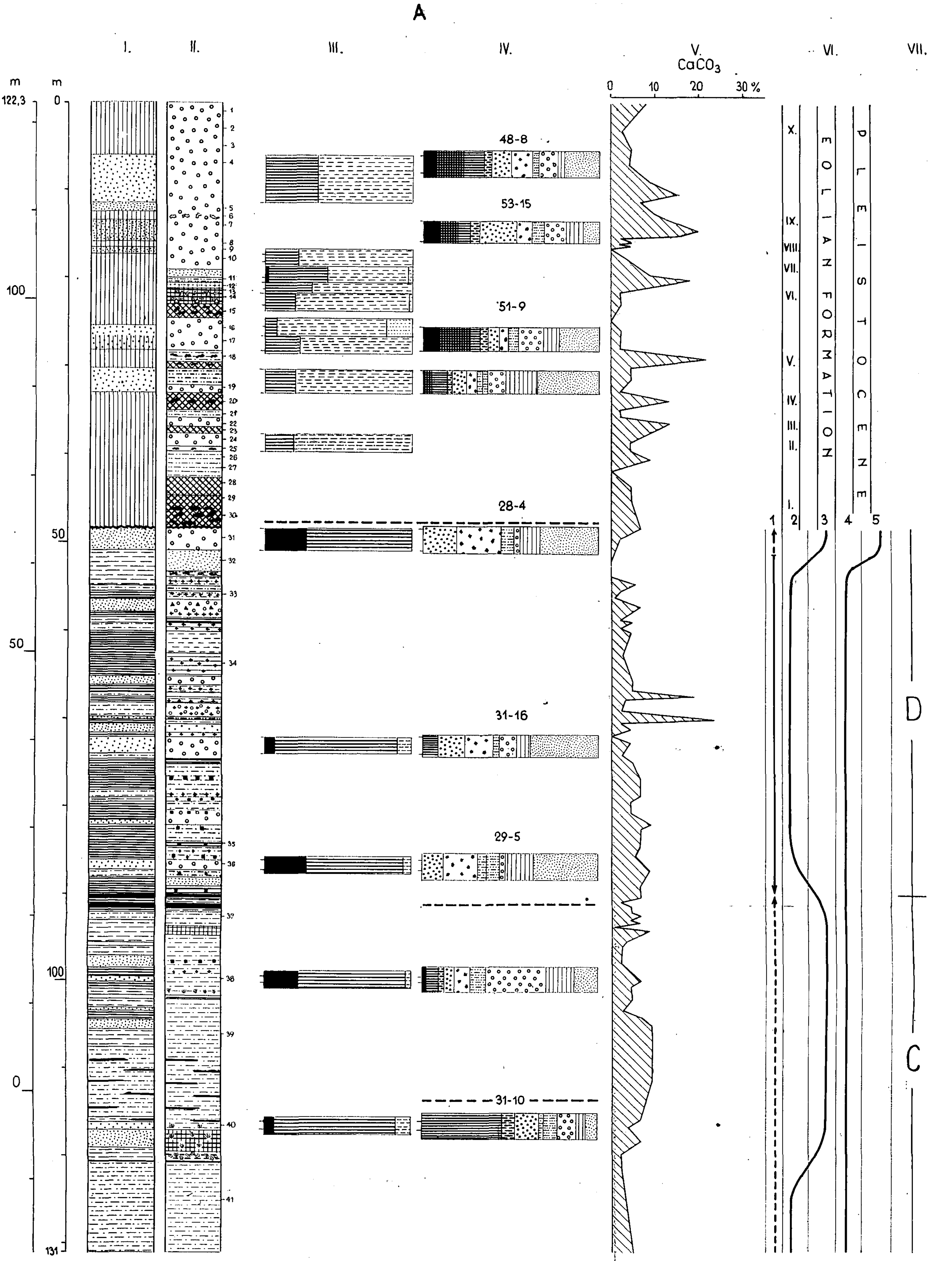


Fig. 2. Lithologic log of the Macs borehole, interval of 0 to 131 m

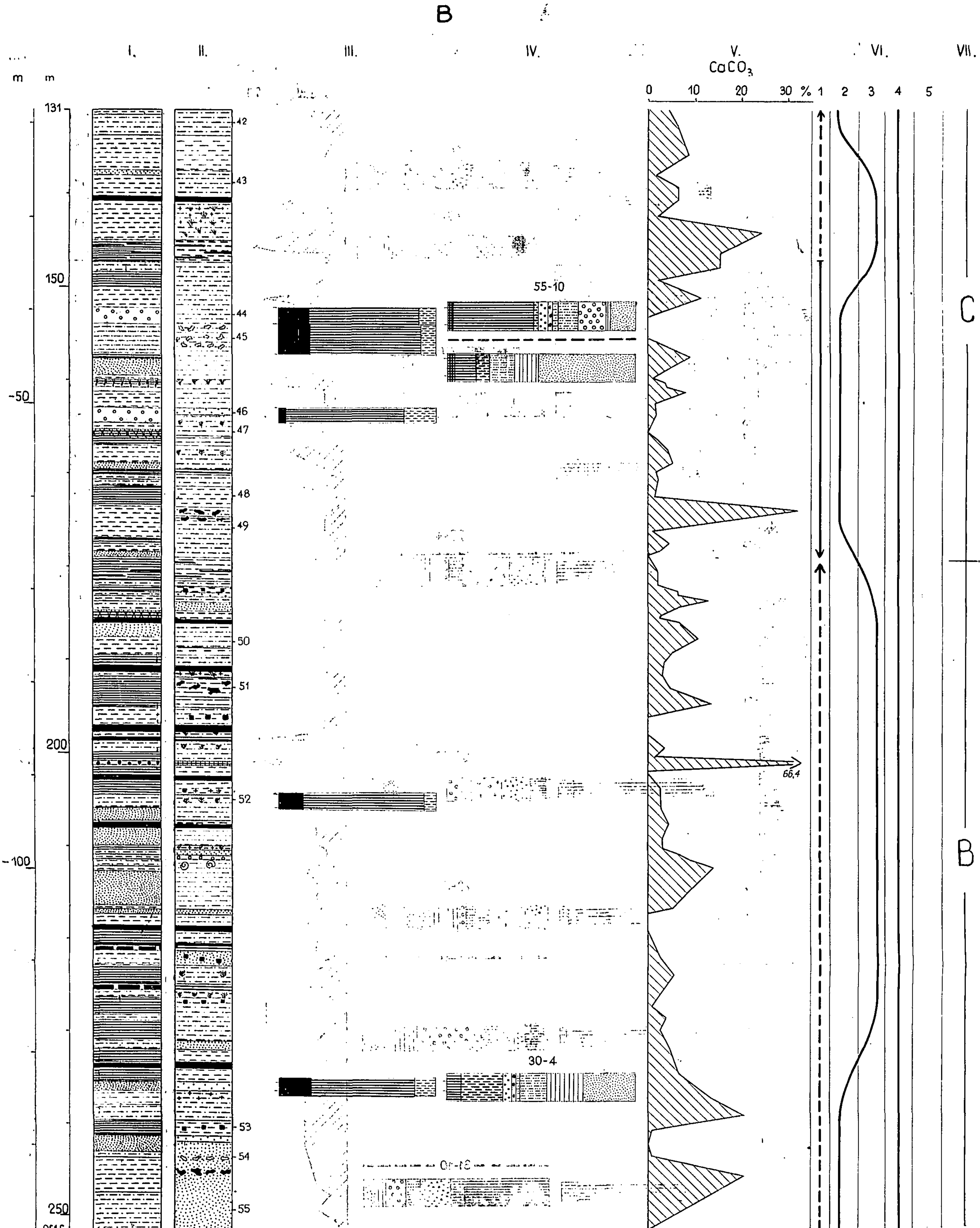


Fig. 3. Lithologic log of the Macs borehole, interval of 131 to 251,6 m

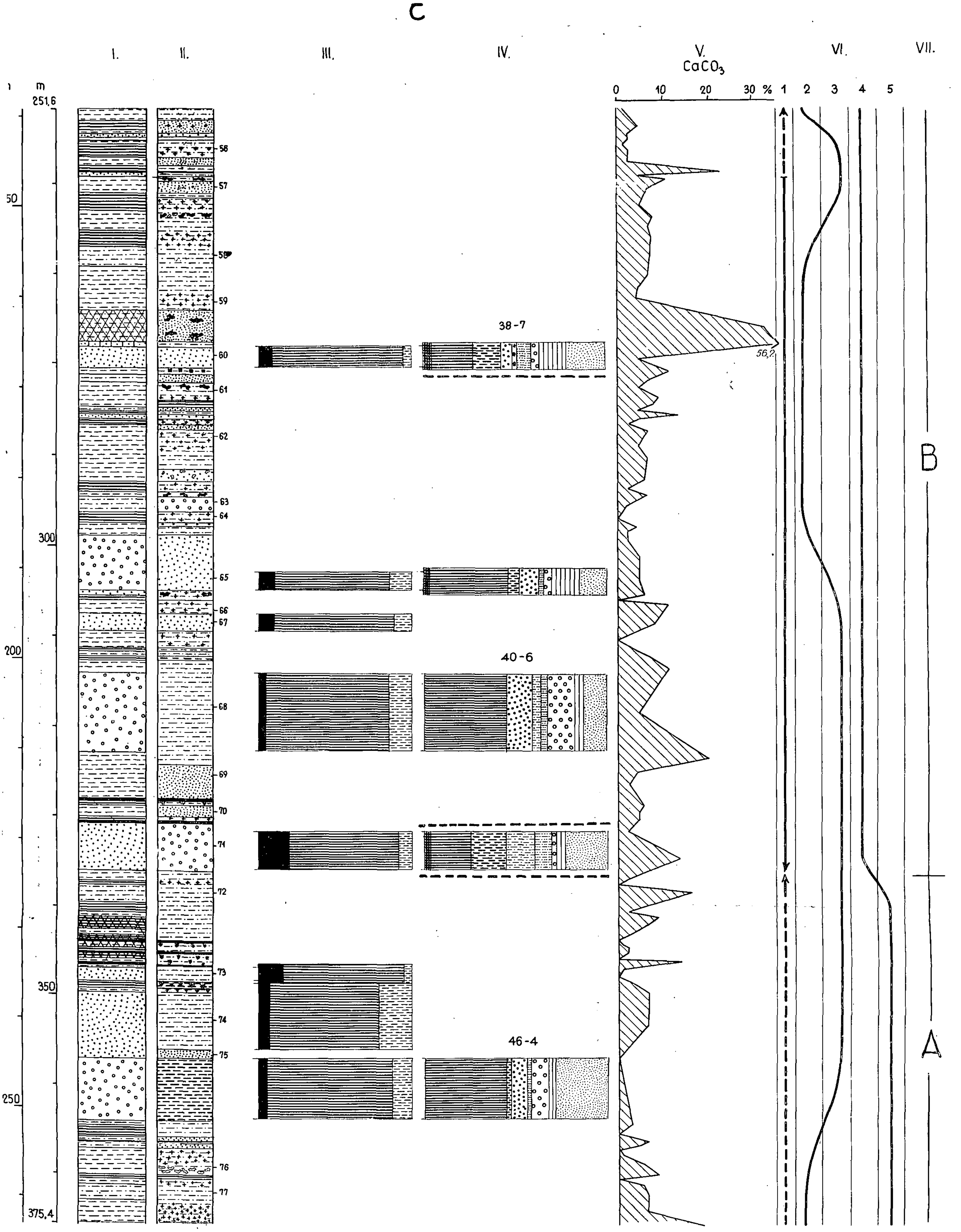


