The "white beds" – a fossil caliche of the Barrandian area: its origin and paleoenvironmental significance

Bílé vrstvy Barrandienu – fosilní caliche: jejich původ a význam pro rekonstrukci paleoprostředí

(15 figs)

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So-called "white beds" – a snowy white to rusty yellow, sandy to chalky weathered carbonate alteration horizons locally developed over the lower Paleozoic limestones – are interpreted in terms of fossil carbonate soil (caliche, calcrete). A typical caliche sequence affects as much as 6–8 meters of the limestone host and develops gradually from a transitional zone exhibiting largely dissolution phenomena. These altered limestones grade upwards into a chalky zone of completely disintegrated carbonate that, in turn, gives way to a zone of coalescing carbonate nodules commonly developed below the recent soil cover. Microscopic phenomena observed in the carbonates closely match those known from both recent and ancient caliche elsewhere, and include calcite nodules, circum-granular cracking, rhizoliths, Microcodium, alveolar septal structures, tangencial needle-fiber calcite cements and floating calcite rhombs. Following the paleosoil formation, some of the caliche deposits were subject to redeposition and/or collapse into the paleorelief depressions and introduction of alluvial gravels and fine siliciclastic material into the caliche matrix. The age of the caliche is not known. Assuming that the formation of caliche paleosoil requires the conditions of long-lasting geomorphologic stability and arid to semi-arid climatic setting with low annual rainfall, the alteration can be tentatively attributed to a protracted period of peneplenization and reduced deposition that occurred in the Bohemian Massif during the Mesozoic-Tertiary era. Alternatively, the caliche facies may have also developed in response to Pliocene-Pleistocene climatic fluctuations.

Key words: Caliche, Calcrete, Paleosoil, Subaerial Exposure, Limestone Diagenesis, Barrandian, Czech Republic.

1. Introduction

The local term of "white beds" refers to soft, snowy-white to cream yellow colored, semi-lithified to chalky loose carbonate deposits that characteristically occur in the Lower Paleozoic Barrandian basin (Martínková 1997). Typical "white beds" are commonly developed above and/or in a close spatial association with underlying upper Silurian – lower Devonian limestones. Some of the "white beds" contain abundant dismembered fossils (e.g. crinoidal particles, corals etc.) and those are known as important paleontological localities (Petr *et al.* 1997, Chlupáč 1999). Many examples of this peculiar carbonate facies can be studied in the eastern part of the Barrandian, in a series of both natural and artificial exposures directly accessible on the territory of the Prague City. Although there has been a general understanding that the "white beds" probably represent some alteration product of nearby lower Paleozoic limestone, the processes responsible for the origin of the facies have been poorly understood. The mechanisms suggested by various workers included alteration of host limestone by circulating ground water (Petr *et al.* 1997, Martínková 1997), Mg-rich solutions (Martínková 1997), or weak organic acids (Žák *et al.* 2001). Enigmatic, vaguely defined processes of "cold metasomatism" have been also called upon to explain the origin of some "white beds" (Bosák *et al.* 1993, Cílek *et al.* 1995).

In this study, we accumulate evidence, both field and microscopic, that the "white beds" represent in fact a fossil caliche (calcrete) – carbonate paleosoil beds. This interpretation has important implications for post-Paleozoic geomorphologic and climatic evolution of the Barrandian area and the central Bohemia in general.

2. Field characteristics of the "white beds"

Martínková (1997) has recently released a review of individual "white beds" localities in the Barrandian area and an interested reader is referred to this work for the details on lithology and stratigraphy. Here we only shortly describe the most characteristic field aspects of the "white beds" that are fundamental with respect to their origin and interpretation.

The "white beds" essentially occur in two principal depositional settings that can be distinguished in the field: 1) as *in situ* alteration horizon over underlying Silurian or Devonian limestone, and 2) redeposited grain flow and debris flow deposits.

In situ "white beds" display characteristic vertical zonation that ranges from unaltered limestone host through altered transitional zone to chalky – nodular and/or platy zones (Figs 1 and 2). The position and development of individual zones in a vertical section and laterally is, however, highly variable and the boundaries between the zones tend to show gradual transitions rather than abrupt changes. The most consistent relation is that the sandy to chalky carbonate rocks (e.g. the "white beds" *sensu stricto*) grade downward into the original carbonate rock through a transition zone, with a strong evidence of both in-place alteration and replacement of the original host. *Transitional*

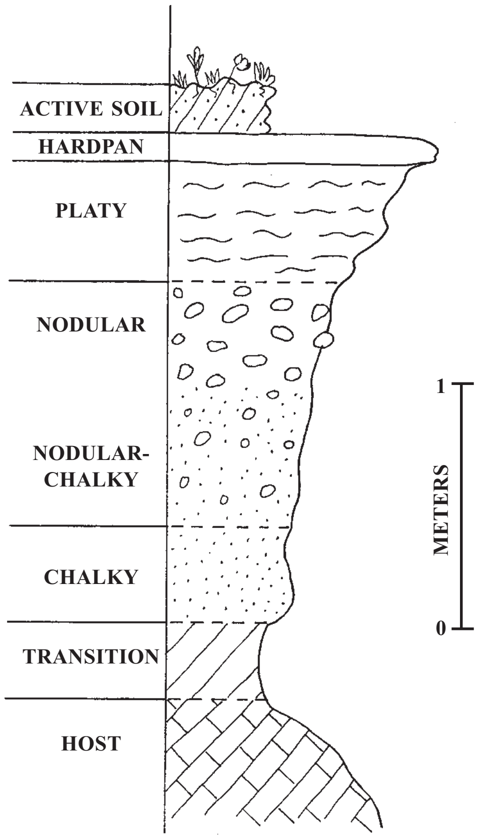


Fig. 1 Idealized caliche profile (modified after Esteban – Klappa 1983). The Barrandian "white beds" caliche profiles commonly lack uppermost platy and hardpan members. See text for more detailed explanation.

