GEOLOGICKÝ ZBORNÍK — GEOLOGICA CARPATHICA XXIII, 2 — BRATISLAVA, NOVEMBER 1972

MAGDA MARKOVÁ, EVA PLANDEROVÁ, MILAN POLÁK*

OLIGOCENE EVAPORITES IN CENTRAL WEST CARPATHIANS

(Pl. I—III, fig. 1—3)

Abstract: Presented are lithology and stratigraphy of Neogene, Paleogene and Cretaceous sediments in the cross-section through the deep borehole GK-4 near the village Bzovík. A new occurrence of an evaporite bed sequence is described in detail. From the view of petrography it is a sulphate-carbonate bed sequence sedimented during the Oligocene, in a period of comparatively arid subtropical climate — as indicated by palynological finds.

Резюме: В работе подается литологическое и стратиграфическое описание неогеновых, палеогеновых и меловых осадков, известных из профиля глубокой скважины при селении Бзовик. Детально описано новое появление эвапоритового слоя. По петрографическим данным речь идет о сульфатно-карбонатном слое олигоценового возраста, который осождался во время сухого субтропического климата, что подтверждают и палинологические результаты.

In Slovakia, most important are evaporites in Permo-Triassic series of the central West Carpathians, and in the Carpathian and Badenian of the East-Slovakian Neogene Basin. Recently, evaporites were also found in the basement of the Neogene filling of the Viennese Inner-Alpine Basin, in the Senonian mantle of the inner Klippen Belt (J. Janáček, V. Šimánek, 1969). Owing to the research in the deep substratum of the Central-Slovakian neovolcanites, a thick (143 m) bed sequence of carbonates, claystones and sulphates was bored in about 1000 m depth near the village Bzovík (borehole GK-IV), on the northern foothill of the Krupinská vrchovina. In its basement are claystones and sandstones of the Central-Carpathian Paleogene and the Upper Cretaceous of Gossau formation. The bed sequence is overlain by Ottnangian clays, Carpathian marly-clayey silts and by a volcanic-sedimentary Badenian bed sequence.

The authors treat the lithology and stratigraphy of Cenozoic pre-Badenian sediments, mainly those of the sulphate-carbonate beds of Lower- to Middle-Oligocene age, as proved by palynological examination. Pollen analyses also served to determine the age of underlying and overlying sediments. Stratigraphically documented microfauna was only in Carpathian sediments; while in evaporite beds was only resedimented Cretaceous microfauna — as stated by V. Kantorová (1970).

Detail petrographical, mineralogical and chemical characteristics of the evaporite beds were given by M. Marková and R. Meier (1972), so here only the most important statements and a brief lithological characteristics of the underlying and overlying sedimentary rocks will be presented together with their palynological evaluation.

Lithology of pre-Badenian Cenozoic sediments

The borehole GK-IV was situated in volcanic-sedimentary continental Badenian beds extending to 790 m depth. Between 790—882.50 m is Carpathian represented by a schlier facies and in the basal part by arcose conglomeratic sandstone (pebbles of

* RNDr. M. Marková, CSc.; RNDr. E. Planderová, CSc.; p. g. M. Polák, Dionýz Štúr Institute of Geology, Bratislava, Mlynská dol. 1.

qartz, quartzite and limestone; up to 10 mm diameter). The sandstone and the lower part of the schlier bear traces of boring organisms. Fine stratification of clay and silt is emphasized also in colour owing to increased content of organic matter in the clay laminae. In the latter also the portion of mica and of small globigerines is increased. Aleurite and sandy component contain tests of the thicker rotaloid microfauna. To the depth of 857 m occur shells and shell fragments of oncophores present not only in underlying Ottnangian but also in the lower part of the Carpathian. In the depth of 855,30 m is a tuffitic layer with abundant acid volcanic glass, sponge spicules and diatomacea.

A comparison of the average values of Trask's granularity coefficients, of the heavy minerals and $CaCO_3$ contents in the samples examined and in the samples of the Carpathian from the Ipeľská kotlina showed that the Carpathian in borehole GK-IV was somewhat coarse-grained, worse sorted and less micaceous.

	GK-IV	Ipeľská kotlina
Md	0,02 mm	0,01 mm
So	3,2	3.03
$CaCO_3$	10.1 %	17.0 %
HM %	1.5	1,18

Andalusite, sillimanite, tremolite present in sediments of Ipeľská kotlina are missing in the association of heavy minerals. The high contents of chlorite and biotite together with garnet and staurolite, tourmaline, amphibole, rutile and apatite indicate prevalence of metamorphic rocks in the source area.

The clay component of the schlier facies consists predominantly of illite less montmorillonite. In the sample of volcanic origin only montmorillonite is present.

Between 882,50 and 890 m is clayey (11.7 %), silty (33.8 %) fine-grained nonmarly (1,95 % $CaCO_3$) sand (54,7 %) representing a fine-grained equivalent of the facies of "Manganese sands" in Ipeľská kotlina.

	GK-IV	Ipeľská kotlina
Md	0.1 mm	0.32 mm
So	1,58	1.6
$CaC0_3$	1.95	0
HM %	0,8	1.9

The heavy minerals association is practically identic with the schlier facies, only the chlorite and biotite ratio (1.5 in the schlier facies, 60 in badly cemented permeable sands) is different. Textural features and the degree of sorting indicate a shallow-water sediment deposited in pericoastal beach environment. The only organic remains are sponge spicules and carbonized plant fragments. Carbonate shells of oncophores present in the underlying and in the overlying beds are absent. That may be regarded as the secondary result of decalcification.

890—941 m. A facies of clayey-sandy marly silts — "oncophora sands" (Ottnangian) with the average value of Md 0.05 mm and low degree of sorting So = 3.73. The volume of heavy minerals varies between 0,9 and 9.23 %, mainly due to varied amount of autigene pyrite. The average content of garnet (9,9 %), biotite (4,8 %), tourmaline (0,9 %), carbonate (14,3 %), chlorite (30,2 %), opact miner. (29,3 % — mostly pyrite) varied, low are amounts of apatite, zircone, andalusite, titanite and rutile.

The light fraction is characterized by high content of mica (25 %, in fraction > 0.25 mm up to 90 %). Upwards the organic remains increase in number, mainly sponge spicules and raxes. In the top part very small pyritized globigerines (0,04 mm in diameter) appear. Oncophora shells are all over the profile.

By X-ray analysis of fraction $< 5\,\mu$ montmorillonite was identified, less illite, little amount of kaolinite, quartz, indications of feldspar and dolomite.

A comparison of the sediments examined with the stratotype locality of Oncophora sands near Malý Krtíš shows differences in sorting and in the content of carbonates. The So coefficient of the sands from Malý Krtíš is 1.3, $CaCO_3$ content 14 %; while the samples examined contain dolomite (6,42 % of $CaCO_3$, 6,06 % of $MgCO_3$). The sediments examined were deposited during quiet sedimentation conditions in a semi-closed or closed reservoir. The source area contained carbonate rocks, especially dolomite, in addition to metamorphic rocks.

