Karst processes along a major seismotectonic zone : an example from the Bohemian Massif, Czech Republic

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ABSTRACT

Fluid movements along major north-south-trending seismotectonic zones were responsible for the development of hydrothermal caves in limestones of the Bohemian karst and elsewhere in the Bohemian Massif, Czech Republic. Many caves and caverns are closely linked to hydrothermal calcite veins and reveal characteristic cupola-form cavities and exotic internal precipitates. A possible role of sulphuric acid speleogenesis in the origin of the caves is also discussed.

KEYWORDS

Calcite Veins, Hydrothermal Karst, Bohemian Karst

I. GEOLOGICAL SETTING

Recent integration of remote sensing data with geophysical and geochemical information has shown that sedimentary and crystalline units of the Bohemian Massif are penetrated by a series of major north-south-striking seismotectonic zones and/or lineaments (Lysenko, 1986 ; Suchy *et al.*, 1997). At least some of these linear structures clearly correspond to deep tectonic faults (Stovickova, 1973). Present-day microearthquakes, discharges of thermal and mineral waters, small-scale shows of gases (N_2, He, CO_2, CH_4, Rn) and liquid hydrocarbons as well as folded and fractured Quaternary sediments are located along these prominent structural trends and provide clear evidence of its persisting fluid and tectonic activity (Fig. 1). In this study we propose that the above outlined system of major faults and tectonic fractures has played an important role in transporting and focussing warm fluids. The available data show that the movements of fluids along fractures may have occurred episodically throughout geological time and may have been tied to the earthquake cycles. Carbonate rocks of various ages that are penetrated by north-south faults show a variety of unusual karstic features, which can be interpreted, as *hydrothermal karst*. Below, we shortly describe characteristics of caves and spelean carbonates of the best studied Bohemian karst, developed in Silurian and Devonian limestones of the Barrandian basin, between Prague, Beroun and Zdice (Fig. 1).

II. CALCITE VEINS, CAVES AND SPELEOTHEMS OF THE BOHEMIAN KARST

Most of the caves in the area bear little or no relation to the modern topography or surficial hydrology. The epikarst is poorly developed, with solution sinkholes and vadose solution conduits being rare. On the other hand, many caves clearly tend to be spatially linked to subvertical, generally north-south-oriented veins mineralized with coarsely crystalline calcite, chalcedonic silica and a variety of manganese species (Zeman *et al.*, 1997). Saddle dolomite and asphaltic bitumen also occur in some veins as late-stage paragenetic phases. Fluid inclusion homogenization measurements on vein calcite samples indicate precipitation from NaCl – KCl – $CaCl_2$- $MgCl_2$ brines of variable salinity (0.35 to 22.4 wt. % NaCl equiv.), at 55-115°C (Dobes, in Zeman *et al.*, 1997). Carbonate rocks adjacent to thick calcite veins are intensely recrystallized and penetrated by dense suites of subvertical fractures.

The caves and caverns are developed both inside calcite veins and in immediate limestone host rock (Fig. 2). Steep subvertical caves that probably originated as corrosive enlargements of tectonic fractures or veins appear to be predominant. Large domes and subhorizontal passages are comparatively rare and occur chiefly along lithological boundaries. The morphology of large caverns and caves indicates activity by uprising corrosive fluids with only minor modifications by vadose erosion later. Cupola-form (convection) cavities up to 1-2 m in diameter and circular ceiling dissolution pockets are commonly present. Ramifying dendritic pattern is less common but many branch passages terminate in circular pockets. Most of the caves virtually lack any internal speleothems, having the wall rocks intensely corroded and locally disintegrated into loose carbonate

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sand. Exotic encrustations are developed only in some caves and include dark brown to black manganese crusts overlain by white pisolitic sinters called the "Koneprusy rosettes". Pisolites of the "Koneprusy rosettes" consist of growth banded alternating layers of calcite and microcrystalline quartz. Both calcite and quartz laminae contain low-salinity fluid inclusions, possibly with a small admixture of higher hydrocarbons (Dobes, 1996 ; unpubl. report). Other petrographic features like convex rhombic calcite crystals (similar to the "gothic-arch calcite" of Folk *et al.*, 1985) and possible calcite replacements after aragonite also point to the crystallization from warm water rich in H_2S. Pisolitic sinters of the "Koneprusy rosettes" are abruptly overlain by radially oriented aggregates of columnar, honey-yellow calcite the origin of which is now under research.

