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September 8 – 12, 2003
Potsdam, Germany

Field Guide

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ANTARCTIC CONTRIBUTIONS TO GLOBAL EARTH SCIENCE

Field Guide

Edited by
Dieter K. Fütterer

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Field Trip A
Famous Localities of German Geology

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Fig. 1: Block model of the Rhinegraben (after CLOOS 1939).

Overview of the Geology of Germany

Germany is underlain by the following major geologic-tectonic units

- The North German Basin,
- The Variscan (Hercynian) Orogen consisting of mainly sedimentary belts in the north and mainly crystalline units in the south,
- The Mesozoic South German Basin,
- The Alpine Orogen with its Foreland Molasse Basin,
- The Rhinegraben.

The Variscan basement is underlying about 2/3 of Germany (Fig. 2). It was formed during the Variscan Orogeny (~350-300 Ma ago) by consumption of oceanic crust between Gondwana in the south and Laurussia (= the "Old Red Continent") in the north and final collision of these major continents producing the super-continent Pangaea. In detail, this complicated process resulted in the formation of a SW-NE-directed pattern of tectonic zones for the German section of the Variscides. Well-known parts of the Central European Variscides are the Harz Mountains, the Rheinisches Schiefergebirge, the Bohemian Massif, the Vosges and the Black Forest (Schwarzwald). The excursion will visit parts of the Variscides in Freiberg/Erzgebirge, in the Granulitgebirge ("Granulite Mountains") of Saxony and in the Schwarzwald.

Flat lying Permian to Mesozoic rocks cover the Variscan basement in large areas. These rocks are partly terrestrial, partly filling a very shallow marine basin ("Germanic Basin"), which is mainly fed from the north via a rift system lining out the future northern Atlantic, but at times from the south via connections with the Tethys. The Lower Permian (Rotliegendes) consists of red beds. The Upper Permian (Zechstein) contains the main northern and central German salt deposits. Terrestrial-fluvial Lower Triassic (Buntsandstein) and Upper Triassic (Keuper) conditions are interrupted by a Middle Triassic (Muschelkalk) marine ingression. Shallow marine sediments also characterize the Jurassic, which in Germany is divided into three stages: Lias (mainly shales), Dogger (shales, sandstones, oolites) and Malm (limestones). The Cretaceous is very heterogeneous and fragmentary. Glacial deposits in North Germany largely hide the Mesozoic sediments; they are rather well exposed between Hannover and the Harz Mountains, in the Thuringian Basin and in South Germany. In the latter area, we will visit Upper Jurassic limestones in Solnhofen (Archaeopteryx), fossiliferous Lower Jurassic shales (Lias ε) south of Stuttgart (Ichthyosaurus) and Middle Jurassic limestones in the Rhinegraben.

The Rhinegraben is part of a continental rift system traversing Central Europe from the Mediterranean to the North Sea and the North Atlantic Ocean. Structurally, the rift may be related to a conjugate fault system (Fig. 3) of SW-NE and NW-SE running structures. This system has been interpreted as mainly resulting from the northward push of the Alpine Orogen. We will visit the Rhinegraben during the last days of our field trip. Alkali magmatism associated with the graben formation (alkali basalts, basanites, trachytes, phonolites, carbonatites) will be studied in the vine-growing area of the Kaiserstuhl volcano.

Deposits of the Pleistocene North European glaciations exceeding 100 m and reaching up to 500 m thickness cover the North German lowland plain. The southernmost ice edge reached Cologne in the west, the Harz Mountains in the centre and Dresden in the east (see Field Trip C). The northern margin of the Alps and their northern foredeep (molasse basin) are exposed in the very south of Germany (see Field Trip B).