941—987,80 m. Silty clays — "overlying clays" — Ottnangian. Grey and dark-grey nonmarly silty clays show the following average values: Md — 0.007 mm, So — 3.42. $CaCO_3$ content 5 %. The amount of heavy minerals depends upon autigene pyrite and varies within 0.7 % and 15.9 %. The samples of overlying clays show the average contents of heavy minerals as follows:

garnet	23,0 %	biotite	0,8 %
tourmaline	0.7 %	chlorite	8.6 %
zircone	0.8 %	carbonates	6.6 %
apatite	0.8 %	pyrite	49.7 %

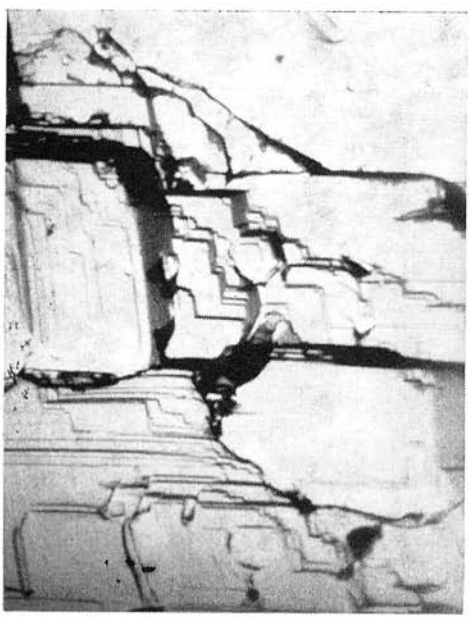

Fig. 1. An electron carbon replica microphotograph of microcrystalline dolomite. GK-IV, 1063,5 m, magn. 6930 ×. Photo M. Ďuriš.

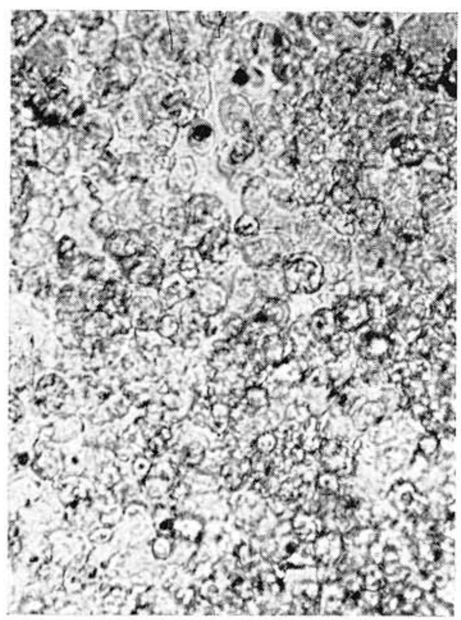

Fig. 2. Microcrystalline porous dolomite. GK-IV, 1004 m, magn. 1000 ×. Photo P. Snopková.

In the light fraction the portions of quartz and feldspars are the same 30—35 %. The contents of micas are somewhat lower. Among organic remains there are only carbonized plant fragments present.

X-ray analysis of the fraction $< 5\,\mu$ recorded illite as the main mineral, the montmorillonite, kaolinite, quartz and plagioclase.

The facies of overlying clays is identic with overlying clays from Ipeľská kotlina.

987,80—1130 m. A sulphate-carbonate sequence that beside chemogene component contains 8—90 % portion of terrigene material (illite, kaolinite, montmorillonite, quartz, mica) of the category of clay and silt, either like an admixture in carbonates or lamines or bodies of carbonate cemented siltstones. The main carbonate mineral is dolomite. Only in the terminal part of the sequence (the topmost 8.2 m) calcite predominates over dolomite and forms pseudomorphoses after gypsum. In the basal part calcite shells and fragments of organisms surrounded with microcrystalline dolomite or dolomitized clayey matrix, were preserved. The dolomite between the bottom and the top layers of calcareous dolomites is cryptocrystalline and microcrystalline, arranged in spherical aggregates of 2—7 or 20 μ diameter. These are composed of dolomite rhombohendrons (fig. 1) covered by dolomite crust, forming small bodies hexagonal in cross section, mutually

Table 1. Molar ratio Ca : Mg in dolomite

depth in m	A	D	1	2	3
1006,5	—	—	—	—	$Ca_{52}Mg_{48}$
1010,5	—	—	—	—	$Ca_{51}Mg_{49}$
1016,4	—	—	—	—	$Ca_{50}Mg_{50}$
1024,0	26,77	66,61	$Ca_{50}Mg_{50}$	$Ca_{50}Mg_{50}$	$Ca_{50}Mg_{50}$
1034,5 a	—	—	—	$Ca_{52}Mg_{48}$	$Ca_{51}Mg_{49}$
1034,5 b	—	—	—	$Ca_{52}Mg_{48}$	—
1055,7	—	—	—	—	$Ca_{51}Mg_{49}$
1059,7	20,48	51,61	$Ca_{51}Mg_{49}$	—	—
1067,7	2,01	86,66	$Ca_{52}Mg_{48}$	—	$Ca_{53}Mg_{47}$
1076,8	2,72	82,43	$Ca_{52}Mg_{48}$	—	—
1084,5	—	—	—	—	$Ca_{50}Mg_{50}$
1087,5	—	—	—	—	$Ca_{51}Mg_{49}$
1091,5	69,11	19,71	$Ca_{54}Mg_{46}$	—	—
1095,5	—	—	—	$Ca_{53}Mg_{47}$	$Ca_{52}Mg_{48}$
1098,8	—	—	—	—	$Ca_{51}Mg_{49}$
1100,6	46,09	29,48	$Ca_{52}Mg_{48}$	—	—
1106,6	4,9	73,77	$Ca_{53}Mg_{47}$	—	$Ca_{53}Mg_{47}$
1110,3	1,05	81,97	$Ca_{50}Mg_{50}$	—	$Ca_{54}Mg_{46}$
1114,4	—	—	—	—	$Ca_{50}Mg_{50}$
1120,0	5,24	90,85	—	$Ca_{51}Mg_{49}$	—
1121,0	—	—	—	—	$Ca_{50}Mg_{50}$
1128,8	—	—	—	—	$Ca_{50}Mg_{50}$
1132,2	—	—	—	—	$Ca_{52}Mg_{48}$

A — anhydrite content calculated from chemical analyses. D — dolomite content calculated from chemical analyses. 1 — molar ratio Ca : Mg calculated from chemical analyses. 2 — molar ratio Ca : Mg calculated from the average values of point analyses by microprobe analyser (The Institute of iron metallurgy, Prague, Ing. Storek, Ing. Kotrba, Ing. Kolman). 3 — molar ratio Ca : Mg according to X-ray analysis, the record of the reflex position 211. 1034,5 a — the analysis of dolomite in matrix. 1034,5 b — the analysis of radial carbonate of organic shells.

connected in the form of a honeycomb (fig. 2). In microcrystalline dolomite, particles are only partially connected, the rock is porous, with a low unit weight (1.76—2.3). In cryptocrystalline dolomite is compact connection of particles. In mixed anhydrite-dolomite rocks the unit weight increases — from 2.6 to 2.9 — according to the anhydrite content. In the insoluble residuum of dolomites of microcrystalline texture the minerals of volcanic origin, indicating dolomitized vitreous tuffs were found. Their thickness varies between some centimetres and metres.

The $CaCO_3/MgCO_3$ ratio in the dolomites varies within 50 : 50 and 54 : 46 mole percent (tab. 1). In most cases dolomite shows excessive amount of Ca-component, which is a phenomenon characteristic of early-diagenetic dolomite of evaporite facies. The more arid the climate, the smaller is the excess of Ca (H. Füchtbauer, G. Müller 1970).

Anhydrite and celestine represent sulphates. Anhydrite forms nodules consisting of felted network of lamellar crystals, predominantly non-oriented, sometimes with indication of the forming spherolites. In some cases anhydrite fills pores, vesicles and cracks, or acquires the shape of pseudomorphoses after gypsum or forms parallel layers of 3—5 mm thickness. The latter are alternatingly composed of prismatic and isometrical crystals separated by dark 1—2 mm thick laminaes consisting of clay, silt, dolomite and organic matter (C_{org} — 2,47—7,43 %). Beginning with dolomite clays the anhydrite content increases. In dolomite clays it is 2—15 %, in dolomites up to 43,5 % in stratified anhydrites up to 80,5 %.

