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of the kaolin sediments
of the Horní Bříza and Kaznějov
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Dedicated to the memory of Karel Kaas, geologist of the West-Bohemian Ceramics Works
Věnováno památce Karla Kaase, geologa Západočeských keramických závodů

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Abstract: The kaolin sediments of two largest kaolin deposits in the Plzeň basin have been categorized according to their grain size into six petrological types. By semi-quantitative analyses an admixture of quartz and micaceous material has been established in washed kaolins; chemical analyses of washed kaolins and tables showing the content of selected trace elements are given. Some technological properties of washed kaolins (viscosity, dry strength) depend on their grain size. The evidence concerning the genesis of the kaolins of these deposits testifies to the prevailing kaolinization in the source area of the sediment; partial kaolinization processes taking place during the Cretaceous-Tertiary times cannot be entirely excluded. The causes of coloration of these kaolins are primary as well as secondary.

INTRODUCTION

The deposits of kaolin of the arkosic type in the Horní Bříza and Kaznějov area have been industrially exploited since the beginning of this century, due to the outstanding technological properties of this raw material used especially as a filler material in the paper and rubber industries and for fine ceramics. Recently, new lines of use have been added to the above traditional industrial branches, especially as far as the Kaznějov kaolins are concerned (paper coating, plastics filling, glass fibres, insulators, chemicals, medicaments and insecticides production etc.).

The geological problems of both deposits have recently been much studied petrologically (GREGOROVÁ 1961; MALECHA 1968; NEUŽIL, ŠINDELÁŘ and KUŽVART 1973; KUŽVART et al. 1975) as well as from the depositional point of view (POUBA et ŠPINAR 1955, 1957a, b, 1958a, b; HRÍBAL et PEŠEK 1961; WILD 1967, 1969, 1971). The conclusions drawn by the authors of the individual papers indicate that there are different views as to the problems concerning the genesis of the kaolin deposits in the Plzeň basin.

In this paper some recent geological field observations are presented together with analytical data and inferences concerning the geology and petrology of the kaolin deposits in the Horní Bříza and Kaznějov area. Particularly treated are the problems of the genesis and coloration of the kaolinitic sediments in the area under consideration. As the present author assumes a secondary origin of both deposits, and as the kaolin-bearing rocks mostly do not carry feldspars or pseudomorphs after feldspars, these rocks are recorded in this paper as kaolinitic sandstones, conglomerates, siltstones etc., in contrast to the term „kaolinitic arkose“ often incorrectly used in the literature (see also GREGOROVÁ 1961; JIRÁNEK — in press).

GEOLOGICAL SETTING

The stratigraphic position of both deposits was for a long time not clear. On the basis of studies by DVOŘÁK and PEŠEK (1962) and MALECHA (1968), these deposits are today assigned to the Týnec (Lower Red) Formation representing the Lower Stephanian filling of the Permo-Carboniferous Plzeň basin.

The two deposits are not quite synchronous. The Horní Bříza kaolin deposit at a stratigraphically lower level, is characterized by brighter tints of the kaolinitic rocks and by an increased frequency of ruddy clay intercalations. These facts can be genetically substantiated by the early stage of peneplanation of the surroundings of the

basin which made possible a frequent wash of variegated weathering product of Proterozoic rocks, and by lack of time for deferrization processes in the source area of the sediment. The main part of the Kaznějov deposit consists of rather fine-grained kaolinitic sediments displaying high whiteness; their brighter coloured analogues with interlayers of ruddy clays are known only from the lowermost parts of this deposit. In fig. 1 is presented an idealized section through the deposits, comprising their main formations. However, the ideal sequence of beds given below did not develop in any portion of the deposits, or has not been preserved in its entire thickness:

1. the upper conglomerate layer (minimum thickness 15 m),
2. mostly fine-grained white kaolinitic sandstones with interlayers of light-coloured clays (thickness about 95 m),
3. medium — to coarse-grained whitish and coloured kaolinitic sandstones with interlayers of light-coloured and ruddy clays (maximum thickness 110 m),
4. transition zone (alternation of kaolinitic sandstones, kaolinitic and non-kaolinitic arkoses; maximum thickness 30 m),
5. bedrock (non-kaolinitic arkoses with clay interbeds).

The rocks overlying and underlying consist here of arkoses and arkosic sandstones (with non-kaolinized feldspars). The same rocks appear in the tectonic vicinity of the kaolinitic rocks. It seems that the raw kaolins of quality from the industrial point of view (content of washable constituents exceeding 12 %, whiteness above 68 % that of MgO) laterally interfinger with raw materials which are unsuitable and of low whiteness, probably constituting the greater part of the area built of kaolinitic sediments (fig. 2). Part of the arkoses underlying the kaolin-bearing sediments already belongs to the Permo-Carboniferous Kladno (Lower Grey) Formation. The Permo-Carboniferous filling of the basin in the area of the deposits attains thicknesses of 180—270 m. The bedrock of the basin consists of Proterozoic rocks. A real geological section through the Plzeň basin at the sites of the main kaolin deposits demonstrate the structural bores shown in fig. 3.

The boundary of the kaolinitic and non-kaolinitic rocks underlying the deposits is not sharp, but in a zone about 30 m thick, kaolinitic sandstones alternate with quite non-kaolinitic arkoses in sharply separated segments from 0.1 to 4 m. The white kaolinitic sandstones sharply contrast rusty up to brown non-kaolinitic arkoses whose feldspars display a maximum degree of weathering analogous to that in other relatively fresh arkoses of the Central Bohemian basins. The alternation of beds in the main basal positions of the kaolin deposits serves as a proof of the secondary position of these layers (JIRÁNEK in press). In addition to the bore HB 8/75 given in the above-mentioned paper, this geological setting is especially clearly marked in the bore VHS 1/72 (Geindustria Praha) in the Kaznějov deposit III (junction of the Horní Bříza and Kaznějov deposits) where the intercalations of non-kaolinitic arkoses are not developed at the base, but within the rock sequence in the deposit. At depths of about 12.4—15.0 m in this bore are pale-grey to greyish and yellowish medium-grained kaolinitic sandstones with thin interlayers of more solid arkose with non-weathered feldspar grains. Kaolinitic sandstones (slightly kaolinitic only at their base) then continue downward for about 50 m at least. Evidence of the alternation of kaolinitic and non-kaolinitic rocks underlying the deposits has also been furnished by further bores. Another bed of the underlying kaolinitic sandstones separated from the main Kaznějov deposit by non-kaolinized arkoses has been reported by MALECHA (1968).

The layers of both deposits dip 5—20° to the W. In the proximity of some tectonic displacements a lowered dip angle was observed (Horní Bříza, opencast). The area of

the deposits is disturbed by normal faults whose strike agrees with the main tectonic lines of the Plzeň basin. The earlier system of faults which is more frequent here and is parallel to the deposits strikes NNW-SSE, whereas the younger transverse system strikes WSW-ESE. In the portion of the Horní Bříza deposit being exploited at the present time a system of longitudinal normal faults has been encountered; they strike 140°, dip to the NE and their normal throw is 0.5—75 m. The assumed age of the faults is Saxonian, but most of them were active during the sedimentation (increased thicknesses of beds in subsided blocks). The exploited part of the Kaznějov deposit was not affected by fault tectonics.

The sediments of both deposits are characterized by the typical features of river-bed facies. The grain size of the sediments suddenly varies, this becoming manifest by the frequent alternation of conglomerate, sandstone, siltstone (a material in Czech called „šlika“) and clay beds. The boundaries between the layers are mostly sharp; locally, gradual transitions with graded bedding have been established. The beds often wedge out and interfinger. Cross bedding is very frequent.

Within the deposits a graded sequence of beds of the (A)BCDEF type can only rarely be observed. The bore VHS 5/73 in the Kaznějov deposit III (fig. 4) may serve as an example:

- 32.4—35.6 conglomeratic kaolinitic arkose with abundant pebbles up to 15 cm in size (A),
- 35.6—37.0 finely sandy claystone (F)
- 37.0—38.5 strongly sandy claystone up to very fine-grained kaolinitic sandstone (E),
- 38.5—39.7 very fine-grained kaolinitic sandstone (D),
- 39.7—40.0 fine-grained kaolinitic sandstone with pebbles up to 5 cm (C),
- 40.0—44.5 medium-grained kaolinitic sandstone with abundant pebbles up to 5 cm in size (B),
- 44.5—45.0 fine-grained kaolinitic sandstone (D),
- 45.0—46.0 finely sandy claystone (F).

The basal conglomerate layer (A) is often absent and siltstone (D) and particularly clay (E, F) beds also are sometimes lacking. Cycles, e. g., AB, BC, ABC, (A)BCE, (A)BCF etc. (fig. 5) are abundant. Some beds lacking in the cycles have probably not been deposited at all. However, many of the layers were provably denuded during short hiatuses in the deposition. Evidence of this is furnished especially by abundant clay balls (derived from the original continuous layers) at the base of the conglomerate beds. Fig. 6 shows an example from the Kaznějov deposit where sedimentation set in after a rather long hiatus associated with a strong washing out of the surface of the underlying beds. The conglomerate bed filled all the of the bedrock, and the clay balls 20—30 cm in diameter concentrated especially in fossil erosion grooves. The deposition of the conglomerate beds was accompanied by a synsedimentary tectonics.

The kaolinitic rocks in the area of the deposits under consideration attain depths of 80 m (Horní Bříza) and 90 m (Kaznějov). In the structural bore SV 62/57 near Horní Bříza, these rocks have been encountered at a depth of 110 m (fig. 3).

GRAIN SIZE FRACTIONS AND PETROGRAPHIC TYPES OF SEDIMENTS

It follows from the above that the petrographic types of the kaolinitic sediments in the Horní Bříza and Kaznějov deposits are to be specified on the basis of their different grain sizes. The variable content of washed kaolin (i. e. washable particles below 15—20 μm) also depends on grain size. The highest washed kaolin content is at

a maximum — irrespective of clays — in the siltstone beds (30–40 % including a very fine quartz), and at a minimum in conglomerates (4–9 %; JIRÁNEK — in press). A further physical property, whiteness (or coloration) strongly varies within the individual types of kaolin.

The determination of the petrographic types of the sediments in the Kaznějov deposit has already been dealt with by GREGOROVÁ (1961) who has differentiated conglomerates with kaolinite cement, kaolinitic sandstones and sandy-silty kaolinitic claystones, and has presented a detailed macroscopic and microscopic description of them.