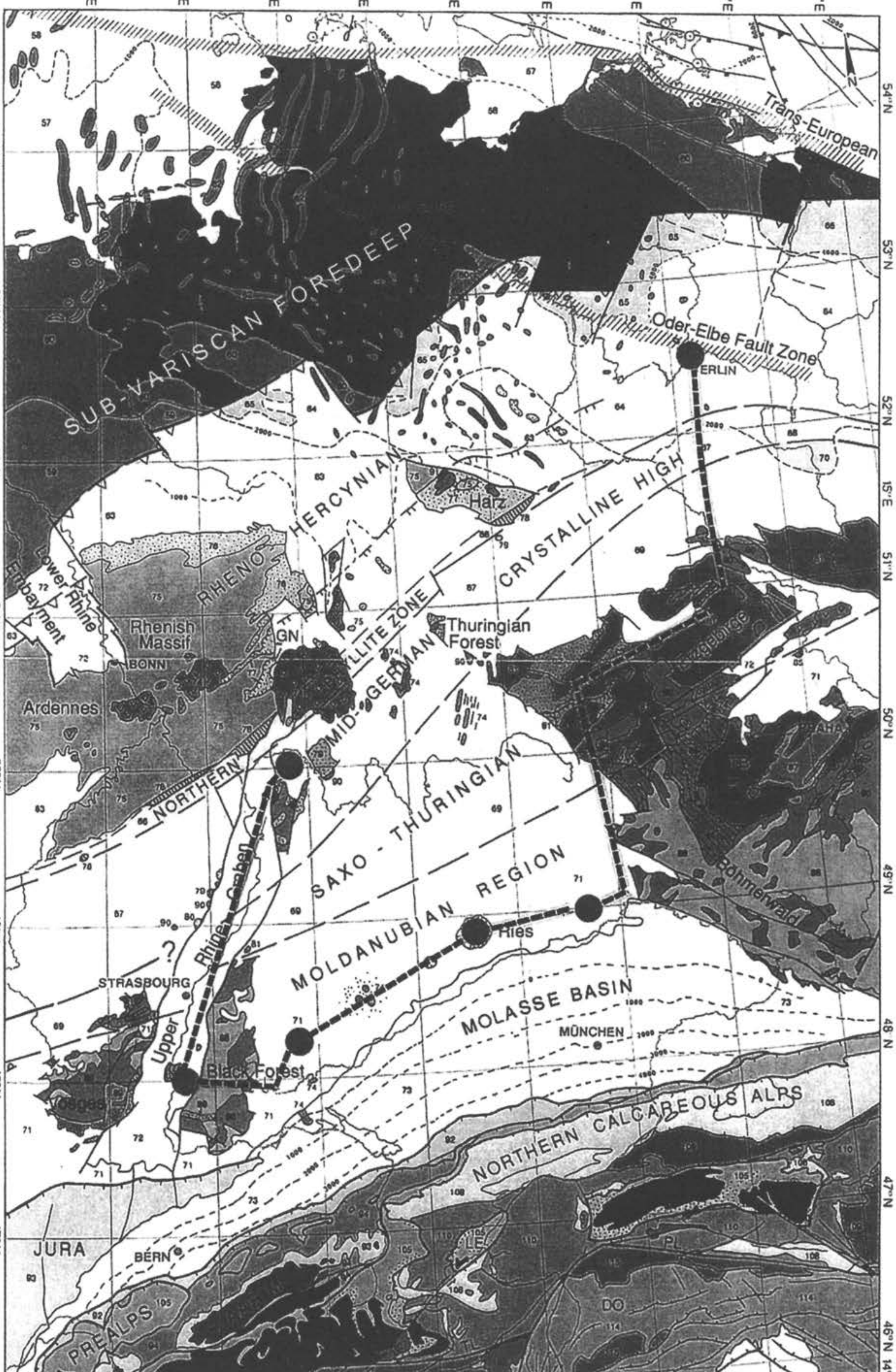


Fig. 2: Tectonic map of Central Europe (from European Geotraverse, 1992).

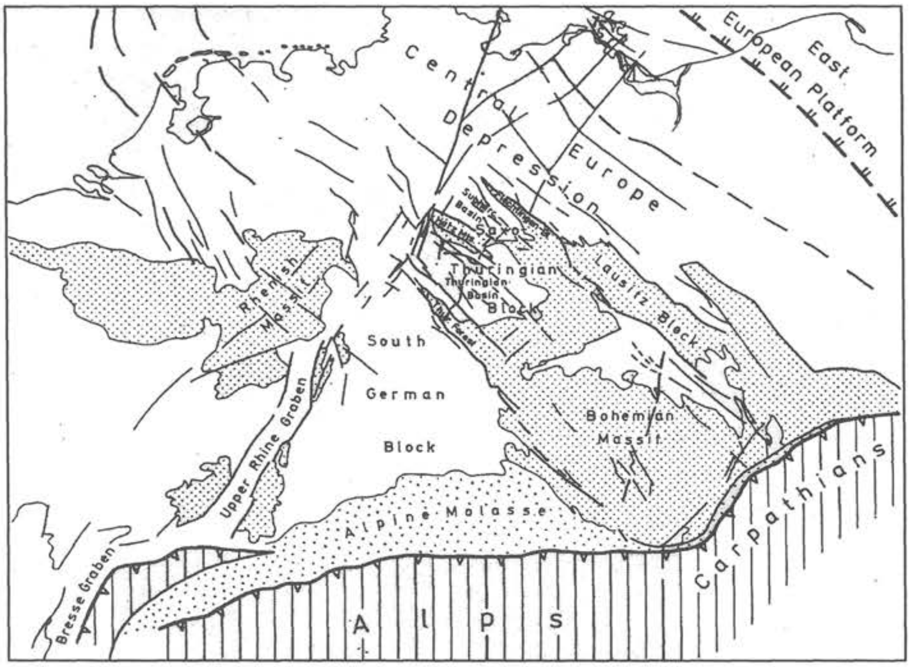


Fig. 3: Structural map of Central Europe (after STACKEBRANDT & FRANZKE 1989)

Variscan Basement

The Variscan orogenic belt was formed by the collision of Laurussia (= the "Old Red Continent") in the north and Gondwana in the south some 350-300 Ma ago. The preceding convergence with the closure of several oceanic basins lasted for about 150 Ma (see Fig. 4). The products of this process are not too well exposed and the apparent simple architecture is complicated in detail. Therefore, it took a rather long time, until plate-tectonic ideas became generally accepted.