In the whole profile of the evaporite sequence is an icreased amount of Sr. As for the order 10 × higher than in underlying and overlying sediments. The average is 0.41 % Sr (0,02—3,3 %). The mineral celestine itself was found only in the sample from the lower part of the sequence on the contact between dolomite and anhydrite sedimen-

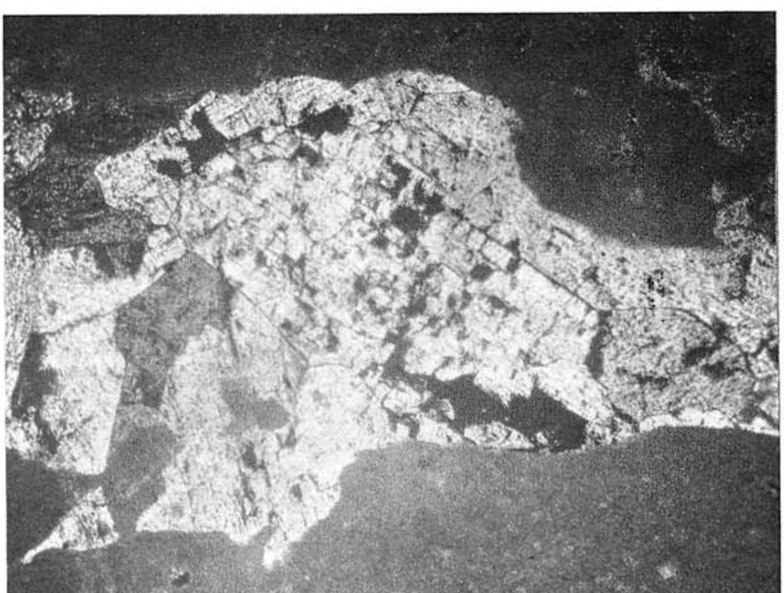

Fig. 3. Celestine in dolomite. GK-IV, 1120 m, magn. 42,5 ×. Photo P. Snopková.

tations, in the depth of 1120 m. Planimetrical analysis determined its content as 5,6 %. Celestine is a secondary filling of pores and vesicles in dolomite (fig. 3).

By electron probe microanalyser minor celestine crystals (as much as 10 μ in diameter) were found in carbonate and sulphate matter in different samples. A little content of Sr, approximately 0,4 % is diadochically built in dolomite, approx. 0,2 % in anhydrite. No relationship of the contents of dolomite or anhydrite to Sr was observed. Indirect dependence was observed between boron and strontium. With the increasing boron content (as well as of clay terrigene component) the Sr content decreases.

The terrigene component of the evaporite sequence consists of illite, kaolinite, quartz and mica. Mixed clayey-carbonate rocks are grey-blue, silty-clayey in structure, cemented by carbonates.

Boron is restricted to the clay component, especially to illite. The boron content was determined in two ways: a) from the original rock (tab. 2), b) from separated fraction 5 μ (tab. 3).

The boron content was recalculated to adjusted boron in the sense of C. T. Walker in H. Harder (1970):

$$\frac{\text{boron content}}{\%\ K_2O} \times 8.5.$$

C. D. Curtis (1963) found in marine sediments 200—350 of adjusted boron. C. T. Walker in H. Harder (1970) quoted the value 652—728 for adjusted boron in limestones owing to increased marine salinity, and 692—769 in slightly evaporite dolomites.

In our samples two extremely high values of adjusted boron appeared. The first one in the lower part of evaporites, in dolomitized clay with porphyroblasts of anhydrite, the next in the depth of 1076,8 m, in a sample regarded as dolomitized tuff. Other values concerning adjusted boron vary within the scope of normal, marine paleosalinity, up to the terminal part of overlying clays. The decrease of values in the terminal part of overlying clays is followed by temporary increase on the base of Oncophora sands, and again by decrease in accordance with brackish environment. In the marine schlier of Carpathian age the boron content increases again. The separated clays of evaporite sequence from layers with increased amount of terrigene material are characterized by more equal distribution of boron than carbonate and sulphate original sediments.

The portion of fibrous SiO_2 in evaporite sequence is 0.8—3.7 % as proved by planimetrical analyses. Spherolites of fibrous SiO_2 in basal and terminal parts have the fast ray parallel to the fibers; in the middle part, there is the slow ray parallel to the fibers. According to R. L. Folk and J. S. Pittman (1971) the LSX (lenght slow chalcedony) is a diagnosite mineral indicating its origin in evaporite sequence.

We may suppose the rise of evaporite sequence to be analogous with recent evaporites formed on a pericoastal flat plain in arid, warm climate, due to evaporation of brines ascending through capillaries to the surface of porous sediments. Dolomite arose in the stage of early diagenesis by the substitution of aragonite in the course of the genesis of gypsum (according to L. V. Illing, A. J. Wels and J. C. M. Taylor 1965). Anhydrite arose diagenetically by the substitution for gypsum forming idiomorph crystals or thin layers, or the secondary filling of vesicles and cracks.

Genetical connection of the evaporite sequence with brines of marine origin may only be supposed on the basis of increased Sr and B contents. Organic remains did not prove their marine origin.

Table 2. Contents of boron and of adjusted boron in original rock

rock	depth	B g/t	adjusted B	facies
CD	992,5	30	190,3	sulphate-carbonate
IDC	1016,4	100	223,1	sulphate-carbonate
DA	1059,5	27	173,7	sulphate-carbonate
DT	1076,8	14	1190,0	sulphate-carbonate
D	1081,5	54	203,1	sulphate-carbonate
A	1091,5	10	236,1	sulphate-carbonate
IDA	1100,6	13	650,0	sulphate-carbonate
ID	1105,8	135	269,0	sulphate-carbonate

Table 3. Contents of boron and of adjusted boron in separated clays

original rock	depth	B g/t	adjusted B	facies
IS	800,5	57	250	schlier Carpathian
IS	810,5	55	216	schlier Carpathian
IS	824,5	67	263	schlier Carpathian
IS	834,6	69	256	schlier Carpathian
IS	841,3	87	308	schlier Carpathian
IS	862,4	60	236	schlier Carpathian
IS	872,3	52	224	schlier Carpathian
IS	882,2	40	200	schlier Carpathian
S	908,8	46	173,0	Oncophora sands
S	916,5	38	184,4	Oncophora sands
S	926,5	29	120,8	Oncophora sands
S	936,5	62	224,3	Oncophora sands
I	946,5	63	98,1	overlying clays
I	956,5	63	94,2	overlying clays
I	966,5	56	171,2	overlying clays
I	976,5	72	231,4	overlying clays
I	986,5	107	302,5	overlying clays
I	986,8	113	255,4	overlying clays
DI	1006,5	85	243,9	evaporite sequence
DI	1012,5	172	357,8	evaporite sequence
DI	1016,5	166	306,7	evaporite sequence
DI	1026,6	194	432,6	evaporite sequence
DI	1033,5	125	301,7	evaporite sequence
DI	1055,7	226	432,6	evaporite sequence
DI	1074,5	190	367,2	evaporite sequence
DI	1087,4	133	300,1	evaporite sequence
DI	1098,8	104	356,2	evaporite sequence
DI	1108,5	255	392,7	evaporite sequence
DI	1115,5	224	396,1	evaporite sequence
SI	1131,8	91	282,2	marly claystones
SI	1137,5	tr.	—	marly claystones
SI	1141,2	156	394,4	marly claystones
SI	1145,6	143	357,0	marly claystones
SI	1149,8	45	238,8	marly claystones

Explanatory notes: I — clay, D — dolomite, A — anhydrite, DT — dolomitized tuff, C — calcite, S — silt, SI — marly claystone.
Analyst: Dr. G. Kupčo, CSc., D. Štúr's Geological Institute.

