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# Westernmost occurrence of the Middle Miocene Badenian gypsum in central Paratethys (Kobeřice, Moravia, Czech Republic)

TADEUSZ M. PERYT[1], STANISLAV KAROLI[2], DANUTA PERYT[3], OLEG I. PETRICHENKO[4], PRZEMYSŁAW GEDL[5], WANDA NARKIEWICZ[1], JARMILA ĎURKOVIČOVÁ[5], ZOFIA DOBIESZYŃSKA[1]

[1]Państwowy Instytut Geologiczny, Rakowiecka 4, 00-975 Warszawa, Poland
[2]Geological Survey of Slovak Republic, Bratislava, Depart.: Werferova 1, 04011 Košice, Slovakia
[3]Institute of Paleobiology, Polish Academy of Sciences, ul. Twarda 51/55, 00-818 Warszawa, Poland
[4]Institute of Geology and Geochemistry of Combustible Minerals, National Academy of Sciences of Ukraine, Naukova 3a, 290053 Lviv, Ukraine
[5]Institute of Geological Sciences, Polish Academy of Sciences, ul. Senacka 1, 31-002 Kraków, Poland
[6]Geological Survey of Slovak Republic, Mlynská dol. 1, 817 04 Bratislava, Slovakia

***Abstract.*** The gypsum sequence outcropping in an active gypsum quarry in Kobeřice shows many similarities to other sections known from the northern marginal part of the Badenian basin. However, the pecularities of Kobeřice gypsum section indicate its more basinward location when compared to other gypsum exposures known from Poland and West Ukraine. The lower part consists of crystalline gypsum (giant gypsum intergrowths, sabre gypsum) accompanied by gypsiferous claystones and microcrystalline gypsum, and the upper part consists of interbedded laminated gypsum, gypsiferous claystones and breccias. These breccias are interpreted as debrites. The laminated gypsum units can be interpreted as fall-out from a low-density turbid layer. The major part of the gypsum sequence of Kobeřice originated thus in deeper, density-stratified waters. The only exceptions to rather deeper water conditions prevailing during gypsum (and related claystone) deposition are exposure episodes following deposition of giant gypsum intergrowths and during the alabastrization phases. Particular gypsum units are common throughout the quarry, although some distinct lateral changes are observed. Amount of clay material in the facies of giant gypsum intergrowths increases toward the east and this increase is accompanied by change of massive facies to skeletal facies of giant gypsum intergrowths. Also the thickness of laminated gypsum units as well as the number and thickness of breccias in the upper part of gypsum sequence increase toward the east, whereas the frequency of amalgamates of supercones decrease toward the east. These changes observed in the quarry reflect the presence of a paleoslope.

***Key words:*** Badenian, gypsum, facies, sedimentology, micropaleontology, geochemistry, Paratethys

## Introduction

In the middle Miocene Badenian evaporite basin of the Carpathian foreland basin, broad zones of sulfate deposits occur in the marginal parts, and narrow zones of chloride sediments are restricted to the basin center. The origin of these evaporites is related to the salinity crisis at the end of middle Badenian that was caused by the regression of the Paratethys Sea toward the Mediterranean Tethys and the Indopacific and the regression of the sea (Seneš, 1989).

The time and facies relations of evaporites occurring in marginal and central parts of the Carpathian foreland basin are still unclear and different correlations have been proposed for particular parts of the basin. However, it is possible to correlate particular marker beds in both domains over a distance of hundreds of kilometers (*e.g.* Garlicki, 1994; Peryt *et al.*, 1994) suggesting common controls of evaporite deposition regardless of the geological setting.

Outcrops of Middle Miocene Badenian gypsum are known from a considerable number of localities. The best studied examples are those from the northern marginal part of the basin in southern Poland (Kwiatkowski, 1972; Bąbel, 1987, 1991; Kubica, 1992; Kasprzyk, 1993; Peryt & Jasionowski, 1994) and West Ukraine (Peryt, 1996). In this paper we would like to characterize the gypsum outcropping in an active gypsum quarry in Kobeřice that is the westernmost occurrence of the Badenian gypsum in the Central Paratethys Basin. The Kobeřice outcrop is also important because it illustrates significant lateral changes in gypsum facies.

The field studies in Kobeřice were done during 1991-1996. Because the exploitation front in the quarry migrates with time, it was possible to establish geometrical relations among the particular gypsum units. The paper summarizes the research done so far that was supported mainly by the National Fund of Environment Protection and Water Management (Projects 2.29.5029.00.0 and 2.14.0100.00.0). The initial results have been presented during the international symposium "Neogene evaporites of Central Paratethys: facies, mineral resources, ecology", Lviv 1994 (Karoli *et al.*, 1994).

**Geological setting**

The Kobeřice quarry lies in front of the flysch nappes of the Western Carpathians, in the Opava Basin that is filled by Badenian deposits which transgressed over the Culm deposits or older rocks (Fig. 1). Lower Badenian rocks that underlie the gypsiferous section occur west of Opava. Their maximum thickness reach 300 m; in Kobeřice the Lower Badenian deposits are 50 m thick