For the scope of this paper, all samples were taken from macroscopically different beds of the 60 m deep bore Ka 40/75 (ZKZ* Horní Břiza) in the NNW foreland of the Kaznějov opencast; and their sieve and sedimentation analyses (according to Andreasen) have been carried out. The results are shown in table 1. From the results of the granulometric analysis, the pebble, sand, silt and clay fractions proportions have been calculated and plotted in a classification diagram (fig. 7) constructed according to KONTA (1972). On the basis of these results and field observations the conclusions drawn by GREGOROVÁ (1961) have been adapted and rendered more precise by a more detailed categorization of the petrographic types of the kaolinitic sediments of the Kaznějov deposit. They are as follows:

I. Conglomerates with a kaolinite cement — rocks of a considerably variable grain size distribution. As follows from the fairly great dispersion of the experimental small triangles in fig. 7, the pebble component predominates and then the sandy, silty or clayey component (i. e. sandy-silty, silty-sandy and clayey-sandy conglomerates) follows. The sandy-silty and silty-sandy conglomerates with a kaolinite cement contain a rather large volume of a clayey admixture, and, in contrast, the clayey-sandy conglomerates contain a considerable amount of silt, as can be inferred from the areas of the small triangles in fig. 7. In addition to the grain size distribution, the size of the pebbles (fragments exceeding 2 mm) varies very strongly. In the literature, these rocks are often incorrectly termed kaolinitic conglomerates and coarse-grained kaolinitic arkoses.

II. Silty-conglomeratic up to conglomeratic-silty kaolinitic sandstones constitute a sharply bounded group of sediments. According to the individual samples given in the classification diagram (fig. 7), they overlap each other forming a continuous row of sandstones — from the silty-conglomeratic through conglomeratic-silty to almost purely silty kaolinitic ones. From the areas of the small triangles an increased content of clay particles can be inferred. The rocks of this group are often incorrectly designated as medium-grained kaolinitic arkoses (i. e. silty-conglomeratic kaolinitic sandstones) and fine-grained kaolinitic arkoses (i. e. conglomeratic-silty to silty kaolinitic sandstones).

III. The grain sizes of the clayey-conglomeratic kaolinitic sandstones with a silty admixture have been found in one sole sample from the bore Ka 40/75 which corresponds to the medium-grained kaolinitic arkoses (an incorrect but deep-rooted term).

IV. Clayey-silty to silty-clayey kaolinitic sandstones form a relatively dispersed group of sediments partly overlapping into conglomeratic-silty kaolinitic sandstones, in this way linking up — after a short interruption — with

* West-Bohemian Ceramics Works

the group given above sub II. Apart from two samples, all the analyzed rocks of this group contain a minor amount of pebble fraction. The rocks of this type are often incorrectly termed very fine-grained kaolinitic arkoses.

V. Sandy to clayey-sandy siltstones also contain a minor amount of pebble, and in the bore studied they are represented by one solitary sample. The low content of the clay component (5.73 % in the sample from a depth of 55.30—55.85 m of the bore Ka 40/75) is the reason why these rocks are unsuitable for the production of washed kaolins. The rocks of this group are usually designated by the Czech name „šlika“ because of their macroscopic appearance which equals that of the mesh fraction of a hydrocyclone 150 mm in diameter, produced during the kaolin washing process.

VI. In the group of claystones, the grain size distribution was not specified in this paper. According to GREGOROVÁ (1961) sandy-silty claystones are involved, that is claystones with a considerable admixture of silt, probably those passing to sandy-clayey siltstones. The claystones from both deposits are distinguished by a low degree of consolidation and it is therefore more convenient to term them clays.

According to the results of grain size analysis, the kaolinitic sediments of the Kaznějov deposit constitute several sharply bounded groups of rocks. All the analyzed rocks are poorly sorted and contain all four grain size components. Fig. 7 illustrates the volume of the poorest fraction, which can be inferred from the areas of the small triangles plotted. In the right-hand half of the figure this is a conglomerate fraction; in the left half a clay fraction, and in two samples shown to the left above the fraction is a silty one.

The typical frequency curves of the rocks chosen from the bore Ka 40/75 are shown in fig. 8. From the course of the curves it follows that with decreasing grain size estimated with unaided eye the content of the conglomeratic component decreases, whereas the amount of the finely sandy component increases greatly, and the contents of the silty and clayey components slightly increase.

As the Horní Bříza deposit is built up of analogous types of sediments, the conclusions of this chapter may be fully applied to it.

MINERALOGICAL ANALYSES

Detailed mineralogical and petrological analyses (descriptions, qualitative optical analysis, granulometric analysis, X-ray and DTA analyses, weight and thermal dehydration, electron microscopy and chemical analysis) of the kaolins from both deposits have been published in the papers by KONTA (1957), GREGOROVÁ (1961), NEUŽIL, ŠINDELÁŘ and KUŽVART (1973) and KUŽVART et al. (1975). This chapter is restricted to some data supplementary to the results already published.

In the washable kaolin fraction below 15—20 μm of the kaolinitic sediments from the Horní Bříza and Kaznějov deposits, the mineral which prevails throughout, is a well crystallized idiomorphic kaolinite displaying a perfectly ordered structure, i. e. kaolinite T (KONTA 1957, GREGOROVÁ 1961). Its perfect ordering has been proved partly by the diffractograms of the respective reflections, partly by photographs taken under the electron microscope (figs. 9 and 10).

The washable fraction (below 15—20 μm) of the kaolinitic sediments from both deposits also contains a small proportion of quartz and a micaceous mineral (sericite and illite). The amount of this admixture has been assessed semi-quantitatively from X-ray diffractograms of washed Kaznějov kaolins carried out using a MÜLLER MIKRO 111 apparatus in the X-ray laboratory of the Geological Survey, Praha (table 2). The amount of quartz is shown by the ratios between the X-ray intensities of the

diffraction lines (001) of kaolinite and (101) of quartz (the lower of the ratio means a higher quartz content). The amount of the micaceous minerals is given directly as a percentage of the total amount of clay minerals (kaolinite+illite) in the sample, which has been determined according to the methods of PIERCE and SIEGEL (1969) and SCHULTZ (1955), on the assumption that the ratio of the areas of reflections (001) of kaolinite and (001) of illite is directly proportional to the weight percentage of kaolinite and illite

$$\frac{w_i}{w_k} = \frac{p_i (001)}{p_k (001)}$$

where w_i and w_k represent the weight proportion of illite and kaolinite, and p_i and p_k are the areas of the peaks (001) of illite and (001) of kaolinite. According to unpublished results obtained by ČANĚK (VÚHU, Most), this method seems to be adequate for a semi-quantitative determination of the micaceous mineral content in the Kaznějov kaolins.

From the results shown in table 2 it follows that the amount of admixed quartz and micaceous mineral decreases with progressing sorting of washed Kaznějov kaolins. As to quartz, this is connected with its presence in the coarsest fractions of washed kaolins. The removal of this quartz by finer sorting is not possible without the simultaneous removal of a portion of the coarser kaolinite whose grain size partially coincides with that of the finest quartz. Likewise, in washed kaolins, in the case of the micaceous mineral, a higher content of sericite and rather coarse illite particles can be inferred. Whereas in finer fractions of washed kaolins the amount of quartz and micaceous mineral decreases, the proportion of an alunite mineral increases in the same direction as has been shown by ČANĚK's unpublished results of an X-ray analysis using the Guinier-de Wolff camera.

In the stratigraphically lowest eastern part of the Horní Bříza opencast, aggregations of a green mass have been found; they have been identified using X-ray, DTA and chemical analyses as illite with some kaolinite. The boundary of this illitic mass with the white kaolinitic mass is sharp. From the occurrence of this mass together with clay-wise weathered green pebbles of Proterozoic volcanics, it may be concluded that locally redeposited weathering products of the above-mentioned rocks are involved.

CHEMICAL ANALYSES

The chemical analyses of the Kaznějov raw kaolin and the washed Kaznějov and Horní Bříza kaolins (fraction below 15–20 μm) carried out in the laboratory of the West-Bohemian Ceramics Works (ZKZ), Horní Bříza, are ordered according to the decreasing grain size of the raw material and the commercial products listed in table 3. Analyses nos. 1, 3 and 5 represent annual means for the years 1970–71, the other analyses concern the products obtained during September 1976. According to expectations, an increase of Al_2O_3 and $\text{H}_2\text{O}+$ and a decrease of SiO_2 with decreasing grain size appeared in the results of the chemical analyses. This is due to a relative rise of the content of kaolinite during the decrease of the amount of quartz in consequence of a finer sorting (see also the chapter Size distribution of washed Kaznějov and Horní Bříza kaolins etc.). The amount of the other elements present mostly in finer clay fractions (Fe_2O_3 , CaO , MgO , K_2O and Na_2O) in the individual kaolins of diverse grain sizes do not differ substantially. Relatively low contents of TiO_2 , Fe_2O_3 , CaO and MgO have been ascertained in the Kaznějov raw kaolin consisting mostly of psephitic-psammitic material.

Table 4 shows the amounts of trace elements in the washed Kaznějov kaolins (in the washed fraction of less than 15—20 μm). In most cases individual determinations are concerned; a study of the bonding of these elements in individual minerals has not yet been carried out. The content of fluorine and cadmium has been determined in all types of washed kaolins of various grain sizes; no dependence between the grain size distribution and the amounts of these elements has been discovered. In the case of fluorine, consideration was given to its bonding in the structure of micaceous minerals. Fluorine was identified in a mica-rich concentrate obtained from the 0.063 mm mesh sieves of a kaolin washing plant, containing micaceous mineral amounting to 42.10 % of the total amount of clay minerals in the sample (according to an X-ray diffractometric semi-quantitative analysis — the method see above). The F content in this micaceous concentrate absolutely agrees with that in washed kaolins (0.023—0.024 %).

In the case of free carbon too, the C amounts determined using the firing method on a Ströhlein apparatus in the laboratory of the Geological Survey, Praha, seem to be constant in the Kaznějov kaolins. MALÁN (Geoindustria, Stříbro) tried to identify carbonaceous organic substances under the microscope using a Reichert apparatus, but the dimensions of these substances being extremely small, this experiments have not yet been successful.

GENESIS OF KAOLIN DEPOSITS

Most authors treating the problem of the genesis of kaolins in the Plzeň basin consider the kaolinitic sediments to be in genetic relationship to feldspar sediments — arkoses forming the main sedimentary filling of the basin. The authors of the earliest hypotheses, now obsolete, considered kaolinization of the feldspars of arkoses to be due to the action of peat waters during the Tertiary (PURKYŇ 1902, 1910; ŠPLÍCHAL 1912) or to the action of artesian waters rich in CO_2 (MALKOWSKI 1925). The influence of climatic conditions upon the origin of kaolins in the Plzeň basin was recognized for the first time by ORLOV (1941, 1944). By his view of two types of origin of kaolinite — the sedimentary (redeposited) kaolinite and post-*es*imentary (in situ) — the latter author closely approached the present-day theories of the origin of this kaolin. The same view is shared by POUBA and ŠPINAR (1954) and POUBA (1959). In addition, these authors have distinguished the effects of the earlier (pre-Miocene) kaolinization in the southern part of the Plzeň basin (Chlumčany deposit). KONTA (1957), GREGOROVÁ (1961) and MALECHA (1968) assume kaolinization to have taken place in another place, in the source area of the sediment and regard the deposits of kaolinitic rocks in the Plzeň basin as sedimentary, generated by redeposition of kaolinitic weathering products. KUŽVART et al. (1975) considers kaolinization to have occurred during sedimentation and after it (in situ). These authors publish arguments for both hypotheses. The author of this paper has assembled comprehensive geological evidence attesting the dominating kaolinization of the source rocks of the Horní Bříza and Kaznějov deposits prior to sedimentation (JIRÁNEK — in press).