The contact of evaporite sequence with the overlying Ottnangian is unclear. In the uppermost part of the evaporite sequence appear abundant carbonized plant remains, due to which the sediments were interpreted as the so called productive Ottnangian sequence. Its contact with the higher constituent of the Ottnangian, i. e. with the facies of overlying clays is tectonically interrupted in the depth of 987—988 m, and indicates the tectonical position of overlying clays on evaporites. Owing to migrating solutions the stratigraphically and genetically different sediments became related by their mineralogical composition. Gypsum released from underlying rocks and deposited in vesicles and pores of claystones, and in the uppermost part of evaporites, calcite aggregated instead of gypsum.

With respects to palynological results indicating Lower- to Middle-Oligocene age of the sequence, most probable seems the deposition of evaporites in the pericoastal part of the water reservoir, the latter being partially or completely separated from the sedimentation area of the Central-Carpathian Paleogene. The thickness of the sequence recalculated to the recent velocity of evaporite sedimentation corresponds approximately to 500 000 years. Increased transport of plant detritus in the uppermost part of the evaporite sequence indicates at least the change of climate and most probably also the fading-out of evaporite sedimentation.

1130—1154,4 m. Marly claystones, siltstones and sandstones containing macrofauna and carbonized plant remains. The basal part of the sequence is formed of grey-green marly claystones with 64.5 % of clay, 33.9 % of silt with admixture of sand (1.54 %). Md 0,005 mm, So 3.32. The heavy fraction contains 95 % of pyrite, the rest is occupied by carbonates and by minerals of epidote-zoisite group. Autigene carbonate is also the most abundant component of the light fraction, in addition to polycrystalline quartz, rare plagioclase and micas. The X-ray and DTA analyses of clay fraction determined illite, kaolinite, calcite, dolomite and organic material.

The overlying marly fine-grained conglomerate with fragments of thin-shelled lamellibranchiates and gastropods contains pebbles consisting of angular and semiangular quartz, quartzite, chert, radiolarite with radiolarian tests filled by chalcedony. Tests of macrofauna are leached and holes are fringed with organic material and pyrite. The conglomerate is cemented by coarse crystalline calcite replacing the original silty matrix preserved in relicts. The matrix is composed of the grains of quartz, feldspars, micas and of clayey cement coloured by organic material. The $CaCO_3$ content is 32.1 %.

The uppermost part of the marly sequence is formed of dark-grey marly silts, composed of quartz, mica and feldspars. The same is the size of dolomite crystals surrounded by calcite cement replacing the original clayey matrix. The X-ray analysis of a macro sample from the depth of 1132.2 m identified dolomite, quartz and calcite.

This marly sequence of 25.4 m thickness comprises several layers with a rich pollen spectrum determined as Eocene, by P. Snopková and E. Planderová. A. Ondrejíčková determined freshwater macrofauna. Leached organic shells prove, that the sediment was effected by emergency and by atmospheric water.

Lithological and petrographical characteristics of Lower Paleogene and Mesozoic sedimentary beds

The borehole reached an extensive complex of sediments in the substratum of the Neogene. The complex may be divided into: a) a variegated conglomerate-psammite bed sequence with intercalations of limestones, shales and redeposits; b) a dolomite-limestone sequence.

a) Palynological analyses proved the upper part of the borehole, beginning in a depth of 1154,4 mm, to be Paleogene sediments. The whole part (1154,40— approx. 1600 m) is a flyschoid complex composed of red, violet, green-grey conglomerates and sandstones alternating with red sandy limestones and variegated sandy schists. Quartz fragments (10—75 %) are the main component of the conglomerates and sandstones. The substantial part consists of quartz and limestone fragments. Texture is psephito-psammitic, with fragment graded or diagonal bedding. Matrix is carbonate-clayey. Cement is carbonate, of contact and porous type. The size of fragments in psephites varies within 0,33 mm and 1,5 cm, in psammites 0,06—0,30 mm.

Thin sections of limestones indicate the intramicritic type of textures as predominating. Intraclasts consist mainly of angular quartz grains (2—10 %), of fragments of dark and light-grey micritic limestones. The size of the terrigene admixture varies between 0,02 and 0,50 mm.

Intercalations of dark-grey brecciated dolomites with intramicritic and pellmicritic textures are regarded as redeposited material. In a block of white marly limestone foraminifers were found: *Semiinvoluta carpatica* nov. spec. Salaj, *Arenovidalina* sp. These forms indicate the Norian-Rhetian.

In the basal part of the Paleogene are dark-red carbonate conglomerates (1545,0—1599,40 m). The average size of pebbles formed by light-grey, brown-grey micritic and intramicritic limestones is 1 cm. Matrix and cement are carbonatic.

b) The dolomite-limestone sequence. The lower part of the borehole consists of Mesozoic sediments (1600,0—2018,0 m). In the substratum of the Paleogene is an about 100 m thick sequence of light-grey, brown-grey marly (less sandy) limestones including intercalations of grey clayey schists with palynologically proved Cretaceous—Lower Paleogene in a depth of 1632,0 m.

Below the former is an about 35 m thick sequence of dark-grey and black marly limestones of intramicritic and biomicritic textures. Intraclasts are composed of quartz grains (2—5 %). Among organic remains are recrystallized echinoderm elements and cross-sections of thin-shell lamellibranchiates. Perhaps the limestone sequence is the basal part of the Cretaceous.

Most frequent and typical Mesozoic complex in the profile of the borehole GK-IV is a dolomite sequence commencing at 1735,5 m, extending approximately to a depth of 2018,0 m, where the borehole terminates. The dolomites are light-grey, dark-grey, compact, frequently brecciated, Middle—Upper Triassic. Microscopical examinations show

Table 4

	1758,50 m	1951,60 m	2004,00 m
insoluble residuum	2,60 %	0,98 %	0,36 %
SiO_2	5,10	2,14	0,10
Al_2O_3	0,89	0,28	0,30
Fe_2O_3	1,19	1,19	0,59
TiO_2	traces	traces	traces
MnO	0,01	0,01	0,01
P_2O_5	0,02	0,02	traces
CaO	30,69	30,69	33,34
MgO	18,55	19,91	19,91

predominantly dolomicrite, intramicrite. The terrigene admixture consists of fragments of angular monocrystalline quartz (size 0.02—0.1 mm). Infrequent is pelletic texture, dark pellets being replaced by dolomite. The average size of pellets is 0.25 mm. In a depth of 2012.80 m the dolomites comprise an intercalation of green-grey dolomite with anomalous content of the terrigene admixture of quartz (40—45 %). The following chemical analyses (tab. 4) may illustrate the general characteristics of the dolomite sequence.

Since the dolomite lithofacies in universal, and any reliable type of lithofacies was found neither in the substratum nor in the overlier, it is hardly possible to include the sequence in some tectonical structural elements of the substratum of the West Carpathians.

Palynological characteristics of the evaporite sequence and of its substratum and overlier

To find the age of sediments around Bzovík, the whole profile of the borehole GK-IV (873—1650 m) was palynologically examined. Sediments were below volcanites, between the Carpathian and the Lower Paleogene, or Upper Cretaceous. The samples were rich in pollen associations favourable for examinations of the sediments (see pl. I—III). In the sedimentation of GK-IV were five paleofloristic types different in paleoecology and stratigraphy (tab. 5).