Fig. 4. Lithologic log of the Macs borehole, interval of 251,6 to 375,4 m

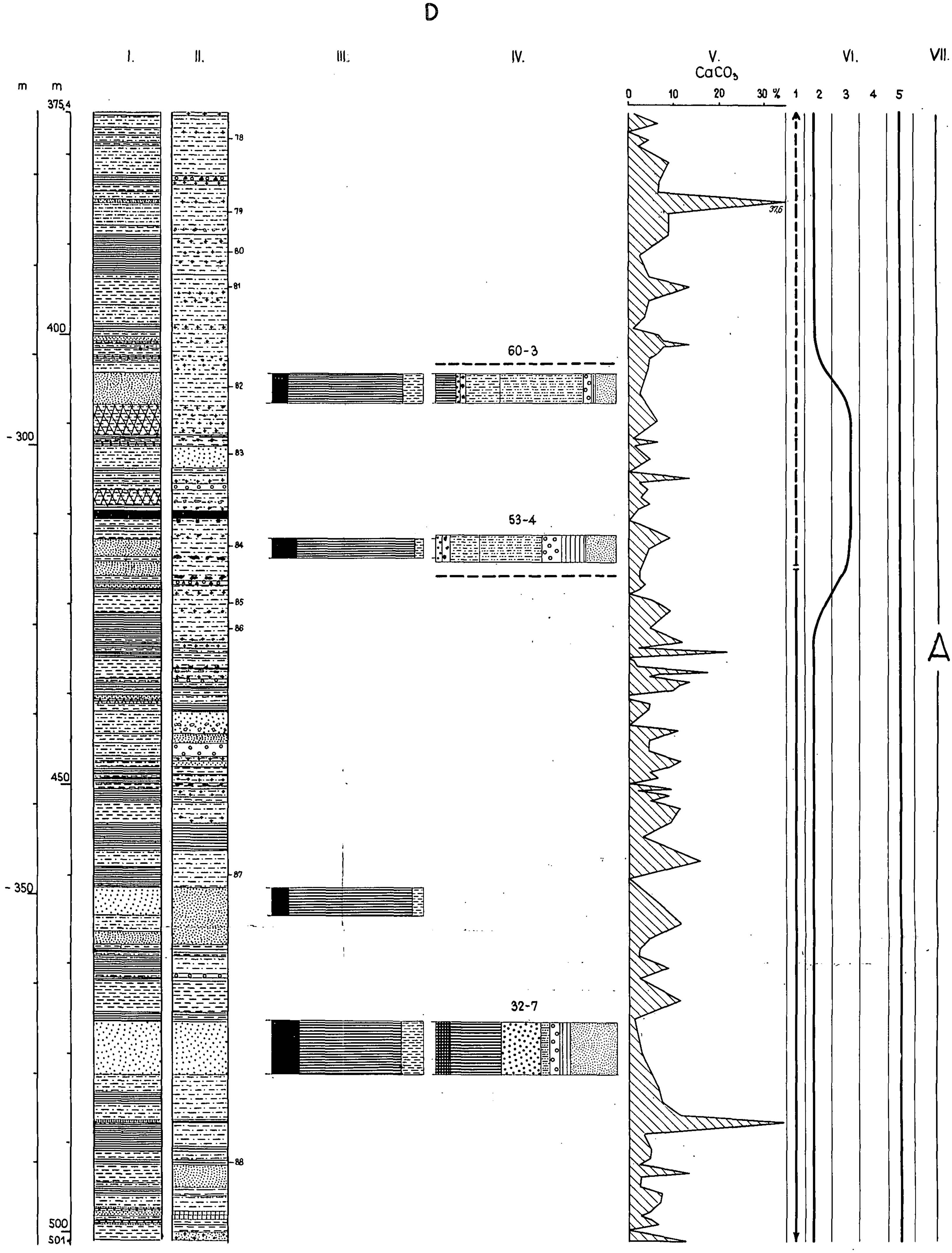


Fig. 5. Lithologic log of the Macs borehole, interval of 375,4 to 501 m

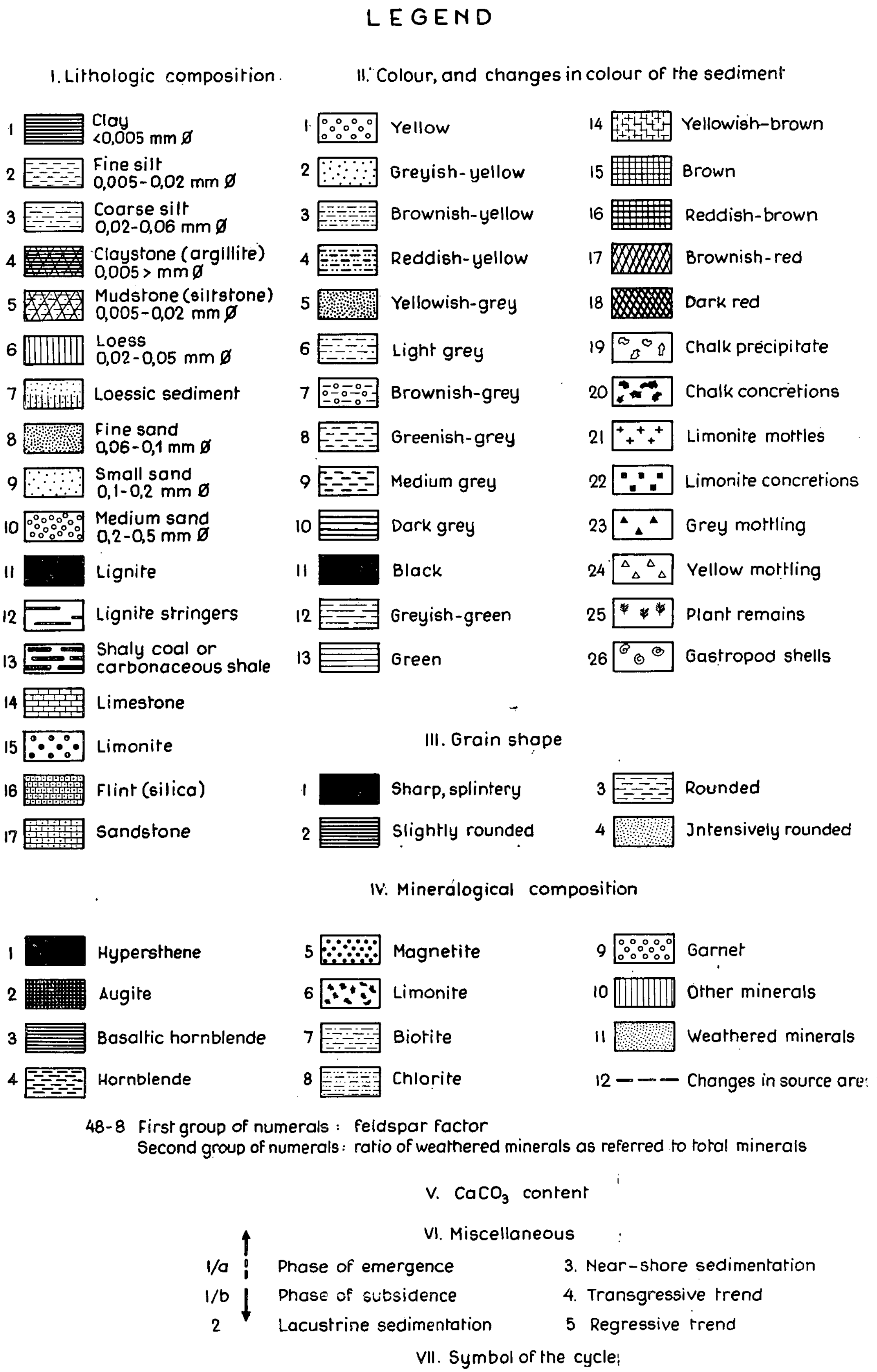


Fig. 6. Legend to *Figs. 2 to 5*

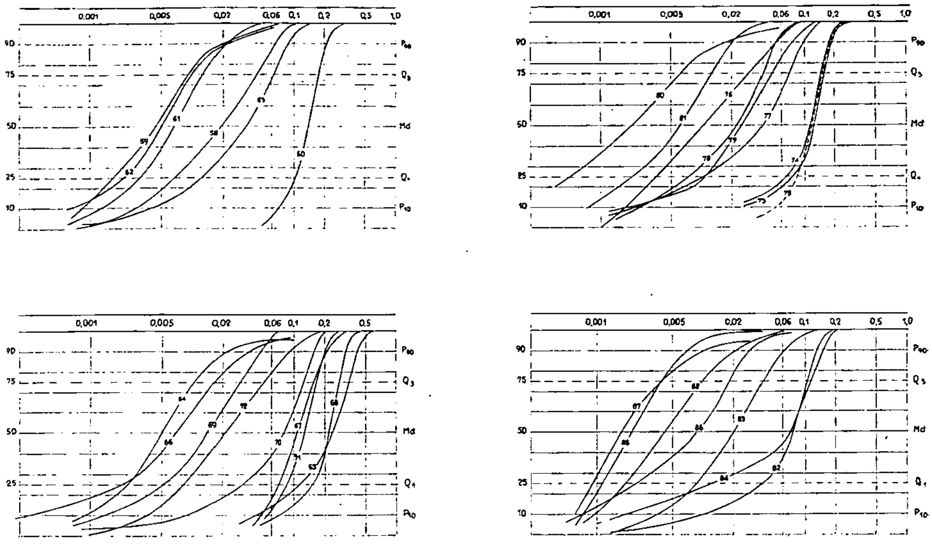
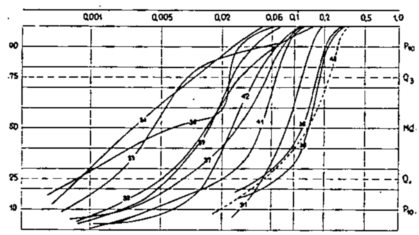


Fig. 7. Granulometric curves of the analysed samples from the interval of 267 to 492 m

The numbers written on the side of Column II of *Figs. 2—5* correspond to the serial numbers of Table 1 and of the samples analysed.