zone between unaltered limestone parent rock and overlying "white beds" consists of partially degraded parent limestone, making it difficult to fix its lower boundary (Fig. 3). Alteration of the original limestone occurred preferentially along bedding and joint planes. The rocks of the transitional horizon often exhibit macroscopically discernible features inherited from the limestone bedrock that involve sedimentary structures such as bedding or in-place relic fossils embedded in partly disintegrated and loose carbonate material. The transitional zone grades upward into white, cream or red *chalky zone* (Figs 4 and 5). Cementation between grains is commonly completely absent so that the material has the consistency of a powder. The chalky zone generally grades upward into the *nodular zone*. The latter consists of nodules (globules) made of discrete, indurated masses of calcium carbonate embedded in a less carbonate-rich matrix that appear to be the result of displacive introduction of vadose carbonate into the soil within the profile (Fig. 6). Individual nodules are subspherical to spherical in shape but some vertically elongated forms were also noted. Maximum nodule size is about 6 cm, but larger dimensions have been found for coalesced nodules. Nodules are white to cream in color and internally structureless or, less frequently, exhibit indistinct concentric zonal arrangement, often with irregular internal voids and fractures (Fig. 7). Matrix surrounding nodules tends to be red brown because of higher concentrations of insoluble residues such as clay minerals and ferric hydroxides. Nodular zone often shows diffuse upper and lower boundaries. In some profiles, the boundary between nodular and chalky zones is very indistinct so that this boundary can be treated as a separate horizon, that is, *the nodular-chalky zone*. The nodular-chalky transition, in addition to the features already described, is also characteristic by the presence of abundant petrified root passages (rhizoliths), calcified insect cocoons and other features indicative of biologic activity. Poorly expressed *platy zone* characteristic by horizontal to subhorizontal, platy or wavy thinly bedding occurs as the uppermost calcareous member in some sections only, just below the recent soil cover (Fig. 8).

The complete zoning characteristic of in situ "white beds" is seldom developed within a single section. Rather, the sections exhibit the preferential development of lower zones only (i.e. transitional and/or chalky zones), with upper nodular-chalky to platy members being often reduced in thickness or completely omitted. The whole thickness of the "white beds" alteration sequence also varies from one place to the other. In the eastern part of Prague City (e.g. Červený lom Quarry near Klukovice, Lobolitová stráň Section near Řeporyje), for instance, the apparent thickness of the alteration zone ranges from 6 to 10 m. Substantially less extensive, rather isolated "pockets" of chalky and/or nodular members are also locally developed along steeply dipping beds of limestone host rock (Fig. 5).

Redeposited "white beds"

Many localities of "white beds" contain evidence of partial to complete redeposition. Probably the most characteristic example can be examined in the Bílá rokle Gorge in Prague-Hlubočepy (Fig. 9). Here the "white beds" originally developed over nearby Zlíchov Limestone (Devonian) were affected by slumping and/or gravitational collapsing to form crude, coarse-grained grain flow- and debris flow accumulations. The macroscopic composition of these "white beds" is different from those of *in situ* facies in that it comprises a range of rectangular, largely unsorted debris of limestone parent rock altered to a various degree. In the breccia, virtually unaltered limestone particles coexist face to face with snowy-white lime residua (chalky alteration) and the dismembered cherts that represent alteration-resistant fragments of the host limestone (Fig. 10). Kaolinite-rich white clayey matrix, well-rounded alluvial pebbles and sandy grains that were apparently introduced into the "white beds" during and/or after its redeposition are also characteristic of this facies (Fig. 11). At some places (e.g. lom Prastav Quarry near Prague-Holyně), the "white beds" appear to fill steeply dipping depressions within the limestone host (Fig. 12). Some sedimentary features particularly the general lack of any apparent grain size sorting and/or grading along with the presence of large chaotic clasts and boulders of chalky-altered limestone suggest that these deposits originated due to the collapse of the original *in situ* "white beds" into the paleo-depressions. The latter may represent the remains of fossil karst surface present during the (re)deposition of the "white beds".