The tropical flora with numerous *Cryptogammae* elements predominating. In this sedimentation period is the oldest flora found (in the depth of 1632—1500 m). Very frequent are also *Angiospermae* predominant in the Upper Cretaceous and Paleogene.

A different flora of Eocene nature was found in a depth of 1140 m. Besides Cryptogammae with predominating *Gleicheniaceae*, very frequent are triatrioporate pollen of *Normapolles, Myricipites, Plicapollis,* palmae of the group of *Monocolpopollenites tranquillis* (palm Phoenix), *Sabalpollenites areolatus*. Among *Coniferae* most frequent are *Ginkgoaceae*. *Cycadophyta* were obviously resedimented from the substratum. As for paleocology, the period was characterized by tropical climate with numerous *Angiospermae*.

Sediments of the evaporite sequence in a depth 1034—1056 m contain predominant *Angiospermae* with younger arctotertiary elements indicating Lower-Oligocene or Middle Oligocene age of the sediments. The next sedimentation period is represented by Ottnangian clays. Flora comprises numerous Middle—Miocene plant species and is analogous with other Ottnangian flora.

Carpathian flora in a depth 820—840 m comprises subtropical plant elements and numerous Middle-Miocene types of Sporomorphs. In that period climate was still subtropical. A comparison with Lower-Miocene flora shows relative temporary warming of climate.

The present article deals with the evaporite sequence, i. e. a short period of the entire sedimentation and of the history of flora in this area.

In a depth of 1034—1054 m flora is monotonous when compared with that of underlying sediments. The pollen pattern of the latter indicates a very abundant tropical hydrophilous vegetation.

Spore-pollen composition: Among *Cryptogammae* frequent are only *Leiotriletes adriennuis, Leiotriletes paramaximus, Corrsporis tuberculatus* (W. Krutsch 1967 quoted that spore from Middle Oligocene) and *Gleichenidites*. The rest of flora comprises *Angiospermae* of triatriopolenites, tricolpate, tricolporate and tetracolporate

1.

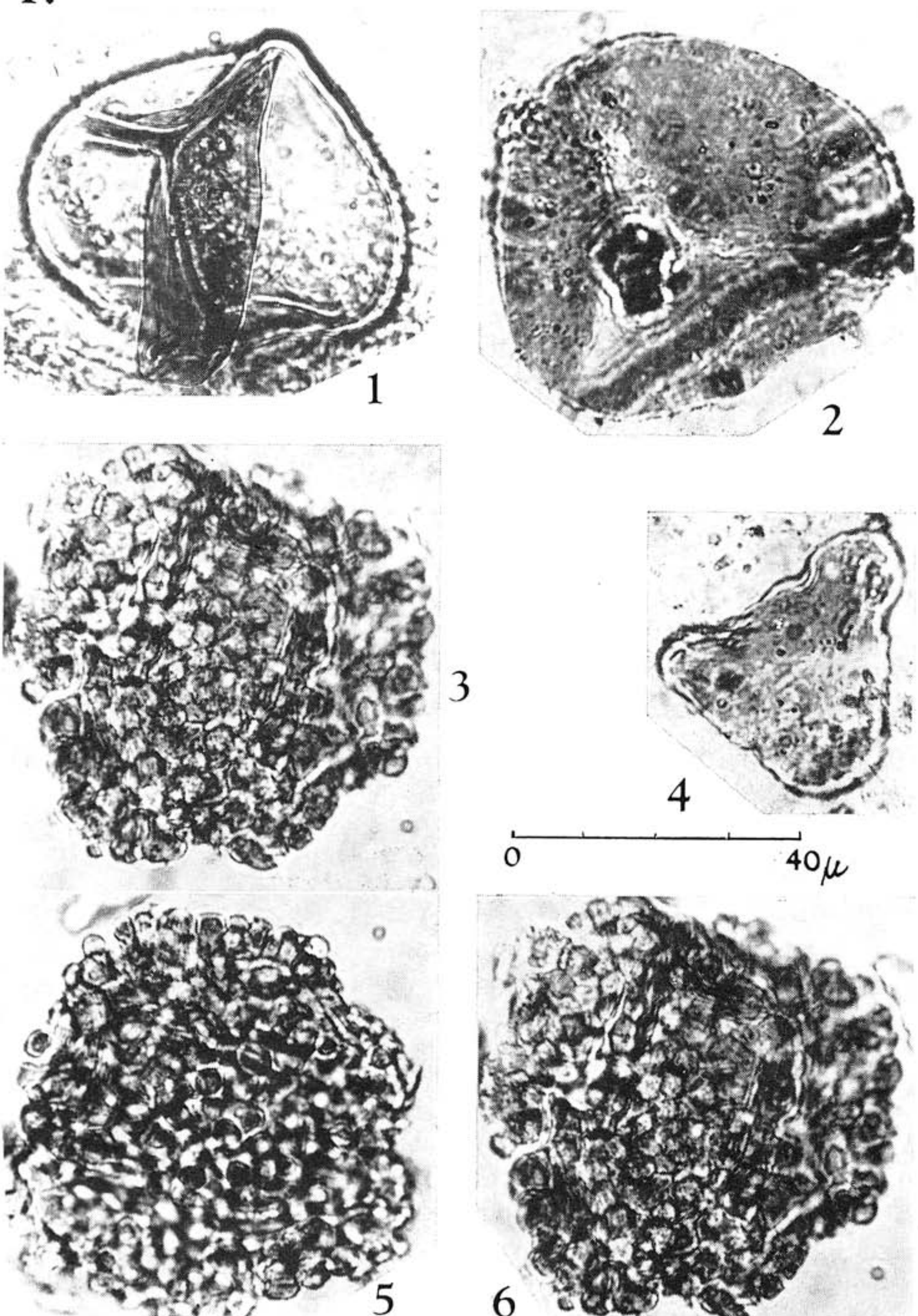

Plate I

Fig. 1. *Leiotriletes paraximus* Krutsch 1959. — Fig. 2. *Leiotriletes adriennis* (R. Pot. et Gell. 1933) W. Kr. 1959. — Fig. 3, 5, 6. *Corrusporis tuberculatus* W. Kr. 1967. — Fig. 4. *Undulatisporites concavus* Kedves 1961.

