PALEOKARST OF THE BOHEMIAN MASSIF IN THE CZECH REPUBLIC: SHORT REVIEW

PALEOKRAS ČEŠKEGA MASIVA (ČEŠKA REPUBLIKA): KRATEK PREGLED

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Pavel Bosák: Paleokras Češkega masiva (Češka republika): kratek pregled

Paleokras Češkega masiva (Češka republika) je razvit v poligenetskih in policikličnih oblikah z večimi fazami fosilizacije in pomlajevanja, glede na tektonske faze in globino kemičnega preperevanja. Za paleotektonske dobe (v glavnem pred permijem) je značilen razvoj relativno majhnih področij sinsedimentnega in lokalnega paleokrasa. V neotektonski dobi (platforma, po permu) so bila daljša obdobja razvoja interregionalnega paleokrasa v več ali manj ločenih fazah zakrasevanja.

Ključne besede: paleokras, kraške dobe, faze zakrasevanja, fosilizacija, pomlajevanje, kemično razpadanje, diageneza karbonatov, Češki masiv, Češka republika

Abstract UDC

Pavel Bosák: Paleokarst of the Bohemian Massif in the Czech Republic: Short review

Paleokarst of the Bohemian Massif on the territory of the Czech Republic developed as polygenetic and polycyclic forms with several phases of fossilization and rejuvenation depending on tectonic phases and deep chemical weathering. Paleotectonic period (pre-Permian in general) was characterized by evolution of relatively minor depositional and local paleokarsts. Neotectonic (platform) period (post-Permian) favoured the prolonged karst evolution of interregional paleokarst in several more or less distinctly separated karst phases.

Key words: paleokarst, karst periods, karst phases, fossilization, rejuvenation, chemical weathering, carbonate diagenesis, Bohemian Massif, Czech Republic

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INTRODUCTION

The Bohemian Massif is known by landforms that have been intricately and unequally developed during many periods and phases of changing climate and of tectonic activity in the geological past. This very complex form of the karst and paleokarst, with relict, fossil, recent, active or rejuvenated features and in periglacial conditions transformed karst, led Panoš (1964) to define it as the Central European Type of polycyclic karst. The polycyclic and polygenetic nature of karsts and paleokarst represents the specific characteristics for karst evolution of the whole Bohemian Massif. The general review of paleokarsts of the Bohemian Massif was presented by Bosák, Horáček and Panoš (1989).

THE GEOLOGICAL BACKROUND

The Bohemian Massif represents the epi-Variscan platform consisting of two major blocks, i.e. the Bohemian Massif proper in the west and partly subducted promontory of the East European Platform - Brunovistulicum (Dudek 1980) - in the east. The eastern and southeastern slopes of the Massif are covered by the Carpathians as a consequence of Alpine nappe overthrusting over the epi-Variscan platform in the foreland of Alpine - Carpathian chain (Grecula and Roth 1978)

Three structural levels can be distinguished in the Massif (e.g. Suk et al. 1984): (1) Precambrian (Cadomian) basement composed dominantly of metamorphites and plutonites. Crystalline limestones and dolostones occur only locally and no paleokarst forms habe been known; (2) Variscan (Paleozoic) level with development of sedimentary and sedimentary-volcanic sequences, dominantly of marine origin, in places metamorphosed and intruded by plutonites. Carbonate rocks of Upper Silurian (Přídolian) to Lower Carboniferous (Tournaisian) occur. Abundant evolution of relatively minor paleokarsts is known, and (3) Platform (post-Variscan) level composed dominantly of sediments (continental and marine) separated by important unconformities. Very broad developments of paleokarsts is known.