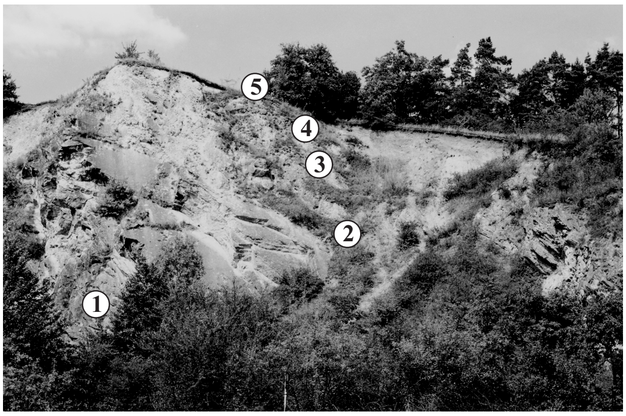


Fig. 2 Almost complete vertical caliche zoning developed in Červený lom Quarry, Dalejské údolí Valley. 1 – unaltered Devonian limestones; 2 – transitional zone; 3 – chalky zone; 4 – nodular zone; 5 – recent soil

Fig. 3 Close-up of altered limestone from the transitional zone, Červený lom Quarry. The traces of steeply inclined sedimentary bedding can be still recognized.

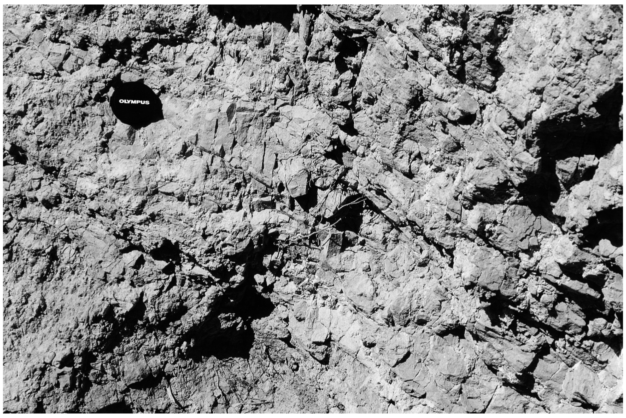


Fig. 4 Strongly altered Silurian limestone that shows evidence of both transitional and chalky zone alterations. Note that the chalky development first appears along the bedding planes (light inclined stripes) whereas rusty yellow rock in between still exhibits somewhat lower degree of decay. Plant roots penetrate the rock along the system of subvertical fractures. Lobolitová stráň Hill near Řeporyje.

Fig. 5 Distinctive occurrence of chalky-white-yellow altered limestone surrounded by intensely red-colored, less altered limestone host. Fossil's collectors probably made the pit inside the chalky zone. Note a steep dip of the limestone host. Červený lom Quarry, Dalejské údolí Valley.

Fig. 6 Upper part of a caliche sequence showing the zone of massive coalescing calcite nodules that grade into a system of isolated nodules embedded in brown-red less carbonate-rich soil matrix. The recent soil cover develops on top. Červený lom Quarry.

Fig. 7 Isolated caliche nodules. Note the cracks that are probably due to the displacive growth of carbonate minerals. Červený lom Quarry.

Fig. 8 Fragment of the platy caliche. Indistinct laminar structure and a small carbonate intraclast (open arrow) embedded within the bed can be recognized. Dark arrow points to the top of the bed. Červený lom Quarry.

Fig. 9 Redeposited "white beds" breccia exposed in Bílá rokle Gorge, Hlubočepy. Arrows point to large ferricrust debris covering the "white beds".

Fig. 10 Close-up of "white beds" crude carbonate breccia in Bílá rokle Gorge, Hlubočepy. Note the presence of unsorted, rectangular clasts made of unaltered to strongly altered limestone debris and early diagenetic silicites (cherts) that were originally parts of the parent limestone.

Fig. 11 Fluvial pebbles filling a cavity within the "white beds". U Kapličky Quarry, Prague.

Fig. 12 "White beds" infilling a paleo-depression in Devonian limestone, Prastav Quarry, Hlubočepy. The wall of a depression with steeply dipping bedding can be seen in the left.

Fig. 13 Strongly altered Silurian crinoidal limestone showing loose sandy consistence and intense rusty yellow coloration that is due to the presence of infiltrated iron hydroxides. Open arrows point to the rhizoliths. A large petrified tubule (shown by a black arrow) is probably a calcified insect cocoon.

3. Microscopic characteristics

Under the optical microscope, the least altered limestone from the *transitional zone* exhibits a range of secondary changes indicative of dominant dissolution processes. In crinoidal grainstones a significant secondary porosity develops due to selective dissolution of syntaxial calcite cements between individual echinoderm particles (Fig. 14G). In wackestone lithologies, tentaculite and brachiopod shells tend to be selectively dissolved giving the way to new intraparticle porosity (Fig. 14F). In both limestone lithologies, however, echinoderm fragments still remain essentially unaltered. Newly formed inter- and intraparticle porosity provided pathways for introduction of iron hydroxides-rich solution into the rock, thus causing a typical reddening of the limestone host.

Crinoidal grainstones of the *chalky zone* display more pronounced stage of alteration. In many samples, the development of secondary porosity proceeds substantially affecting all the sparite cements that tends to recrystallize into a relatively fine-grained calcite matrix (Fig. 14E). Abundant, ovoid to irregular pores forming a honeycomb type of arrangement that develop in the matrix create about 30–40 % rock porosity. Crinoidal particles also commonly exhibit some alteration being partially dissolved and/or obliterated to form the “ghosts” within the carbonate matrix. Root molds (rhizoliths) that penetrate the rock also contribute to the increase of overall porosity (Fig. 13). Secondary replacement of some altered bioclasts with fine aggregates of chalcedonic silica has also been noted in some samples (Fig. 14D).