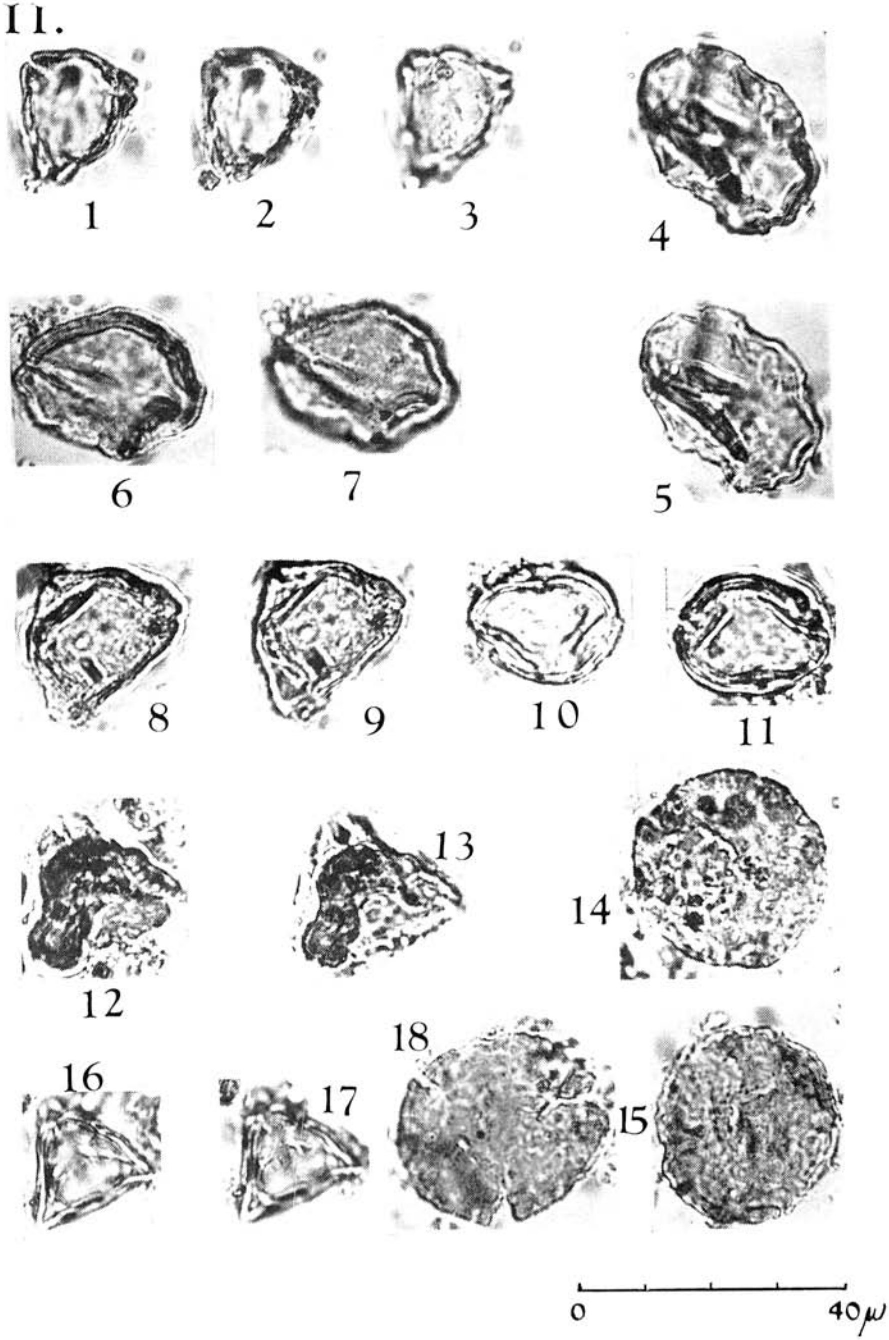

Plate II

Fig. 1—3. *Triatriopollenites excelsus* subsp. *turgidus* P f. 1953. — Fig. 4—5. *Pterocaryapollenites* sp. — Fig. 6—7. *Momipites* sp. — Fig. 8—9. *Myricipites myricoides* (K r e m p 1950) N a g y 1969. — Fig. 10—11. *Myricipites rurensis* (T h. et P f. 1953) N a g y 1969. — Fig. 12—13. *Oculopollis* sp. — Fig. 14—15. *Nothofagidites makinsenii laesigatus* K e d v. 1962, — Fig. 15—17. *Slowakipollis* sp. — Fig. 18. *Pollenites laesus* R. P o t. 1934.

III.

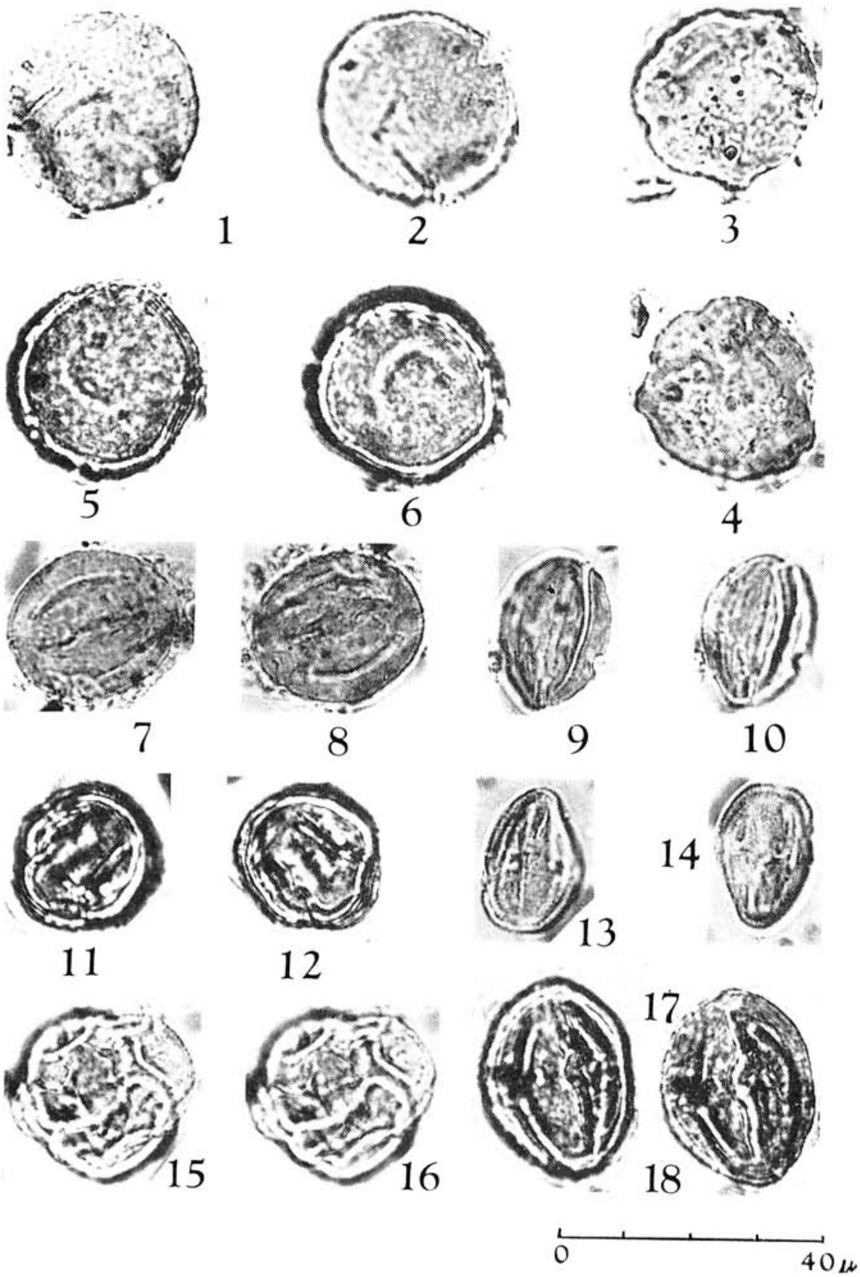

Plate III

Fig. 1—3. *Caryapollenites simplex.* — Fig. 4—5. *Carpinuspollenites stellatus.* — Fig. 5—6. *Subtriporopollenites* cf. *vadosus* (P f. 1953) W. K r. 1962. — Fig. 7—8. *Tricolporopollenites parmularius* (R. P o t.) P f. et T h. 1953. — Fig. 9—10. *Tricolporopollenites* sp. — Fig. 11—12. *Cyrillaceaepollenites megaexactus* (R. P o t. 1931) R. P o t. 1960. — Fig. 13—14. *Tricolporopollenites* typus *microreticulatus.* — Fig. 15—16. *Ericipites* sp. — Fig. 17—18. *Tricolporopollenites villensis* (T h. 1950) P f. et T h. 1953.