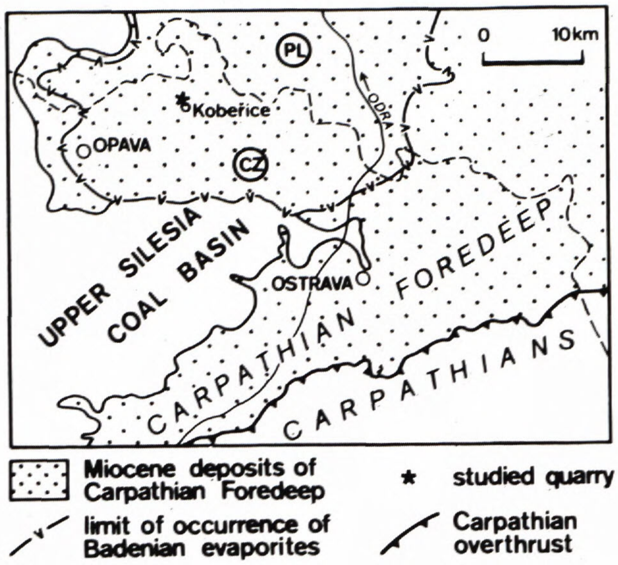


*Fig. 1. Location of the Kobeřice quarry.*

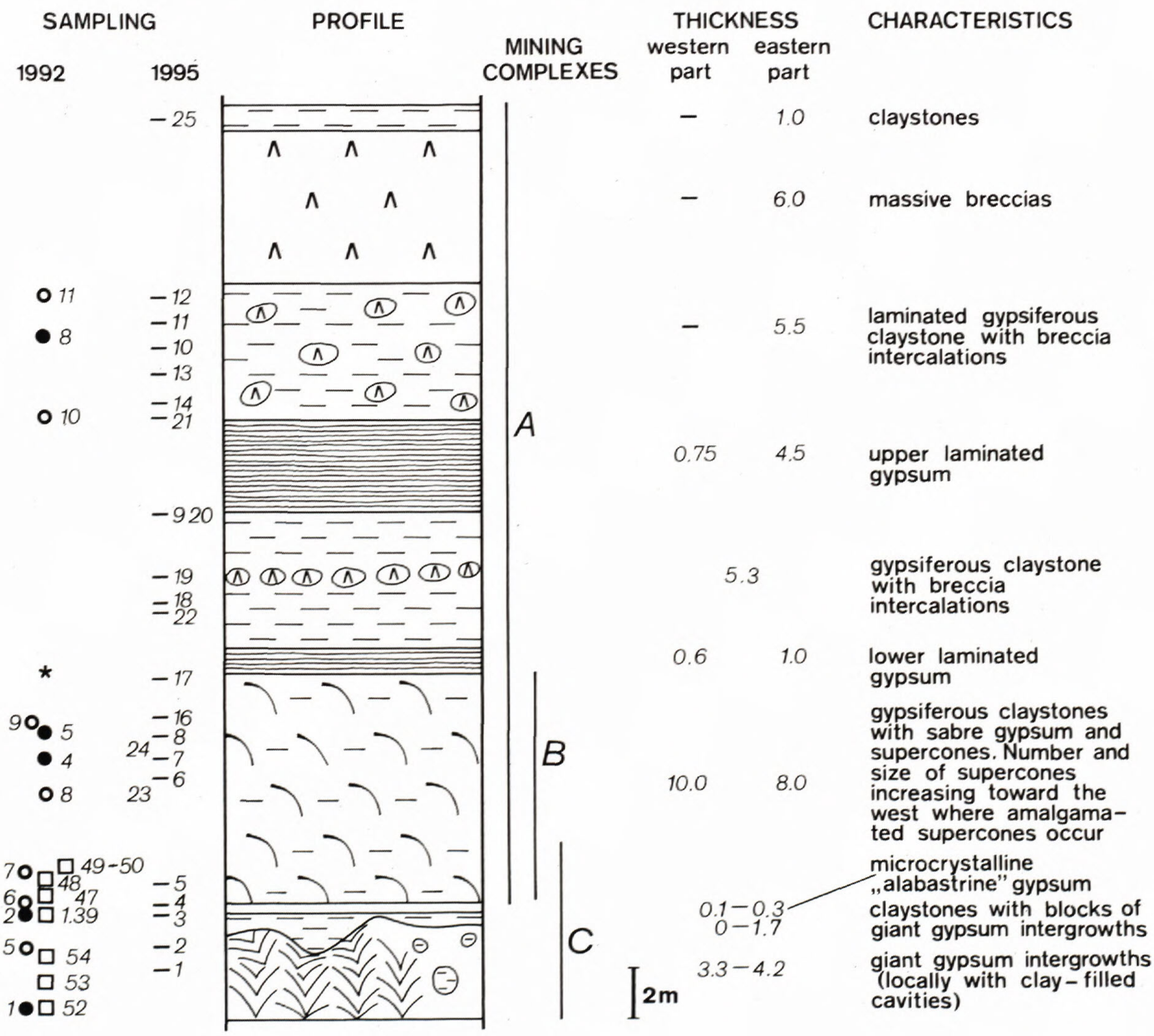


*Fig. 2. The gypsum section exposed in the Kobeřice quarry showing the sampling points in 1992 and 1995. In 1992 sampling, filled circles show samples for isotopes, empty circles are for micropaleontological studies, squares are for fluid inclusion study, and the star is the sample used for organic geochemical study.*

(Matl et al., 1979). The Lower Badenian sequence begins with basal conglomerates although these are lacking in places; variegated clays and sands occur locally (Roth *et al.*, 1962). At Kobeřice, the sequence contains volcanites and beds of breccia and conglomerates with volcanic material.These beds are overlain by red or grey clays that contain thin beds of volcanoclastics, occasionally with effusives or nepheline basanite. A rich microfauna with *Orbulina suturalis*, the Moravian index species (Matl *et al.*, 1979), characterizes these deposits.

The Middle Badenian deposits are 50-300 m thick; thinner parts are related to paleo-highs in the Culm deposits. In Kobeřice the thickness of the Middle Badenian is 50-70 m. The basal part contains clays with *Bulimina striata*, *Uvigerina asperula*, *Globigerina decoraperta* and others, and the upper part contains a gypsum complex with clay intercalations. Below the gypsum complex, glauconite grains as well as coal fragments occur on paleo-highs.

Three general varieties of gypsum development are distinguished by mining engineers (Fig. 2). In the basal part (complex C in the mining terminology) that is 1 - 9 m thick, coarsely crystalline gypsum occurs, overlain by thin microcrystalline gypsum and claystone laminated with gypsum. The middle part (complex B) is 1 - 10 m thick and is called blocky because it is composed of blocks of crystalline gypsum that are enclosed in grey clays. The upper part (complex A) is 20 m - 40 m thick and consists of microcrystalline gypsum and clays with locally occurring gypsum-filled druses.

Above the gypsum complex are Upper Badenian sandy clays, 250 m in maximum thickness that contain an impoverished *Bulimina* microfauna (Matl *et al.*, 1979). At Kobeřice, the Upper Badenian is only 20 m thick; limestone intercalations 0.5 m thick are present. Above the Badenian sequence are youngest Neogene sediments: Pliocene breccias 30 m thick.

The Kobeřice quarry is 600 m long. The greatest thickness of gypsum complex was recorded in the eastern part of the quarry. Particular gypsum units are common for the entire quarry (Fig. 2) but some distinct lateral trends of thickness and facies are visible as discussed below.

### Description of the section

The gypsum is conventionally subdivided into two parts. The lower part (12.5-14.5 m thick) consists of crystalline gypsum (giant gypsum intergrowths, sabre gypsum) accompanied by claystones and microcrystalline gypsum, and the upper part (up to 23.5 thick) is built of interbedded laminated gypsum, gypsiferous claystones and breccias.

The mineralogical composition of claystones associated with gypsum in Kobeřice as indicated by X-ray diffraction studies is discussed in the next chapter.

**Unit of giant gypsum intergrowths.** A 4-m-thick unit of giant gypsum intergrowths occurs at the base of the sequence (Fig. 3a). The measured thickness of the unit is 3.3 to 4.2 m, and the variation results mostly from a very irregular relief of the upper surface of the unit.

The unit is built of big (up to 2.5 m high in the western part of the quarry) blocky crystalline intergrowths (Fig. 3b). Such large, vertically arranged gypsum crystals that form giant intergrowths have been earlier recorded in southern Poland (Bąbel, 1987, 1996) and West Ukraine (Peryt, 1996). The gypsum crystals are rich in clay material which results in their dark coloration. The amount of clay material increases towards the eastern part of the quarry. Bąbel (1987) discussed the arrangement of clay impurities in the gypsum crystals of central Poland and showed that the clay material was trapped along the boundaries between lenticular subcrystals (Bąbel, 1987, p. 11). Along with the increase of clay material in the unit, the facies changes from massive to skeletal. In the Nida Valley where such lateral changes have earlier been recorded by Bąbel (1996), massive facies of giant gypsum intergrowths is related to bottom elevations while skeletal facies characterizes bottom depressions (Bąbel, 1996, Fig. 7).

Large cavities (up to 1 m across) filled with claystones within the skeletal facies of giant gypsum intergrowths have been recorded in the unit of giant gypsum intergrowths in the eastern part of the quarry. Their distribution in the vertical profile is random. The large cavieties are sedimentary features as indicated by growth directions of giant gypsum crystals toward these cavities that were filled initially by brine and clay. Within the unit of giant gypsum intergrowths in the eastern part of the quarry, common manifestations of alabastrization (crusts a few cm thick, clear nodules) can be seen; the ditribution of these features is random.

The upper surface of the unit of giant gypsum intergrowths is furrowed (Fig. 3a), and the irregularities reach 1 m. These furrows are filled by clays and clasts of giant gypsum intergrowths, in places as much as 50 cm across. A similar, although not so intensively corroded, contact of giant gypsum intergrowths with overlying clays (not more than a few tens of centimeters thick) was recorded in southern Poland (Bąbel, 1987).

**Unit of clays overlying the unit of giant gypsum intergrowths.** The unit is a few tens of centimeters thick (Fig. 3a), rarely only 10 cm thick, and in a few places it is lacking. In such places, grass-like gypsum occurs (Fig. 3c). In these clays, planktonic foraminifers abound. Considering the existence of irregularities of the top of the overlying unit, the actual thickness of clays may be as much as 170 cm.

**Unit of microcrystalline ("alabastrine") gypsum.** The clays are overlain by a 10-32-cm-thick layer of alabastrine gypsum in the western part of the quarry (Fig. 3d).

A similarly developed unit has been recorded in other peripheral parts of the Badenian gypsum basin (Kasprzyk, 1993; Peryt *et al.*, 1994; Peryt, 1996). Toward the eastern part of the quarry, the number of alabastrine layers increases; the thickest of these is the uppermost one. Rarely, alabastrine gypsum overlies directly the giant gypsum intergrowths unit (Fig. 3c). The upper surface of the alabastrine gypsum unit is commonly rippled (with irregularities up to 1 cm) although in places it is very even. White alabastrine gypsum is considered as having been formed diagenetically by dehydration of gypsum to anhydrite and rehydration of anhydrite back to gypsum, as in the Messinian of Tuscany, Italy (Lugli & Testa, 1996).

Unit of gypsiferous laminated clays with sabre gypsum. The unit of microcrystalline ("alabastrine") gypsum is overlain by a unit of gypsiferous clays with sabre gypsum crystals as well as supercones built of sabre gypsum crystals and their amalgamates forming large gypsum bodies within the gypsiferous claystones (Fig. 4, 5). The sabre gypsum crystals in Kobeřice (Fig. 4d) have many similarities to characteristically curved, strongly elongated crystals known from the middle part of Badenian gypsum sequence of southern Poland (sabre-like gypsum - Kwiatkowski, 1972) and Ukraine (sabre gypsum - Peryt, 1996).

The thickness of the unit is 10 m in the western part, where the gypsum content is the greatest, and decreases to the east to 8 m. The lower part of the unit is built of interlaminated gypsum and claystones (Fig. 4a, b). Higher up in the sequence clays occur with isolated bent sabre gypsum crystals (Fig. 4d) or with gypsum bodies (nucleation cones and their amalgamates - Fig. 4b, e, Fig. 5c). Sabre gypsum crystals have a very constant dip (10-20$^o$) and strike (170$^o$) throughout the quarry. Within the claystone framework, the distribution of supercones is bizzare. It is clearly seen that toward the east the number of gypsum bodies and their size decreases and the thickness of claystone between the alabastrine gypsum unit and the first gypsum body increases. In the central part of the quarry this distance is 140 cm.