Carbonate rocks from the upper *nodular and platy zones* typically exhibit a complete lack of features characteristic of bioclastic limestone host. These represent, in fact, completely newly formed pedogenic carbonates showing a range of diagnostic micro-fabrics. The crystal size ranges from micrite to spar and a common feature is “mottling” or clotted fabrics (e.g. Brewer 1964) reflecting patches with different crystal sizes. Some of these mottles define the nodules within a less crystalline matrix. Many nodules are also defined by circum-granular cracks filled with spar cement or open that is indicative of displacive growth (Fig. 14B). Alveolar septal structure (Wright 1986) represents another typical microfrabrics of this facies. It consists of arcuate septa up to a few hundred microns long and up to 200 mm wide, within pore spaces (Fig. 14A, B). The septa are made of minute, parallel-oriented needle-fiber calcite arranged into tight bundles (Fig. 14C). Similar needle-fiber “whisker” calcite cements (lublinite) have been recorded from many Quaternary and older carbonate paleosoils and other freshwater vadose diagenetic settings (Klappa 1980, Longman 1980, see also Němeček *et al.* 1990). The cause of this crystal morphology is still unclear but James (1972) suggested that such needle fibers are the result of crystallization from highly supersaturated solutions caused by strong near-surface evaporation of void solutions. An alternative explanation of the origin of needle-like calcite is through the activities of living organisms, especially fungi (Phillips – Self 1987) or root hairs (Longman 1980). Another biogenic fabrics observed in nodular-platy zone samples is the problematic *“Microcodium”* (*sensu* Klappa 1978). It consists of sheets, tubules and spheroids composed of cell-like calcite crystals (Fig. 14A). Klappa (1978) explained this structure as a calcification product of a mycorrhizae-cortical root cell association, a view supported by the finds of biogenic filamentous structures inside the calcite cells (see also Esteban – Klappa 1983 for the details). Brush-like bladed calcite cements extending outwards at the margins of some carbonate globules and distinctive “floating” rhombic calcite crystals have also been recorded in some samples. The latter type of calcite crystals is characteristic for some carbonate paleosoils and is believed to form under conditions of slow precipitation (Chafetz – Butler 1980).

Thus, the above described characteristic microfabrics evidence changes in a vertical sequence of the “white beds” that range upwards from well cemented Paleozoic limestone host through friable carbonate deposits in the middle, to the secondary calcareous precipitates near the top of the profile. Fresh-water vadose flushing leaves grains of the limestone host rock and causes formation of extensive secondary porosity in the transitional zone. In the middle and upper zones, the prevailing dissolution seems to coexist intimately with biogenic actions of living organisms; plant roots, fungi, bacteria or algae which produce various irregular borings and mediate carbonate re-precipitation. The overall effect of these processes is to break down original detrital carbonate particles and enclose them into a newly formed crypto-crystalline micrite matrix.