According to the results of the granulometric analysis, the sediments of the borehole are dominantly fine-grained, mainly corresponding to clay and fine- and coarse-silt fractions. Sand is scant and what is available is chiefly fine- or coarse-grained, so that even the greatest grain size does not exceed the size of medium sand (*Figs. 7—8*, samples 31—88). The fineness of the granulometric composition is also indicated by the *median* (*Md*= diameter of grains accounting for 50 per cent of the sediment) and the representative grain size (diameter of grains represented by the highest percentage in the sample) values (see *Md* and *M* values in Table 1). The interval characterized by the coarsest grain size composition within the lithologic log of the borehole is between 298 and 363 m. This sandy interval is interrupted, however, by a



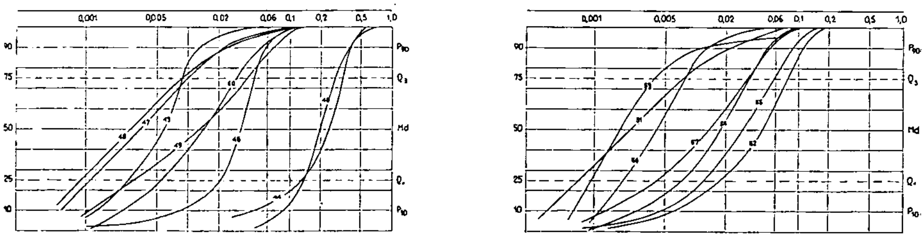


Fig. 8. Granulometric curves of the samples from the interval of 48 to 261 m

Table 1
Lithologic statistics of the studied Upper Pannonian material of the Macs borehole

Number	Depth m	P_{10}	Q_1	Md	M	Q_3	P_{90}	$So=\sqrt{\frac{Q_3}{Q_1}}$	$K=\frac{Q_3-Q_1}{2(P_{90}-P_{10})}$	$Sk=\frac{Q_1 \cdot Q_3}{Md^2}$	$CaCO_3$	Type of Sediment
31.	48,3—50,8	0,03	0,05	0,085	0,098	0,12	0,16	1,55	0,27	0,83	2,2	F.S.
32.	50,8—53,3	0,0015	0,0052	0,014	0,015	0,03	0,067	2,40	0,19	0,80	—	F.Si.
33.	55,5—56,4	0,00057	0,0016	0,0042	0,005	0,0095	0,055	2,44	0,52	0,86	0,9	CL.
34.	59,9—65,2	0,00039	0,0080	0,0027	0,0045	0,011	0,026	3,70	0,59	1,20	2,2	CL.
35.	84,0—84,7	—	0,00078	0,007	0,0026	0,024	0,030	5,55	—	—	6,6	CL.
36.	86,0—88,0	—	0,045	0,12	0,15	0,17	0,21	1,94	—	0,53	8,8	S.S.
37.	92,9—93,3	0,0024	0,0082	0,028	0,03	0,055	0,077	2,58	0,18	0,52	6,6	C.Si.
38.	98,8—100,4	—	0,067	0,14	0,16	0,18	0,22	1,64	—	0,61	6,6	S.S.
39.	105 —107,5	0,0022	0,006	0,015	0,016	0,026	0,043	2,08	0,49	0,69	8,8	F.Si.
40.	115,8—117	0,019	0,047	0,13	0,15	0,21	0,25	2,11	0,42	0,58	3,5	S.S.
41.	120,5—131	0,0038	0,019	0,045	0,05	0,062	0,080	1,80	0,28	0,74	5,3	C.Si.
42.	131,4—132,7	0,0062	0,014	0,024	0,025	0,040	0,065	1,69	0,22	0,97	6,6	C.Si.
43.	138,1—140,3	0,0013	0,0026	0,0058	0,0065	0,0085	0,013	1,81	0,25	0,66	6,6	F.Si.
44.	153,0—154,0	0,042	0,13	0,24	0,027	0,32	0,35	1,57	0,32	0,72	—	M.S.
45.	154,0—157,6	0,009	0,021	0,033	0,036	0,044	0,058	1,44	0,23	0,85	—	C.Si.
46.	163,8—165,3	0,087	0,14	0,2	0,24	0,28	0,36	1,43	0,26	0,98	1,3	M.S.
47.	165,3—166,0	0,00057	0,0012	0,0036	0,0042	0,01	0,024	2,89	0,19	0,92	—	CL.
48.	171,4—173,6	0,00045	0,0009	0,0028	0,0038	0,009	0,026	3,16	0,16	1,02	1,3	CL.
49.	175,0—177,0	0,0011	0,003	0,013	0,016	0,039	0,072	3,60	0,25	0,69	0,9	F.Si.
50.	186,0—188,8	0,0022	0,0057	0,014	0,016	0,030	0,062	2,29	0,20	0,87	9,7	F.Si.
51.	191,8—194,0	0,0003	0,00065	0,002	0,0038	0,0068	0,02	3,17	0,16	1,10	4,4	CL.
52.	204,5—207,6	0,0054	0,013	0,04	0,042	0,072	0,098	2,35	0,32	0,59	2,2	C.Si.
53.	239,7—241,5	0,00056	0,00087	0,0016	0,0019	0,0036	0,01	2,03	0,29	1,22	0,9	CL.
54.	243,2—244	0,0022	0,0065	0,016	0,017	0,029	0,045	2,11	0,26	0,73	0,9	C.Si.
55.	247,6—251,6	0,004	0,01	0,026	0,03	0,052	0,08	2,28	0,28	0,89	—	C.Si.
56.	255,5—257,0	0,0098	0,0019	0,0038	0,0044	0,007	0,011	1,91	0,21	0,91	2,2	CL.
57.	259,7—261,0	0,0011	0,0036	0,012	0,012	0,029	0,048	2,84	0,27	0,73	6,6	F.Si.
58.	267,0—270,6/a	0,0028	0,0067	0,019	0,022	0,044	0,066	2,56	0,30	0,82	6,6	C.Si.
59.	273,2—274,0	0,0008	0,0017	0,0045	0,0055	0,0095	0,02	2,36	0,13	0,80	4,4	F.Si.
60.	277,7—280,4	0,071	0,11	0,14	0,14	0,18	0,21	1,30	0,25	1,00	4,4	S.S.
61.	282,5—283,8	0,0012	0,0031	0,0066	0,0075	0,013	0,022	2,04	0,24	0,93	8,8	F.Si.
62.	287,1—290,0	0,00055	0,0022	0,0048	0,0058	0,01.	0,021	2,13	0,19	0,96	4,4	F.Si.
63.	294,5—296,4	0,0039	0,012	0,034	0,028	0,066	0,090	2,34	0,31	0,70	2,2	C.Si.
64.	296,4—297,5	0,00085	0,0024	0,005	0,0055	0,011	0,022	2,14	0,20	1,07	—	CL.
65.	303,0—305,0	0,042	0,12	0,24	0,26	0,34	0,43	1,68	0,28	0,71	2,2	M.S.
66.	307,0—307,2	0,00024	0,002	0,0069	0,007	0,017	0,036	2,92	0,21	0,71	11,1	F.Si.
67.	307,5—309,5	0,047	0,07	0,11	0,12	0,18	0,22	1,60	0,32	1,04	6,0	S.S.
68.	314,2—322,9	0,067	0,15	0,22	0,24	0,27	0,32	1,34	0,24	0,84	4,4	M.S.
69.	324,1—328,0	0,0014	0,0052	0,014	0,016	0,029	0,046	2,36	0,27	0,77	4,4	F.Si.
70.	328,6—330,0	0,0084	0,032	0,077	0,090	0,12	0,16	1,93	0,29	0,65	4,4	F.S.
71.	331,7—336,0	0,055	0,080	0,12	0,13	0,16	0,21	1,41	0,26	0,89	13,7	S.S.
72.	337,5—339,6	0,0034	0,0082	0,02	0,023	0,05	0,058	2,47	0,38	1,03	16,4	C.Si.
73.	347,0—348,4	0,024	0,080	0,12	0,13	0,16	0,19	1,41	0,24	0,89	2,2	S.S.
74.	349,1—356,0	0,02	0,069	0,11	0,13	0,15	0,18	1,47	0,25	0,86	2,2	S.S.
75.	356,0—357,0	0,056	0,085	0,12	0,13	0,15	0,18	1,33	0,26	0,89	—	S.S.
76.	369,0—369,5	0,0018	0,0035	0,010	0,011	0,03	0,055	2,92	0,25	1,05	0,9	F.Si.
77.	371,2—372,8	0,0023	0,011	0,04	0,05	0,075	0,1	2,61	0,33	0,52	6,6	C.Si.
78.	378,0—378,8	0,0025	0,0075	0,022	0,026	0,040	0,055	2,31	0,31	0,62	4,4	C.Si.
79.	385,4—388,1	0,0019	0,011	0,025	0,03	0,050	0,080	2,13	0,25	0,88	8,8	C.Si.
80.	388,9—393,5	—	0,0005	0,0022	0,003	0,0065	0,018	3,60	—	0,67	2,2	CL.
81.	393,9—395,0	0,0008	0,0021	0,0062	0,007	0,015	0,021	2,67	0,32	0,82	13,3	F.Si.
82.	404,3—408,0	0,0092	0,039	0,075	0,08	0,11	0,13	1,67	0,29	0,75	4,4	F.Si.
83.	412,4—415	0,0034	0,0085	0,020	0,023	0,04	0,062	2,16	0,27	0,98	4,4	C.Si.
84.	422,8—424,9	0,0018	0,012	0,07	0,08	0,12	0,16	3,16	0,21	0,29	4,4	F.S.
85.	428,9—430,0	0,00062	0,0022	0,009	0,01	0,019	0,029	2,94	0,30	0,59	4,4	F.Si.
86.	431,0—433,8	0,00065	0,0010	0,002	0,0022	0,004	0,0072	2,00	0,23	1,00	4,4	CL.
87.	459,3—461,5	0,00055	0,00082	0,0016	0,002	0,0039	0,011	2,18	0,15	1,25	—	CL.
88.	492,0—492,6	0,0008	0,0018	0,0043	0,005	0,01	0,021	2,35	0,20	0,97	2,2	CL.