The evidence for a pre-sedimentary kaolinization is as follows:

1. The depth of kaolinization (the advocates of weathering in situ explain this by recurrent kaolinization processes after the deposition of partial sets of beds KUŽVART et al. 1975).
2. The alternation of kaolinitic sandstones and non-kaolinitic arkoses in segments 0.1—4.0 m thick closely underlying the deposits; this testifies to a rapid variable supply of kaolinized and non-kaolinized material from the source area.

3. The presence of markedly coloured (often conglomeratic) beds ± 1 m thick, sharply separated from white kaolinitic sandstones in their roof or floor which — if a post-sedimentary kaolinization is taken into consideration — must be coloured secondarily by circulating solutions.
4. The up to 5 m thick intercalations of grey-white claystones within the kaolinitic sandstones, arisen probably by separation of finer fractions during the transport of the material already kaolinized.
5. The presence of fresh quite isolated clastic fragments of feldspar in actual kaolinitic sandstones (e. g. Horní Bříza, bore HB 8/75).

The factors favourable to kaolinization could naturally act also during the further phases of the transport of weathered material. In spite of the statement given above sub 5, partial kaolinization occurring after sedimentation of all the rocks of the deposit cannot be fully rejected. Some observations by POUBA and ŠPINAR [1954] on the Chlumčany deposit as well as the evidence presented by GREGOROVÁ [1961], KUŽVART et al. [1975] and some field observation of the author of this paper testify to it. Such observations include the presence of isolated kaolinized angular pseudomorphs after feldspar, leucoxen rims of ilmenites and clay-wise weathered fragments and pebbles of Proterozoic volcanics which could not outlast the transport, local occurrences of partly silicified layers in kaolinitic sandstone etc. For this post-sedimentary kaolinization the present author assumes a younger age, probably Cretaceous to pre-Miocene, already proved by POUBA and ŠPINAR [1954] for the Chlumčany deposit. During this time span solutions circulated on the faults, affecting the Horní Bříza and perhaps partly also the Kaznějov deposits, which by deferrization produced bleaching of kaolinitic sediments underlying the faults ([JIRÁNEK — in press, fig. 2]). The acid chemistry of these solutions could also act as kaolinization factor. In any case in the Horní Bříza and Kaznějov deposits only isolated grains and fragments of feldspar, ilmenite and Proterozoic rocks could become weathered or kaolinized, as the kaolinization of both these deposits mostly ended already in the Carboniferous (prior to sedimentation) as is evidenced by the following facts ([JIRÁNEK — in press]):

- (a) the kaolinization followed the Permo-Carboniferous paleorelief (dip of beds) and its level changed due to the Saxonian faults;
- (b) in the vicinity of the Saxonian faults there exists neither a major amount of washable kaolin particles nor any rather deep roots of kaolinized rocks. (However, this statement has not yet been supported by sufficient evidence from bores.)

The deferrization processes took place partly already in the source area prior to sedimentation as it is attested by the alternation of thin, sharply bounded layers of primarily coloured and white kaolinitic sediments (bore HB 8/75) and by the direct linear dependence of whiteness on the amount of washable kaolin particles ([JIRÁNEK — in press, fig. 3]); these processes also partly occurred during the Cretaceous up to Tertiary due to the action of solutions along the system of Saxonian normal faults. In the Cretaceous-Tertiary, the effect upon deferrization of a fault whose throw was 75 m was the same as that of a fault with a throw of 0.5 m ([JIRÁNEK, in press, fig. 2]).

Partial deferrization has also been taking place at recent times by the action of organic acids in the close proximity of plant roots (for a distance of at most 3 cm). The bleaching capability of these acids is considerable. For instance, in an excavation of about 300 m to the NW of Kaznějov, at a depth of 1.5 m bleaching of dark red kaolinitic conglomerates from 29.3 to 65.2 % whiteness of MgO, produced in this way, has been established.

CAUSES AND ORIGIN OF COLORATION OF KAOLINITIC SEDIMENTS

In practice, in raw kaolins instead of hue and brightness of colouring, the whiteness is expressed as a physical value of washed kaolin (fraction below 15–20 μm). This physical value corresponds to the quantity of light reflected by the surface of the sample examined as a percentage of the analogous light reflection produced by a reference material, i. e. BaSO_4 , MgO or snow whiteness representing ideal whiteness. The raw kaolins of the Horní Bříza and Kaznějov deposits are sorted, according to whiteness, into several types (table 5). In judging the possibility of artificial bleaching of kaolins, a study of the nature and intensity of the kaolin coloration and its causes is important.

The causes of a low whiteness of some kaolins in the Plzeň basin have not yet been completely recognized, and they are of diverse characters. In addition to really colouring admixtures removable only by chemical means (Fe and Ti compounds, organic substances, illite), also a variously coloured micaceous mineral such as muscovite or sericite, or a fine quartz (pink, red, smoke-coloured or even grey) admixed to kaoli may lower its whiteness. The quartz can only partly be removed by a normal operational sorting or by further finer sorting also connected with the removal of coarser particles of kaolinite. From the practical point of view a yellowish or reddish tint of kaolin is most undesirable; this is due to hydrated oxides of iron. The present author assumes that the yellowish tint is due to minerals of the limonite group, the red tint to hematite. The influence of organic substances on kaolin coloration is assumed only (yellow or grey tints).

The coloration of the kaolinitic sediments of both deposits is primary and secondary. The present author regards as primary the intercalations of ruddy clays which are present particularly in the Horní Bříza deposit. These clays are thought to have their source in the Proterozoic kaolinitic eluvia, to which their coloration is also due (KUŽVART et al. 1975). In the upward direction, the ruddy clay interbeds become sparser and in their place appear intercalations of grey-white clay (in the Kaznějov deposit). Part of these interlayers contains thin, sharply bounded dark red bands, in some places forming a network. At the second mining level of the western part of the Kaznějov opencast, one such interlayer was interrupted by a number of synsedimentary normal faults and reverse faults of a low throw (fig. 11). This interruption is quite clear and furnishes evidence of the primary origin of the bands. The present author sees the cause of the above-mentioned normal and reverse faults in synsedimentary gliding.

Primary coloration should also be assumed in the sharply separated layers of reddish kaolinitic conglomerates and coarse-grained sandstones which, as shown above, provide evidence of the sedimentary origin of the kaolin deposits under consideration. The deposition of these layers took place after marked hiatuses. In the Horní Bříza deposit, thinner layers of reddish and deep yellow fine-grained kaolinitic sandstones were encountered under the ruddy clay beds, above white kaolinitic sandstones, testifying a change in the supply of material (e. g. bore HB 5/74). These coloured layers contain a proportion of variegated Proterozoic weathering products which during the subsequent quiet sedimentation participated in the generation of the ruddy clays.

The secondary coloration of kaolinitic sediments is in genetic connection with the deferrization processes during the Cretaceous up to Tertiary along the system of Saxonian faults. The iron washed by deferrization solutions precipitated at the upper and lower boundaries with impermeable clays and sandy clays. The character of these ferruginous precipitates depends on the intensity of coloration of the original sediment and on the deferrization intensity. When bleaching of the surrounding rocks is complete, a hard dark red ironstone arises (e. g. in bore KA 24/76 in the Kaznějov



deposit in the beds over — and underlying a 0.4 m thick bed of yellowish clay surrounded by white kaolinitic sandstones). When the bleaching is less intense, the rocks become yellow-rusty up to red only at their junction with clays (the surrounding kaolinitic sandstones retain a pink or yellowish colour) or any indications of precipitation of iron are lacking throughout. The ferruginous layers originated in this way attain thicknesses of 3—5 cm.

Another example of secondary colouring is the reddish tint of the uppermost portions of the Horní Bříza deposit (e. g. in the area of the bores RV 2/57 and RV 3/57). These portions consist of Neogene up to Quaternary eluvia of Permo-Carboniferous rocks and form part of the overburden of the deposits. Compounds of iron are concentrated here, which have been released partly from the ruddy clays intercalations, partly from the interlayers of coloured kaolinitic psephites and psammites. Within the secondarily coloured layers of kaolinitic sandstones and conglomerates, white sandy clay and clayey siltstone beds occur. An exposure at the road at the southern margin of Kaznějov filled with Permocarboniferous and Tertiary sedimentary rocks is instructive for the explanation of the above facts. The red colour due to the iron content proceeds from the overlying eluvia along normal faults (of a low throw) and fissures into gravelly and rather coarse-grained sandy beds. The layers of finer sands occurring between these beds remained yellow. From the above described facts it follows that the iron solutions readily penetrated into more porous coarse-grained sands and gravels, whereas the layers of fine sands, sandstones and siltstones remained impermeable for these solutions.

In the vicinity of fragments of Proterozoic rocks in the kaolinitic sandstones and conglomerates a secondary yellow-rusty coloration was observed, and at the same time also an increase of the proportion of clay and its balls in the host rock (Kaznějov, bore Ka 40/75). Similar rocks have been described in WILD' s (1967, 1969, 1971) reports as „clayey kaolinitic arkoses“ (better: sandstones). The present author assumes that in these rocks the above-mentioned „clayey“ proportion consists of kaolinitically weathered Proterozoic rocks. The frequent yellow-rusty coloration or streaks is probably due to limonitic weathering products of the original pyritic shales. As the colouring substance is very finely dispersed in the clay mass, an artificial bleaching of these so-called „clayey-kaolinitic“ rocks from the Kaznějov deposit is impossible as has been ascertained by BERAN (1975).

SIZE DISTRIBUTION OF WASHED KAZNĚJOV AND HORNÍ BŘÍZA KAOLINS IN RELATION TO THEIR PHYSICAL PROPERTIES AND CHEMICAL COMPOSITION

KONTA (in press) has revealed the dependence between the grain size distribution of washed Karlovy Vary kaolins and some of their technological properties. This author defined the granularity by the relation

$$P_{16} + P_{50} + P_{84}$$

5

where P = percentile. This relation appeared as most sensitive for the purposes under consideration.

In this paper the dependence between the grain size distribution expressed by the above-mentioned formula and the physical and chemical properties of washed kaolins were also studied. However, only 4 samples were available on which granulometric analysis was carried out as well as some special physical tests (viscosity and dry

strength) and chemical analyses. Usually only the determination of whiteness and amount of washable kaolin particles are made. Thus the statements in this chapter should be regarded as orientational only. A more accurate elaboration of this problems would require a separate more comprehensive study. The above four specimens are washed kaolins differing in grain size distribution, designated Sp ex-F Kaznějov, Sp 85 Kaznějov, KKH Kaznějov and Sp ex Horní Bříza of October 1976. The results are presented in fig. 12.

