The late and post-Variscan tectonic evolution of the KTB-drilling site area - a short workshop report

A. PETEREK (Institute of Geology, Schloßgarten 5, D-91054 Erlangen)
and
R. BISCHOFF, D. COYLE, U. HAACK, G. HIRSCHMANN, S. LICH, H. RAUCHE, S. RUST, B. SCHRÖDER, A. SEMMEL, G. STETTNER, B. STÖCKHERT, T. UMSONST, G.A. WAGNER, K. WEMMER, G. ZULAUF (participants of the workshop)

Introduction

This paper discusses aspects of the late and post-Variscan tectonic evolution of the KTB-drilling site area. This report has been compiled during a workshop held from 1-2 November 1993 in Gießen. In the course of the workshop results of various working groups have been discussed in order to decipher the tectonic evolution of the KTB-drilling site area from the Late Variscan onwards. The following topics were addressed:

1) Reconstruction of the cooling history of the rocks recovered at the KTB-drilling site and the adjoining area (WAGNER, BISCHOFF, COYLE, WEMMER)

2) The evolution of the Mesozoic to Cenozoic sedimentation, including the uplift and denudation of the KTB-drilling site area (SCHRÖDER, BISCHOFF, WAGNER, STETTNER, PETEREK, SEMMEL)

3) Reconstruction of the brittle deformation path, especially with respect to the determination of the kinematics and paleostresses of faulting (mainly ZULAUF, PETEREK, RAUCHE, HIRSCHMANN)

4) P-T conditions and mineralisation during brittle deformation (LICH, RUST, ZULAUF).

Most of the results of the different working groups have already been published. Since the results of the workshop will be profoundly documented in one of the next KTB-Reports only a brief summary will be presented here. This paper is mainly based on the unpublished workshop report (RAUCHE 1994) revised by PETEREK, HIRSCHMANN, SCHRÖDER, RAUCHE and WAGNER.

Results

The initial point of the late and post-Variscan tectonic evolution considered here is marked by the intrusion of the Carboniferous granites (310 my). The intrusion of the granites may be linked to NNW/SSE and NE/SW striking fault zones. Kinematic data are not available