Paleotectonic period, prior to the consolidation of the epi-Variscan platform, is characterized by high mobility and resulted in a great changes in facies development. The neotectonic period is more quiet with only several

important marine transgressions covering larger extent od the Massif (Upper Jurassic, Cenomanian, Middle Miocene). The evolution of eastern and south-eastern margins of the Massif (majority of Brunovistulicum) facing the Tethys realm as passive continetal margins was especially strongly influenced by the Alpine Orogeny as being submerged under thick pile of flysh nappes and molasse deposits. The neotectonic stage was strongly influenced by single phases of Alpine Orogeny (cf. Malkovský 1979).

TERMINOLOGY

The terminological problems appeared as the reflectance of the complexity of the problem in our geological and geomorphological environment. Therefore *paleokarst* is refered to phenomena defined by Bosák, Ford and Glazek (1989) with the application of the *fossil karst* in the strict sense (forms completely originated in the past, entirely fossilized and loosing its hydrological characteristics without any traces of present development). Stratigraphy of paleokarst is defined here according to definitons of Bosák, Ford and Glazek (1989) using *karstification periods* and *karstification phases.* The application of *interregional, local* nad *depositional paleokarst* is here based on sense and definitions of Choquette and James (1988) and is assumed to be very usefull.

PALEOKARST PERIODS AND PHASES

The evolution of paleokarst can be connected with Variscan and platform stages of the evolution of the Bohemian Massif. The majority of forms developed in Devonian limestones, now buried or uncovered, which were also highly metamorphosed by Variscan Orogeny, in places. Some forms developed in Proterozoic carbonates and a limited number has been known from Upper Jurassic carbonate sequence deeply submerged on eastern margins of the Massif.

The evolution of paleokarst, its origin, development, fossilization and rejuvenation have been affected by numerous lithological and structural conditions. In general, three types of paleokarsts could be distinguished.

Depositional paleokarst was typical by low relief, freshwater vadose and phreatic and mixing freshwater/ marine diagenesis. Its evolution followed cyclic nature of deposition without tectonic influence and the Milankovich cycles of the 5th to 4th orders. The role of freshwater/marine mixing diagenesis was substantial. Its evolution was connected with the evolution and accretion of Devonian carbonate sequences.

Local paleokarst was product of longer emersion caused by regressions in individual blocks. Karst relief was developed up to first hundreds of metres (shafts, dolines, caves) with well defined hydrological zonation. The evolution followed tectonic movements of individual, even very small, tectonic blocks

together in the combination with cyclic events or sea level changes (unconformities of the 3rd and the 2th orders). Biozone to stage is missing. Effect of drowned platforms followed the polarity of orogenic movemets from W to E within the Brunovistulicum. Results of the local paleokarstification can substantially differ place to place owing to the altitudinal position of emerged carbonate surface. Low altitudinal position led to undeveloped paleokarsts similar to depositional paleokarst forms even through longer hiatus, while high altitudes of distinct elevations created mature paleokarsts. Its evolution was connected with the evolution of sedimentary basins during Lower/Middle Devonian in the Barrandian and Middle Devonian/Lower Carboniferous in Brunovistulicum. Some of Jurassic carbonates suffered also by this kind of evolution.

Interregional paleokarst was product of long-lasting erosion and karstification connected with deep weathering and formation of planation surfaces. There was developed substantial karst relief and deep groundwater circulation. There was a close connection to individual tectonic phases reflecting major impacts of the Alpine Orogeny leading to the rejuvenation of relief and the acceleration of karstification. There was the clear relation to marine transgressions/ regressions separating individual karst phases within karst periods or to periods of mass continental deposition. This evolution was typical for post-Upper Carboniferous evolution of the whole Massif.

There are several typical conditions affecting the evolution of the interregional paleokarst in the Massif: (1) the prevalence of a continental regime since the Permian; (2) relatively short-lasting marine transgressions in Upper Jurassic, Late Cretaceous and Middle Miocene times; (3) increasing tectonic activity since the Late Paleogene as impacts of the Alpine Orogeny; (4) evolution of the Paratethys sea on the eastern margins of the Massif; (5) increasing relief dynamics resulting in a considerable increase of erosion rates exhuming and rejuvenating old planation surfaces and karst forms, and (6) a continual fall of the base level following stabilisation of the river system in the Pliocene (Bosák and Horáček 1981). Nevertheless, the phases of accelerated erosion were interrupted by relatively long-lasting quiet periods with stabilized conditions favouring the development of subsurface karst forms (Bosák, Cílek and Tipková 1992).