CL. = CLAY = 0,005 > mm ⌀, F.Si. = FINE SILT = 0,005—0,02 mm ⌀, C.Si. = COARSE SILT = = 0,02—0,06 mm ⌀ F.S. = FINE SAND = 0,06—0,1 mm ⌀, S.S. = SMALL SAND = 0,1 —0,2 mm ⌀, M.S. = MEDIUM SAND = 0,2—0,5 mm ⌀

Table 2

Heavy mineral composition of the Upper Pannonian and Pleistocene sands of the Macs borehole

Number	Depth m	DOMINANTLY MAGMATIC MINERALS											DOMINANTLY METAMORPHIC MINERALS											OTHER MINERALS				Total quantity minerals in the examined fraction	Dominant grain diameter mm	Age
		Hypersthene	Other rhombic piroxenes	Augite	Diopside	Basaltic-Hornblende	Magnetite	Ilmenite	Biotite	Olivine	Apatite	Zircon	Chlorite	Tourmaline	Epidote	Zoizite	Rutile	Hornblende	Actinolite-tremolite	Garnet	Staurolite	Cyanite	Glaukop-hane	Calcite-dolomite	Limonite	Other micas	Weathered minerale			
1.	6—8	7,0	1,0	16,2	1,0	11,1	11,1	—	0,5	0,5	2,5	—	3,0	1,0	1,0	—	—	4,5	0,5	11,6	—	0,5	—	0,5	12,1	0,5	19,3	0,69	0,1—0,2	Pleistocene
2.	15,5—16,0	9,2	1,1	10,3	0,6	7,0	21,2	—	0,6	—	1,7	0,6	6,3	3,4	0,6	—	—	5,2	0,6	12,6	0,6	0,6	—	—	9,2	—	8,6	0,72	0,06—0,1	
3.	24,5—26,5	9,5	0,6	16,9	1,3	6,3	6,3	—	—	—	0,6	—	5,6	3,1	0,6	—	—	4,4	—	14,4	2,5	0,6	—	—	5,0	—	22,5	0,87	0,1—0,2	
4.	32,2—34,9	1,1	3,3	4,9	2,2	7,8	8,4	—	2,7	—	0,6	0,6	3,8	4,4	2,7	—	1,1	3,8	—	9,9	2,2	—	—	—	6,0	—	34,5	0,46	0,1—0,2	
5.	48,3—50,8	—	2,4	—	0,8	0,8	19,5	—	—	—	2,4	0,8	7,1	1,6	—	—	0,8	—	0,8	3,2	0,8	—	—	—	25,4	—	33,6	0,46	0,1—0,2	Upper pannonian
6.	72,0—74,0	—	—	—	0,8	9,0	14,7	—	—	—	1,6	—	4,1	4,9	—	—	0,8	—	—	9,8	—	—	—	—	16,6	—	37,7	0,62	0,1—0,2	
7.	86,0—88,0	—	2,0	—	1,4	—	11,8	0,7	4,8	—	3,4	—	7,5	2,7	0,7	—	2,0	—	—	3,4	—	0,7	—	—	19,9	2,0	37,0	0,52	0,1—0,2	
8.	98,8—100,4	1,6	2,3	—	0,8	6,8	6,0	1,6	0,8	—	4,5	—	8,3	0,8	1,6	—	1,6	3,0	0,8	34,8	0,8	0,8	—	—	9,0	—	14,1	1,04	0,1—0,2	
9.	115,8—117	—	—	—	—	45,5	13,9	—	2,2	—	1,4	0,7	8,8	1,4	0,7	—	1,4	7,3	—	10,2	0,7	—	0,7	—	0,7	—	6,6	1,48	0,1—0,2	
10.	153 —154	—	—	2,2	—	43,3	5,6	—	2,8	—	0,6	—	12,0	0,6	—	—	0,6	2,2	—	14,7	—	—	—	—	2,2	—	14,0	3,39	0,2—0,5	
11.	157,8—157,9	—	2,8	1,4	1,4	11,7	—	—	—	—	2,1	—	13,2	2,1	0,7	0,7	—	7,5	1,4	2,9	—	0,7	—	—	—	—	51,4	4,10	0,06—0,1	
12.	235,6—236,6	—	2,1	0,7	2,9	6,6	4,4	—	1,4	—	2,9	—	15,1	2,2	2,2	2,2	—	22,9	3,7	0,7	—	—	—	—	2,2	—	27,8	0,68	0,06—0,1	
13.	277,7—280,4	—	—	3,8	4,8	23,2	5,7	—	—	—	0,9	—	8,6	1,9	1,9	—	0,9	16,3	5,7	3,8	—	—	—	—	1,9	—	20,6	2,40	0,1—0,2	
14.	303 —305	—	1,8	1,8	1,2	44,4	11,2	—	—	—	5,4	0,6	2,4	1,8	—	—	—	5,4	3,6	5,4	0,6	—	—	—	—	—	14,4	4,60	0,2—0,5	
15.	314,2—322,9	—	—	0,6	—	44,0	15,0	—	4,2	—	—	—	3,5	1,8	—	—	0,6	0,6	—	15,5	0,6	0,6	—	—	—	—	13,0	4,45	0,2—0,5	
16.	331,7—336	0,6	0,6	2,5	—	23,0	1,2	—	16,0	—	—	—	9,9	0,6	—	—	0,6	19,2	0,6	1,8	—	—	—	—	1,2	0,6	21,6	1,84	0,1—0,2	
17.	357 —364	—	—	0,8	—	44,4	9,8	—	—	—	1,6	—	1,6	0,8	—	—	—	1,6	0,8	9,8	—	—	—	—	—	—	28,8	3,80	0,2—0,5	
18.	404,3—408,0	—	0,7	—	—	10,7	2,0	—	19,7	—	2,7	—	47,0	1,4	—	—	—	1,4	0,7	4,0	—	—	—	—	2,7	3,4	13,6	0,43	0,06—0,1	
19.	422,8—424,9	0,6	0,6	—	—	—	2,8	—	16,8	—	8,5	—	43,5	1,7	0,6	—	0,6	—	—	11,3	1,1	—	—	—	4,5	0,6	15,8	0,38	0,06—0,1	
20.	476 —482,9	—	—	6,8	—	28,7	21,9	—	0,8	1,7	0,8	—	5,1	0,8	—	0,8	—	0,8	—	5,1	—	—	—	—	0,8	—	25,9	1,00	0,1—0,2	