A comparison of the grain size distribution and physical properties (fig. 12) revealed (in agreement with KONTA — in press) that viscosity (measured by flow viscosimeter at 55 % dry matter in suspension; results in seconds) is directly proportional to granularity, and in addition, dry strength indirectly proportional to granularity. Neither drying shrinkage nor cation exchange capacity (KONTA — in press) were investigated in washed Kaznějov and Horní Bříza kaolins.

The relation between the grain size distribution and chemical composition (fig. 13) is much more marked. As finer sorting is connected with a decrease of the admixed quartz (and some accessory minerals) and thus also with a relative increase of the kaolinite content, a directly proportional dependence of SiO_2 and TiO_2 (and a weak one of Fe_2O_3) on the grain size distribution is fully substantiated; likewise the indirectly proportional dependence of Al_2O_3 and of the loss by ignition (H_2O^+) also on granularity. In all samples studied, the CaO , MgO and Na_2O contents remain approximately the same; only the K_2O content moderately increases with increasing grain size (see also table 5). In recalculations of a rational analysis, the same trend is manifested by a directly proportional relation of the grain size distribution to the contents of quartz and feldspar and by an indirectly proportional relation to the clay mass content.

CONCLUSION

The Horní Bříza and Kaznějov raw kaolins are kaolinitic sediments displaying differing properties of the individual petrological types determined on the basis of granulometric analyses. All the rocks studied contain all four grain size components of clastic sediments. The grain size distribution itself shows maximum deviations in the group of conglomerates with a kaolinite cement. The silty-conglomeratic up to conglomeratic-silty sandstones and clayey-silty up to silty-clayey sandstones constitute marked groups of sediments, which are relatively clearly defined. Kaolinite is the main mineral of the silty and clayey fractions; it is associated with quartz and micaceous mineral (5–14 %). With sorting becoming finer, the quartz and micaceous mineral contents decrease while the kaolinite percentage relatively increases. No dependence has been discovered between the content of trace elements and granularity. In washed kaolins, some of their physical properties (viscosity and dry strength), their chemical composition and proportions of mineral constituents (according to rational analysis) are related to their grain size distribution.

The major part of the kaolinitic sediments of both deposits arose by kaolinization prior to sedimentation, probably in the source area of the sediments. Isolated fragments of feldspar could become kaolinized (further minerals could have become weathered) during the Cretaceous up to Tertiary under conditions favourable for kaolinization, i. e. those which in the area of the deposits were manifested by deferrization bleaching of kaolinitic sediments along the Saxonian faults, this being the case particularly in the Horní Bříza deposit. Part of the coloration of the kaolinitic sediments could be designated as primary, part was of secondary origin, mostly in connection with deferrization processes during the Cretaceous-Tertiary times.

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GEOLOGIE, PETROLOGIE A GENEZE KAOLINITICKÝCH SEDIMENTŮ LOŽISEK HORNÍ BŘÍZA A KAZNĚJOV V PLZEŇSKÉ PÁNVI

Hornobřízské a kaznějovské kaolinové suroviny jsou kaolinitické sedimenty odlišných vlastností mezi jednotlivými petrologickými typy, stanovenými na základě zrnitostních rozborů. Všechny studované horniny obsahují všechny čtyři zrnitostní složky klastických sedimentů. V samotné zrnitosti existují maximální výchylky ve skupině slepenců s kaolinitovým tmelem. Prachovito-konglomerátické až konglomeráticko-prachovité pískovce a jílovito-prachovité až prachovito-jílovité pískovce tvoří výrazné poměrně ostře vymezené skupiny sedimentů. Hlavním minerálem prachovité a jílovité frakce je kaolinit; k němu se druží křemen, a dále slídový materiál (5–14 %). S rostoucím vytříděním obsah křemene a slídového minerálu (sericitu a illitu) klesá a obsah kaolinitu relativně vzrůstá. Mezi sledovanými obsahy stopových prvků a zrnitostí nebyla zjištěna závislost. Na zrnitosti plavených kaolinů jsou závislé některé jejich technologické vlastnosti (viskozita, pevnost v ohybu) a chemické i racionelní složení.

Převážná část kaolinitických sedimentů obou ložisek vznikla kaolinizací před sedimentací, pravděpodobně ve zdrojové oblasti sedimentu. Ojedinelá klastická živcová zrna mohla být kaolinitizována (a další minerály mohly navětrat) v křídě až terciéru za podmínek příznivých kaolinizaci, které se v prostoru ložisek uplatnily, deferizačním vybělením kaolinitických sedimentů podél saxonských poklesů, především na ložisku Horní Bříza. Část zbarvení kaolinitických sedimentů bylo možné označit za primární, část vznikla sekundárně, převážně v souvislosti s křídloterciérními deferizačními pochody.

Table 1

Sieve and sedimentation analysis of samples from bore Ka 40/75 (Kaznějov deposit). Petrographic types of sediments: 1 — conglomerates with kaolinite cement; 2 — silty-conglomeratic to conglomeratic-silty and silty kaolinitic sandstones; 3 — clayey-conglomeratic kaolinitic sandstone; 4 — clayey-silty to silty-clayey kaolinitic sandstones; 5 — clayey-sandy kaolinitic siltstone.

Type	Depth in metres	Over 7 mm	7—4 mm	4—2 mm	2—1 mm	1—0.063 mm	0.063—0.02 mm	0.02—0.004 mm	Below 0.004 mm
1	3,3 — 6,2	31,23	7,56	5,90	16,21	21,63	4,88	2,01	10,58
3	6,2 — 7,3	7,90	8,51	8,90	27,50	25,04	6,76	1,80	13,59
1	7,3 — 9,0	21,99	10,95	8,25	8,76	28,66	2,99	9,59	8,81
1	9,3 — 9,6	18,30	17,62	8,81	9,02	10,53	7,11	21,27	7,34
2	9,6 — 12,0	0,32	2,01	4,40	11,50	49,72	4,07	23,60	4,38
2	12,0 — 15,0	4,53	3,76	5,71	9,70	47,18	14,25	4,52	10,35
2	15,0 — 18,0	4,45	5,28	11,84	8,75	36,83	13,68	9,62	9,55
2	18,0 — 21,3	5,87	5,92	8,58	13,82	35,11	10,50	11,17	9,03
2	21,3 — 23,4	13,29	7,11	9,62	13,70	32,04	8,75	9,44	6,05
2	23,4 — 28,0	2,81	2,52	3,86	7,01	53,20	8,07	18,45	4,08
4	28,0 — 29,9	1,75	0,30	0,19	0,34	57,46	5,12	7,29	27,55
4	29,9 — 33,4	0,14	2,41	0,85	1,20	63,02	6,53	9,69	16,16
—	33,4 — 35,3	2,08	7,47	21,34	8,61	31,56	14,74	10,15	4,05
2	35,3 — 36,3	4,46	4,19	6,54	9,20	51,28	10,08	10,36	3,89
2	36,3 — 37,75	7,52	7,06	13,65	17,29	33,82	13,34	5,31	2,01
4	37,75 — 38,7	0,39	0,69	3,25	7,72	45,04	7,62	13,46	21,83
4	38,8 — 39,1	1,02	1,11	3,29	6,53	52,70	9,86	16,72	8,77
4	39,15 — 39,6	0,00	0,26	0,72	2,32	45,12	15,90	4,30	31,38
2	39,6 — 40,1	0,37	1,25	5,12	13,02	49,90	15,94	9,15	5,25
4	40,1 — 41,3	0,25	1,22	1,99	4,68	54,85	13,04	16,44	7,53
2	41,3 — 44,0	9,92	2,81	8,59	13,27	36,76	11,64	13,52	3,49
2	44,0 — 47,0	5,90	3,80	6,80	14,62	41,32	5,44	15,10	7,02
2	47,0 — 50,0	4,53	5,61	10,82	13,79	38,12	8,42	10,57	8,14
2	50,0 — 52,2	2,96	9,07	16,71	3,06	42,87	12,31	9,04	3,98
2	52,2 — 52,8	11,20	4,72	6,58	9,30	37,28	10,32	15,54	5,06
2	52,8 — 53,9	10,77	6,49	10,46	13,16	30,65	7,98	16,90	3,59
2	54,05 — 55,3	14,03	6,26	11,24	10,18	31,15	6,16	15,46	5,52
5	55,3 — 55,85	1,62	1,41	2,05	1,91	34,05	22,95	20,28	5,73
4	55,85 — 56,2	0,00	0,03	0,14	1,07	54,36	12,84	15,44	16,12
4	56,2 — 56,8	1,71	0,39	0,34	0,58	43,12	19,51	9,22	25,13
4	57,4 — 58,3	0,00	0,93	1,40	5,26	50,78	11,95	13,63	16,05
2	58,3 — 60,1	9,10	4,45	12,60	8,79	34,73	7,18	15,85	7,30

Table 2

Semi-quantitative X-ray diffractometric determination of a quartz admixture (ratio of X-ray intensities 001 of kaolinite to 101 of quartz) and micaceous minerals (in %) in the washed Kaznějov kaolins. Washed kaolins follow according to the decreasing grain size.

Characterization of washed kaolins	$\frac{I K (001)}{I Q (101)}$	Micaceous mineral (% of clay minerals)
KKH {Oversize amount from a hydrocyclone of 50 mm Ø}	1.6	13.85
KK {Undersize amount from a hydrocyclone of 150 mm Ø}	3.6	8.68
Sp ex-F {Undersize amount from a hydrocyclone of 50 mm Ø}	6.6	6.93
KKN {Coating kaolin; ± 80 % particles below 2/um}	8.9	5.51

Table 3

Chemical analyses of raw and washed kaolins from Kaznějov and Horní Bříza (analyzed by the laboratory of the West-Bohemian Ceramics Works, Horní Bříza). Washed kaolins follow according to the decreasing grain size.

	1	2	3	4	5	6
	Raw kaolin	KKH	KKA	Sp 85	Sp ex	Sp ex-F
	Kaznějov	Kaznějov	Kaznějov	Kaznějov	Horní Bříza	Kaznějov
SiO ₂	85,00	58,70	51,39	50,50	49,70	48,45
TiO ₂	0,39	1,30	0,96	0,95	1,01	0,92
Al ₂ O ₃	9,47	28,25	34,62	34,80	35,70	36,30
Fe ₂ O ₃	0,18	0,50	0,45	0,37	0,50	0,43
Na ₂ O	—	0,10	0,05	0,19	0,04	0,12
K ₂ O	—	1,00	0,76	0,83	0,73	0,93
CaO + MgO	0,35	0,50	0,46	0,40	0,42	0,46
H ₂ O ⁺	4,03	9,70	11,66	11,89	11,96	12,40
	99,42	100,05	100,35	99,93	100,06	100,01

Table 4

Trace elements in washed Kaznějov kaolins (fraction below 15–20 μm) in ppm.