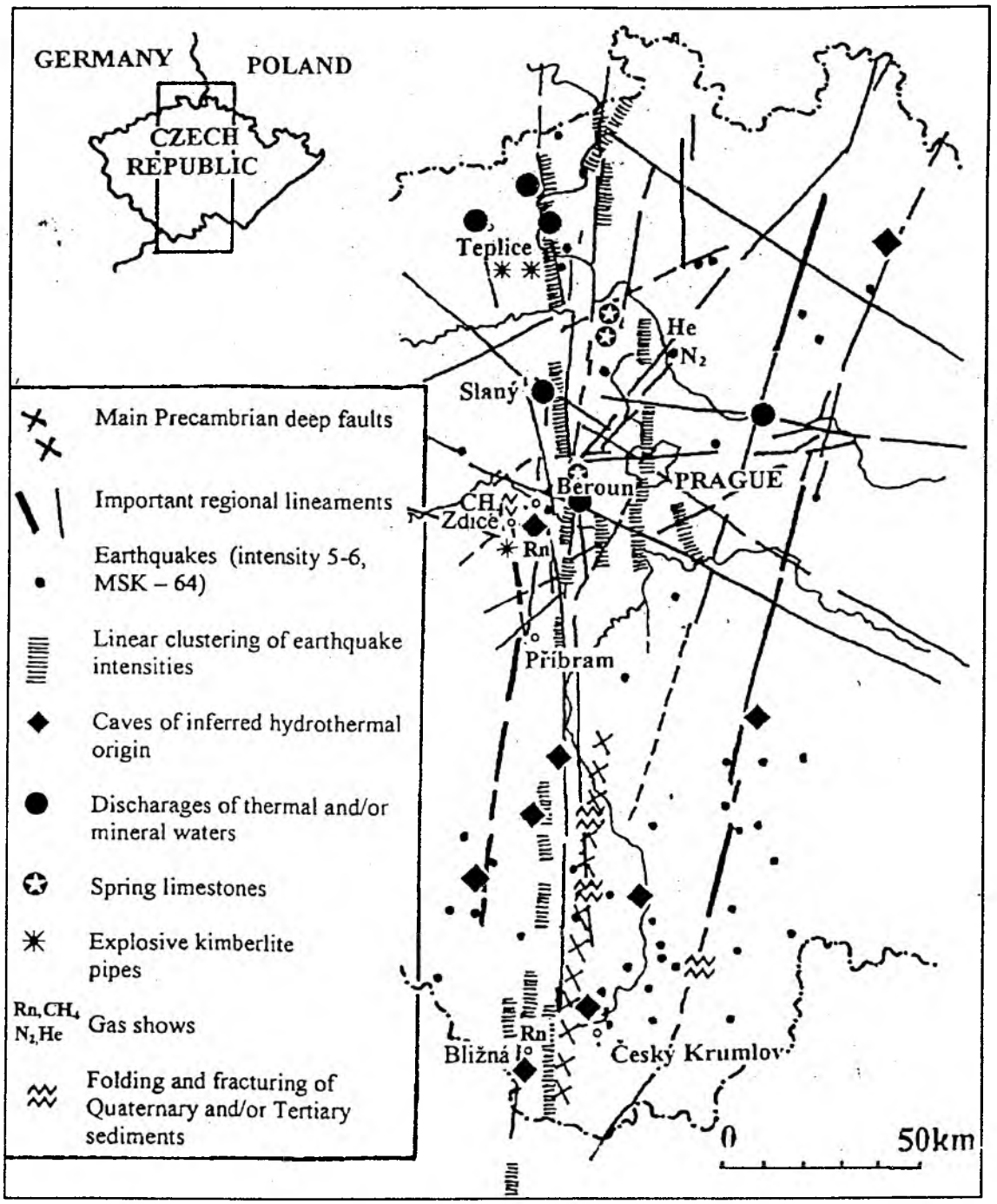

Figure 1. Schematic presentation of prominent lineaments of the central part of the Bohemian Massif (modified after Lysenko, 1986). Various geological phenomena linked to the lineaments are also shown (see text for more details).