Lower Devonian - Pragian. Local paleokarst related to freshwater vadose and phreatic karstification (diagenesis) of the Koněprusy Reef (central Bohemia) was connected with tectonic uplift and major sea level changes. Deep neptunic dikes developed associated with the system of vuggy to cavern macroporosity filled with lithologically variable internal sediment.

Climate was tropical, wet and hot. Correlate sediments are proved in overlying Dalejan to Eifelian limestones content of iron oxides derived from lateritic weathering of mainland

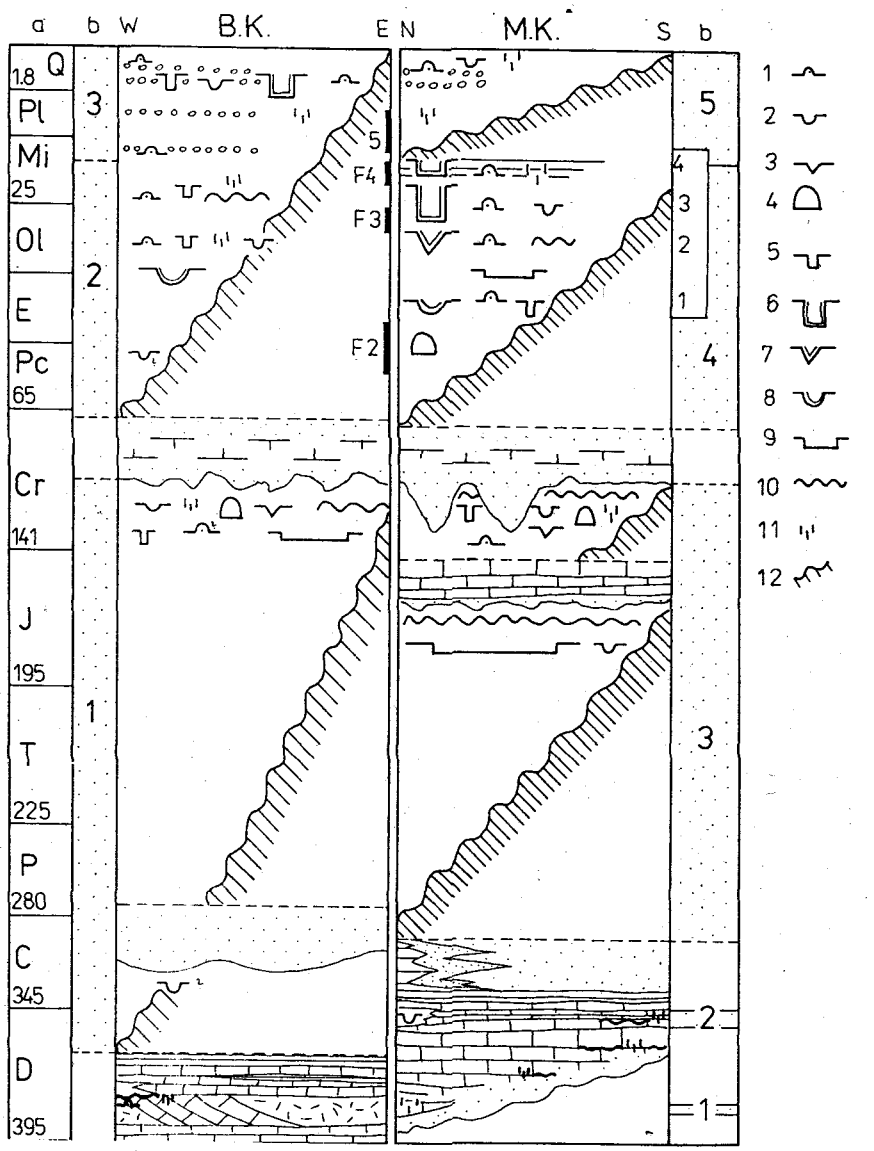

Fig. 1 - Distribution of paleokarst within the geological history of the Bohemian Karst (B.K.) and Moravian Karst (M.K.).