4. Interpretation

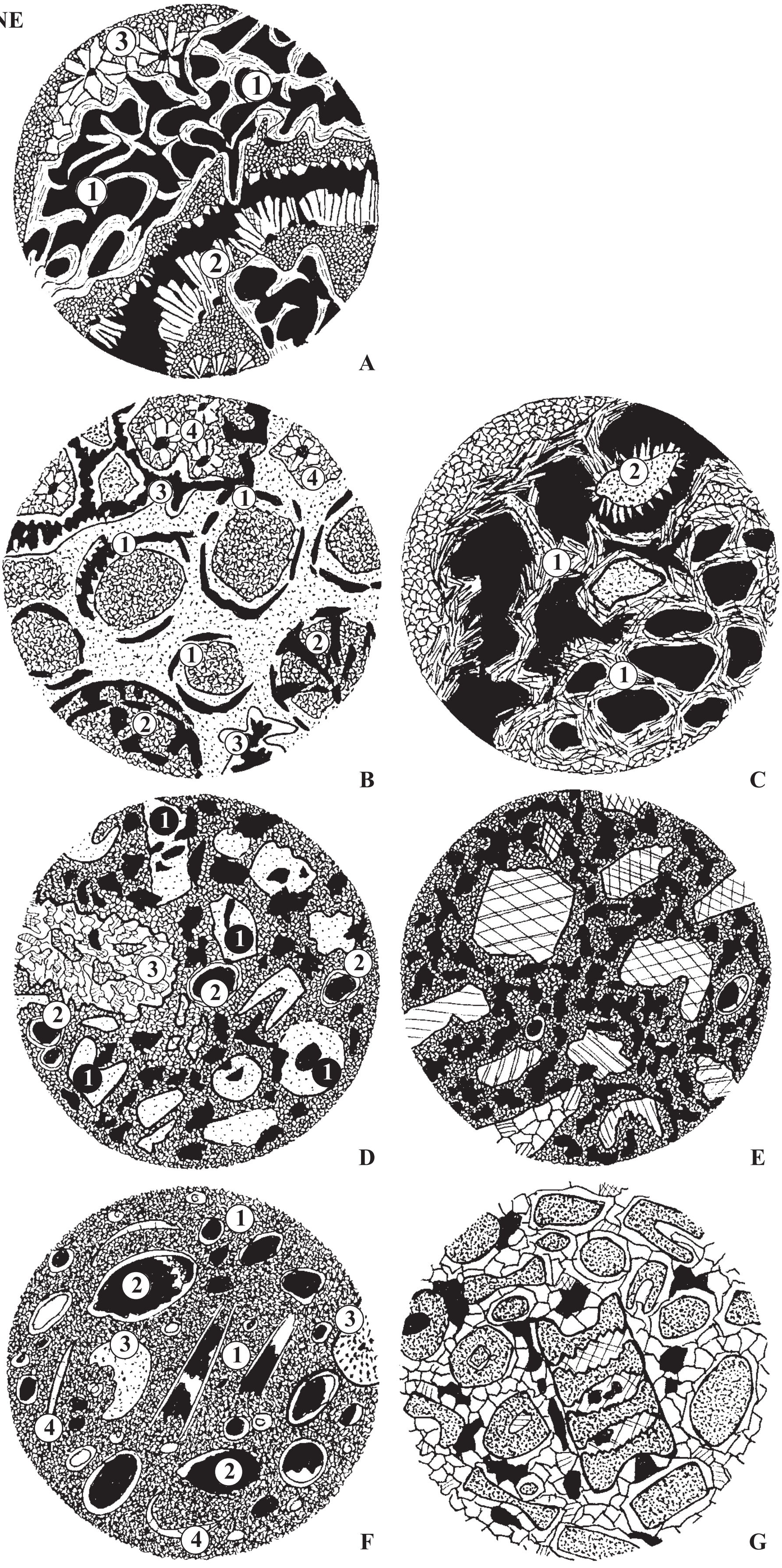
The above characteristics of the “white beds”, both macroscopic and microscopic, conclusively show that these deposits can be interpreted in terms of fossil caliche (calcrete) – an ancient carbonate-rich soil. Although different definitions exist, caliche is commonly referred to as a fine-grained, chalky to well-cemented calcite deposits that formed as a soil on pre-existing rocks or soils in semiarid environments (see Goudie 1973, Reeves 1976, Read 1976, Goudie 1983, Klappa 1983, Wright – Tucker 1991 for the reviews). Field macroscopic evidence for caliche origin of the “white beds” is primarily based on an apparent similarity of “white beds” vertical profiles with those recognized as typical caliche elsewhere. Essentially all the vertical zones characteristic of a typical caliche profile including transitional, chalky, nodular and platy members, are present in the Barrandian “white beds” sections and, more importantly, its successive position within the sections is similar as in “idealized” caliche profiles (compare Figs 1 and 2). Most of the Barrandian “white beds” sections, however, are incomplete in that they often lack upper platy horizon and the hardpan – a well indurated, hard, sheet-like carbonate layer

INITIAL PLATY ZONE

NODULAR ZONE

CHALKY ZONE

TRANSITION ZONE



developed in many recent and ancient caliches. The absence of these upper carbonate beds can be readily explained by the fact that during the geological past, most of the Barrandian sections were influenced by intense slope movements and/or erosion that probably destroyed these upper layers, if once developed. In fact, as already outlined, many "white beds" were clearly redeposited by slumping and/or collapsing to form secondary accumulations of crude caliche breccias.

Microscopic features observed in "white beds" also closely match those in caliche forming either today or in the past. In particular, virtually all diagnostic microscopic criteria of caliche facies, as reviewed by Esteban – Klappa (1983; p. 49) are present in the samples studied, including caliche nodules, circum-granular cracking, calcified cocoons, rhizoliths, *Microcodium*, tangencial needle fibrous calcite cement and alveolar structure. Another very common microscopic phenomenon known from the caliche facies – textural inversion (c.f. Arakel 1982) – can be also clearly demonstrated in "white beds" samples. Original grain-supported limestone host that was subject to alteration resulted in secondary matrices forming diagenetic packstones in the upper parts of the sections. In accord with that development, the microscopic observations clearly point to the combined replacive and, more important, displacive introduction of calcite into the altered sediment and soil that increases towards the top of the sections (Fig. 14).

Although the conditions and mechanisms that govern the evolution of caliche profiles may differ from one place to the other (see Wright – Tucker 1991 for a review on caliche-forming mechanisms and environments), the overall geological context shows that the Barrandian "white beds" most probably represent pedogenic caliche that originated through the *"per ascendum"* mechanisms (Fig. 15). In this model of caliche formation, downward moving soil water penetrates to a certain depth, leaches the limestone host and returns towards the surface or near-surface zone by capillary action bringing with them dissolved carbonate which is subsequently deposited as a result of evaporation and biogenic mediation (Goudie 1983).

5. Discussion

Fossil carbonate soils developed over the lower Paleozoic limestones have not been recognized previously in the Barrandian basin. Rare lateritic deposits preserved in karst cavities near Koněprusy and elsewhere in the Barrandian were interpreted as ancient tropical soils (Homola 1950, Němeček *et al.* 1990) but no carbonate paleosoil horizons *sensu stricto* have been reported from the area till this study. In view of the apparent extent and thickness of the "white beds", especially in the eastern Barrandian, this fact seems to be rather surprising.

