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Shear faults in Tertiary clay formation of the Eger Basin (Czech Republic) and their role for the degassing of the uppermost mantle

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With 2 Figures

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1. Introduction

The NW corner of the Bohemian Massif is characterized by the ENE-WNW trending Eger Graben (with lignite), the NNW-SSE trending Eger (Cheb) Basin, mafic volcanics of Tertiary to Quarternary age, mineral water springs, and mofettes of a high CO_2 degassing flow rate, and by swarm earthquakes. The most recent swarm event lasted from August to November 2000 with more than 10 000 single events (FISCHER & al. 2000). The hypocentres depth is between 5 and 11 km. From isotope geochemical (C, N, He) investigations it was determined that the total amount of gas (> 99 vol.% CO_2) entering the atmosphere is about 9 Mio m^3 p.a. (WEINLICH & al. 1999). The delta $^{13}C_{CO2}$ value (–1.8 to –4.0‰), the $^3He/^4He$ ratios (R/R_a = 5), features from upper mantle xenolith studies and deep seismic profiling hints at an active magmatic reservoir in the uppermost mantle beneath the NW-Bohemia/ Vogtland area (KÄMPF & al. 1999, WEINLICH & al. 1999).

The morphology along the western boundary of the Eger Basin (Fig. 1) is dominated by the down dipping Fichtelgebirge Granite (which was drilled beneath the basin filling), and towards east the basin is bordered by the escarpment of the NW-SE-running Marianske Lazne fault. There the basement is offset for more than 200 meters. To the north and south the bottom of the basin rises slowly to the surface.

2. Seismic active faults

The earthquake activity is known since centuries, as from several other seismic N-S zones in Europe (BANKWITZ & al. 2000). Only since the last years it became obvious (from mobile stations) that the hypocenters of the swarm earthquakes around the Eger Basin are aligned in N-S direction (HORALEK & al. 2000). The neighbouring Marianske Lazne fault (MLF) is itself seismically not active. The MLF seems to block up the sinistral creep movements along N-S faults (the most important seismic active fault was not known before [Fig. 1]). By this reason stress can be accumulated, and thereby it causes earthquakes at the crossing point of strike slip faults, a feature which seems to be common in Central Europe (SCHNEIDER 1993). Focal solutions and recent crustal movements give evidence of the NW oriented maximum horizontal stress, that coincides with sinistral

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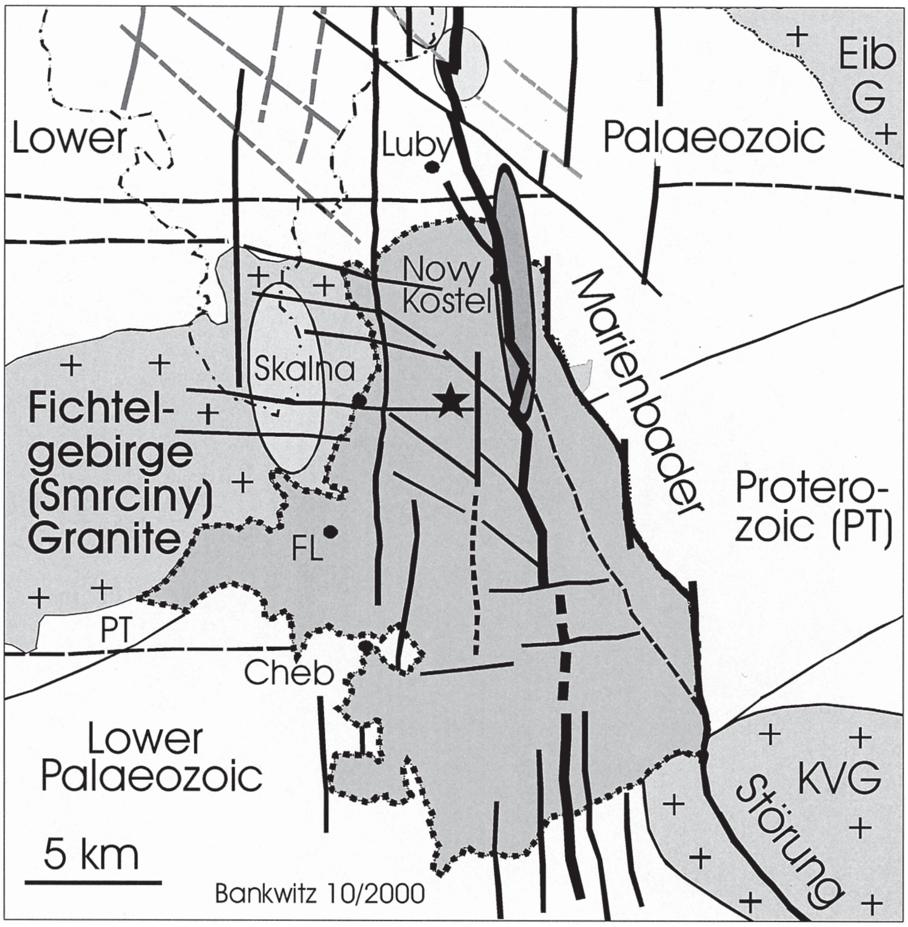