Element	Number of determinations	Average (ppm)	Range (ppm)	Analyzed by
C free	3	397	380–410	Geological Survey (ÚÚG), Praha
CO ₂	6	91	63–140	Geological Survey (ÚÚG), Praha
F	11	245	200–280	(1), MAPE Mydlovary, SCHHV Ústí n. Labem
Zn	1	35	—	West-Bohemian Ceramics Works, Horní Bříza
As	1	0,32	—	(1)
Cd	10	5,76	5,0–6,7	Geoindustria, Praha
Ba	1	27	—	West-Bohemian Ceramics Works, Horní Bříza
Hg	1	0,14	—	(1)
Pb	1	178	—	(1)

(1) Landwirtschaftliche Untersuchungs- und Forschungsanstalt, Kiel.

Table 5

Types of raw kaolins (kaolinitic sediments) of the Horní Bříza and Kaznějov deposits. Whiteness (% of standard MgO whiteness) measured on an Elrepho apparatus.

Type	Minimum amount of washed kaolin (%)	Whiteness (% of MgO whiteness)
Kaolin K 1	10	Over 84
Kaolin K 2	10	84–80
Kaolin K 3	12	80–76
Kaolin K 4	12	76–68
Unsuitable kaolin	—	Below 68

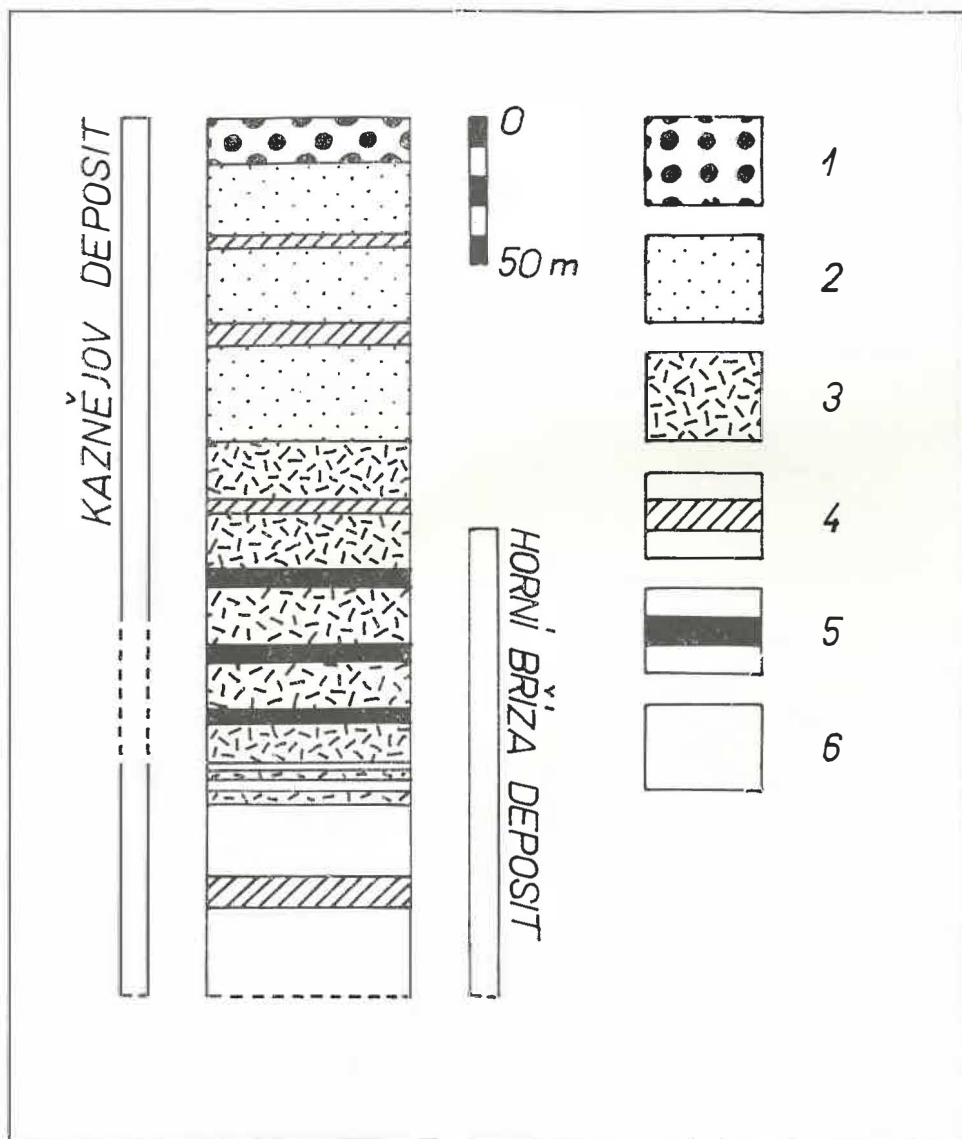


Fig. 1. Idealized stratigraphic section through the group of the Horní Bříza and Kaznějov depositz [Lower Stephanian, Týnec Formation] 1 — conglomerates with kaolinite cement; 2 — white kaolinitic sandstones; 3 — kaolinitic mostly coloured sandstones; 4 — yellow and grey claystones; 5 — ruddy claystones; 6 — not kaolinized arkoses.

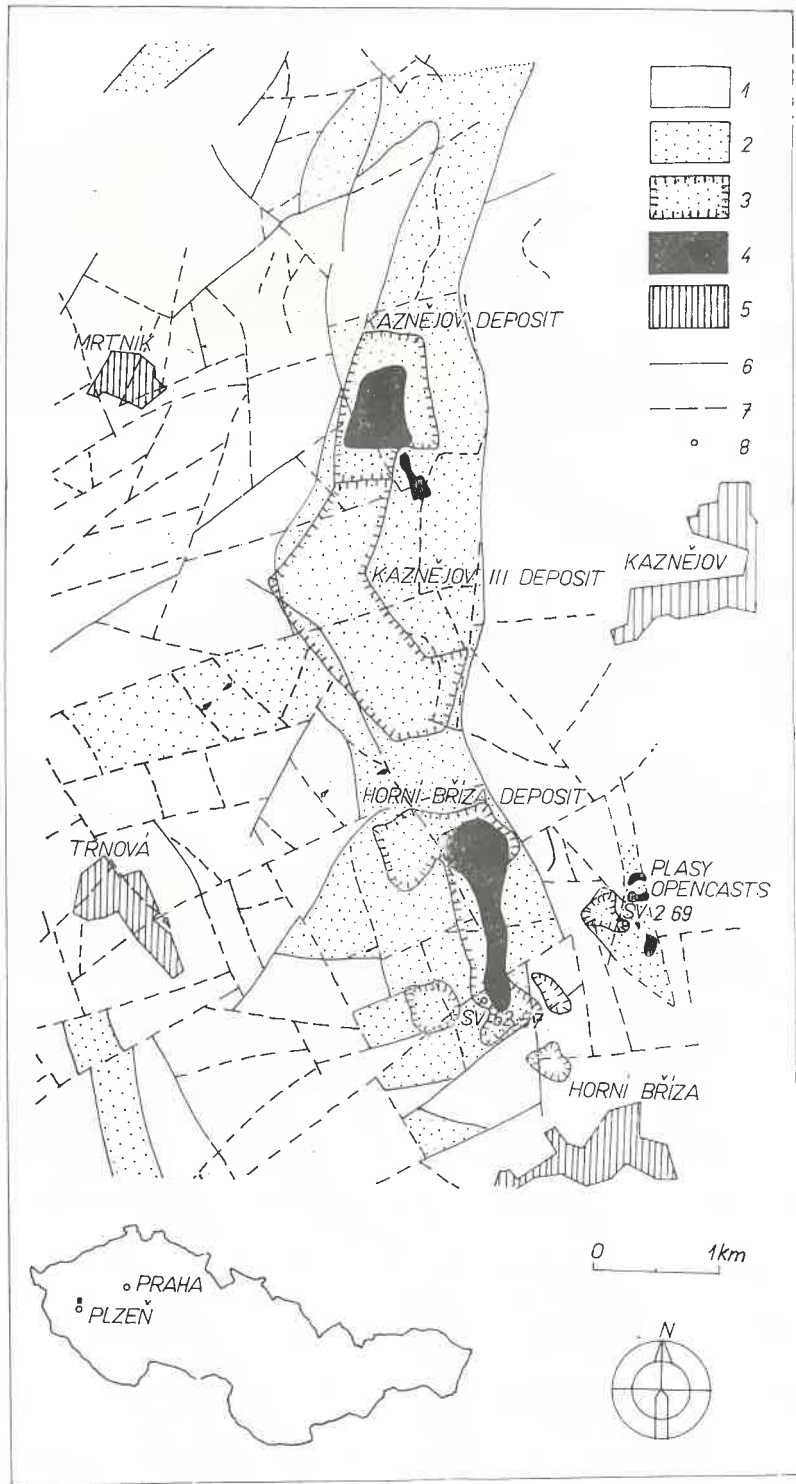


Fig. 2. Geological setting and geographic position of the kaolin deposits at Horní Bříza and Kaznějov (according to PEŠEK, WILD et al. 1971) with indicated structural bores (fig. 3) 1 — non-kaolinitic arkoses of the Plzeň basin; 2 — kaolinitic sediments; 3 — boundaries of kaolin deposits; 4 — mined and already exploited portions; 5 — villages; 6 — faults checked by geophysical investigation; 7 — assumed faults; 8 — structural bores.