Our interpretation of Barrandian "white beds" as ancient caliche clearly differs from previous studies that attempted to explain the origin of these deposits. Bosák *et al.* (1993) and Cílek *et al.* (1995), for example, introduced the plethora of bizarre mechanisms termed "intergranular corrosion", "infiltration kaolinization" and "cold selective metasomatose" to explain the development of chalky and kaolinite-rich residua, respectively in some "white beds" of the Bohemian Karst. They correctly concluded that these sediments represent a result of certain paleo-weathering alterations (probably of Cretaceous and/or Tertiary age) and discussed its relationship to karst-forming processes but completely failed to recognize both the intrinsic nature and the position of the altered horizons within the caliche vertical sequence. In fact, the process of "intergranular corrosion", as described by Cílek *et al.* (1995), is a synonymous to a selective dissolution of syntaxial calcite cements in bioclastic grainstone; a process that long has been appreciated as a characteristic feature of fresh-water vadose diagenetic realm (Longman 1980). On the other hand, the terms of "infiltration kaolinization" and "cold selective metasomatose" proposed by Bosák *et al.* (1993) and Cílek *et al.* (1995) refer to complex alteration processes that primarily affected redeposited caliche facies, as we have described elsewhere in this paper. Martínková (1997) advocated similarly confusing explanation suggesting that the "white beds" were due to the processes related to the karstification but possibly combined with other mechanisms (e.g.

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Fig. 14 Characteristic features of the "white beds" in vertical section (stratigraphical top upward), as seen under the optical microscope. The pore space is shown in black. The natural diameter of the circles is 1.5 cm, if not otherwise stated.

A – Laminar platy caliche, uppermost part of the profile in the Červený lom Quarry, Dalejské údolí Valley, sample No. 7949. 1 – alveolar septal structure; 2 – bladed calcite (aragonite?) cement; 3 – *Microcodium*.

B – Composite caliche nodule, Červený lom Quarry, Dalejské údolí Valley, sample No. 148/149. 1 – small calcite nodules defined by different grain size and circum-granular cracking; 2 – intergranular cracking within the nodules; 3 – alveolar structure; 4 – *Microcodium.*

C – Close-up of the upper part of the sample B. The diameter of the circle is 0.8 mm. 1 – bundles of tightly-arranged needle-fiber calcite; 2 – bladed calcite cement at the margin of a small nodule.

D – Strongly altered crinoidal limestone, Lobolitová stráň Hill near Řeporyje, sample No. 7947. 1 – altered crinoidal segments; 2 – rhizoliths; 3 – large bioclast replaced by chalcedonic silica.

E – Strongly altered bioclastic limestone, Bílá rokle Gorge, Prague-Hlubočepy, sample No. 7957. Note the development of characteristic honeycomb pore network within the matrix.

F – Slightly altered wackestone, Červený lom Quarry, Dalejské údolí Valley, sample No. 7953. Note the predominant biomoldic porosity. 1 – longitudal and transverse cross sections of tentaculitids; 2 – section of both valves of brachiopod; 3 – echinoid spine showing radial pattern of pores; 4 – possibly disarticulated ostracodes.

G – Incipient alteration stage in coarse-grained crinoidal grainstone, lower part of the Lobolitová stráň Hill near Řeporyje, sample No. 7954. Secondary porosity develops due to the dissolution of calcite cement between individual crinoidal particles.