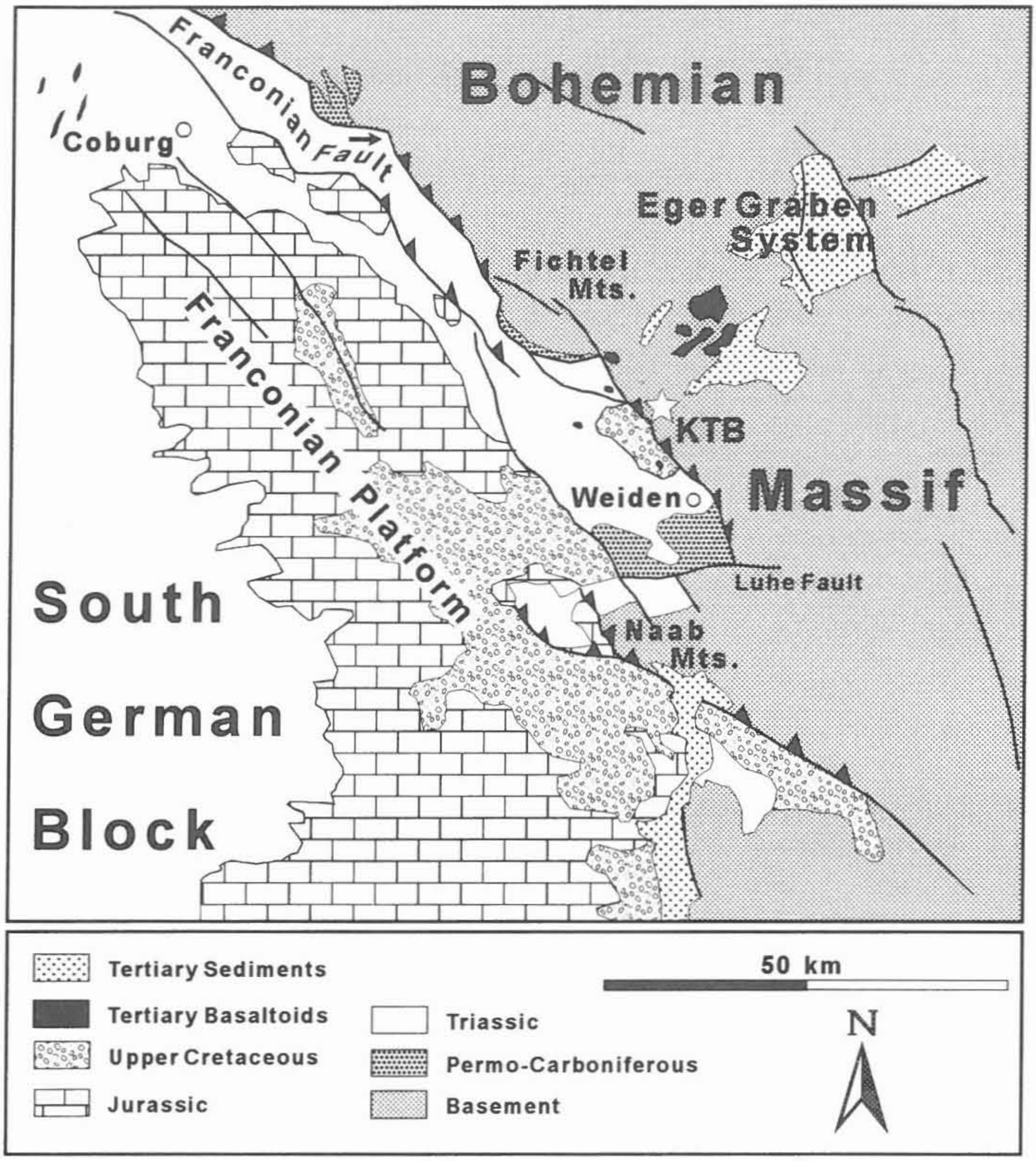

Abb. 1. Generalized geological map of the surroundings of the KTB drilling site.

yet. The main stages of the late to post-Variscan deformation history will be discussed briefly.

1st Period: 325 ... 295 my, including an interval from the cooling of the granites to the subsidence of the Permo-Carboniferous molasse basins

During this first period the dilatation of subvertical tension gashes reflects the oldest brittle deformation within the Carboniferous granites (ZULAUF 1993). It corresponds to a sub-horizontal NE/SW position of the minimum compressive stress σ_3. Reverse fault zones that were enriched with graphite postdates the older subvertical veins and indicate a following NE to E compressional stage of deformation (ZULAUF 1993). The reverse faults are cross-cut by lamprophyric dykes which were emplaced at the Permian-Carboniferous boundary (295 my, KREUZER et al. 1993).

2nd Period: 295 ... 250 my, including the subsidence of the Permo-Carboniferous Molasse Basins

Variation of lateral thickness and facies changes of the sediments of the Permo-Carboniferous troughs indicate that their development has been controlled by synsedimentary fault activity (SCHRÖDER 1988, LÜTZNER 1988). Distribution and structural features of the individual basins suggest that their structural development has been connected to wrench faulting (SCHRÖDER 1987, MATTERN 1993). Some basins can be interpreted as pull-apart basins (LÜTZNER 1988). The few kinematic data available indicate a subhorizontal orientation of the maximum compressive stress σ_1 in N/S to NNW/SSE position (SCHRÖDER et al. 1994, ZULAUF per. com.). An extremely rapid uplift and a high erosional rate in the late Carboniferous/early Permian has been postulated by WELZEL (1991) and WELZEL et al. (1992). This assumption is based on white mica from the post-Variscan granites (see above) that were deposited as detritical components in the Permo-Carboniferous troughs only 5-10 my later. An uplift in Permo-Carboniferous time of about 4 to 5 km has been also suggested by HELMKAMPF et al. (1982).