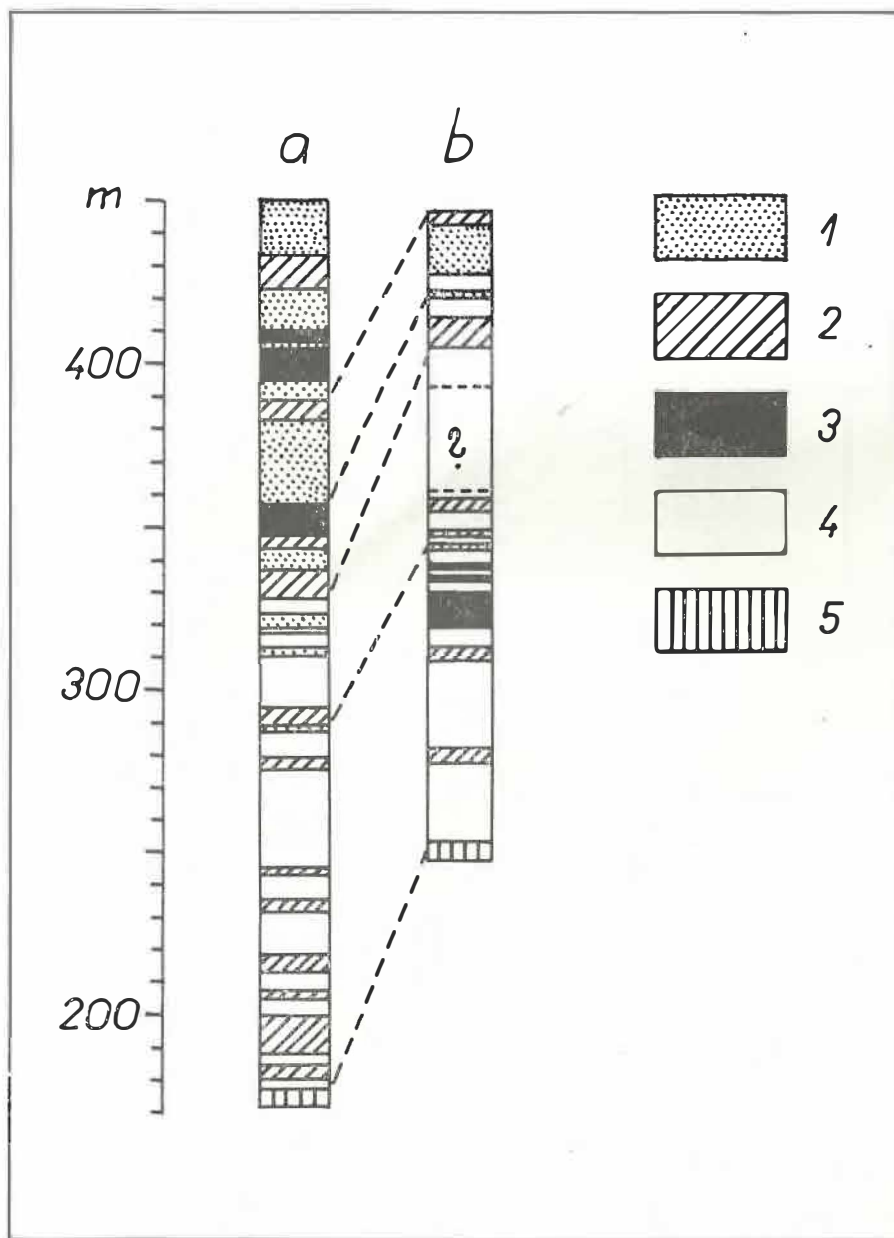


Fig. 3. Structural bores (a) SV 62/57, the Horní Břiza deposit; (b) SV 2/69, the „Plasy“ opencasts; Permo-Carboniferous: 1 — kaolinitic sandstones and conglomerates; 2 — yellow and grey claystones; 3 — ruddy claystones; 4 — non-kaolinitic arkoses. Proterozoic: 5 — clayey shales.

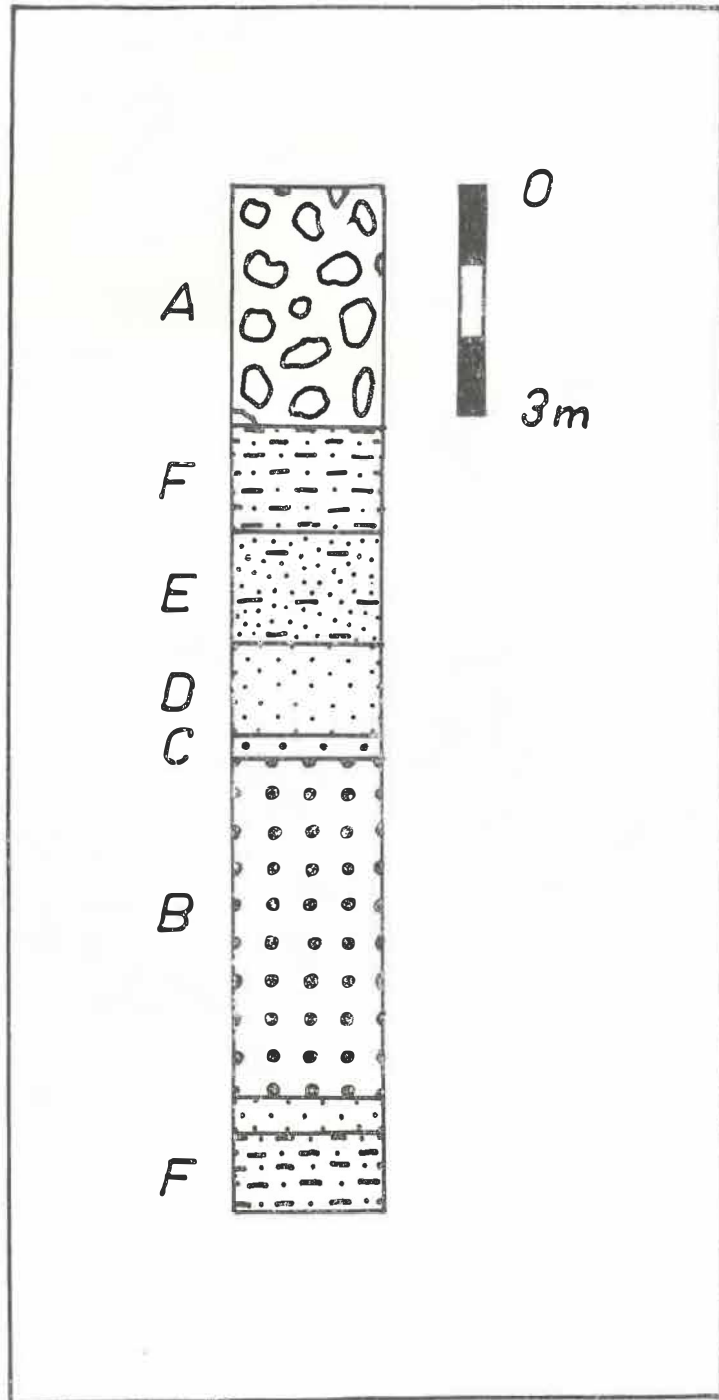


Fig. 4. Graded sequence of beds in the bore VHS 5/73, Kaznějov III deposit (for the description of the beds see the text).

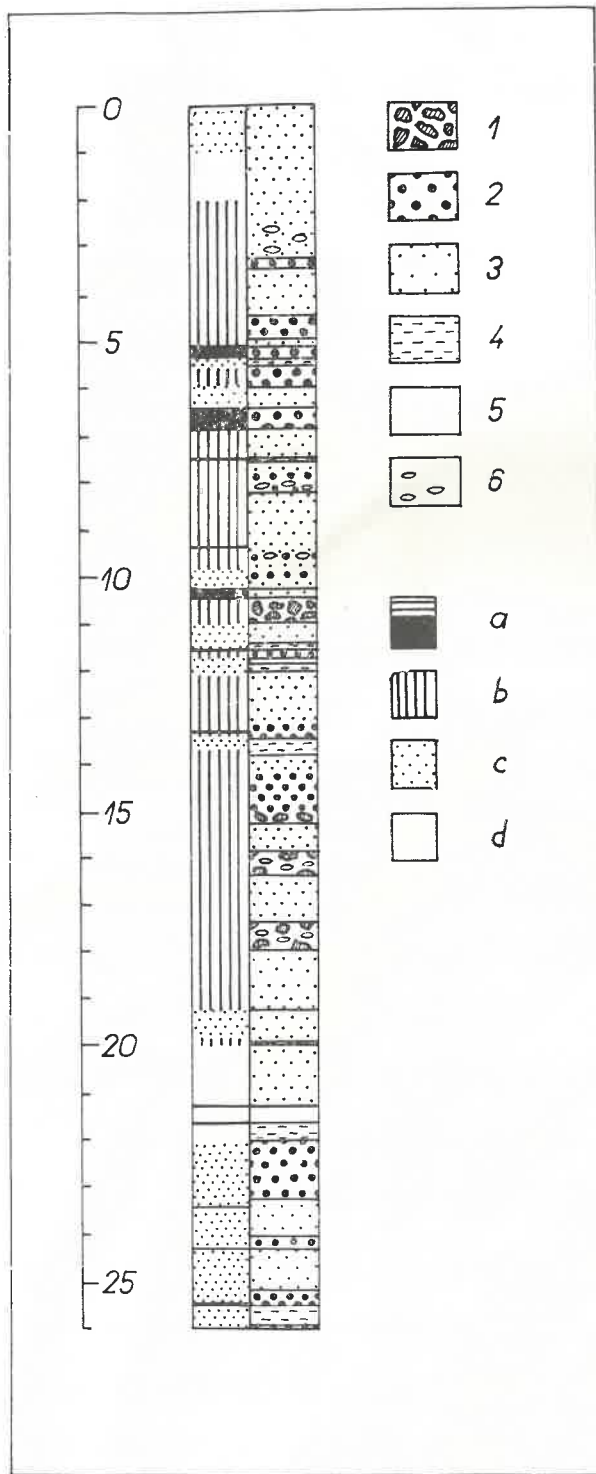


Fig. 5. Bore Ka I/73 (Kaznějov deposit), cyclic sedimentation and colour of sediments; 1 — conglomerates with kaolinite cement; 2 — coarse-grained kaolinitic sandstones; 3 — medium — to fine grained kaolinitic sandstones; 4 — very fine-grained kaolinitic sandstones up to siltstones; 5 — sandy claystones and claystones; 6 — clay balls; (a) — red; (b) — pink; (c) — yellow; (d) — white, grey-white and white-grey.

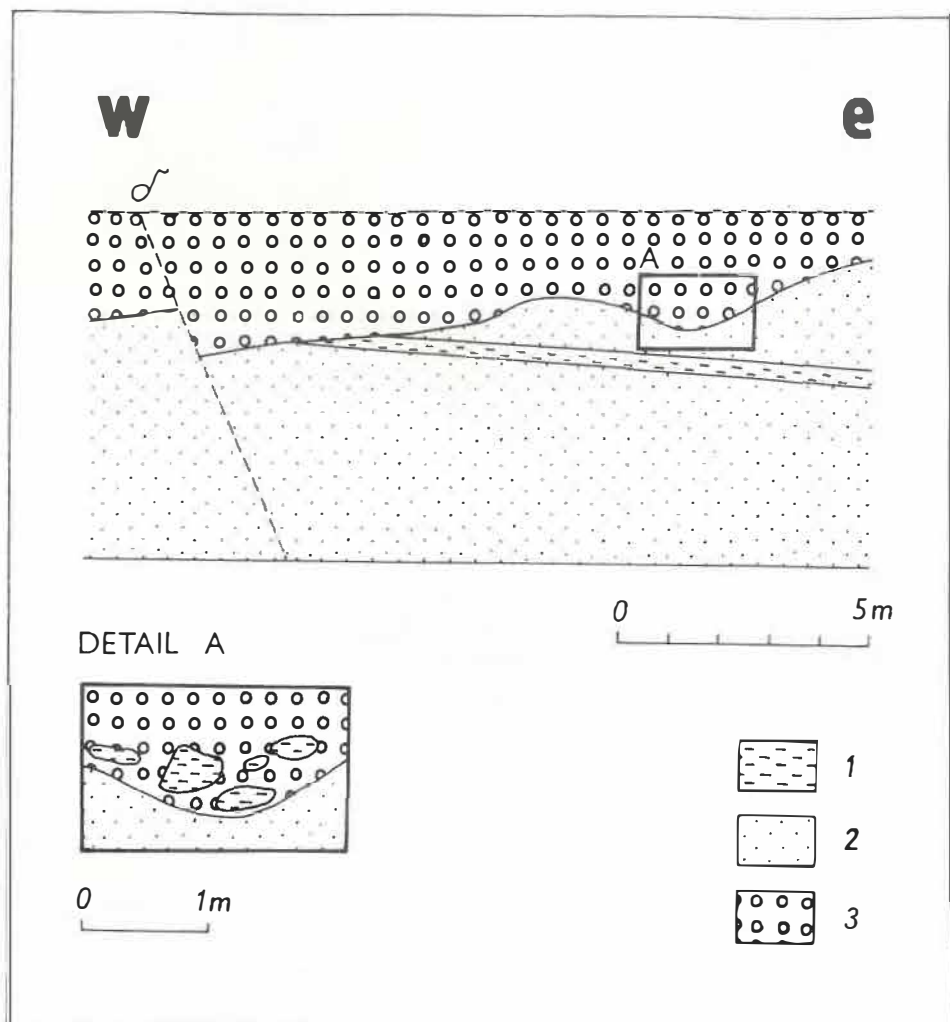


Fig. 6. Detail of the second mining level of the northern wall of the kaolin opencast at Kaznějov; 1 — rusty-brown conglomerates with kaolinite cement; 2 — white kaolinitic sandstones; 3 — white-grey claystones.