Fig. 1: Eger Basin (grey) with seismic N-S-fault zone. Thick line: Seismic active fault, not known before (Bankwitz et al. 2000). Ellipses: Epicentre areas; dark grey ellipse near Novy Kostel: Epicentres after Fischer et al. (2000). FL: Frantiskovy Lazne (Franzensbad); EibG: Eibenstock Granite Massif; KVG: Karlovy Vary (Karlsbad) Granite. Star: Study area, open mine Nova Ves.

strike slip movements along ENE faults and dextral shear sense at E-W fault zones. Both are realized in the open mine Nova Ves (Fig. 1).

2.1 Fluid migration through the Wildstein Clay Formation

Sediments of the Eger Basin, especially clay and gravel, are intensively exploited. Only since last years the depth of the open mines reached about 40–50 m beneath surface level which seems to be the prerequisite for the undermentioned champagne effect of the outcoming gas, because only now the overlying barrier system of the thick clay layers was taken off. In different levels the sediments are in some 5–10 m thick layers folded due to different reasons (tectonically, by compaction processes including water ascent, maybe by the gas pressure). The clay layer (ca. 10 m thick) above the degassing level is deformed by shear folds and is intensely faulted, marked by cleavage-like laminae injected from lower beds. The fluid migration and degassing is focussed on shear zones (10 m width), with different meso and micro fault systems down to 0,01 mm distances.

The Wildstein Clay Formation is separated by distinct fault zones of about 500 distances. NNW (to N-S) and the ENE (to E-W) directions dominate. The studied outcrop is located east of Skalna (Fig. 1), neighbouring the mofette field of Soos. In the Eger (Cheb) Basin such fields are striking in WSW-ENE direction and mark the prolongation of the northern flank of the Eger Graben into the Eger Basin (Weinlich & al. 1998)

3. Fault tectonics of the clay formation with fluid migration and degassing

In one of the open mines such an ENE-WSW wrench faulting zone (width of 20 m) is temporarily exposed. It consists of numerous en echelon faults of nearly all dimensions (from meso to micro), covered with sub-horizontal striae. Most of them are from half a meter distance and 1 m size to 0,01 mm distances and 0,1 mm size. Altogether they form an anostomosing complex shear zone. The single planes are subvertical or are dipping up to 60° NW. The fault zone was exposed in December 2000 and January 2001 over a length of ca. 300 m; its continuation is hidden. An unusual feature is the noise which is caused by the high-pressure CO_2 flux from the Earth's mantle finally through these faults. The noise is to hear due to the lowering of the sub-soil water. One of these gas jet bearing faults was studied in detail (see below). In experiments (Galle 2000) the gas breakthrough pressure for H_2 flux penetrating pores of clay is nearly 20 MPa. The Eger Basin gas stream can be felt (on the hand) and can be made visible by putting a band of paper above one of the gas bearing faults. The fault surfaces look like polished. Partly the surfaces have a yellow, greenish or black colour which is caused by pure clay mineral sheets. They were transported to their position by the gas/fluid jet. The sediments are Upper Pliocene, up to 1,6 Ma. It is unknown how long during the last 1,6 Ma the gas jet is active. Because of the mining intensity the studied outcrop (in soft rock) will not exist for longer times.