3rd Period: 250 ... 145 my, including sedimentation, uplift and denudation from the Upper Permian to the latest Jurassic

Sediments of late Permian age (Saxonian and Zechstein, SCHRÖDER 1987) rest unconformably Permo-Carboniferous strata (LEITZ & SCHRÖDER unpubl.). This unconformity indicates the beginning of the regional subsidence of the South German Block and the adjacent Bohemian Massif. The accumulation of coarse alluvial fan deposits west of the Franconian Fault zone (KLARE 1989, KLARE et al. 1990) corresponds to synsedimentary tectonic activity during the early Triassic (Lower Buntsandstein). Well-defined features of sphene fission-track ages support a rapid uplift and denudation of the Bohemian Massif during the early Triassic (COYLE & WAGNER, this volume). Mesozoic subsidence of the South German Block and progressive extension of the sedimentary cover over the basement now exposed is accompanied by a NE/SW to NNE/SSW directed crustal thinning (PETEREK et al. 1994, SCHRÖDER et al. 1994). The existence of cogenetic NE/SW trending normal faults suggests only little differences between the two horizontal stresses σ_H and σ_h.

4th Period: 145 ... 95 my, including denudation in the Lower Cretaceous

In the Lower Cretaceous tectonic activity along the Bohemian borderzone accelerated again involving fault-bounded block uplift and denudation (KLARE & SCHRÖDER 1990, KLARE et al. 1990). In the Permo-Carboniferous graben zone (between the Franconian Fault and the Franconian Platform) the Mesozoic strata were tilted and uplifted by some 1000 m (SCHRÖ-

DER 1987). To the west the Franconian Platform was uplifted only about 100 m before the Cenomanian. East of the Franconian Fault zone, however, rapid uplift induced the total erosion of the Triassic-Jurassic sedimentary cover (uplift > 1500 m, SCHRÖDER 1987). During the early Cretaceous the Triassic-Jurassic sediments underwent three stages of tectonic deformation (see PETEREK et al. 1994, SCHRÖDER et al. 1994):

1) NW trending normal faults and an orthogonal NW resp. NE trending joint system

2) Reverse faults, indicating a NNE position of the maximum compressive stress σ_1, and probably associated horizontal stylolites (see also SCHRÖDER et al. 1992)

3) Normal faults originated under N to NNE crustal extension.

In the region of the crystalline basement evidence for early Cretaceous compression is provided by a K/Ar-radiometric age of synkinematically grown illite within a reverse fault of the KTB pilot well.

5th Period: 95 ... 60 my, including Upper Cretaceous sedimentation and latest Cretaceous to early Paleogene inversion

During the Upper Cretaceous the uplift and denudation of the Bohemian borderzone continued, although locally late Cretaceous sediments rest on the basement (see MEYER 1989). The development of most of the Cretaceous basins seems to be controlled by synsedimentary fault activity. In the region of the Hessenreuther Forst the coarse alluvial fan deposits at the foot of the Franconian Fault zone give clear evidence for uplift and upthrusting of the basement block. Fission-track data from the KTB pilot and the KTB main borehole indicate simultaneous uplift and reverse faulting with vertical displacement along the Franconian Fault of at least 3 kilometers (WAGNER et al. 1991, JACOBS et al. 1993, COYLE & WAGNER 1994). An extremely rapid uplift of individual fault bounded basement blocks is also indicated by late Cretaceous fission-track ages in granite pebbles deposited in the Upper Cretaceous sediments (WAGNER et al. 1991).

Latest Cretaceous to early Paleogene compression and inversion is documented by reverse and strike-slip faults (SCHRÖDER et al. 1994, ZULAUF 1993). Kinematic data clearly hint to a NNE to N position of the maximum compressive stress σ_1 (ZULAUF 1993, PETEREK et al. 1994). Due to an incomplete stratigraphic record it is not clear whether the latest Cretaceous/early Paleogene inversion occured in one or in several phases.

6th Period: 60 ... 30 my, including denudation during Paleocene to middle Oligocene

Following the complex latest Cretaceous/early Paleogene inversion and deformation, a tectonically quiet period allowed the development of widespread planation surfaces. However, in the area of the KTB drilling site uplift and denudation of about 1 to 2 km continued. This is illustrated by the apatite fission-track ages t_m (about 100 °C) between 68 to 45 my and t_f (about 60 °C) between 20 to 38 my (BISCHOFF et al. 1993).