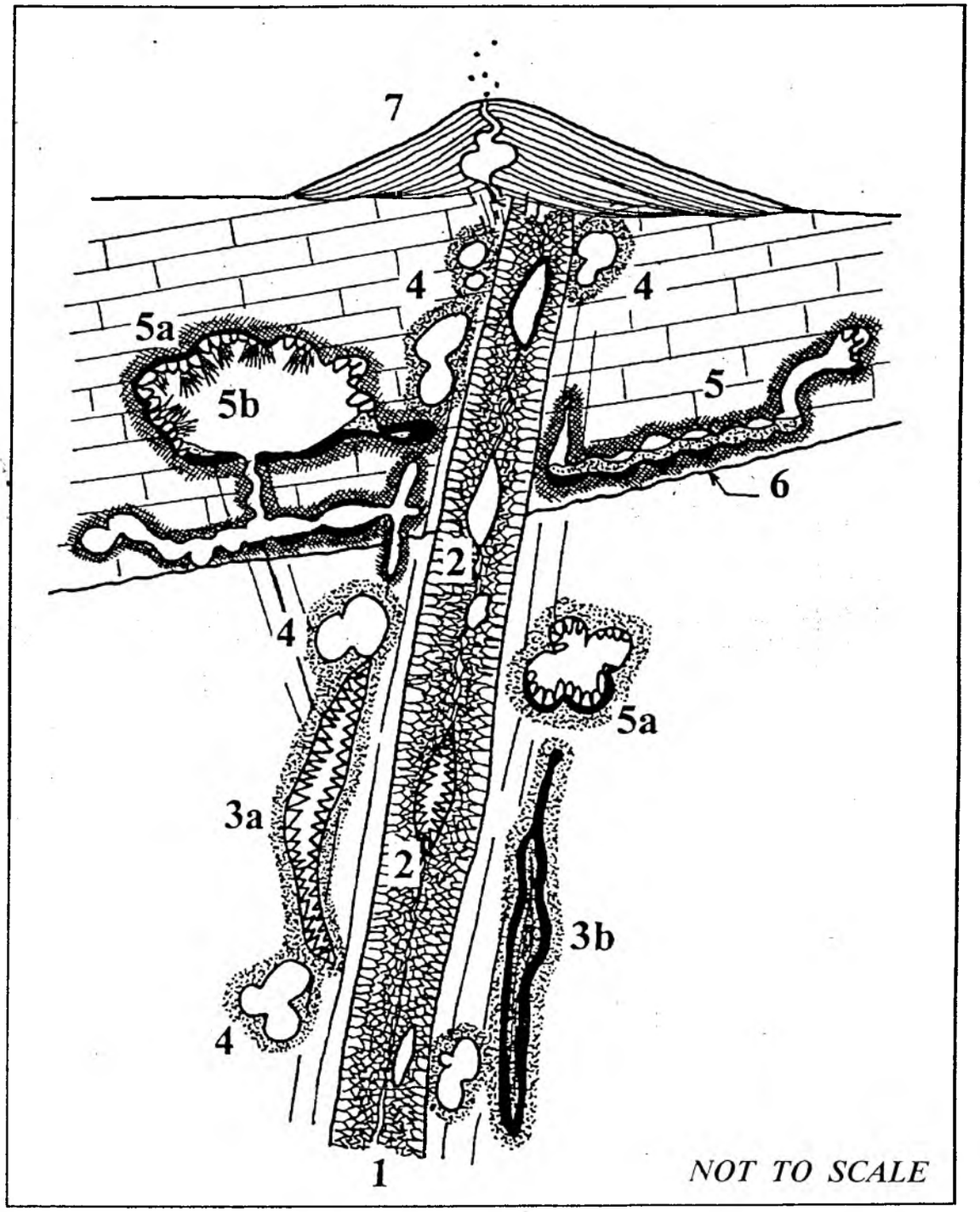

Fig. 2
Sketch to illustrate genetic relationship between hydrothermal calcite veins, adjacent caverns and caves and its internal speleothems. The model, which is largely based on geological observations in the Koneprusy area, is probably also applicable to other localities of the Bohemian Karst.
Explanations :
1 – Hydrothermal calcite vein; 2 – Cavities inside the calcite vein; 3 – Subvertical caverns in adjacent limestone host rock filled with calcite spar crystals (3a) or Mn-Fe oxyhydroxide encrustations and carbonate residual sands (3b); 4 – Spherical cavities and caves in host limestone; 5 – Caves partly filled with Mn-Fe deposits (shown in black) and/or carbonate sands (dotted areas). Carbonate/siliceous pisolites („Koneprusy rosettes") on the walls have been probably formed during late stage of hydrothermal process (5a). Subrecent aragonite also occurs in some caves (5b) ; 6 – Lithological boundary between carbonate sequences; 7 – Subaerial accumulations of spring limestones ; note the development of a subsurface cave within the travertine body.

Within the karstified sequences, cave morphology and speleothems show indistinct vertical zoning. Large caves with exotic precipitates are often developed in the upper part of the column whereas subvertical caverns and shafts coated with coarsely crystalline calcite spar crystals tend to be concentrated at lower levels (Fig. 2).

The origin of caves is interpreted as hydrothermal because of its close relationship to hydrothermal calcite veins, cave morphology and unusual internal mineralization. On the other hand, spongework pattern of some caverns and the presence of early mineral and fluid phases characteristic of H_2S-rich fluids may point to solution by oxidation by rising H_2S to sulfuric acid. The potential role of sulfuric acid speleogenesis is also indirectly supported by the burial history of Barrandian Lower Paleozoic sediments. Recent studies have documented significant burial (> 2 – 3 km) and oil window temperatures in excess of 100 °C which were attained probably during or after Late Devonian (Suchy *et al.*, 1996). This makes hydrocarbon and H_2S generating processes likely to have occurred. Therefore, it might be perhaps more appropriate to designate Bohemian karst caves as geochemical or hydrothermal-geochemical rather than purely hydrothermal.

At present, neither the ages of the alterations nor those of the calcite veins nor speleothems are known. Recent precipitation of aragonite, emissions of CO_2 and Rn in some caves, and thick subaerial deposits of calcareous sinters may indicate that fault-controlled endogenous karst-forming processes in the Bohemian karst are still partly active.

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