Irregular lenticles of laminated claystone are observed within some larger gypsum bodies in the western part of the quarry (Fig. 4c). Contact of bodies built of sabre gypsum crystals with gypsiferous claystones is usually abrupt (Fig. 4d). Such contacts occur both at the base of the gypsum bodies and at their flanks.

The development of clusters or stellate groupings of gypsum is common where crystal nucleation took place on a soft substrate (Schreiber, 1988). The crystals sank into the underlying substrate under their own weight as they grew; the base of one such grouping is shown in Figure 5b. The sinking was partly responsible for greater dips of sabre gypsum crystals. On the other hand, crystallization of such groupings could have led to disturbances above the grouping, such as thinning on laminae in the overlying claystones closer to the top of the grouping, as well as contortions of clay laminae on upper flanks of the grouping (Fig. 5a). These disturbances in laminae arrangement over the groupings resulted from compaction. In such cases, the selenite crystals are commonly upright, and their depositional origin is supported by the inclusions of microorganisms in gypsum crystals (cf. Fig. 11b, g).

The nucleation cones clearly depress the underlying laminated claystones (Fig. 5b, c). Such features are known from the Messinian gypsum of Sicily (Lo Cicero & Catalano, 1976) and Sorbas Basin (Dronkert, 1976, 1985). The supercones are thought to have formed by overgrowth of smaller precursors and by crystallization within a soft mud/clay.

These gypsum bodies built of sabre gypsum crystals are interpreted to have formed owing to brine circulation through a still partly soft and water-saturated sediment; accordingly, these bodies are early diagenetic formations (but depositional as they originated within the depositional environment - Spencer & Lowenstein, 1990). The sabre gypsum crystals are mostly sedimentary forms as indicated by inclusions of microorganisms (see below).

Upper part of the gypsum sequence. The upper part of the gypsum sequence consists of interbedded laminated gypsum, gypsiferous claystones and gypsum breccias (Fig. 6). At the base of this part, a unit of laminated gypsum occurs. It is 100 cm thick in the eastern part of the quarry, and toward the western part its thickness decreases to 60 cm. The unit is built of very finely laminated gypsum that is locally accompanied by internal folding which is attributed to lateral displacement (slumping) (Fig. 6b).

The unit of laminated gypsum in the quarry is overlain by a complex of 5.3-m-thick gypsiferous claystone that contains massive breccia intercalation in its middle part (Fig. 6a). The thickness of this intercalation varies: in some places it is lacking and in others it is a few meters thick. The breccias are characterized by blocks of the laminated gypsum as well as coal fragments. The base of these bodies is locally erosional (channels?) but more commonly it is sharp, and non erosional.

The upper laminated gypsum unit that overlies the unit of claystones and breccias is 75 cm thick in the western part of the quarry, and eastward the thickness increases and reaches 4.5 m in the easternmost part of the quarry. In this upper unit of laminated gypsum, pseudomorphs after halite crystals abound. The unit contains layers and flasers of more massive gypsum as well as breccias, very similar to those occurring in the laminated gypsum of the upper part of the gypsum sequence (unit "n") in Borków, southern Poland (Peryt & Jasionowski, 1994).

The upper laminated gypsum unit gradually passes into laminated gypsiferous claystones (5.5 m thick; Fig. 6c) containing common breccia intercalations (Fig. 6d); this part of the section occurs only in the eastern part of the quarry. Above the laminated gypsiferous claystones, in the easternmost part of the quarry, 6 m of massive breccias occurs where thick irregular beds can be distinguished in places. The breccias are overlain by 1-m-thick claystones that contain massive breccias, covered by Quaternary gravels. In these claystones, planktonic foraminifers have been recorded.

It seems that a considerable part of the upper part of gypsum sequence is made of coarse-grained gypsrudites or breccias that are interpreted as debrites

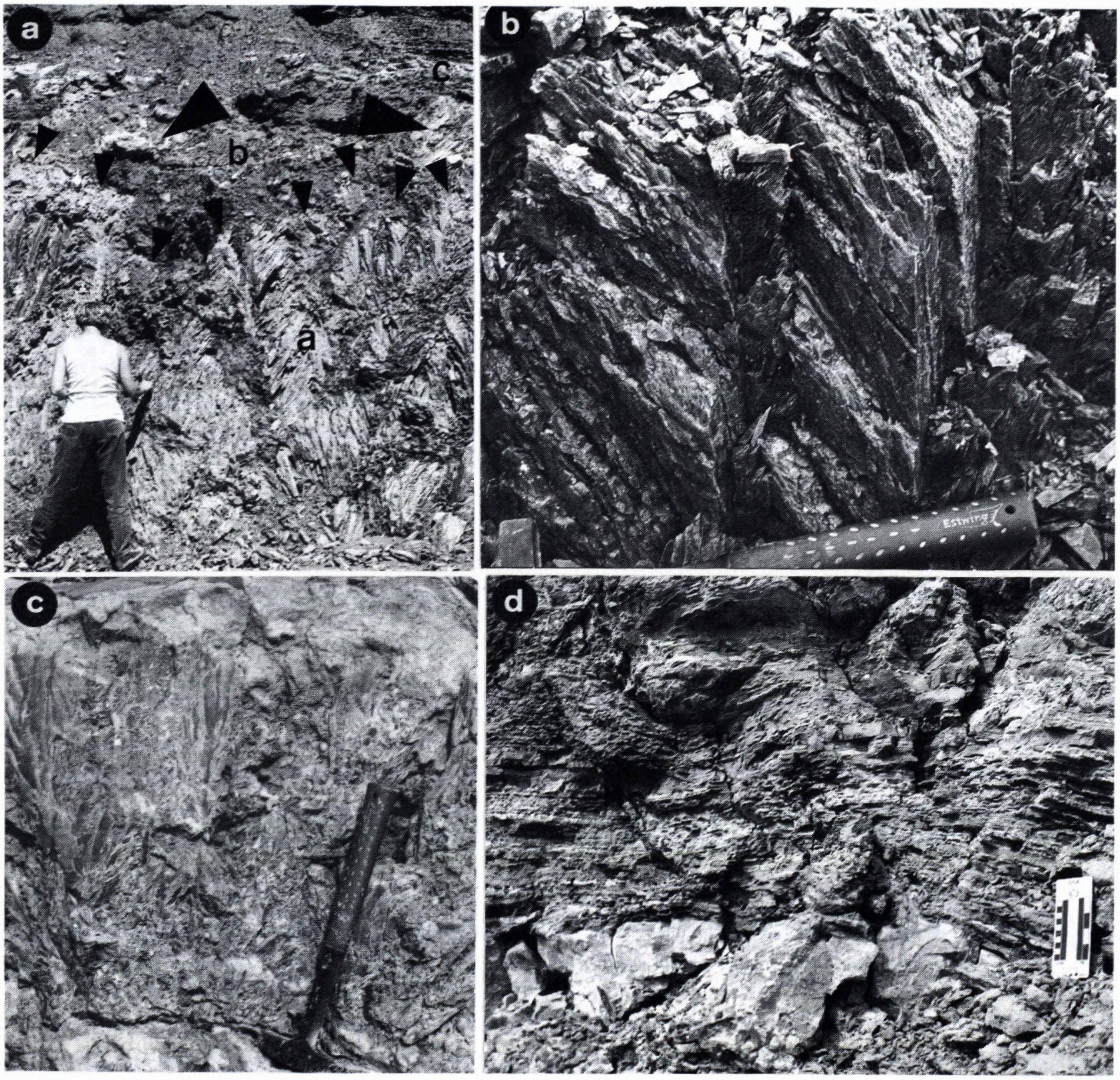


*Fig. 3. The lower part of gypsum sequence in Kobeřice.*
*a - The lower part of gypsum complex: unit of giant gypsum intergrowths (a) showing a very irregular upper surface (arrowed) overlain by claystones (b) with large clasts of giant gypsum intergrowths (arrows) and then by a layer of white microcrystalline ("alabastrine") gypsum (c) followed by claystones interlaminated with gypsum (d). East-central part of the quarry; b - Giant gypsum intergrowths. Western part of the quarry; c - Two beds of white microcrystalline gypsum separated by grass-like gypsum. East-central part of the quarry; d - White microcrystalline gypsum overlain by claystones interlaminated with gypsum. West-central part of the quarry.*