Grain shape

The shape of the sand grains was studied by the method of I. MIHÁLTZ—T. UNGÁR—P. DÁVID [1954, 1955] distinguishing four types of grains: from water-transported sediments (types 1 and 2) to dominantly wind-blown ones (types 3 and 4). The method being a statistical one, the origin of the sand sediment is determined by the grain types prevailing in the strata. In the Upper Pannonian samples examined this way, the types 1 and 2 have been found to predominate in every case, type 3 has been represented by a low percentage only, a fact testifying to transportation by — or deposition in — water. In the Pleistocene sequence — whose data have been presented for comparison in *Fig. 2* — has been dominated throughout by types 2 and 3, and also type 4 appeared in several cases, a phenomenon reflecting the different conditions of sedimentation referred to above.

Mineral composition

1. Heavy minerals. Within the 453 m of the Upper Pannonian sequence, changes in mineralogic composition, i.e. in source area, can be observed nine times. Proceeding from the bottom to the top, the following types could be distinguished: *a)* The sample of the interval 476 to 483 m is dominated by augite, basaltic hornblende, and magnetite (*Fig. 5*, Table, 2, Sample 20). *b)* The samples from 404 m and 422 m depths (*Fig. 5*, Table 2, Samples 18 and 19) show the abundance of micas (chlorite, biotite). *c)* The composition of the sample from 357 m depth is nearly the same as that of the lowermost sample (*Fig. 4*, Table 2, Sample 17). *d)* Between 331 and 336 m, the common hornblende is fairly abundant (19%). a phenomenon distinguishing this interval from the sequences lying below and above it (*Fig. 4*, Table 2, Sample 16). *e)* Between 303 and 314 m, the basaltic hornblende is, again, of considerable amount (*Fig. 4*, Table 2, Samples 14 and 15). *f)* Between 157 and 280 m, the weathered minerals increasing upwards and basaltic and common hornblende, are of importance (*Figs. 3* and *4*, Table 2, Samples 11 and 13). *g)* Between 115 and 154 m, the mineralogic composition is characterized, again, by the abundance of basaltic hornblende (43—45%) (*Figs. 2* and *3*, Table 2, Samples 9, 10). *h)* The sample deriving from 98 m depth is conspicuous for its high garnet content (35%). A connection with the earlier source area is still indicated, however, by augite and basaltic hornblende present in low percentages (*Fig. 2*, Table 2, Sample 8). *i)* The rest of the Upper Pannonian sequence (depth interval of 48 to 88 m) shows a completely different composition: high percentage of magnetite and limonite. In these samples too, the weathered minerals are represented by a very marked percentage (*Fig. 2*, Table 2, Samples 5 to 7).

For a comparison, in *Fig. 2* and Table 2 the heavy minerals composition of the Pleistocene sequence is also shown. The sample from 32 m still exhibits transitions between the underlying, Upper Pannonian, samples and the overlying, later Pleistocene, ones. The transitional character is due to an admixture from the Upper Pannonian sandy surface (*Fig. 2*, Table 2, Sample 4). The rest of the Pleistocene shows an identity with the sediment being transported by the Tisza river and its tributaries in the northern Trans-Tisza Region. In these samples, the hypersthene, barely attaining 1 to 2 per cent in the above-discussed sediments, is enriched to 7 to 9 per cent, being associated with abundant augite (10—16 per cent) and basaltic hornblende (7—11 per cent). (*Fig. 2*, Table 2, Samples 1 to 3).

Beside the minerals listed above, other minerals have though been also present in the samples, but the examplified ones are representative and readily characnumber of clay, silt and lignite layers testifying to a marked unsteadiness of sedimentation even in this phase of high-rate accumulation.

The statistical values of the lithology of the strata studied are shown, in depth oderr, in *Fig. 9* and Table 1. Although not every layer has been analysed in detail, the investigation included all types of sediment, and the analysed samples have been selected evenly, as possible, throughout the profile. Thus, the vertical succession and variation of the results obtained are suitable for depicting the character of the processes.

The value of *sorting (So)* varies within very ample limits (1.3—5.5). This variation is fairly irregular, yet it is possible to select such intervals within the profile, where the sediment is well sorted or rather badly sorted. For instance, well-sorted sediments occur in samples 67 to 75 and 38 to 46. Less sorted are the samples 76 to 86 and 47 to 53, and, particularly so, the samples 31 to 37 representing the topmost Upper Pannonian.

Kurtosis (K) does not show any regular change. What is noteworthy is, however, that the greatest deviation from the average occurs in the samples 32 to 41 of the topmost Upper Pannonian. Just the same phenomenon can be observed in the variation of *skewness (Sk)*. The last-mentioned two characteristics, however, could not be computed for all samples, of the uppermost part of the profile, as the finer size fraction is very abundand there (curves 35, 36, 38).

Consequently, the statistical characteristics of grain size and the grain size itself show, in the Upper Pannonian interval, a substantially greater range of variation than do in the 48 -m-thick Pleistocene sequence. This very fact readily shows the essential difference between lacustrine sedimentation and eolian deposition on a dry surface, as was the case with the two formations of dissimilar age, respectively.