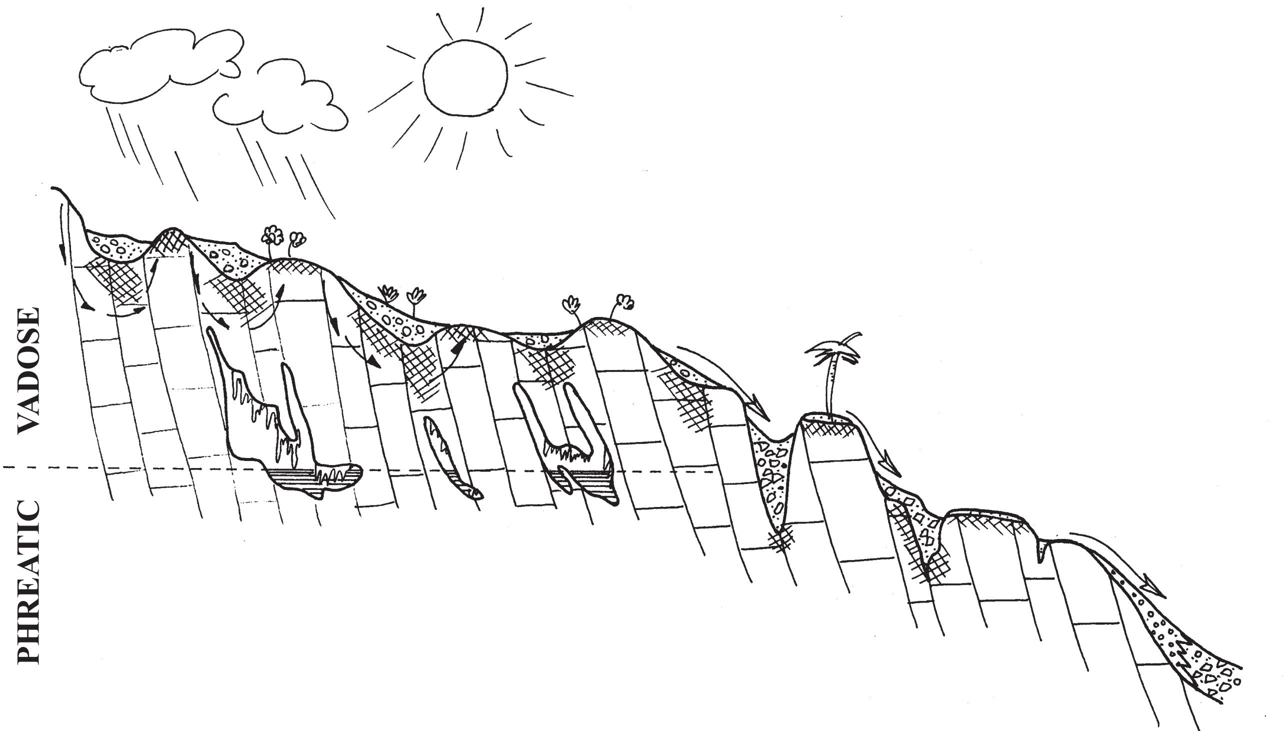

Fig. 15 Sketch showing conceptual model for the origin of the "white beds" of the Barrandian area. The full arrows show the movement of surface water in the upper vadose zone as predicted by *"per ascendum"* model of caliche formation. The vertical extent of the resulting alteration zone is shown as hatched areas. The open arrows point to the redeposition of the alteration crust into local depressions of the paleo-relief (paleokarst depressions?). The deeper vadose to phreatic caves and/or surface karst landforms often develop ponecontemporaneously with the caliche profiles, especially under less arid climatic conditions.

dolomitization). To make the whole issue even more perplexing, Žák *et al.* (2001) have recently suggested that at least some "white beds" deposits developed through deep phreatic circulation of organic acid-rich groundwater.

The present recognition of the "white beds" as fossil caliche may have wider geological implications for geomorphologic and paleoclimatic evolution of the Barrandian area and central Bohemia in general. The presence of caliche especially of pedogenic types have certain potential to provide information on time resolution, paleovegetation and paleoclimates (Esteban – Klappa 1983, Wright – Tucker 1991). The rate of caliche formation, however, appears to be variable and probably dependent on many factors, of which the rainfall regime and the source and availability of carbonate ions may be the most principal (Gile 1977). Well-developed caliche profiles can be formed within as short a period as of the order of 10^3 years or may require pedogenic processes over as long as 10^5–10^6 years (Allen 1986). Nothing directly is known about the timing and duration of pedogenesis represented by Barandian "white beds", but some constraints can be indicated by reference to stratigraphical evidence. At some localities of the "white beds" situated in the valley of the Vltava River (e.g. lom u Kapličky Quarry), well-rounded alluvial pebbles infill erosion and/or dissolution pockets within the "white beds", located 10–15 meters above the river (Fig. 11). The age of these pebbles can be broadly defined as late Pleistocene (Würm) based on its position within the system of Vltava River terraces (see also Záruba *et al.* 1977 for the details on chronology of Vltava alluvial terraces). If so, the "white beds" can be generally regarded as pre-Würm in age. Some earlier authors have also speculated that the "white beds" may originated, at least in part, substantially earlier, perhaps during the Tertiary of even pre-Cenomanian period (Cílek *et al.*, 1995, Martínková 1997). Although no decisive evidence for this statement is presently available, this hypothesis seems to be quite viable following a line of indirect observations. First, there is an obvious spatial link between the position of individual localities of the "white beds" and the transgressive boundary of the Cenomanian sediments that commonly occur immediately above the top of "white beds" profiles (Martínková 1997). Second, some authors inferred that before the Cenomanian transgression, the lower Paleozoic Barrandian carbonate sequences must have been deeply eroded, and probably, intensely weathered and/or karstified (Turnovec 1979, Zelenka 1980, 1984, Bosák 1985, Klein – Zelenka 1991). In fact, through the whole pre-Cenomanian Mesozoic, the area of central Bohemian Massif was probably subject to only moderate erosion and/or nondeposition (Malkovský 1979, Filip 2001, Suchý *et al.* 2002), allowing for the formation of a thick weathering crust and/or paleosoil above the lower Paleozoic carbonates. Alternatively, the caliche may have also formed much later, possibly during the Tertiary-Quaternary period. Leeder (1982; p. 289) has pointed out that many thick caliche profiles represent the remnants from Pleistocene times and reflect episodic carbonate accumulation in response to Pliocene-Pleistocene climatic fluctuations.