7th Period: 30 ... 20 my, including block faulting during late Oligocene to Middle Miocene

In the surroundings of the KTB location block faulting activity started again in the late Oligocene and early Miocene. Uplift of the Fichtel Gebirge and contemporary volcanic activity in the area north of the KTB drill site can be related to the evolution of the ENE/-WSW striking Eger Graben (HECKHOFF-WACHMANN 1993, SCHRÖDER 1994, MALKOWSKY 1980). Nowaday distribution of late Oligocene/early Miocene continental clastic sediments within the fault-bounded basins show a close relationship to the Eger Graben fault system. NNW/SSE extension suggested by the Eger Graben trend seems to be incompatible to the contemporary compression within the Alpine orogene. On the contrary, in the area of Southern Thuringia and Northeastern Bavaria the emplacement of the basaltic dykes took place within an extensive strike-slip system which was characterized by a NNE/SSW orientation of the maximum compressive stress σ_1 (PETEREK et al. 1994, SCHRÖDER et al. 1994).

8th Period: 20 ... 0 my, including uplift and morphogenesis since the middle Miocene

From the middle Miocene to early Pliocene a system of widespread planation surfaces ("Rumpfflächen") developed (LOUIS 1984, PETEREK unpubl.). North of the Luhe fault individually uplifted and downthrown planation surfaces indicate fault block activity during late Neogene to Quaternary period (SCHRÖDER 1992, STETTNER 1992). On the contrary, south of the Luhe fault the Neogene sediments that were preserved in the area of the Naab Gebirge (20 to 8 my, HECKHOFF-WACHMANN 1993) unconformably overlie the older, not reactivated fault zones (SCHRÖDER 1992).

Within the basaltoides kinematic data concerning Neogene and younger fault activity are available. They show clear evidence for an older WNW/ESE extension that is postdated by a second normal fault generation. This younger faults indicate a NE/SW orientation of the minimum compressive stress σ_3. Reactivation of the older fault planes by strike-slip movement shows a subhorizontal orientation of the maximum compressive stress σ_1 in N to NNE position. This may indicate the transition to the recent tectonic stress field in the surroundings of the KTB drilling site (BAUMGÄRTNER et al. 1990, MASTIN et al. 1991).

Conclusions

In the surroundings of the KTB drilling site the late and post-Variscan tectonic history is characterized by several periods of fault tectonic activity and rapid uplift of the Bohemian borderzone. From the Permo-Carboniferous onwards the main fault zones (especially the Franconican Fault zone) were repeatedly reactivated, mainly during the early Triassic, the early Cretaceous, the latest Cretaceous/early Paleogene and during the Neogene. Following the Permo-Carboniferous period of individual basin development, subsidence — corresponding to a NE/SW crustal thinning — of the South German Block and the adjacent Bohemian borderzone characterizes the Mesozoic (Triassic to latest Jurassic) evolution. During the early Triassic a belt of coarse alluvial fan deposits west of the Franconian Fault zone indicate a short interruption of the subsidence of the Bohemian Massif. Early Cretaceous and latest Cretaceous to early Paleogene inversion tectonics can be related to the Alpine plate collision (see also ZIEGLER 1993). A causal relationship can also be suggested between the acceleration of block fault activity during the latest Oligocene to early Miocene and the latest Alpine orogeny.

References

BAUMGÄRTNER, J., RUMMEL, F. & ZOBACK, M.D. (1990): Hydraulic fracturing in situ stress measurements.— KTB-Report, **90/6**: 353-400, Hannover.

BISCHOFF, R., SEMMEL, A. & WAGNER, G.A. (1993): Fission-track analysis and geomorphology in surroundings of the drill site of the German Continental Deep Drilling Project (KTB)(Northeast Bavaria).— Z. Geomorph. N.F., Suppl., **92**: 127-143.

COYLE, D. & WAGNER, G.A.(1994): Fission-track investigations on sphene from the KTB Deep Drilling Project (Germany): Post-Permian cooling history and in situ annealing.— KTB-Report (in press).

HECKHOFF-WACHMANN, P. (1993): Känozoische Hebungs-/Abtragungsgeschichte zwischen Egergraben und Naabtaltertiär.— Diss. Univ. Bochum.