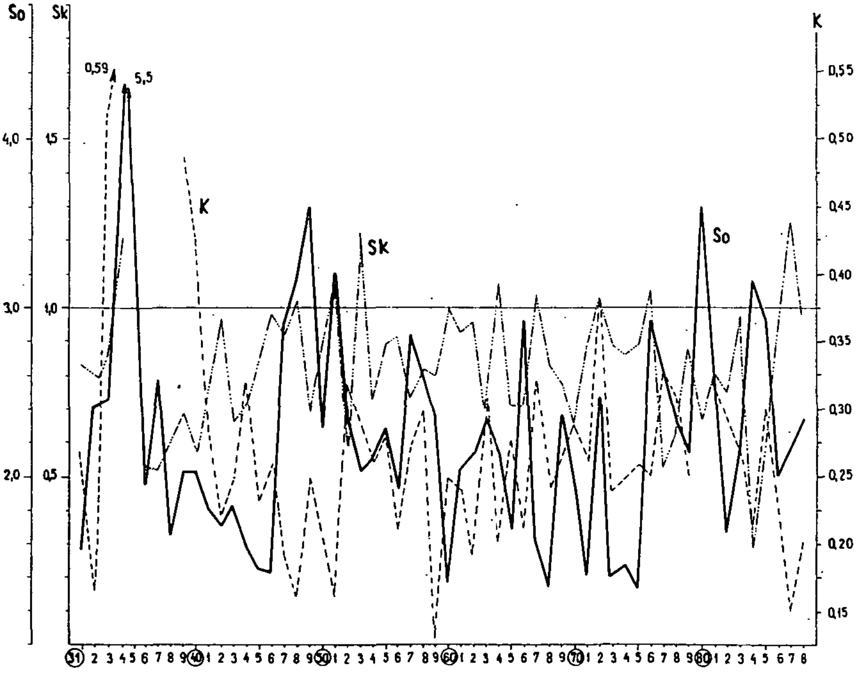


Fig. 9. Lithological statistics of the analysed samples (The numerals equal the serial numbers on the side of Column II, *Figs. 2—5* as well as those of Table 1.)

teristic of the particular heavy mineral levels, both with their aggregate appearance and relative proportions.

Such frequent changes in the heavy minerals composition are indicative of the rapid variation of the source area, a phenomenon which can be ascribed to crust movements. Associated with the predominant magmatic minerals, the repeated concentration peaks of chlorite also indicate that erosion was not confined to the volcanics of the marginal zone; on the contrary, the basin-deposited sediment has partly come from a crystalline-schist-built area, or possibly from the deposition of older sedimentary rocks.

2. Light minerals. First of all, the quantitative changes of feldspar grains in the sequence was studied. A. Cailleux (1965) developed a method for the evaluation of the amount of feldspar in clastic sediments. On the basis of the results obtained for a number of samples from different places, he could prove the dependence of the petrographic composition not only on the rejuvenation of the morphology (tectonics) but also on the climate and the vegetation.

Under cold and arid climate — and because of the rapidity of erosion in many mountains — there is no time for chemical weathering, the rock is only mechanically disaggregated, so that feldspar is enriched in the sandy sediment. On a hot and humid, forest-clad plain, however, it is the chemical weathering that gains prominence, so that the feldspars are altered into clay or bauxite minerals. The amount of heavy minerals removed from granite or gneiss surfaces into the sedimentation basin, is rather low. For this reason, the sand grains primarily consist of quartz.

Feldspar-rich sediments can be formed under various conditions. Beside climatic effects, the erosion of volcanic rocks, for instance, may also provoke an enrichment of feldspar. On the contrary, a decrease in the concentration of feldspar is always due to chemical weathering (rather than to physical disintegration). This fact was proved by F. J. Pettijohn [1949] on Mississippi-transported sediments in which the originally 25% concentration of feldspar decreased by mere 5 per cent after being transported for 1800 km in the river.

The *Cailleux feldspar factor* can be calculated by using the following formula:

$$\text{Feldspar factor} = \frac{100 \times \text{feldspar}}{\text{feldspar} + \text{quartz} + \text{mica} + \text{other minerals}}$$

„other minerals", the carbonates (calcite, dolomite) and the minerals indeterminable because of their advanced weathering or coating, have been omitted. Sediments showing 10- to 80% concentration are held for feldspar-rich, those of 4- to 5% concentration, for feldspar-poor.

The material of the Macs profile can be considered feldspar-rich. Within the Upper Pannonian sequence, the *Cailleux factor* varies between 28 and 60, the highest value occurring in the interval of 150 to 501 m (*Figs. 2—5*, column IV, first group of numerals). So high a ratio of feldspar in the Pannonian has not been found heretofore anywhere in the more central, southern, part of the basin, the average value has varied within the range of 20 to 35 [B. Molnár, 1967 *c*, 1967 *d*].

The high feldspar ratio here is a proof for the rapid removal of considerable amounts of volcanic material, a fact confirmed by the heavy minerals already presented above.

Between 48 and 150 m, the feldspar ratio decreases from 28 to 31. This fact can only partly be due to a change of source area. Nota bene, the heavy minerals composition of the sample from 115 m depth is identical with that of the deepersited, but more feldspar-rich, deposits. The lower concentration of feldspar may be due to the lower rate of accumulation, conditions under which the chemical weathering could have time enough for influencing the feldspars of the sediment. No information suggesting a latest Pannonian climate, considerably warmer than formerly, is available. And given the subequal climate, the chemical weathering could attain a comparatively higher intensity only in case of a lower rate of deposition.

In accordance with the colder climate, the Pleistocene samples yield a higher feldspar factor — from 48 to 53.

The percentage ratio of the weathered, coated grains to the total of mineral grains has been established. In the Upper Pannonian section, the samples which were generally more abundant in feldspar, showed lower concentrations in the lower part of the section (3—10%) and higher concentrations in the less feldspar-rich interval (4—16%) (Legend, *Figs. 2—5*). In the upper part of the Upper Pannonian section, this fact is an evidence of the more intensive effect of chemical weathering.

Carbonate content

After the samples had been attacked by hydrochloric acid, the weight loss of CO_2 was calculated for $CaCO_3$. It can be considered rather low throughout the profile, as compared to the rest of the Great Hungarian Plain [B. Molnár, 1967 *b*]. Layers with a carbonate content attaining 30 per cent have not been numerous, and only five samples showed a higher figure. A strikingly high value, 37 to 66 per cent, was obtained for three intervals only.

Relationship between tectonic movement and sedimentation

The Lower Pannonian of the Hajdúság is 200 to 250 m thick, the Upper Pannonian attains 1,000 m thickness [L. Körössy, 1962]. Hence, the 453 m thickness of the Macs profile exposes nearly the half of the Upper Pannonian sequence. Exhibiting a swift variation in lithology throughout the vertical range of the borehole, the profile is represented by about 18 layers of lignite, 7 stringers of lignite, shaly lignite and carbonaceous shale as well as by 17 diagenized interlayers. The matrix of the latter is not always a carbonate one. So, e.g. the samples taken from 487.5 or 277.5 m depths have a siliceous matrix. The diagenized matter, immediately overlying these points, however, shows again a calcareous matrix, the sample from 201 m being, in addition, limonitized.

The colours of the sediments being considered are very diversified (*Figs. 2—5*, Column II). Concretions or precipitates of chalk and limonite are frequent. The mottled nature of the sediments is indicative of reduction and oxidation processes.

In the lithofacies-dated Upper Pannonian interval, M. Faragó [1960] has identified a rich pollen assemblage which is considered to comprise shallow-water and swamp communities of Upper Pannonian flora.