4. Micro-fabrics and substantial features related to the gas/fluid jet

SEM observations on the surface of one gas/fluid jet fault plane (GJF, Fig. 2 A: from the ENE shear zone) reveal traces of two other shear planes, crossing and modifying the relief of the main GJF shear plane (parallel to the photo plane). The dominant traces of the subordinate system have a 0.02 mm distance. The sigmoidal curved sections of the GJF (240°/80° NW) between these traces give evidence for a dextral shear sense along the second system. The third shear plane, which is proven to be the latest (Fig. 2 B), is opened by a wrench movement along the second plane. This deformation has initiated numerous holes (or chimneys) of 0.002–0.05 mm diameter. We suppose that the gas jet uses these secondary porosity on its way to the surface.

The third shear planes in Fig. 2 A wear small channels, in intervals of 0,001 mm. Partly these microfaults displace the traces of the second fault system. It should be noted that the described fabrics are not to recognize on the meso-scale fault plane. The clay minerals wich cover the fault planes are extremely tiny. This can be caused by sedimentation from water/gas flow during the ascent.

The way-up of the fluids is discussed since decades. In the Upper Mantle it is supposed that fluids (CO_2 saturated silicate melts or carbonatitic melts or CO_2 dominated fluids) rise along grain boundaries and fracture zones. Within the crust mostly the hypothesis of vertical drain along faults or fault zones for the fluids ascent is favoured. Evidence for gas overpressure is given by fluid eruptions from drill holes in the Eger