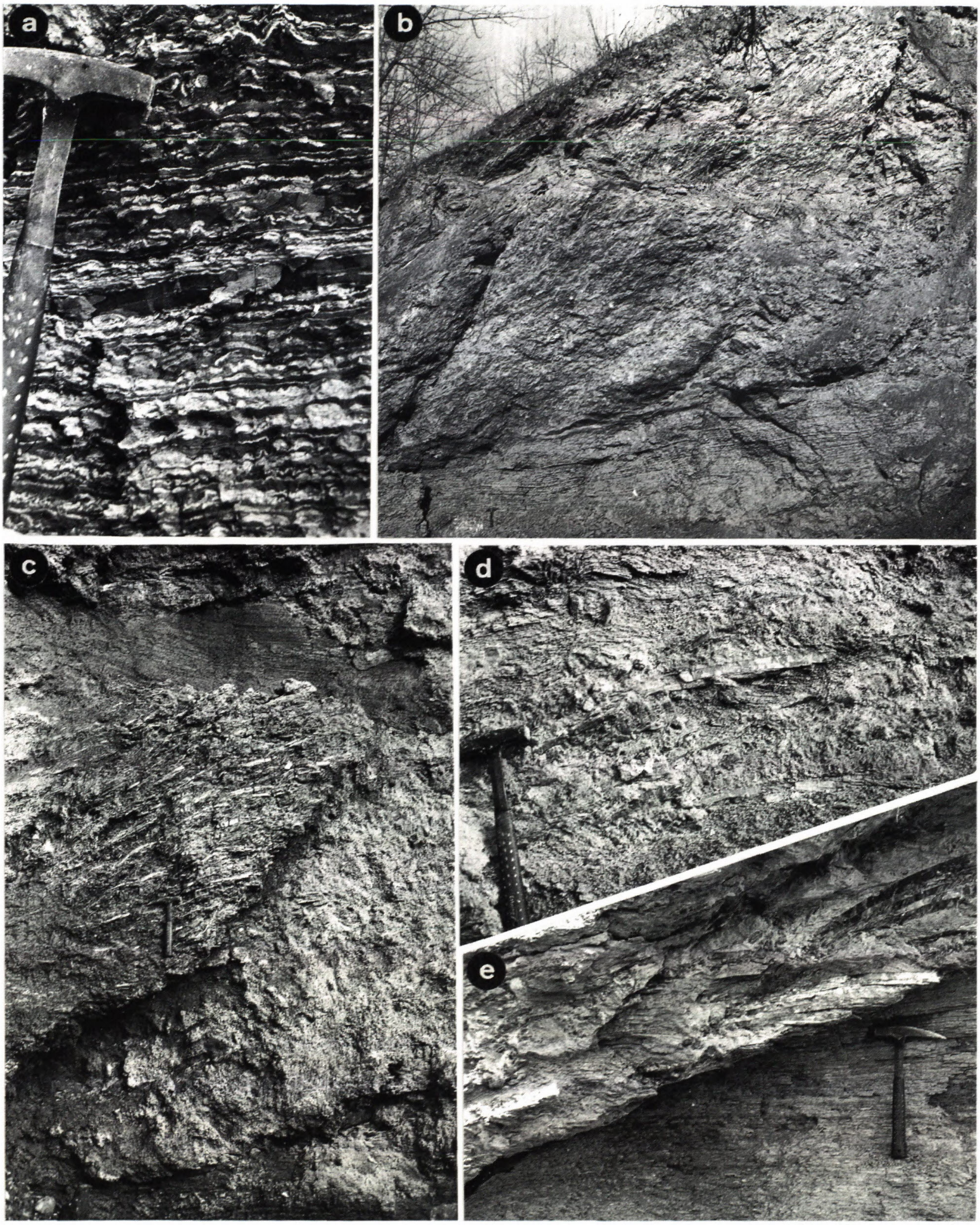


*Fig. 4. Unit of gypsum laminated clays with sabre gypsum (a, c-e - west-central part of the quarry, b - western part of the quarry). a - Aspect of claystones with gypsum laminae that are continual or composed of nodules; b - Claystones with gypsum laminae (in the lower part) overlain by amalgamated bodies composed of sabre gypsum crystals; c - Photo showing relations of claystones and amalgamated bodies built of sabre gypsum crystals; d - Sabre gypsum crystals occurring in claystones; e - Contąct of a body built of sabre gypsum crystals with claystones.*

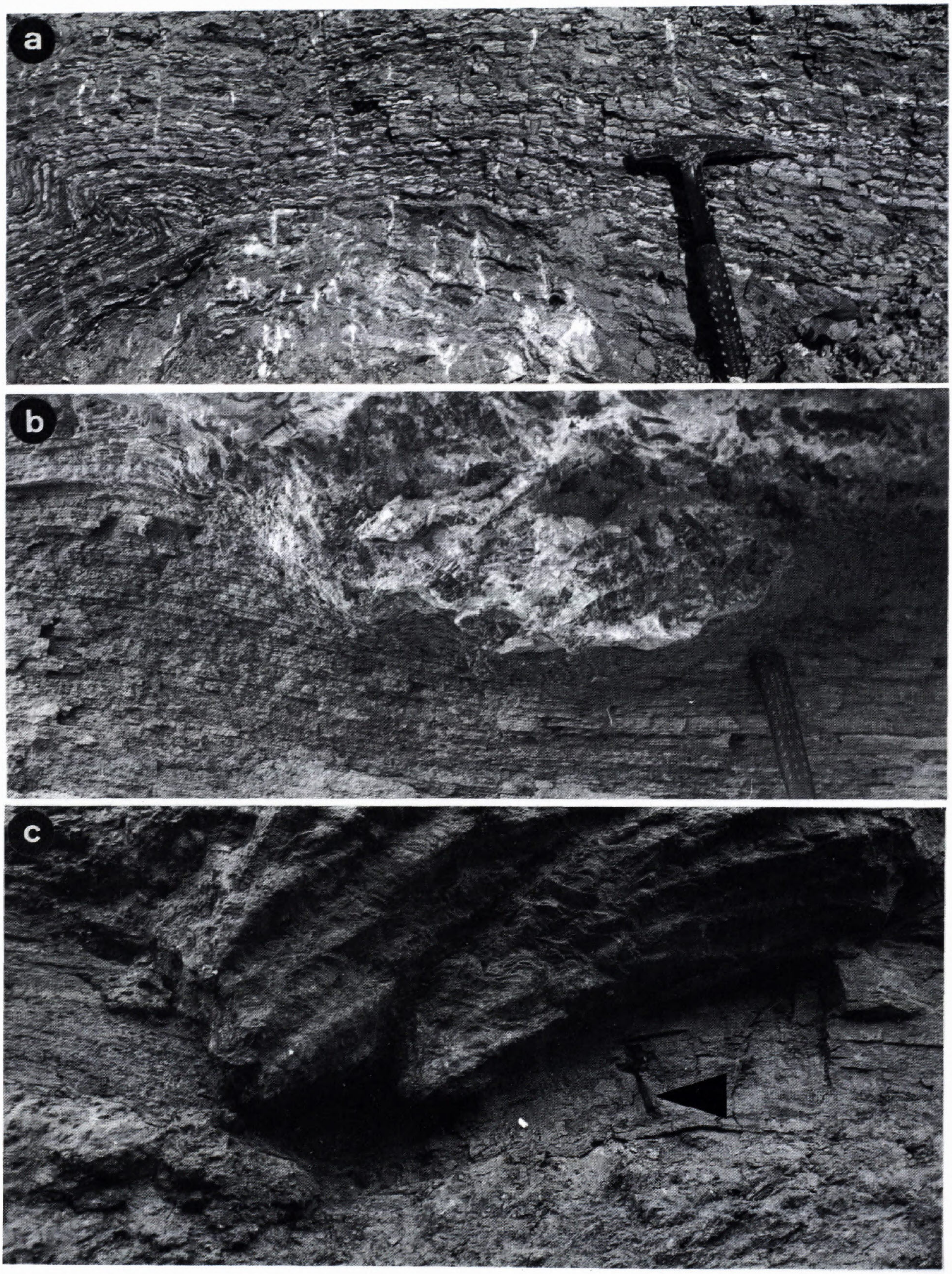

*Fig. 5. Deformations related to supercones (west-central part of the quarry).*
*a - Top of a grouping of gypsum affecting the cover; b - Base of another grouping that sank into the substrate during growth, forming a typical depression cone; c - Contact of supercone with underlying claystones; hammer (arrowed) as a scale.*