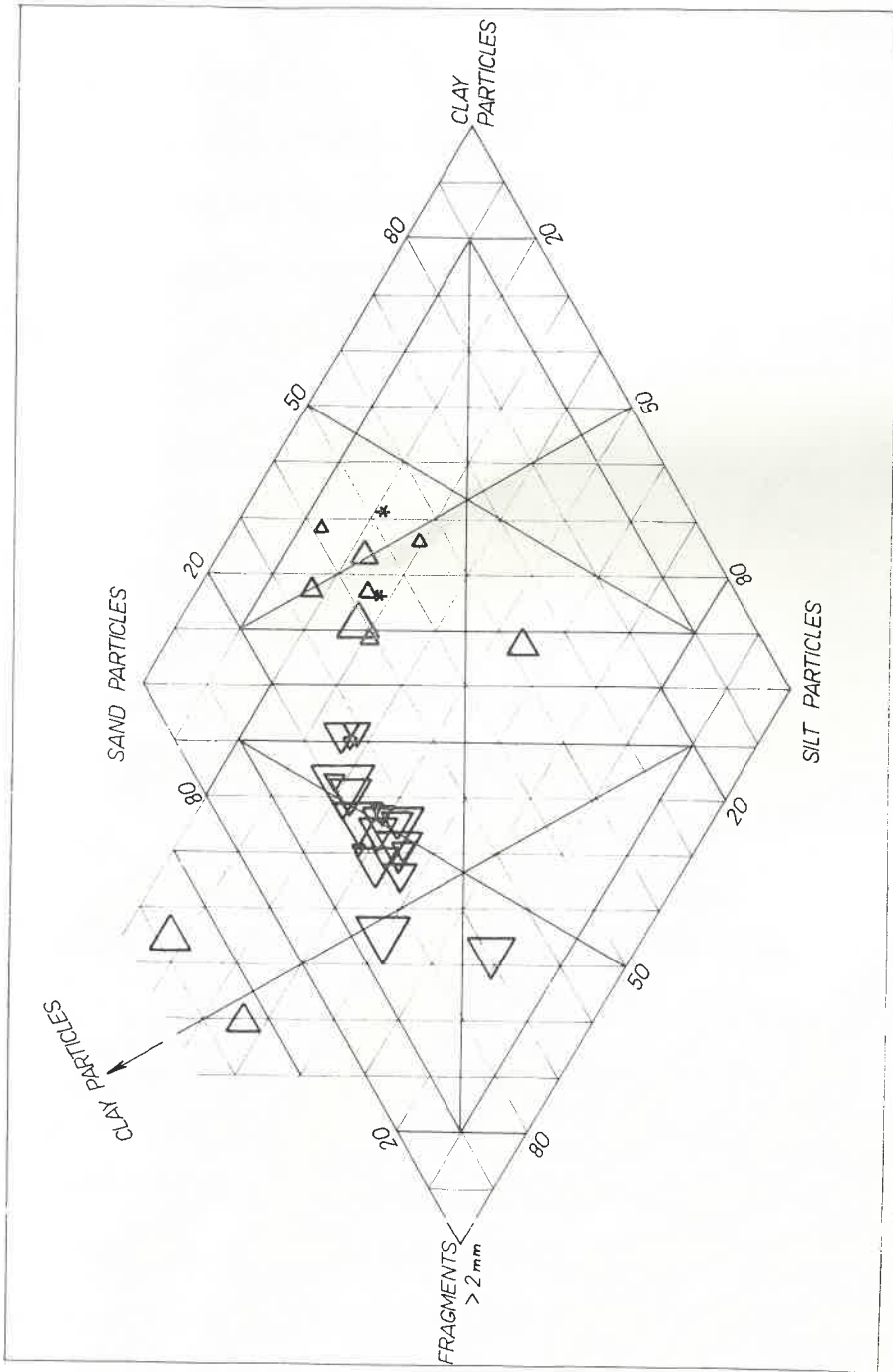


Fig. 7. Classification diagram of kaolinitic sediments from bore Ka 40/75 (Kaznějov deposit) on the basis of the grain size fractions of clastic sediments content (according to KONTA 1972).

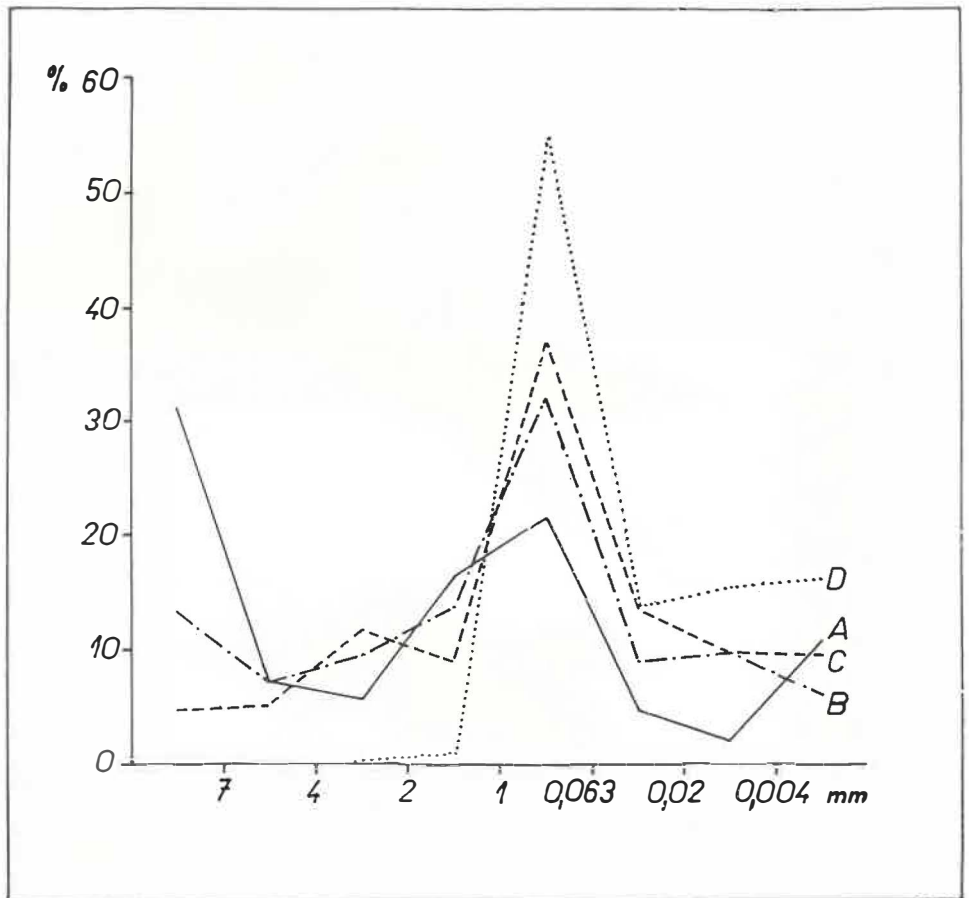
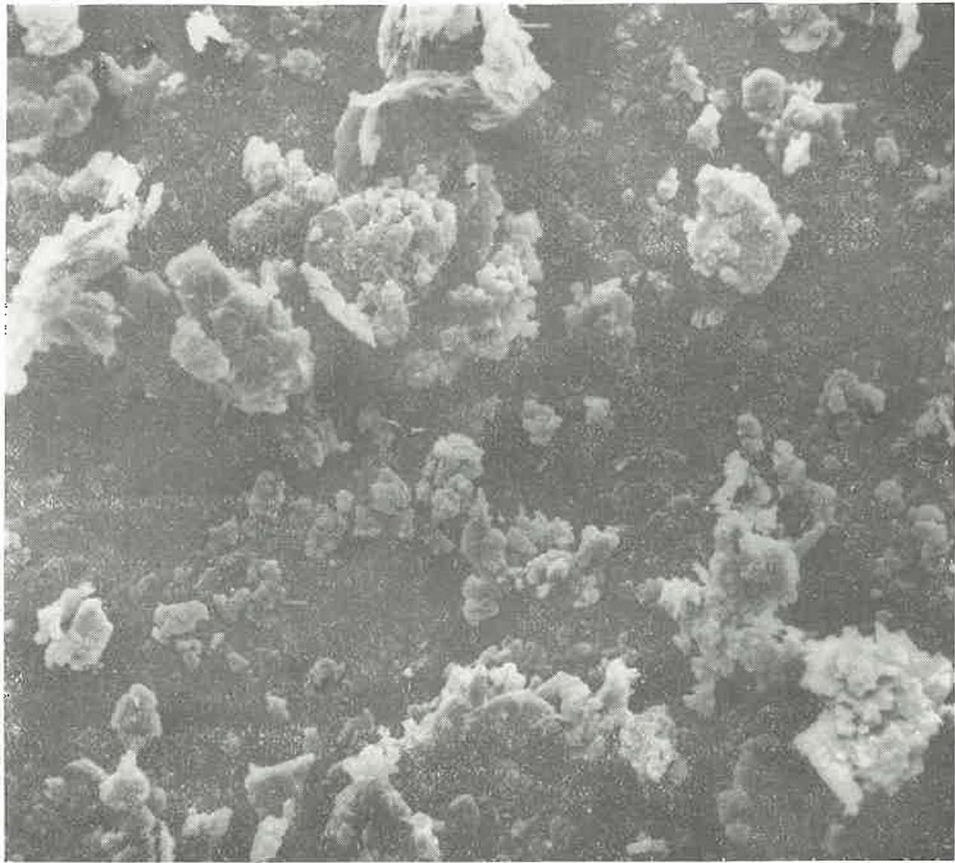
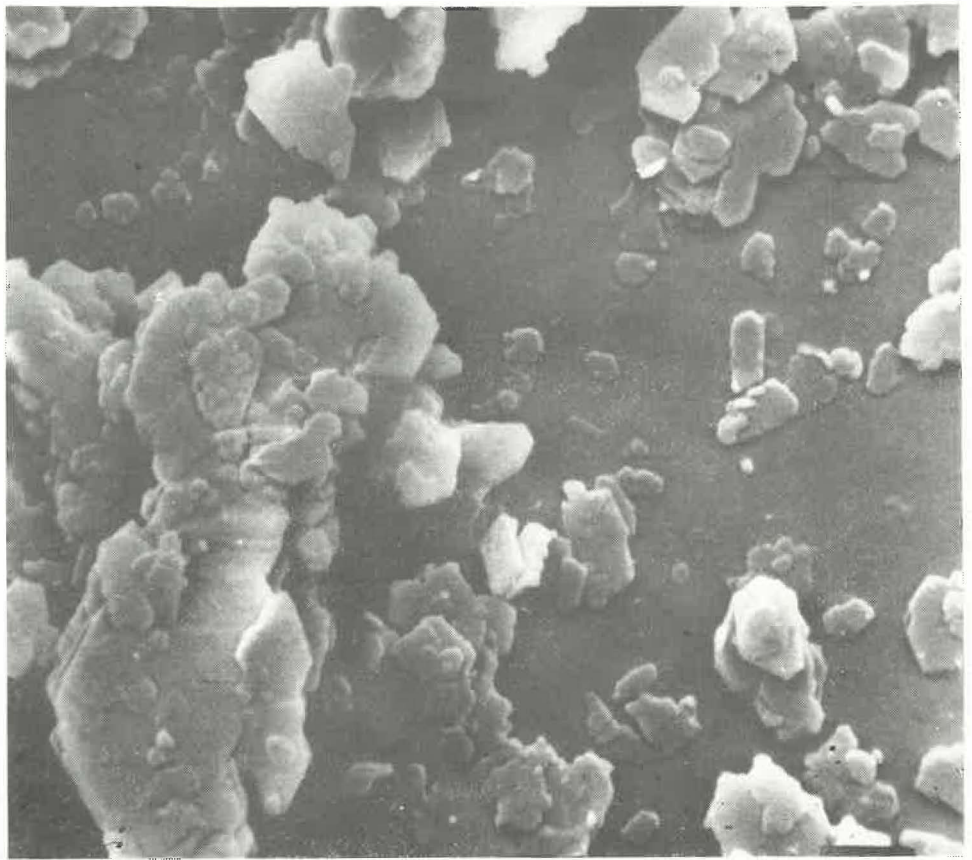