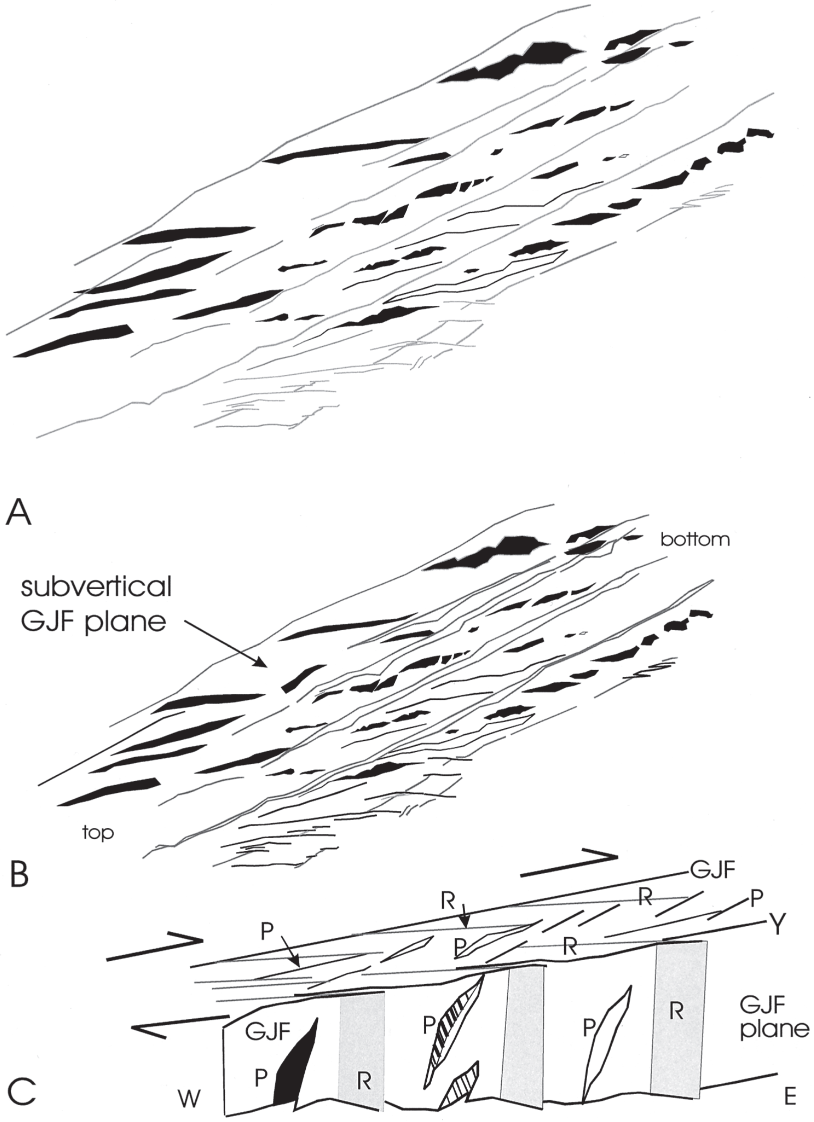

Fig. 2: SEM photograph of the microfabrics of one gas/fluid jet fault plane (GJF) ENE shear zone near Skalna. A Photograph (Störr), B documentation of fabric traces on the GJF, C interpretation of the dextral movement and related three shear systems (Y, R, P).

Basin. In our case we can show that the degassing follows a tectonically induced porosity in the otherwise extremely compact clay formation.

The mineral composition (SEM Jeol 840) differs in the two clay layers of several meters where the degassing is to observe: the upper and brighter bed is built up from kaolinite with illite, the lower and darker bed is composed of fireclay. Quartz and feldspar are less than 5%; gypsum is more frequent along open faults.

5. Tectonic-induced secondary porosity and fluid overpressure induced cave formation

Dominantly the en echelon faults of the third shear system are characterized by small holes (black dots in the SEM photograph) partly like a chain within the opened trace. It can be located at the lower end of the open trace, where the trace is broadened. This fact give evidence of small initial jet streams. It is to suppose, that the holes became enlarged by fluids.

A comparable meso-scale structure is a cave (length: 5 m, depth: 1 m, width: 0.5 m), which was exposed within the ENE shear zone, but at the next deeper level than the object of the SEM photograph. The wall of the cave is partly mineralized (gypsum). Sand cover on the cave walls exists, nevertheless no sand layers exist in the mine below the clay formation. We suppose that the cavity system within the shear zone was filled with CO_2 saturated water (sand inflow) and works as a gas separator system (inflow from below: mineralized and CO_2 saturated water; in the cave: gas/water separation; outflow: mostly gas). Furthermore we suppose that the cavity system works like a cold geyser, and that the process of fluid migration in the shear zone could be influenced by active liquefaction during earthquakes (sand veins).

6. Conclusions

A hidden southwestern prolongation of the southern border fault of the Erzgebirge beneath the Pliocene Eger Basin is a degassing fault zone (ENE-WSW). Within a complex system of countless strike slip laminae in a distance less than 1 mm, partly broken and brecciated by the gas/fluid jet, fluid escape and degassing occur over a width of 20 m (exposed length: > 300 m). The study of different samples of the smooth fault planes reveals that by three interacting shear planes a secondary tectonically induced porosity was formed. Through tube like pores (0,001 mm in diameter) the mantle fluids/gas discharge with high pressure and with noise. Gas and water have polished the shear planes on which single clay minerals are deposited by the fluid/gas stream. The described phenomena were observable because the overlying barrier system of sediments only recently was mined.

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