The representatives of fauna are very scant throughout the profile; F. Bartha [in M. Erdélyi, 1962] identified *Viviparus sadleri* Partsch, *Melanopsis fuchsi* Handm., *Limnocardium* sp. and *Anodonta* sp. from the 217,3 to 220,6 m interval. From the interval of 211,4 to 212,3 m, he described *Viviparus sadleri* Partsch, *Congeria* sp., *Limnocardium* sp., *Anodonta* sp. According to him, these forms are indices of the Upper Pannonian brackwater facies. On the basis of the lithologic composition of the 453 m thick profile, four periods of subsidence (a) and four periods of emergence (or standstill) (b), forming — couple by couple — individual sedimentation cycles (A to D), can be distinguished.

Aa) Most difficult to qualify is the lower, 425 to 501 m, interval, as its downward continuation is unexplored. At a depth of some 420 m, however, the heavy minerals composition will change, as shown above, giving rise to the first lignite seam. The worse sorting of the sediment also applies to this interval. Taken all together, these data are data evidencing the tectonic movement of the area.

The role of sandy sediments declines from bottom to top (the samples from 463, 466, 480, and 490 m depths are represented by sand, whereas the interval of 425 to 463 m — i.e. a thickness of nearly 40 m — includes but a few decimeters of sand). Consequently, between 425 and 501 m, a subsidence of the area and a deepening of the contemporaneous lake can be revealed (*Fig. 5*, Column VI, 1 and Legend).

Ab) At 420 m depth, the appearance of the first lignite layer, the variegated stain of the sediments, their limonite and chalk concretions, and the changes of the source area are indicaters of a movement of geometrically opposite sence— emergence or, possibly, a static condition leading to accumulation of sediment. The appearance of the lignite layer also is an evidence of shallowing, i.e. of the rate of emergence. In fact, the sediment now occurring at 420 m depth may have been deposited nowhere else but at the water front (*Figs. 4—5*, Column VI, 1, 2, 3).

The rise-causing effect of tectonic movement resulted — as opposed to the formerly magmatic nature of the heavy minerals — in the predominance of the metamorphic minerals — such as chlorite which must have come from a metamorphic source area. Farther upwards within the same interval, however, it is again the magmatic character that begins to dominate. In the lower portion of the interval the sediments is more badly sorted, the parts farther up show a better sorting. The greatest number of diagenized layers is found here within the entire profile. This type of sedimentation can be traced from 420 m to 334 m depth. Consequently, the interval of 334 to 501 m as a whole represents a minor cycle of sedimentation (A).

Ba) At 334 m a new change in source area, manifested by the comparatively higher percentage of common hornblende, sets in. From this depth upwards, the amount of sandy sediment will suddenly increase, a penomenon indicating the final sedimentation of the preceding cycle and the initial, coarser-grained, one of the new cycle, respectively. Between 258 and 334 m, no lignite layer or stringer can be found and the sediment becomes gradually finer farther upwards. All these phenomena combined, are indicative of a subsidence of the area *(Fig. 3)*.

Above 334 m — a level where the growth of the ratio of hornblende has shown an inversion of crust movement — the magmatic mineral paragenesis becomes, again, characteristic.

Bb) In the interval of 180 to 258 m there are many lignite layers attaining the highest frequency here in the entire profile. The Upper Pannonian mollusks determined by F. BARTHA have come from this interval. Within this interval the heavy minerals composition has shown the first change before the appearance of the first lignite layer, at 283 m, a change indicative of an inversion of crust movement. At the base of the interval, the sediments are well sorted, in the upper part less sorted *(Fig. 8)*. The calcareous-limonitic hardground occurring at 202 m is an evidence for swamp sedimentation. The higher amount of weathered minerals can also be accounted for by an oxidation in swamps.

As suggested by the above features, the sediments deposited within the interval of 180 to 258 m may have been formed in the ascendent, or possibly static, phase of tectonic movement.

Consequently, the 180- to 334 m interval indicates a new sedimentation cycle (B).

Ca) Between 148 and 180 m, the characters of lithofacies, including the smaller thickness of the sediment, suggest a sedimentation of short duration due to subsidence.

Cb) In the interval of 90 to 148 m, however, a phase of emergence or static condition can be shown to have taken place, again.

Between 90 and 180 m, appears, in turn, a third sedimentation cycle as counted from the bottom of the hole upwards. This cycle is, however, represented by a thickness considerably lower than the preceding ones are (C).

Da) The last phase of subsidence within the profile under consideration occurs between 51 and 90 m.

Db) Finally, between 48 and 51 m there are small-grained sands—regressive sediments corresponding to the complete withdrawal of the Pannonian lake. They may be partly absent, as in the Levantine the sedimentation was replaced by erosion. As shown above, the Pannonian sediments were redeposited even in the Pleistocene.

Consequently, it is the last cycle of the profile that appears between 48 and 90 m (D).

SUMMARY

In conclusion, it can be stated that the 453-m-thick Upper Pannonian of Macs is composed of four minor cycles of sedimentation. The sedimentation cycles differ in grain size from one another, as the grains first become finer, then, again, coarser from bottom to top. Here in the regression phase, the kinetics of the crust — subsidence, emergence or static condition, respectively — are indicated, in several cases, by the lignite seams and by the general changes of sedimentation (sorting and heavy minerals composition of the sediments) rather than by grain-size variation.

In Table 3 the thicknesses of the subsidence and emergence phases (or possibly of static phase) of the individual cycles as well as the thickness of the sediments of the particular cycles have been shown. The upward-decreasing thickness of the individual sedimentation cycles is conspicuous.

Table 3

Thickness of the sedimentation cycles of the Upper Pannonian sequence of Macs

Symbol of cycle	Thickness of subsidence-recording sediments m	Thickness of sediments recording emergence or static conditon m	Total thicknes of sedimentation cycle m
D	39	3	42
C	32	58	90
B	76	78	154
A	79	88	167
Total thickness m	226	227	453

Accordingly, the latest Pannonian tectonic movement was a rhythmical one. Preceding the overall latest Pannonian regression, these rhythms were of shorter and shorter duration. The thickness of the second — emergent or static — phase of the particular cycles is always higher than that of the sedimentary sequence formed in the subsidence phase. (Table 3). Hence, the Pannonian lake vanished in such a way that subsidence was gradually outscored by emergence or static condition which became longer and longer.

Within the 453-m-thick Upper Pannonian section, at a depth of about 354 m, the over-all trend of tectonic movements and their cumulative effect have changed with the appearance of the coarsest sediment. Heretofore rather subsiding and slowly deepening (with simultaneous accumulation), the lake-covered area now began to become shallower, despite the minor subsidences which intervened from time to time (*Figs. 2—5*, Column VI, 5).

In other parts of the Great Hungarian Plain, e.g. at Jászladány and Kemecse, the above cycles could also be shown to occur within the Pannonian sedimentary sequence (*Fig. 1*). The lignite layers, however, played a less significant role there, the lithofacies of the individual cycles being different. The cyclicity is, however, an evidence for rhythmical tectonic movements, here too [A. Rónai, 1968].

In the southern Great Plain, where the Pleistocene epoch witnessed fluviatile accumulation, the rhythmicity of crust movement is proven [Molnár, 1967 *a*, 1968] for the Pleistocene, too (Szentes, Makó). Consequently, this peculiarity of tectonic movement was preserved in the Pleistocene.

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