a. periods; numbers indicate the age of the period base in Ma; b. karstification periods and phases; 1. caves, 2. dolines, 3. deep corrosional organs (geological organs, pockets), 4. karst cones, towers and inselbergs, 5. shafts, 6.-8. valleys and canyons (shape is indicated), 9. poljes and large depressions, 10. corrosional surfaces, 11. karren, 12. periods of paleorelief evolution, F1-F5 - planation phases (modified from Bosák, Horáček and Panoš 1989).

Middle Devonian - Eifelian/Givetian. Depositional freshwater vadose and phreatic karstification (diagenesis) of limestone cycles in Old Red complex in the Moravian Karst and Carpathian foredeep The evolution was connected with minor cyclic sea level change (Milankovich's cycles).

Climate was hot, seasonally dry and wet. Correlate sediments are represented by red beds of the basal clastics themselves.

Upper Devonian to Lower Carboniferous - Fammenian to Upper Viséan. Local paleokarst, sometimes with substantial relief and developed shafts, sinkholes, depressions and caves in Upper Devonian limestones in the Moravian Karst (pre-Upper Tournaisian), the Tišnov area (pre-lower Visean), the Ostrava area (pre-upper Viséan). Emergence caused by the tectonic uplifts and tilting of individual blocks combined with 2nd-3rd order of sea level changes. Paradox of drowned platforms is often developed, as karstified shallow marine carbonates are overlain by relatively deep water facies.

Climate was subtropical to tropical. Correlate sediments are represented by variocoloured pelitic matrix of the Křtiny nodular Limestone (Upper Frasnian to Tournaisian) and of the Jedovnice breccia (Fammenian to Tournaisian) derived from lateritic weathering of the mainland, lateritic material and phosphorites in the Ostrov Shales (Tournaisian)

Upper Carboniferous - Westphalian/Stephanian. *The interregional paleokarst* proved by pebbles of karstified Devonian limestones and speleothems in red beds of the Mšeno Basin (Upper Stephanian). The karst phase caused by the tectonic uplift as a consequence of Variscan Orogeny and emplacement of plutonic bodies.

Climate was dry, seasonally wet, warm (subtropical). Correlate sediments are represented by kaolinization of the Plzeň - Podbořany group of deposits (west Bohemia)

Permian to Upper Jurassic. Extensive interregional paleokarst developed. The macroform of the Moravian Karst completed prior the Callovian transgression In the Hranice Karst (north Moravia) some Permian to Paleogene karstification has been supposed without identified extent and in the Bohemian Karst without identified karstification.

Climate has no direct evidence on the Bohemian Massif. Correlate sediments represent kaolinic clastics of the Bohdašín Formation (Bundsandstein, north Bohemia), lateritic material in the Kimmeridgian breccia finishing the sequence of Upper Jurassic in the Moravian Karst and no correlate sediments in the Bohemian Karst.

Lower Cretaceous (post-Kimmeridgian - pre-Cenomanian). The interregional paleokarst developed in regionally widespread karstification phase which products are preserved mostly thanks to overburden of the Upper Cretaceous (?Albian - Cenomaian - Santonian) platform cover. Known in the Bohemian Karst (narrow depressions with kaolinic sands and clays), in the Moravian Karst (the Rudice Formation, i.e. kaolinic sands and clays, quartzose sands,

kaolins, filling extensive corrosional depressions, cone karst), in the Vratíkov - Němčice Karst (central Moravia, mogotes, iron ores in caves, relics of the Rudice Formation), in the Tišnov Karst (relics of sands and clays in sinkholes), and nearby of Kunštát and Olešnice (both in central Moravia, terrae calcis and lateritic weathering products in fissures of crystalline limestones), in Moravský Krumlov (south Moravia, the Rudice Formation in sinkholes), in the Carpathian Foredeep (inselbergs on Jurassic limestones), on the Turold Hill (Mikulov, south Moravia, tectonic clippe, planated surface with depressions and Fe-Mn incrustations on upper Jurassic limestones covered by Turonian flysh).