In terms of paleoclimatic controls, carbonate soils are most characteristic of warm areas with limited precipitation and low but seasonal rainfall between 100–600 mm annually (Reeves 1976, Goudie 1983). Climatic controls on caliche-forming processes can be also deduced, at least in part, from caliche microfabrics. Wright (1990) has suggested that the calcretes having a crystic plasmatic fabric in sense of Brewer (1964) and showing prevailing inorganic structures like nodules, circum-granular cracks and rhombic calcite grains (i.e. so-called alpha–calcretes) occur preferentially in areas with an arid climate and reduced biological activity. On the other hand, the calcretes exhibiting a variety of micro-scale features attributable to the existence and activities of macro- and micro-organisms (*Microcodium*, needle-fiber calcite, alveolar septal structure, calcified tubules; i.e. so-called beta-calcretes) appear to be best developed in semi-arid to subhumid areas with extensive vegetation cover, the biofabric of the pedogenic carbonate seeming to reflect this relatively high degree of biological activity (Wright 1990). With respect to the presence of these paleoclimate-indicative calcrete fabrics, the Barrandian “white beds” provide, unfortunately, rather inconclusive evidence. In fact, both contrasting micro-scale features are present in the sediments, often coexisting intimately face-to-face in one single sample. This relationship can be probably explained in two ways. First option is that the climate prevailing during the caliche formation was intermediate and/or oscillating between arid and subhumid thus allowing for the development of both types of microfabrics. An alternative explanation possible is that the “white beds” may have formed during two or more paleoclimatically contrasting periods. A possibility that the “white beds” may actually resulted from several superimposed weathering and/or climatic cycles has already been advocated by Cílek *et al.* (1995), based on independent geomorphologic ground.

Finally, it should be pointed out that the processes of caliche formation, as described in this study, *are not synonymous* with the karstification processes although a close spatial link between these two may develop. The processes responsible for the formation of caliche weathering crust are exclusively shallowly subaerial in nature and operate only in the uppermost part of the fresh-water vadose zone. They may or may not coexist in time and space with shallow surface karst landforms that is largely controlled by local climatic conditions (see also Esteban – Klappa 1983, their Fig. 8). True cave-forming dissolution-precipitation processes, on the contrary, characteristically dominate only below the zone of caliche formation affecting chiefly the deeper part of the vadose realm (Fig. 15).

6. Conclusions

The significant points resulting from this study are summarized as follows:

(1) The “white beds” of the Barrandian area exhibit vertical zonality and internal microfabrics strongly indicative of ancient pedogenic caliche (calcrete). Complete idealized vertical zoning starts with a zone of altered lower Paleozoic limestone host and grades upwards through a chalky-nodular horizon into platy horizon beneath the (sub)recent soil cover. Microfabrics indicative of caliche origin comprise calcite nodules, circum-granular crackings, rhizoliths, alveolar septal structures, *Microcodium*, needle-fiber calcite cements, floating calcite rhombs and clotted structure.

(2) Caliche facies were commonly redeposited to form a variety of slope deposits, debris flows and/or collapse breccias that accumulated in the depressions of pre-Cenomanian (?) paleo-landscape. Some caliche deposits were also altered by introduction of kaolinite-rich silts and fluvial sands and gravels, probably during the Tertiary or Quaternary period.

(3) The age of caliche formation is unknown. Indirect evidence points to a possible Tertiary or pre-Cenomanian age but polygenetic, multi-stage evolution of the profiles and/or much younger, even the Quaternary age of the deposits are also possible. Whatever its age, the presence of caliche profiles itself implies the prevailing semi-arid climatic conditions with low but seasonal annual rainfall, geomorphic stability and conditions of low to almost reduced deposition that once prevailed in the Barrandian area.

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Bílé vrstvy Barrandienu – fosilní caliche: jejich původ a význam pro rekonstrukci paleoprostředí

Tzv. bílé vrstvy Barrandienu – bílá, žlutá nebo okrově rezavá, píščitě rozpadavá karbonátová residua, která jsou místy přítomna nad silurskými nebo devonskými vápencovými výchozy, jsou interpretovány jako fosilní karbonátové půdy typu caliche (calcrete). Typická sekvence caliche představuje 6–8 m mocnou alterační polohu s nezřetelně vyvinutou vertikální zonalitou, jež se postupně vyvíjí z podložních nepozměněných vápenců. Nad přechodovou zónou částečně alterovaných matečných hornin, je přítomna poloha charakteristického křídovitého rozpadu, jež výše přechází do zóny novotvořených nodulárních, případně vrstevnatých karbonátů pod recentním půdním pokryvem. Mikroskopické stavby v karbonátech jsou zcela analogické typickým recentním i fosilním caliche popisovaným v literatuře, a zahrnují kalcitové nodule s koncentrickými puklinami, petrifikované dutiny po kořenech (rhizolity), biosedimentační texturu *Microcodium*, alveolární septální textury, jemnozrnný jehličkovitý kalcitový tmel orientovaný tangenciálně ke stěnám pórů a rombické kalcitové krystaly „plovoucí“ v novotvořenné jemnozrnné karbonátové matrici . Mimo „bílých vrstev“ vyvinutých ve formě typických autochtonních paleopůd, lze rozlišit i redeponované facie těchto zvětralin (alochtonní fosilní půdy), které vznikly skluzy nebo prosedáním „bílých vrstev“ do depresí původního vápencového paleoreliéfu. Stáří caliche zůstává otevřeno. Jelikož, z podstaty věci, vznik caliche vyžaduje podmínky dlouhodobé geomorfologické stability a aridní nebo semi-aridní klima s nízkým srážkovým průměrem, lze vznik těchto profilů obecně spojovat s dlouhým geologickým obdobím peneplenizace, eroze nebo omezené sedimentace a semi-aridního klimatu, jež v oblasti Českého masívu panovaly během mesozoika – tercieru. Další otevřenou možností ovšem je, že polohy caliche vznikly až podstatně později, během klimatických fluktuací v pliocenu-pleistocenu.