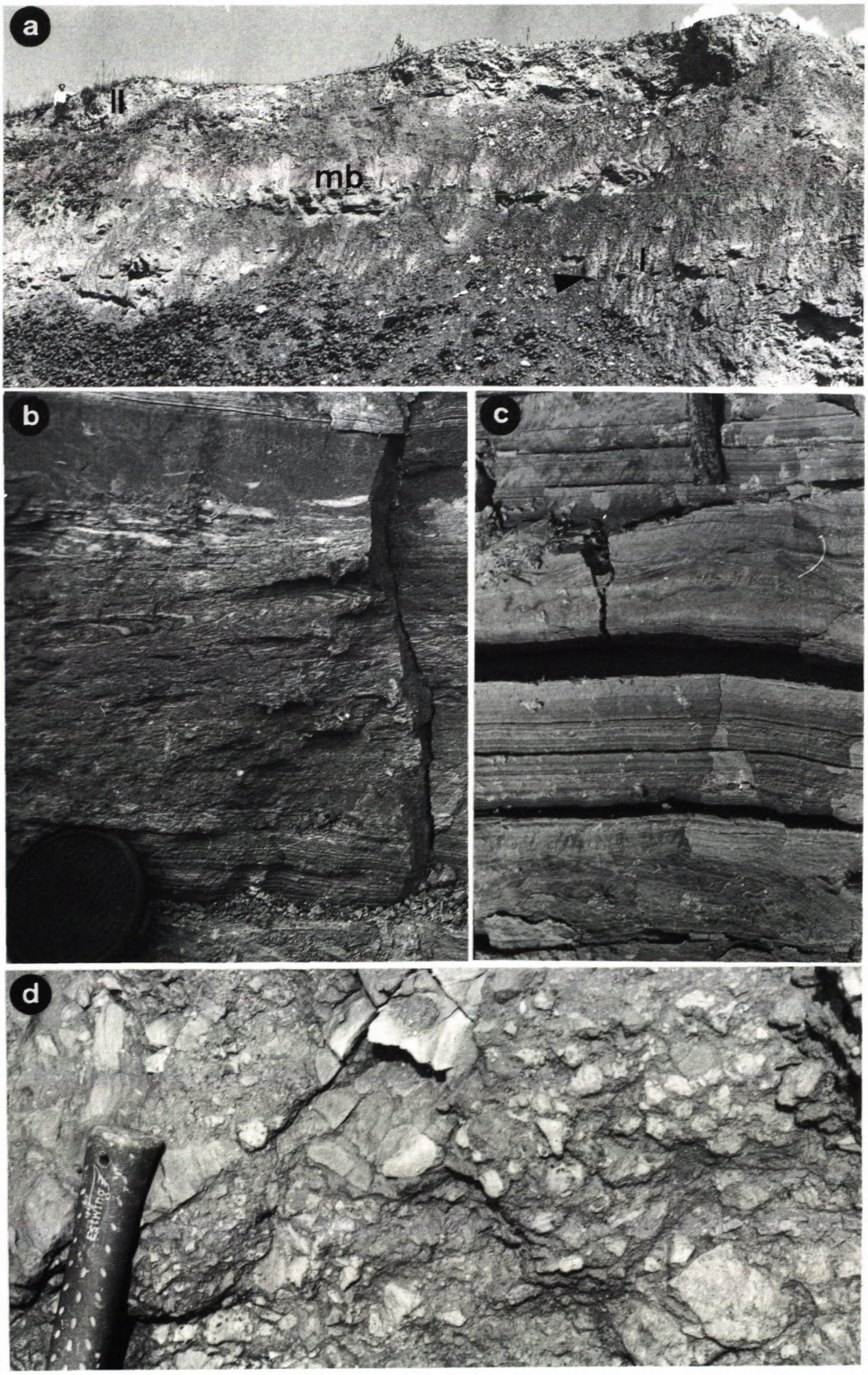


*Fig. 6. Upper part of the gypsum sequence (a - west-central part of the quarry, b - east-central part, c, d - eastern part of the quarry).*

*a - Field photo showing the first (I) and second (II) units of laminated gypsum. The unit in the middle (mb) has an irregular form and is related to slumping. Arrow shows the place sampled for organical geochemical study; b - Laminated gypsum overlain by distorted and massive gypsum; c - Deformations within the gypsiferous claystones (3 m above the upper laminated gypsum unit); d - Gypsum breccia above the second unit of laminated gypsum.*

(*cf.* Peryt & Jasionowski, 1994). The laminated gypsum units can be interpreted as fall-out from a low-density turbid layer. These deposits are related to a large body of brine present during deposition (*cf.* Kendall, 1992, p. 396).

**Analyses of mineralogical composition**

Analyses of mineralogical composition were made using the X-ray diffraction method. The Philips Compact X-ray Diffractometer System PW1840 with Cu-tube and solid state detector provided with an automatic computerized powder identification system APD 1877 was used. The system allows a direct printout of the values of spacings in crystal planes and the counts (in pulses) of corresponding peaks, or a measurement of net intensity of selected peaks. Diffractometer measurements were made on raw samples in the $3^{o}$-$60^{o}$ $2\theta$ range of angles on pressed specimens, and on clayey fraction (<0.002 mm) samples in the $3^{o}$-$20^{o}$ $2\theta$ range on oriented and heated specimens.

These studies showed that the main constituents are gypsum (occurring also in the clay fraction), quartz (10-25%, usually 15-20%), calcite (up to 5%). Iron compounds (1-2%) occur in only two samples (95-3 and 95-4; pyrite and goetite, respectively). The content of clay minerals is 2-10% (usually 5 to 8%) except in two samples where clay minerals are lacking. The following clay minerals have been identified: kaolinite, illite, chlorite, and in samples 95-19, 95-21 and 95-22 illite-montmorillonite mixed-layered minerals. The content of clay minerals varies. It is especially low (2%) in the unit of gypsiferous claystones with sabre gypsum and supercones where in particular samples illite or kaolinite dominate, and in samples 95-13 and 95-14 where they are practically lacking. The sample 95-25 from the top of the gypsum sequence is very similar in terms of phase composition to sample 95-12.

**Micropaleontological studies**

Micropaleontological studies included examination of foraminifers, calcareous nannoplankton and palynofacies.

Seven samples have been examined aiming to establish the presence of foraminifers and calcareous nannoplankton; their location is shown in Figure 2. In addition, twenty four samples (the same set that was studied for mineralogy and palynofacies) have been used to study the foraminifers.

Preparation of slides with calcareous nannoplankton for study under the optical microscope was by the method described by Gorostidi and Lamolda (1995). Two samples appeared to be barren (see Fig. 7). In the remaining samples the calcareous nannoplankton are very scarce and very poorly preserved, with a few dominant cosmopolitan species (*Coccolithus pelagicus*, *Reticulofenestra pseudoumbilica*, *R. minuta*, *R. minutula* and *Helicosphaera carteri*) (Fig. 7). Occasional occurrence of *Sphenolithus abies* and *Helicosphaera walbersdorfensis* was recorded. It should be stressed that no *Discoaster* was found in the section and in many samples redeposited Cretaceous forms occur. Such an assemblage makes it difficult to date precisely the Kobeřice section although the lack of *Sphenolithus heteromorphus* (known from NN4 and NN5 zones - Martini, 1971; Lehotayová & Molčikova, 1978; Backman, 1984; Theodoridis, 1984; Perch-Nielsen, 1985) and the occurrence of *Helicosphaera walbersdorfensis* (known in the Central Paratethys from NN6 and NN7 zones - Müller, 1974; Rögl & Müller, 1976; Lehotayová & Molčikova, 1978) suggests that the studied interval belongs to a part of the NN6/7 zone.

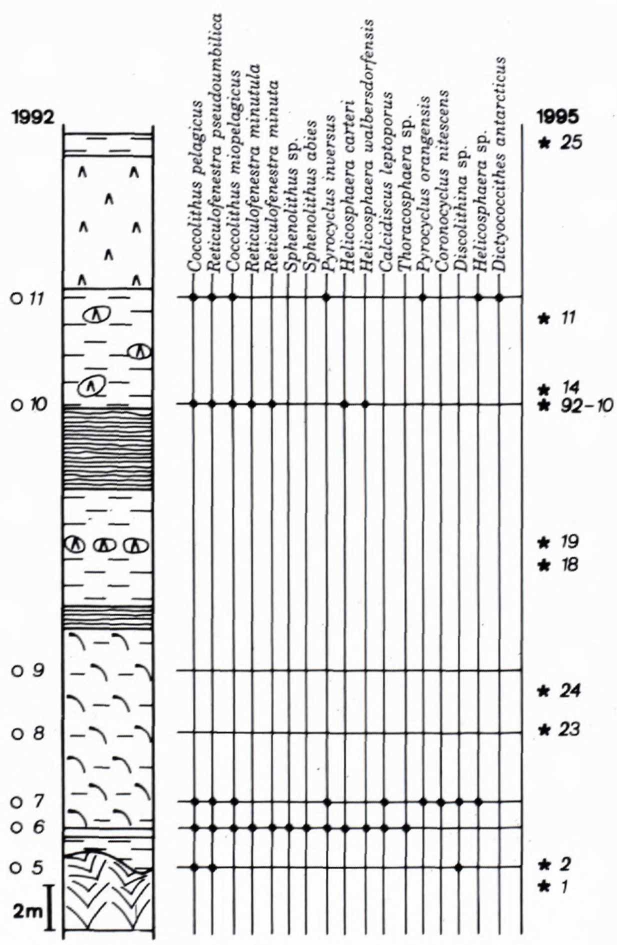


*Fig. 7. Occurrence of coccoliths in the Kobeřice section.*

In many samples planktonic foraminifers have been recorded; the location of those samples is asterisked in Figure 7. The following species have been found: *Globigerinoides trilobus* (Reuss), *Globigerina praebulloides* Blow (Fig. 8i-k), *G. bulloides* Blow, *G. falconensis* Blow