Depositional paleokarst developed in authochthonous Mesozoic cover of eastern margins of the Bohemian Massif. Known at the Kotouč Hill (Štramberk, north Moravia) in two karstification phases in Upper Valanginian and Upper Hauterivian to Aptian related too oscillating sea level (3th to 4th order cycles).

Climate was tropical, wet and hot, at the end temperate. Correlate sediments are widespread as weathering profiles under the Upper Cretaceous platform cover are widespread, e.g. laterites on basic to ultramafic rocks, kaolins on acidic rocks, weathering profiles with paleosols, kaolinization of some deposits in west Bohemia, the Rudice Formation and the Amberg Ore Formation (NE Bavaria, FRG) etc.

Paleogene to Lower Miocene. Interregional paleokarst developed during widespread karst period without possibilities of precise dating of phases and sites (general absence of paleontologically dated localities). The period is characterized by the main phase of cave formation in the Bohemian Massif with origin of largest karst systems in the Bohemian, Moravian, Javoříčko Karsts and smaller karst regions also in crystalline complexes (Bližná, south Bohemia). Karst surfaces with depressions and conical hills developed (Tišnov (?pre-Badenian), Lažánky (pre-Karpatian), Hranice (pre-Karpatian and pre-Badenian), Branná, Vápenná, Supíkovice, karst of the Drahany Upland - Mladeč, Červenka, Javoříčko, Hvozdečko). Numerous sites in the Carpathian Foredeep on Devonian and Jurassic limestones is known covered under thick Miocene siliciclastics and covered by overthrusted flysh nappes.

Climate in Paleocene to Eocene was tropical, wet and hot. During Oligocene-Lower Miocene oscillations from tropical to Mediterranean type occurred. Correlate sediments are reprezented by kaolins of Vidnava (north Moravian) and Znojmo (south Moravia, pre-Eggenburgian), Lažánky (central Moravia, pre-Karpatian), Hranice (pre-Karpatian kaolinic and lateritic weathering products), kaolinic clays of Vížina (central Bohemia). Quartzose to quartzitic conglomerates and sandstones of the Staré Sedlo Formation (Upper Eocene - Oligocene) and pre-Oligocene kaolinitization occur in North Bohemian Coal Basins.

FOSILIZATION AND REJUVENATION

Karst becomes fossil or inactive when it loses its hydrological function. The general cause for this are changes of local or regional geotectonic conditions or of global sea level. Fossilization can be a result of uplift or of subsidence, of marine transgression or of mass continental deposition. Continental drift (plate motion) may change the latitudinal position of karst areas in different geologic stages resulting in climatic changes, i.e. to arid or to humid, which may contribute to fossilization or rejuvenation (Bosák 1981, 1989, Zhang 1986).

Fossilization of karst forms in the Bohemian Massif are closely related to above mentioned factors. But the polycyclic and polygenetic nature of karsts and paleokarst represents the specific characteristics for karst evolution of the whole Bohemian Massif, and leads to the presence of polycyclic and polygenetic features attributed to paleokarst also within the present landscape. They sometimes form a great part of present objects of the speleological interest. To distinguish what is ancient and what can be remodeled at the present time is therefore very difficult. In such terrane, the substantial role was played by the change of hydrological circulation loosing its hydraulic head, at least partially, when not covered by younger deposits. Such evolution is typical e.g. for the Koněprusy region of the Barrandian following the development of river network entrenching since Upper Miocene times. Caves were partially or completely filled with Sarmatian and Lower Pliocene deposits disappearing its hydrological function completely. Paleokarst contains, by such way, a lot of evidence missing on the baren surface and represents true conservers of the geological and environmental past and sometimes also the missing link in regional and global chronostratigraphy.