Table 5

bore-hole	facies	strati-graphical age	samples for pa-lynology	main types of sporomorphs	paleoecology
790 m 882 m	clayey silt slightly calcareous	Carpathian	820 m 823 m	*Pinus silvestris, Pinus Haploxylon, T. henrici, Lauraceae, Myricaceae, T. liblarensis, T. cingulum, Liquidambar, Rhus, Betulaceae, Oleaceae, Tsuga, Momipites punctatus, Sapotaceae, Engelhardtia, Quercus, Ulmus, Alnus*	subtropical humid
882 m 890 m	silty sand		832 m		
890 m 941 m	sandy silt slightly calcareous	Ottnangian	976 m 980 m	*Cyrillaceae, Lauraceae, Engelhardtia, Sapotaceae, Ilexpollenites, Diospyros, T. villensis, Nyssaceae, Myricaceae, Lygodium, Myricipites plicatus, Pterocarya, Taxodiaceae, Polypodiaceae, Pinus silvestris, Symplocaceae*	subtropical humid
941 m 987,8 m	silty clay		986 m		
987,8 m 1006 m	dolomitized clayey limestone	Upper Paleogene	1030 m 1034 m	*Triplanosporites, Saxosporites, Cyathidites, Triatripoll. excelsus, Caryapollenites, Pterocaryapollenites, Slowakipollis, Nyssaceae, Quercus, Cyrillaceae, T. microhenrici, T. henrici, Ilex, Engelhardtia*	tropical-subtropical arid
1006 m 1130 m	anhydrite-dolomite sequence	Lower Paleogene	1054 m		
1130 m 1155,4 m	claystone slightly calcareous, siltstone and sandstone	Eocene	1130 m 1140 m 1142 m 1147 m	*M. tranquillus, Sabalpoll. areolatum, Trilites, Gleichenidites, Stereisporites, Toroisporites, Cyathidites, Plicapollis, Oculopollis, Triatriopoll. bituitus, T. cingulum, T. liblarensis, Tetracolporopoll., Engelhardtia*	tropical-subtropical humid
1155,4 m 2018 m	many-coloured conglomerates and sandstones	Lower Paleogene Cretaceous	1550 m 1632 m	*Monocolp. tranquillus, T. cingulum, Polypodiaceoispor., T. villensis, Concavisporites, Oculopollis, Tetracol. sapatoides, Caryapoll. triangulus, Gleichenidites, Alnus, Triletes*	humid tropical with rich spores of Pteridophyta

morphological groups. These groups are very frequent in the evaporite samples and comprises ecologically mixed and varied elements. Among these are pollen of typical Paleogene genera and species absent in Miocene and morphological species which are also in Lower Miocene. These are: *Pterocaryapollenites*, various species of the genus *Myricipites*, *Tricolporopollenites microhenrici*, *Tricoloporollenites henrici*. On the other hand there are pollen of Younger Oligocene—Miocene flora including the genus *Slowakipollis* sp. with two different species and *Juglanspollenites*. The Oligo-Miocene flora in the evaporite sequence comprises pollen of the families *Nyssaceae*, *Carya*, *Ulmus*, *Chenopodiaceae*, *Castanea*, *Cupuliferae*, *Engelhardtia*, *Typha*, *Cyrillaceae*.

This sporomorph pattern represents two mixed types of flora. Some species of tropical flora are gradually replaced by subtropical species with more numerous arctotertiary plant types.

Paleoecological study of the evolution of flora, beginning with underlying Eocene sediments points out to a regressive period in the course of the genesis of evaporite sediments. Here is much poorer flora in species than Eocene flora, and among *Cryptogammae* only few species are preserved in the evaporite sediments. The conspicuous climatic change took place between the Eocene and Middle Oligocene in this area. Its cause is perhaps in regression of the sea, in a longlasting arid period accompanied with the extinction of abundant fern-like vegetation. Due to this period also the marsh areas were replaced by small drying lakes with only a non-extensive zone of humid soil. During this period no coniferous species appeared, being very frequent in the Central-Carpathian Paleogene (P. S n o p k o v á 1971).

An analogous regressive period was also in the Lower Oligocene of the area around the Hron river (Polomka-Brezna, E. P l a n d e r o v á in print). Flora is somewhat different here, still its xerophilous character is in common with the former.

As for the age of the sediments examined, it is Lower—Middle Oligocene, as indicated mainly by the presence of the genus Slowakipollis. The latter used to appear only as late as the Oligocene.

Conclusions

1. A detailed evaluation of all the positive samples with sporomorphs from the borehole GK-IV, concerning the evolution of flora from Upper Cretaceous to Carpathian (in Neogene), showed that Upper-Cretaceous or Lower Paleogene hydrophilous tropical flora gradually changed. In the evaporite sequence it is replaced by suptropical xerophilous flora and in Ottnangian comprises arctotertiary genera and families that may be correlated with pollen spectra known from the area of Modrý Kameň.

2. The evaporite sequence is of Lower to Middle Oligocene age.

3. In the period studied, climate was subtropical, arid, with the rests of Paleogene and arctotertiary flora.

4. The results of pollen analyses were correlated with pollen spectra of the West-Carpathian Paleogene (P. S n o p k o v á 1971) and the inner depressions (E. P l a n d e r o v á in lit.).

5. Miocene sediments in the substratum of the volcanic Badenian in the borehole GK-IV — Ottnangian — a facies of overlying clays and Oncophora sands, and Carpathian — a facies of manganese sands and a schlier facies show only slight difference from the Ottnangian and the Carpathian of the Ipeľská kotlina. Different is the degree of sorting in Oncophora sands — a proof that the sedimentation around Bzovík pro-

ceeded in a quiet, partially closed environment. Absent are some minerals of metamorphic origin, typical of sandy facies in the Carpathian of the Ipeľská kotlina: the pebble and sandy material are Mesozoic, and especially dolomite clastic material.

6. A sulphate-carbonate sequence with 8—90 % of terrigene material either as an admixture in carbonates or as siltstone beds with carbonate cement. The sequence contains dolomite with a slight excess of Ca-component — up to $Ca_{54}Mg_{46}$ mole %. Calcite is in basal and terminal parts of the evaporite sequence. In the basal part are calcite relicts of organisms, mainly of algae, in the terminal — calcite pseudomorphoses after gypsum. Anhydrite either forms pseudomorphoses after gypsum or fills pores and cracks, or forms fine layers separated by lamines of dark clay. Its content varies between 2 and 80 %.

7. The average content of Sr is 10 x higher in the evaporite sequence than in underlying and overlying sediments. Sr is bound mainly to the mineral celestine which is the filling of pores and vesicles on the contact of dolomite and dolomite-anhydrite sedimentation. Fine crystals of celestine (up to 10 μ) were found in dolomite and anhydrite by electron microanalyser. A little amount of Sr (approx. 0.4 %) is diadochically built in dolomite, approx. 0.2 % in anhydrite. The Sr content decreases with the increasing portion of the terrigene component and boron.

8. The B-content is greatest in separated clays of the evaporite sequence, decreasing gradually in overlying clays and in Oncophora sands of the Ottnangian. The amount of adjusted boron in dolomites has 2 maximums corresponding to the values for slight-evaporite dolomites: other values being within the scope of values for marine sediments.

9. The genesis of the evaporite sequence is supposed to be analogous with recent evaporites forming on a pericoastal flat plain in arid warm climate due to evaporation of brines ascending through capillaries to the surface of porous sediments. Dolomite arose in early diagenesis by substitution of aragonite in the process of forming of gypsum. Anhydrite arose diagenetically by substitution for gypsum forming idiomorph crystals or layers, or secondary filling of vesicles and cracks.

10. Light porous dolomites of microcrystalline texture arose perhaps by dolomitization of vitreous volcanic tuffs or tuffites — as indicated by the presence of pyroxene, amphibole, and volcanic glass in the insoluble residuum.