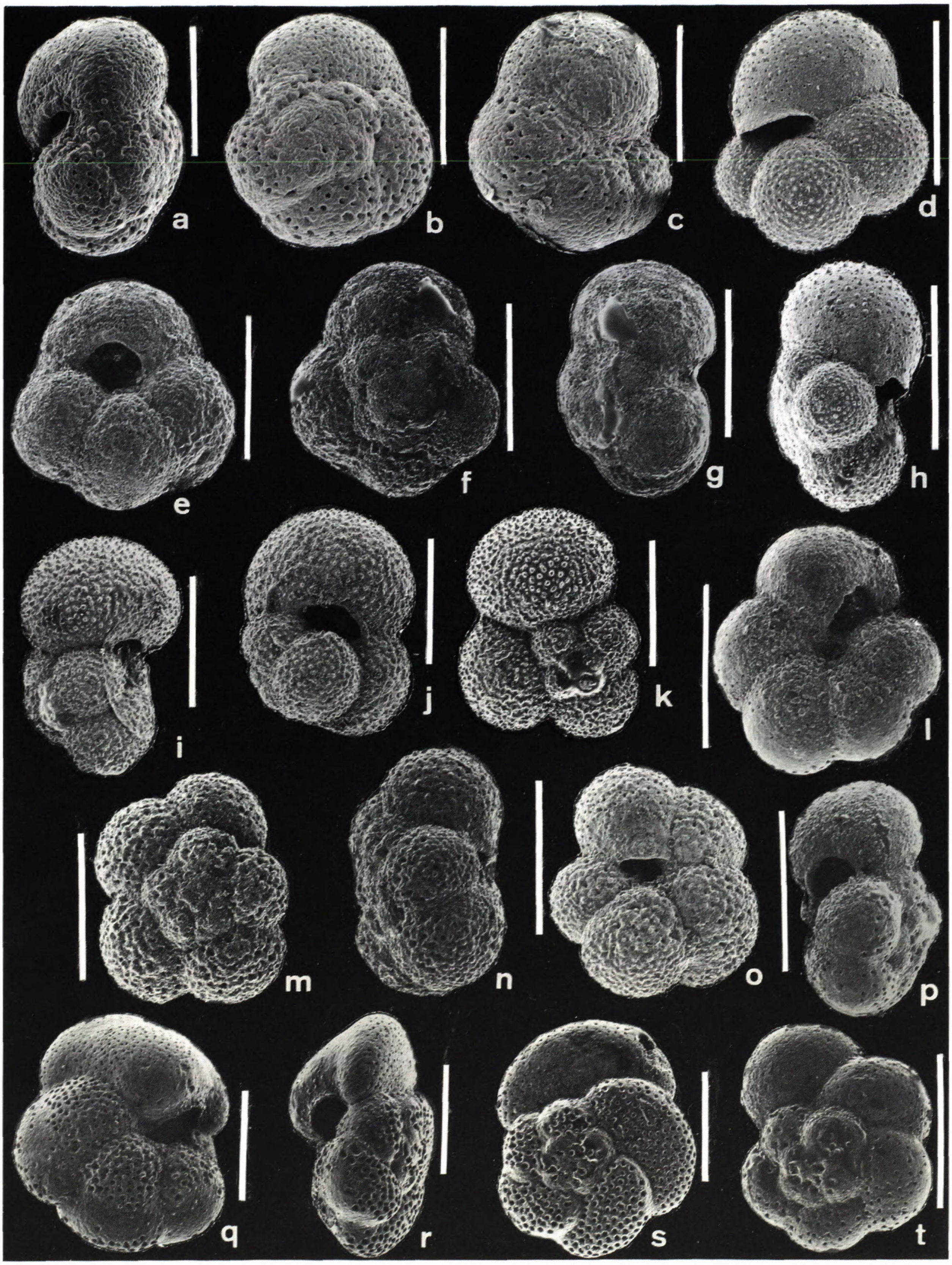


*Fig. 8. Planktonic foraminifers in the Kobeřice gypsum sequence (scale bar = 100 μm).*
*a-c - Paragloborotalia continuosa (Blow); d,h - Globigerina falconensis Blow; e-g - Globoturborotalita druryi (Akers); i-k - Globigerina praebulloides Blow; l,p,t - Paragloborotalia mayeri (Cushman & Ellisor);m-o - Globigerina concinna Reuss.; q-s - Globorotalia bykovae (Aisenstat).*

(Fig. 8d,h), *G. concinna* Reuss (Fig. 8m-o), *Globoturborotalita druryi* (Akers) (Fig. 8e-g), *Paragloborotalia tarchanensis* Subbotina & Chutzieva, *P. sp. cf. acostaensis* (Blow), *P. continuosa* (Blow) (Fig. 8a-c), *P. siakensis* (Le Roy), *P. mayeri* (Cushman & Ellisor) (Fig. 8l,p,t), and *Globorotalia bykovae* (Aisenstat) (Fig. 8q-s). Considering the ranges of those species except of *Globorotalia bykovae* (Aisenstat) in the Mediterranean Miocene (Iaccarino, 1985) it may be concluded that this assemblage represents Serravalian. *Globorotalia bykovae* (Aisenstat) has its last appearance in Central Paratethys in Wielician (Rögl, 1985).

It should be mentioned that in samples 95-1 and 95-2 coming from the unit of gypsiferous claystones overlying the unit of giant gypsum intergrowths, early Miocene planktonic foraminifers (such as *Globigerina dubia* Egger and *Globigerina bollii lentiana* Rögl) and calcareous nannoplankton (e.g. *Helicosphaera ampliaperta* Bramlette & Wilcoxon) have been recorded. The redeposition of microfauna and microflora postdated the subaerial exposure following deposition of the unit of giant gypsum intergrowths.

Twenty four samples of claystones have been studied palynologically (Fig. 9). About 30 g of a sample have been processed in 40% HCl, then sieved through 15 μm sieve, again processed in 38% HF and sieved, and next separated in heavy fluids (of density 2 g/cm$^3$). It was found that all studied samples contain rich organic material that was subdivided into four groups according to the state of preservation and the origin: black non-translucent woody particles, brown structureless organic matter, fragments of plant tissues, sporomorphs and algae (Fig. 9).

The Kobeřice sequence is characterized by relatively constant distribution of palynofacies. Commonly the content of particular components is as follows: black woody particles, 18-25%; brown organic matter, 8-12%; plant tissues, 4-8%; sporomorphs (represented mainly by bisaccate pollen grains), 50-70%; and algae, 0-5%. No dinocysts have been recorded. In one sample (no. 95-3) the content of plant tissues reaches ca. 30%, and the content of black woody particles in samples nos. 95-18, 95-19, 95-13 and 95-14 reaches ca. 40% palynofacies. Accordingly, terrestrial elements strongly dominate, constituting almost 100% of the palynofacies. This indicates a close proximity of the land, although the predominance of sporomorphs may suggest a slightly more distant further located source area for organic material found in the Kobeřice section. A wider distribution of sporomorphs is suggested because of greater buoyancy potential of these bisaccate pollen grains. A relatively good state of preservation of palynomorphs indicates a decreased deposit oxidation and/or fast delivery of organic matter. The lack of dinocysts, commonly occurring in marine Miocene deposits, suggests the stress conditions (*e.g.* high salinity level) prevailing during deposition of the Kobeřice gypsum sequence.

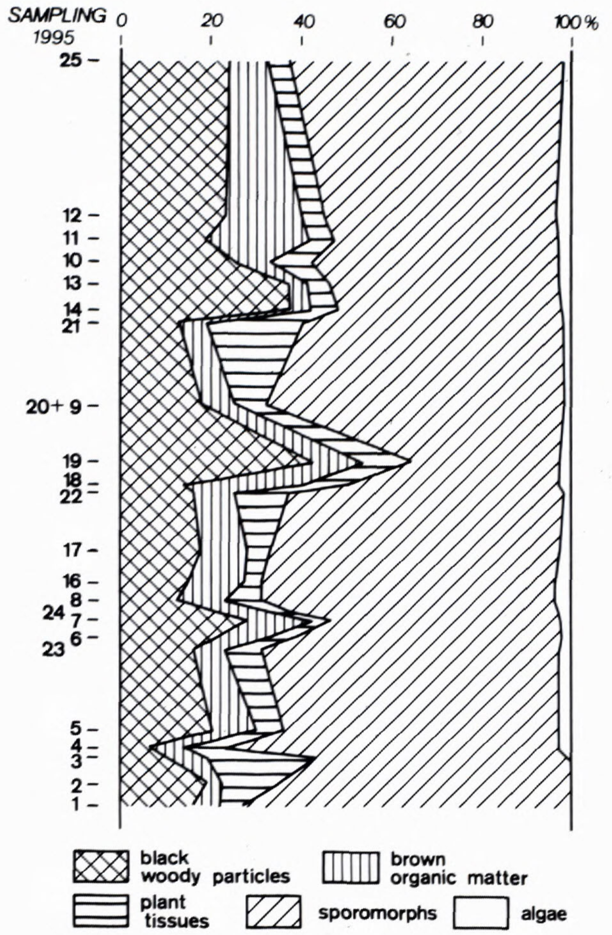


*Fig. 9. Palynofacies in the Kobeřice section.*

## Geochemical studies

Geochemical studies included the determination of boron content in claystones associated with gypsum (Fig. 10), study of fluid inclusions in crystalline gypsum units (Fig. 11), isotopic (oxygen and sulfur) analyses of gypsum samples (Table 1) as well as one analysis of organic matter (Fig. 12).