HELMKAMPF, K.E., KUHLMANN, J. & KAISER, D. (1982): Das Rotliegende im Randbereich der Weidener Bucht.— Geol. Bavarica, **83**: 167-186, München.

HUCKENHOLZ, H.G. & KUNZMANN, T. (1993): Tertiärer Vulkanismus im bayerischen Teil des Egergrabens und des mesozoischen Vorlandes.— Beih. z. Eur. J. Mineral., **5**: 1-34, Stuttgart.

JACOBS, J., HEJL, E., VAN DEN HAUTE, P. & WAGNER, G.A. (1993): A preliminary tectono-thermal model for the KTB deduced from apatite, zircon and sphene fission-track analysis.— KTB-Report, **92/2**: 125-128, Hannover.

KLARE, B. (1989): Gliederung und Paläogeographie des Buntsandsteins im Ostteil der Süddeutschen Scholle.— Diss. Univ. Bochum.

KLARE, B. & SCHRÖDER, B. (1990): Extreme Randfazies der Oberkreide vor der ZEV.— KTB-Report, **90/4**: 300-309, Hannover.

KLARE, B., KÜGEL, H.-W., SCHRÖDER, B., SCHWARZ, S., STETTNER, G. & TOETZ, A. (1990): Intra- und post-oberkretazische Schollentektonik im Umfeld-Areal.— KTB-Report, **90/4**: 522.

KREUZER, H., HENJES-KUNST, F., SEIDEL, E., SCHÜßLER, U. & BÜHN, B. (1993): Ar-Ar spectra on minerals from KTB and related medium-pressure units.— KTB-Report, **93/2**: 133-136.

LOUIS, H. (1984): Zur Reliefentwicklung der Oberpfalz.— Relief, Boden, Paläoklima, **3**: 1-66, Berlin.

LÜTZNER, H. (1988): Sedimentology and basin development of intramontane Rotliegend Basins in Central Europe.— Z. geol. Wiss., **16**: 845-863, Berlin.

MALKOWSKY, M. (1980): Saxon tectongenesis of the Bohemian Massif.— Sb. Geol. Ved. Geol., **34**: 67-101, Prag.

MASTIN, L.G., HEINEMANN, B., KRAMMER, A., FUCHS, K. & ZOBACK, M.D. (1991): Stress orientation in the KTB pilot hole determined from wellbore breakouts.— Sci. Drill, **2**: 1-12.

MATTERN, F. (1993): Schersinnwechsel vom Oberkarbon bis zur Untertrias in der ostbayerischen Seitenverschiebungszone.— 9. Rundgespräch:"Geodynamik des Europäischen Variszikums", Werningerode/Harz, 15./16.10.1993, Abstract-Band: 19, Halle.

MEYER, R.K.F. (1989): Die Entwicklung der Pfahl-Störungszone und des Bodenwöhrer Halbgrabens auf Blatt Wackersdorf (mit einem geophysikalischen Beitrag von K. Bader).— Erlanger. geol. Abh., **117**: 1-24, Erlangen.

PETEREK, A., MAIER, M., BANKWITZ, P., BANKWITZ, P., FRANZKE, H.-J., RAUCHE, H. & SCHRÖDER, B. (1993): Contribution to the late- and post-Variscan Tectonic Evolution of the Western Margin of the Bohemian Massif.— KTB-Report, **93/2**: 107-111, Hannover.

PETEREK, A., RAUCHE, H., SCHRÖDER, B., FRANZKE, H.-J., BANKWITZ, P. & BANKWITZ, E. (1994): Spätmesozoisch-känozoische tektonische Entwicklung am SW-Rand der Böhmischen Masse.— Göttinger Arb. Geol. Paläont., **Sb1**: 174-176, Göttingen.

RAUCHE, H. (1994): Protokoll zum Workshop im KTB-Schwerpunktprogramm "Postvariskische Tektonik im Umfeld der Kontinentalen Tiefbohrung".— Unpubl. workshop report Gießen 1.-2. Nov. 1993, 18 S., Bochum.