Fig. 8. Frequency curves of grain size fractions of selected kaolinitic sediments from bore Ka 40/75 (Kaznějov deposit).





Figs. 9 and 10. Electron photomicrographs of the washed Kaznějov KK kaolin taken at different magnifications. Photographed by the Zentrum für Elektronenmikroskopie, Graz.

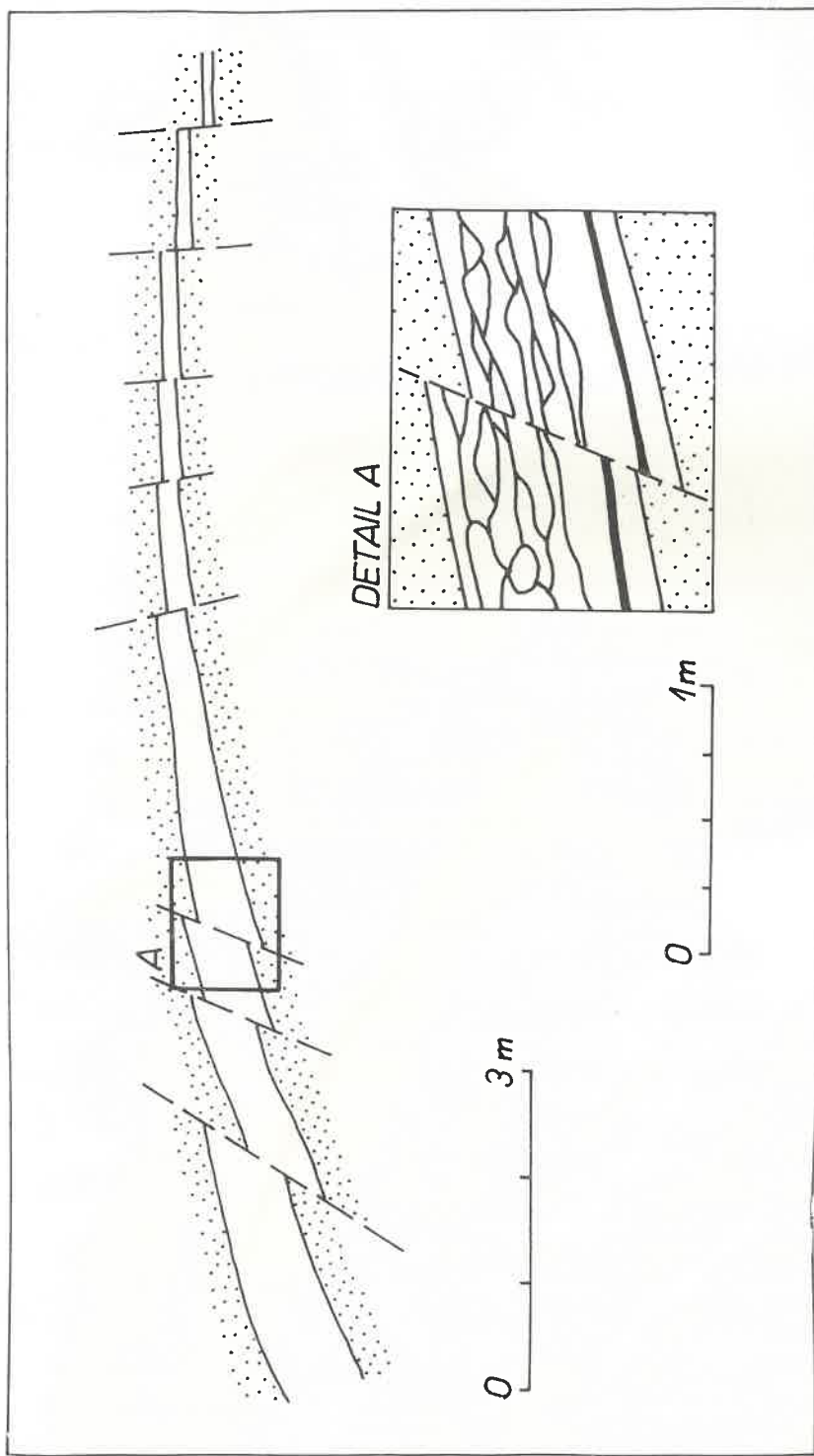


Fig. 11. Layer of a white, red-banded clay in white kaolinitic sand stones with syndimentary reverse and normal faults. Kaznějov opencast, western wall, 2nd mining level.

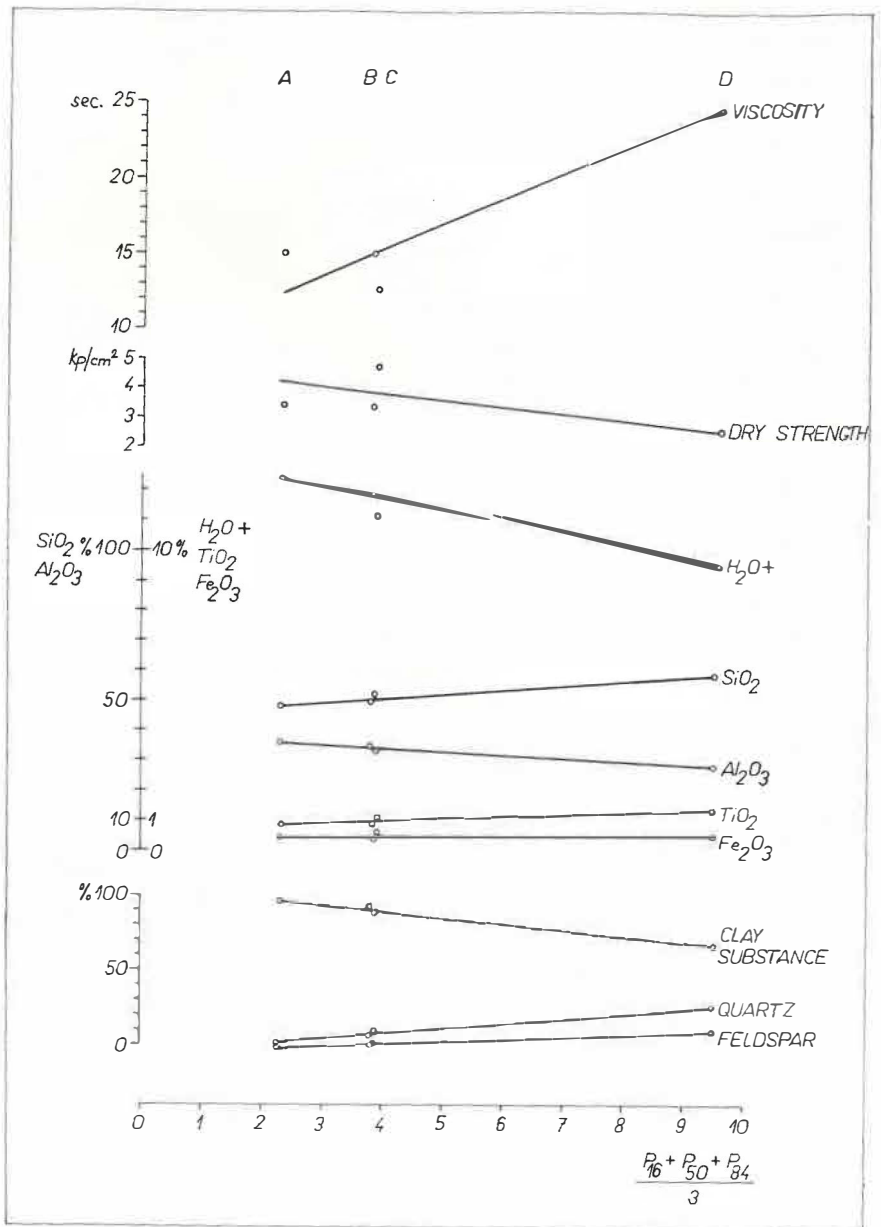


Fig. 12. Ratios: granularity/technological properties, granularity/chemical composition, and granularity/rational composition of washed Kaznějov and Horní Bříza kaolins. Viscosity measured with a flow viscosimeter, at 55% dry matter in suspension (in seconds). A — Sp ex-F; B — Sp 85; D — KKH; Kaznějov deposit; C — Sp ex; Horní Bříza deposit.

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