Determination of boron in claystones in the same set of samples that was subject to palynofacies and X-ray diffraction studies were done at the Central Chemical Laboratory of the Polish Geological Institute; locations of those samples (95-1 to 95-25) are shown in Fig. 2. The boron content was measured using Philips PV8060 Spectrometer; the error of determination is 3-5%. The values measured are from 24 to 111 ppm (average is 64 ppm), and such low values are considered to be characteristic for clay deposits of freshwater origin (see Pasieczna, 1983, Table 4).

Nine samples of selenite gypsum have been studied for fluid inclusions; five samples came from the giant gypsum intergrowths (Nos. 1, 39, 52-54/1992) and four from the sabre gypsum crystals in a supercone from the lowest part of the unit (Nos. 47-50/1992). The studies have been performed in the Institute of Geology and Geochemistry of Combustible Minerals, National Academy of Sciences of Ukraine (Lviv) following the thermobarogeochemical procedure used there (Petrichenko, 1973, 1977). Inclusions are typically fluid. Most inclusions are dehermetized. Considering the freezing temperature (that is about 0°C) of fluid inclusions, the concentration of basin brines did not exceed 5-10 g/l. This conclusion is also supported by the lack of precipitate on the surface of plates following the evaporation of fluid inclusions. The analyses of water leachates and analysis of one fluid inclusion shows the following ratios of major components: Chlorine, 1.0; sulfate ion, 0.65; magnesium, 0,06; potassium, 0.05; calcium, 0.03. Sodium was not determined but its presence is clearly indicated by presence of mirabilite and halite in the solid phase of water leachates. Accordingly, it is assumed that basin waters were saturated in respect to calcium sulfate (what is evident considering that gypsum has precipitated) and also contained, along with sodium chlorine, a high amount of sodium sulfate and small amount of potassium and magnesium salts. As a whole, such a composition would imply that the waters have been continental-marine and saturated in respect to calcium sulfate. The temperature of bottom water is hard to determine precisely but considering the presence of one-phase fluid inclusions it may be supposed that it was below 39-40°C.

Mineral inclusions (Fig. 11h) and inclusions of microorganisms are common. The latter have been recorded in giant gypsum intergrowths (Fig. 11a, c, f, h) as well as in sabre gypsum. Most common are inclusions of algae. The inclusions of microorganisms contain organic solutions (Fig. 11f) in addition to water solutions. The inclusions recorded in the gypsum of Kobeřice are very similar to the earlier-described inclusions of microorganisms from the Badenian gypsum of southern Poland and West Ukraine (Petryczenko *et al.*, 1995).

Oxygen and sulfur isotopic studies of five samples were done at Geologický ústav Dionýza Štúra (Bratislava); the locations of these samples are shown in Figure 2. $\delta^{34}S$ values as well as $\delta^{18}O$ values in the gypsum of Kobeřice (Table 1) are very similar to values earlier recorded from the Badenian gypsum of Borków quarry, southern Poland (Hałas *et al.*, 1996) and are characteristic of Tertiary sulfates of marine origin (cf. Claypool *et al.*, 1980).

One sample from the lower laminated gypsum unit, where bituminous material abounds, has been analysed

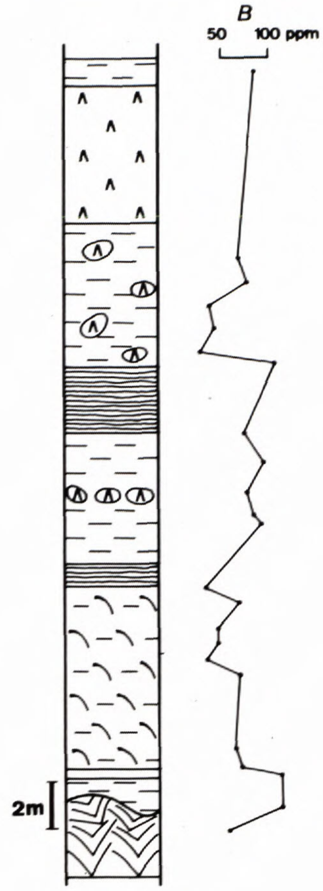


*Fig. 10. Content of boron in the rocks of Kobeřice section.*

at the Central Chemical Laboratory of the Polish Geological Institute, Warsaw. This bituminous material commonly is associated with sulfur efflorescences; the place from which the sample was taken is shown in Fig. 6a. The laminated gypsum sample contains 0.01% of bitumen, and the content of hydrocarbon in bitumens is 41%. The ratio of saturated to aromatic hydrocarbons is 41% which indicates the autochthonous nature of the hydrocarbons. The composition of n-alkanes is shown in Fig. 12. Such a pattern is related to primary mixture but with dominance of sapropel material. $CPI_{\Sigma}$ is 1.26 which indicates a low metamorphism of organic matter.

*Table 1. Results of stable isotopic study of samples from the gypsum sequence in Kobeřice.*

| Sample No. | $\delta^{18}O$ SMOW | $\delta^{34}S$ CDT |
|---|---|---|
| 92-1 | +13.47 | 23.00 |
| 92-2 | +13.19 | 22.49 |
| 92-4 | +11.99 | no data |
| 92-5 | +13.00 | 22.19 |
| 92-8 | no data | 23.32 |