The rejuvenation of karst making the conserved fossil record degraded and unreadable is caused by numerous factors generally leading to the renewal of the hydrological function of the karst and of karst water circulation. It is typical for periods of introduction of energy to the whole karst/relief system. It is contradictory to the fossilization. The new creative and destructive karst and landform processes, deposition and redeposition, exhumation and weathering disturb the paleokarst content. The rejuvenation processes are very typical for karsts of the Bohemian Massif. The most striking example is represented by polyphase evolution of karst levels in the Moravian Karst since Lower/Middle Miocene times with several repeated filling and exhumation of karst canyons and cave horizons, and creation of inserted cave levels and subvertical invasion vadose connections. Low levels of Miocene caves are now serving as phreatic conduits.

PALEOKARST, PLANATION SURFACES AND DEEP CHEMICAL WEATHERING

The evolution of paleokarsts are often linked with the formation of planation surfaces, as the result of the uniform process of relief-forming agents. Planation surfaces are proved to be very often connected with periods of deep chemical weathering. The evolution of surfaces is connected with prolonged periods of tectonic stability, so they originated inbetween impacts of orogenic phases. Such conditions are also favourable for the origin of mature endokarst.

To correlate periods of karstification and of formation of weathering crusts in the Bohemian Massif is relatively complex owing to the lack of well defined chronostratigraphic horizons within long periods of nondeposition and continental regime. The foreland and flanks of the Massif are covered by complex sucession of marine formations, sometimes of high thicknesses (e.g. Alpine and Carpathian Foredeeps, pre-Sudetes block). In the centre of the Massif, marine formations younger than Lower Carboniferous (except of Cenomanian to Turonian) are rare and preserved in very small areas (topmost Doggerian to Kimmeridgian, Badenian). Also the extent of continental deposits of post-Variscan age is limited to certain regional geological units. Such formations do not cover the whole time span of hiatuses between marine transgresion - regression cycles, but offer paleogeographic and paleoclimatic data enabling to roughly date periods of karstification.

The best link between periods of intensive chemical weathering and karstification can be stated for two periods. During topmost Jurassic and Lower Cretaceous (or pre-Cenomanian), large karst forms of tropical paleokarst are preserved under thick kaolinitic (-lateritic) weathering crusts in the Moravian Karst and some adjacent areas including Carpathian-Alpine Foredeeps; similar situation can be stated in the Bohemian Karst (weathering crusts are thinner). These phenomena can be correlated e.g. with identical forms and sediments of the northeastern Bavaria (Amberg Ore Unit). The Paleogene to Lower Miocene karstification (i.e. the main phase of cave formation) can be correlate with Paleogene-Miocene weathering period. The origin of caves was iniciated under the cover of Upper Cretaceous rocks. Surface paleokarst of identical or somewhat younger age (Miocene) is also relatively abundant, sometimes containing kaolinic fill (Lažánky near Tišnov), variegated and other weathering products (Bohemian, Hranice and other karsts). Indications of simultaneous weathering and karstification exist for Upper Carboniferous (Stephanian). Pebbles of limestones and speleothems were found in molasse red beds in central Bohemia. The karstification occured in the same time-span in which some of large kaoline deposits in west Bohemia were formed (e.g. Kaznějov).

The link between periods of intensive chemical weathering/origin of

planation surfaces and karstification is evident in the Bohemian Massif. Both the intensive chemical weathering (lateritization, kaolinization) and evolution of planation surfaces, and the karstification are linked rather with prolonged periods of relative tectonic stability. The link between intesive weathering and karstification is important indicator for prospection of economic mineral deposits in paleokarst terrains.