11. Underlying Eocene sediments of 25.4 m thickness differ from the evaporite sequence in their high content of calcite, in the presence of carbonised plant remains and of leached shells of freshwater macrofauna, indicating that the sediment was affected by emergency and by atmospheric water.

Translated by E. JASSINGEROVÁ.

REFERENCES

BALOGH, K., PANTÓ, G., 1953: Mezozoikum severného Maďarska a priľahlých častí Juhoslovenského krasu. Sbor. Ústř. úst. geol., odd. geol. (Praha), 20, p. 613—631.

BIELY, A., 1962: Ročná zpráva o výskume na úkole 01-0-5. Štúdium štruktúr na okraji neovulkanitov. Manuscript, Archiv Geol. úst. D. Štúra, Bratislava.

BIELY, A., 1964: Zpráva o výskume mezozoika v levických ostrovoch. Zprávy o geol. výskumoch v roku 1964 (Bratislava), 2, p. 60—62.

BYSTRICKÝ, J., 1963: Stratigrafia a vývin triasu série Drienka. Zprávy o geol. výskumoch v r. 1963 (Bratislava), 2, p. 94—96.

CURTIS, C. D., 1964: Studies on the use of boron as a paleoenvironmental indicator. Geochim. cosmochim. Acta (London), 28, p. 1125-1137.

ĎURATNÝ, S., FUSÁN, O., KUTHAN, M., PLANČÁR, J., ZBOŘIL, L., 1967: Výskum hlbokého podložia neovulkanitov stredného Slovenska. Správa pre priebežnú oponentúru. Manuscript, Archiv Geol. úst. D. Štúra, Bratislava.

FOLK, R., L., 1959: Practical petrographic classification of limestones. Bull. Amer. Assoc. Petrol. Geologist (Tulsa), 43, 1, p. 1—38.

FOLK, R., L., PITTMAN, J., S., 1971: Length slow chalcedony, a valuable criterion for recognition of evaporitic strata. Abstracts of VIIIth Intern. Sedimentol. Congress (Heidelberg), p. 1—30.

FÜCHTBAUER, H., MÜLLER, G., 1970: Sedimente und Sedimentgesteine. E. Schweizerbartsche Verlagsbuchhandlung (Stuttgart), p. 1—726.

HARDER, H., 1970: Boron content of sediments as a tool in facies analysis. Sedimentary Geology, Elsevier (Amsterdam), 5, 1.

ILLING, L., V., WELLS, A., J., TAYLOR, J., C.; M., 1965: Penecontemporary dolomite in the Persian Gulf. In: Murray, R., C., Pray, L., C. (Editors): Dolomitization and limestone diagenesis. A Symposium (Tulsa), p. 89—111.

JANÁČEK, J., ŠIMÁNEK, V., 1969: Die Vorkommen chemischer Sedimente in der Slowakei und die geochemischen Probleme ihrer Sedimentation. Ber. deutsch. Ges. geol. Wiss. B, Miner. Lagerstätten (Berlin), 14, 1, p. 31—42.

KANTOROVÁ, V., 1970: Foraminifery a ich sprievodné mikrofosílie z podložia tortonských vulkanitov Krupinskej vrchoviny z vrtu GK-IV pri Bzovíku. Manuscript, Geofond (Bratislava), p. 1—65.

KEDVES, M., 1961: Zur palynologischen Kenntnis des unteren Eozäns von Halimba. Acta Biol., N. S. (Szeged), 7, No. 3—4, p. 25—41.

KEDVES, M., 1962: Études palynologiques de quelques échantillons du bassin de Tatabánya. Pollen et Spores (Paris), 4, No. 1, p. 155—168.

KONEČNÝ, V., 1969: Záverečná správa štruktúrneho vrtu GK-IV (Bzovík). Manuscript, Geofond (Bratislava), p. 1—244.

KRUTZSCH, W., 1967: Atlas der mittel und jungtertiären dispersen Sporen und Pollen sowie der Mikroplanktonformen des nördlichen Mitteleuropas. Lief. IV und V. Berlin.

KREMP, G., 1950: Pollenanalytische Untersuchung des miozänen Braunkohlenlagers von Konin an der Warthe. Palaeontographica B (Stuttgart), 90, p. 53—93.

KRUTZSCH, W., 1959: Mikropaleontologische (sporenpaleontologische) Untersuchungen in der Braunkohle des Geiseltales. Geologie (Berlin), 22, p. 15—53.

KUTHAN, M., KAROLUSOVÁ, E., 1966: Dielčia záverečná správa za rok 1964—1966 k vrtu GF-2. Manuscript, Archiv Geol. ústavu D. Štúra, Bratislava.

KUTHAN, M., KONEČNÝ, V., 1964: Výskum hlbokého podložia neovulkanitov stredného Slovenska. Zprávy o geol. výskumoch za rok 1964 (Bratislava), 2, p. 142—144.

MARKOVÁ, M., MEIER, R., 1972: Terciérne evapority v podloží neovulkanitov Krupinskej vrchoviny. Geol. práce, Správy (Bratislava), 58.

PLANDEROVÁ, E., 1971: Nové poznatky o vývoji centrálnokarpatského paleogénu. Geol. práce, Zprávy (Bratislava).

PFLUG, H., D., 1953: Zur Entstehung und Entwicklung der angiospermiden Pollen in der Erdgeschichte. Palaeontographica (Stuttgart), 95, p. 60—171.

POTONIÉ, R., 1931: Pollenformen der miozänen Braunkohle (2. Mitt.). Sitzb. Gesselsch. Naturf. Feund. (Berlin), p. 2—26.

POTONIÉ, R., 1934: Zur Morphologie der fossilen Pollen und Sporen. Arb. Inst. für Paleobot. und Pet. der Brennsteine (Berlin), p. 1—125.

POTONIÉ, R., 1956—1970: Synopsis der Gattungen der Sporae dispersae. Beih. Geol. Jb. (Berlin), 1. N. p. 1—103, 2. II.

SNOPKOVÁ, P., SAMUEL, O., 1971: Stratigrafia eocénu budínskeho vývoja na základe sporomorf a malých foraminifer. Dielčia záverečná zpráva. Manuscript, Archiv Geol. úst. D. Štúra, Bratislava.

THOMSON, P. W., 1950: Grundsätzliches zur tertiären Pollen und Sporenmikrostratigraphie auf Grund einer Untersuchung des Haupflözes der rheinischen Braunkohle in Liblar, Neurath, Fortuna. Geol. Jahrbuch (Hannover), 65, p. 102—130.

THOMSON, P., W., PFLUG, H., 1953: Pollen und Sporen des mitteleuropäischen Tertiärs. Paleontographica (Stuttgart), 94, p. 1—138.

USDOWSKI, H., E., 1967: Die Genese von Dolomit in Sedimenten. Mineralogie und Petrographie in Einzelldarstellung, B IV. Springer Verlag (Berlin), p. 1—95.

VASS, D., MARKOVÁ, M., FUSÁN, O., 1968: Dependence of the development of tertiary basins in the inner side of the West-Carpathian arch upon the structure of the substratum Geol. práce, Správy (Bratislava), 44—45, p. 137—147.

VOZÁR, J., 1969: Litologicko-petrografický výskum mezozoických hornín z podložia neovulkanitov prevŕtaných štruktúrnym vrtom KOV-40 Podsitnianska. Manuscript, Archiv Geol. ústavu D. Štúra, Bratislava.
VYSVETLIVKY k prehľadnej geologickej mape ČSSR 1 : 200 000, M-34-XXXIII Rimavská Sobota. Geofond, Bratislava, 1962.

Review by J. GAŠPARÍK.