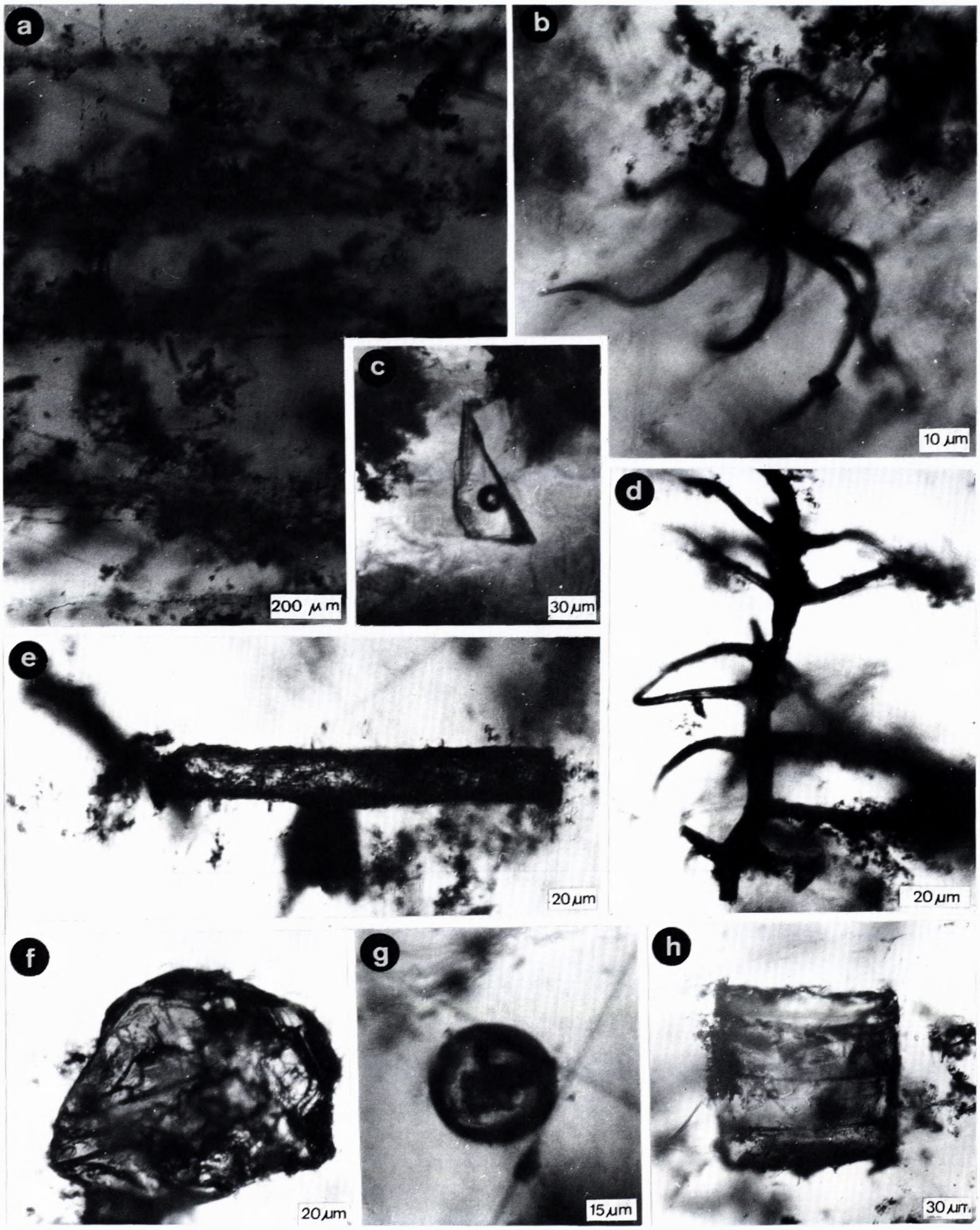


*Fig. 11. Inclusions in gypsum crystals.*
*a - Rhythmic pattern of inclusion occurrence in gypsum caused by periodic changes of gypsum crystallization at the bottom of the basin;b, d - Characean fragments; c - Two-phase inclusion; the air bubble may result from dehermetization of the inclusion; e - Inclusion originated through coupling of algal segments; f - Fluid (brine) inclusion with oily matter;g - Coccoid inclusion; h - Gypsum inclusion of zoned gypsum in giant gypsum intergrowths. The zoning is regarded to reflect the changes of crystallization conditions during day and night.*

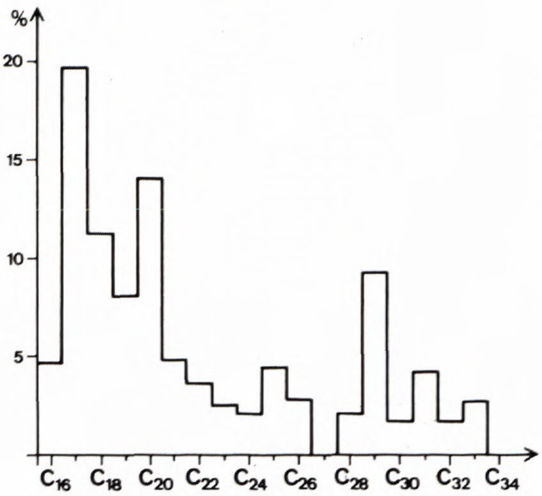


*Fig. 12. Composition of n-alkanes in one sample (no. 92-21) of laminated gypsum.*

## Discussion and conclusions

As proved by Garlicki (1994), a detailed lithostratigraphic examination of the Badenian salt deposits and the distinction of a number of key horizons within these deposits makes it possible to correlate the Upper Silesia salt sections with those known from Wieliczka even though Upper Silesia and Wieliczka salt basins are separated by sulfate facies. Such a similarity of evaporite facies through the Badenian basin seems to be related to an extrabasinal control that did not obscured important local and regional tectonics. Intrabasinal marker beds occurring in the evaporite sequences record distinct phases of brine body evolution (frequent refreshing episodes) or diagenesis related to subaerial exposure.

In Kobeřice it is possible to distinguish some marker horizons typical of other parts of the northern marginal area of the Badenian sulfate basin:

(1) Unit of giant gypsum intergrowths, forming the basal part of gypsum sequences in southern Poland (Bąbel, 1987; Kubica, 1992) and West Ukraine (Peryt, 1996). In particular, Kobeřice giant gypsum intergrowths are very similar to a massive-skeletal facies transition that was earlier recorded in the Nida Valley area, southern Poland, and regarded as a deeper-water deposit when compared to other facies of giant gypsum intergrowths (Bąbel, 1996).

(2) Unit of microcrystalline ("alabastrine") gypsum that can be traced out in the peripheral part of the basin over a distance of almost 700 km from Kobeřice through southern Poland ("unit c" - Kasprzyk, 1993; Peryt *et al.*, 1994) to eastern Galicia in the east (Peryt, 1996). It should be mentioned that in the marginal part of the Badenian gypsum basin there are several alabastrine gypsum beds which can be traced throughout individual exposures or group of exposures, over a distance of hundreds of meters to kilometers (*e.g.* Kasprzyk, 1993; Peryt, 1996), and also in Kobeřice there is an "alabastrine" gypsum bed underlying the proper (main) bed of microcrystalline gypsum. However, only one alabastrine gypsum bed is of regional importance. The occurrence of this unit is roughly related to the zone of occurrence of giant gypsum intergrowths and therefore it is not recorded in the nearshore facies of the gypsum (see Peryt, 1996).

(3) Unit of the upper laminated gypsum has many striking similarities to a unit of laminated gypsum occurring in the lower part of unit "n" in Borków, southern Poland (Peryt & Jasionowski, 1994) including the presence of pseudomorphs after halite crystals.

In addition, considering development and position in the sequence, the unit with sabre gypsum is common for Kobeřice and other peripheral northern parts of the Badenian basin (Kwiatkowski, 1972; Bąbel, 1986; Kubica, 1992; Peryt *et al.*, 1994; Peryt, 1996) although Kobeřice sabre gypsum differs from other sabre gypsum occurrences by its relation to associated claystones that are coeval with gypsum precipitation. A clayey nature of the Kobeřice gypsum is explained by a very important and continual clay delivery to the Upper Silesia evaporite basin. Like other sabre gypsum crystals, those recorded in Kobeřice show very constant orientation that is interpreted by Bąbel (1986, 1996) as due to directional growth of sabre crystals that was enforced by the inflow of calcium sulfate-saturated brines.

The upper part of the gypsum sequence in Kobeřice shows widespread redeposition phenomena that are also characteristic of the upper part of the Badenian gypsum elsewhere (Peryt & Kasprzyk, 1992; Peryt & Jasionowski, 1994; Peryt, 1996). These redeposition phenomena are related to the existence of a paleoslope. Paleoslopes are rarely observed in the field and their presence is inferred from the analysis of lateral facies changes of evaporite sequences. In particular, the presence of redeposition phenomena is important to determine the existence of slope zones in evaporite basins (*e.g.* Peryt *et al.*, 1993; Peryt, 1994) although the uncertainity of lateral correlations of evaporite facies is a limiting factor in reconstruction of paleogeographical and facies patterns (see discussion in Sonnenfeld, 1984). In Kobeřice, the presence of paleoslope is well expressed during deposition of the entire gypsum sequence. Amount of clay material in the facies of giant gypsum intergrowths increases eastward, and this increase is accompanied by a change of massive facies to skeletal facies of giant gypsum intergrowths, decrease in frequency of amalgamates of supercones, as well as increase in the thickness of laminated gypsum units and the number and thickness of breccias in the upper part of gypsum sequence. The basin was located east of Kobeřice, and as recognized by Krach (1958), the basinal zone of evaporites in Upper Silesia is characterized by occurrence of laminated gypsum, anhydrite and halite.

Although the evidence of redeposition indicates paleoslope and not necessarily deeper water conditions, it seems that the upper part of the gypsum sequence as well as the major part of the lower part represent deeper water deposits. The presence of planktonic foraminifers throughout the entire section (except in giant gypsum intergrowths and both units of laminated gypsum) indicates that there existed water stratification in which the bottom gypsum-saturated brines were overlain by normal marine waters containing planktonic fauna. Such a water stratification was already suggested by Krach (1956). The surficial water layer was affected by dilution by floods supplying clays as well as terrestrial elements of palynofacies. Accordingly, the salinity in the upper, nearsurface part of the water column was subject to major variation. On the other hand, the occurrence of pseudomorphs after halite in the upper laminated gypsum unit is possibly related to bottom brines that were temporarily saturated with halite (*cf.* Bąbel, 1996). It is thus difficult to assume that the multiple dilution phases of the surface water could reach concentration that allowed precipitation of halite crystals. The occurrence of pseudomorphs of halite thus would imply the existence of halite-saturated brines overlain by gypsum-saturated brines which in turn were overlain by waters of changing, but usually low, salinity. Accordingly, strongly stratified waters in a relatively small basin exerted an important control on gypsum turbidite deposition (*cf.* Rimoldi *et al.*, 1996).

Summarizing, the major part of the gypsum sequence of Kobeřice originated in rather deeper water conditions in density-stratified waters. The only exceptions to rather deeper water conditions prevailing during gypsum (and related claystone) deposition are exposure episodes following formation of the giant gypsum intergrowths and during the alabastrization phase(s). The same major stages in the basin evolution can be recognized throughout the northern marginal basin (Peryt *et al.*, 1994; Peryt, 1996; Bąbel, 1996). The pecularities of Kobeřice gypsum section indicate its more basinward location compared to other gypsum exposures known from Poland and West Ukraine.

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