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PALEOKRAS ČEŠKEGA MASIVA (ČEŠKA REPUBLIKA): KRATEK PREGLED

Povzetek

Češki masiv je znan po policiklični in poligenetski naravi krasa in paleokrasa (srednjeevropskega tipa), razvitega na posameznih, manjših kraških področjih. Matične kamnine so predvsem devonski apnenci (deloma metamorfozirani), ponekod pa jurske karbonatne kamnine. Matična kamnina je bila vključena v strukturo epi-varističnih platform, kjer je mogoče razmejiti paleotektonsko od neotektonske dobe z mejo v permiju. Za paleotektonsko dobo je značilna velika mobilnost, zaradi česar so velike spremembe v razvoju faciesov, posledica tega pa je nastanek zgolj sinsedimentnega in lokalnega paleokrasa. Neotektonska doba (platforma) je bila bolj umirjena, le z nekaj pomembnimi morskimi transgresijami, ki so zajele velik del češkega masiva. Nanj so tudi močno vplivale posamezne faze alpidske orogeneze. Razvila so se obsežna interregionalna paleokraška področja v večih, med seboj bolj ali manj ločenih fazah.

Spodnjedevonska in spodnjekarbonska faza zakrasevanja sta bili povezani z lokalnimi tektonskimi dviganji in regionalnimi regresijskimi oziroma transgresijskimi cikli 3. reda ter z osciliranjem morske gladine 4. in 5. reda. Sinsedimentni in celo zreli lokalni paleokras se je razvil v pragiju, na meji eifelij - givetij in od famennija do zgornjega viseija. Za razlago razvoja tega krasa lahko uporabimo karibski model, kjer je zelo pomembno mešanje sladke vadozne in freatične vode ter prepletanje sladkovodnih in morskih diagenetskih faciesov.

Razvoj paleokrasa v zgornjem karbonu in med permijem ter zgornjo juro je navzgor omejen s callovijsko morsko transgresijo. Spodnjo mejo predstavljajo zaključne faze variskične orogeneze z odlaganjem obsežnih rdečih molasnih sedimentov. Interregionalni tip krasa se je razvijal izključno v kontinentalnem okolju. Pred zgornjim juro je bilo površje močno uravnano.

Spodnjekredna faza zakrasevanja se je končala s cenomanijsko transgresijo. S številnih krajev so znani primeri dobro razvitega interregionalnega paleokrasa, za katerega so značilne globoke oziroma visoke oblike s pisanimi produkti kemičnega preperevanja.

Paleogena do spodnjemiocenska faza zakrasevanja se je končala z mlado alpsko tektonsko fazo, ko je badenijsko morje deloma preplavilo vzhodne robove masiva. Interregionalni paleokras je nastajal v fazi zakrasevanja, ki je obsegala zelo široko področje, vendar posameznih faz in regij ni mogoče natančno določiti (zaradi splošnega pomanjkanja paleontološko datiranih nahajališč). To je glavna faza nastajanja jam v Češkem masivu, vključno nastanek največjih kraških sistemov v večini najobsežnejših kraških ozemelj. Znani so številni primeri iz karpatskega jarka v devonskih in jurskih apnencih, kjer so pod apnenci kremenčevi klastiti, nad njimi pa flišni narivni pokrovi. Čas od srednjega miocena do kvartarja je bolj čas fosilizacije kot pa masovnega

nastajanja kraških oblik.

Povezava med periodami intenzivnega kemičnega razpadanja oziroma nastajanjem uravnav in zakrasevanjem je vidna v Češkem masivu. Tako intenzivno kemično razpadanje (lateritizacija, kaolinizacija) kot razvoj uravnav in zakrasevanje so v povezavi s podaljšanimi periodami relativne tektonske stabilnosti. Zveza med intenzivnim razpadanjem in zakrasevanjem je pomemben pokazatelj za odkrivanje ekonomsko pomembnih nahajališč mineralov v paleokraških ozemljih.