SCHRÖDER, B. (1987): Inversion tectonics along the western margin of the Bohemian Massif.— Tectonophysics, **137**: 93-100, Amsterdam.

SCHRÖDER, B. (1988): Outline of the Permo-Carboniferous basin at the western margin of the Bohemian Massif.— Z. geol. Wiss., **16**: 993-1001, Berlin.

SCHRÖDER, B. (1992): Post-Hercynian fault block activities in the basement area near KTB-Drilling Site.— KTB-Report, **92/4**: 287-294, Hannover.

SCHRÖDER, B. (1994): Cenozoic degradation history at the western margin of the Bohemian Massif.— KTB-Report, **94** (in press), Hannover.

SCHRÖDER, B., BANKWITZ, P., FRANZKE, H.-J. & BANKWITZ, E. (1992): Die Fränkische Linie und ihr geologischer Rahmen.— In: BANKWITZ, P., KÄMPF, H. & BIELEFELD, E. (eds.): Münchberger Gneismasse und ihr geologischer Rahmen.— Excursion guide Ges. für Geowiss.: 99-126, Berlin.

SCHRÖDER, B., BANKWITZ, P., PETEREK, A., RAUCHE, H., FRANZKE, H.-J. & BANKWITZ, E. (1994): Spät- und postvariskische tektonische Entwicklung am SW-Rand der Böhmischen Masse.— Unpubl. DFG-report.

STETTNER, G. (1989): Geologische Kartierungen im engen und weiteren Umfeld der Tiefbohrung, Beispiele und deren Auswertung in Beziehung zum Profil der Vorbohrung und das Vorhaben einer geologischen KTB-Umfeldkarte 1:10.000.— KTB-Report, **89/3**: 10-23, Hannover.

WAGNER, G.A., HEJL, E., VAN DEn HAUTE, P. & VERCOUTERE, C. (1991): Spaltspuruntersuchungen am Kern der KTB-Vorbohrung und an Umfeldgesteinen.— KTB-Report, **91/1**: 259-268, Hannover.

WAGNER, G.A., VAN DEN HAUTE, P. & HEJL, E. (1989): Apatit-Spaltspuruntersuchungen an Gesteinen der KTB-Vorbohrung: Ein Beitrag zur spätkretazischen und tertiären Hebungsgeschichte.— KTB-Report, **89/9**: 207-215, Hannover.

WELZEL, B. (1991): Die Bedeutung von K-/Ar-Abkühlaltern an detritischen Muskoviten für die Rekonstruktion tektonometamorpher Einheiten im orogenen Liefergebiet - ein Beitrag zur

Frage der variskischen Krustenentwicklung in der Böhmischen Masse.— Göttinger Arb. Geol. Paläont., **49**: 61 p., Göttingen.

WELZEL, B., AHRENDT, H., BEHR, H.-J., SCHRÖDER, B. & WEBER, K. (1992): Die Bedeutung von K-/Ar-Datierungen an detritischen Muskoviten für die Rekonstruktion tektonometamorpher Einheiten im erweiterten KTB-Lokationsgebiet.— KTB-Report, **92/4**: 373-397, Hannover.

WEMMER, K. (1991): K/Ar-Altersdatierungsmöglichkeiten für retrograde Deformationsprozesse im spröden und duktilen Bereich - Beispiele aus der KTB-Vorbohrung (Oberpfalz) und dem Bereich der Insubrischen Linie (N-Italien).— Göttinger Arb. Geol. Paläont., **51**: 63 S., Göttingen.

ZIEGLER, P. A. (1987): Late Cretaceous and Cenozoic intra-plate compressional deformations in the Alpine foreland - a geodynamic model.— Tectonopyhsics, **137**: 389-420, Amsterdam.

ZIEGLER, P.A. (1993): Geodynamic model for Alpine intra-plate compressional deformation in Western and Central Europe.— In. COOPER, M.A. & WILLIAMS, G.D. (1993): Inversion Tectonics.— Geol. Soc. Spec. Public.: 63-85, London.

ZULAUF, G. (1993): Brittle deformation events at the western border of the Bohemian Massif.— Geol. Rundsch., **82**: 489-504, Berlin.