Instead, a "fixist model" with "vertical tectonics" was proposed by KREBS (1976) or an "intracontinental fold belt" by MARTIN & EDER (1983). Even today, there is a certain disagreement about the mode of the Variscan orogeny, and different ideas exist, especially on the amount of oceanic crust and the number of oceans consumed (e.g. NEUGEBAUER 1988, 1989 *versus* FRANKE 2000). Anyhow, all ideas start off from the tectonic zones of the Variscides in Central Europe established by SUESS (1926) and KOSSMAT (1927). This architecture consists of about five WSW-ENE trending relatively narrow tectono-stratigraphic units (Fig. 2). These are from north to south:

- The Sub-Variscan foredeep,
- the Rheno-Hercynian,
- the Mid-German Crystalline Rise,
- the Saxo-Thuringian,
- the Moldanubian.

Plate tectonic concepts of the Variscan belt (DALLMEYER et al. 1995, FRANKE et al. 2000) interpret these units as micro-continents or terranes, separated from Gondwana and accreted at the Laurussian margin before and during the Variscan orogeny. Most of these splinters had been formed at the "northern" margin of Gondwana during the Cadomian orogeny (~550 Ma ago) (Fig. 5). Between these continental splinters, ocean basins are supposed to have opened andclosed time after time, i.e. the "Rheic Ocean", the "Giessen Ocean", the "Saxo-Thuringian Ocean", the "Massif Central Ocean" and others (see ZULAUF 1997; Fig. 4).

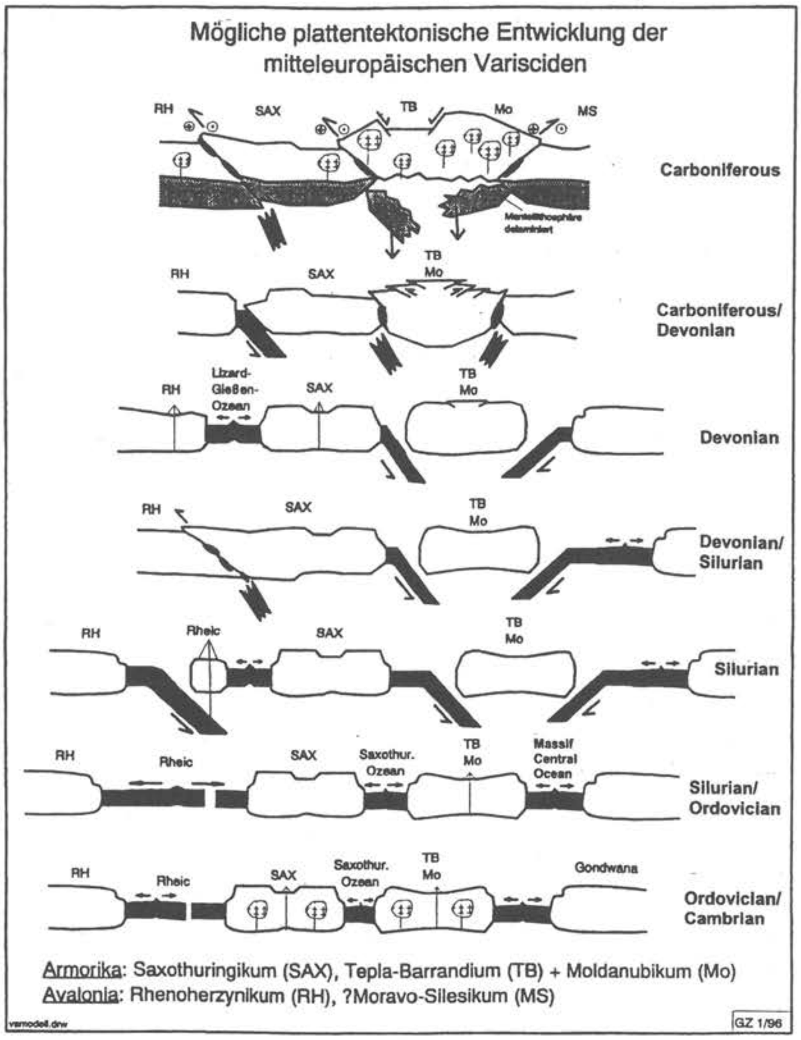


Fig. 4: Possible plate tectonic evolution of the European Variscides (ZULAUF, unpublished).

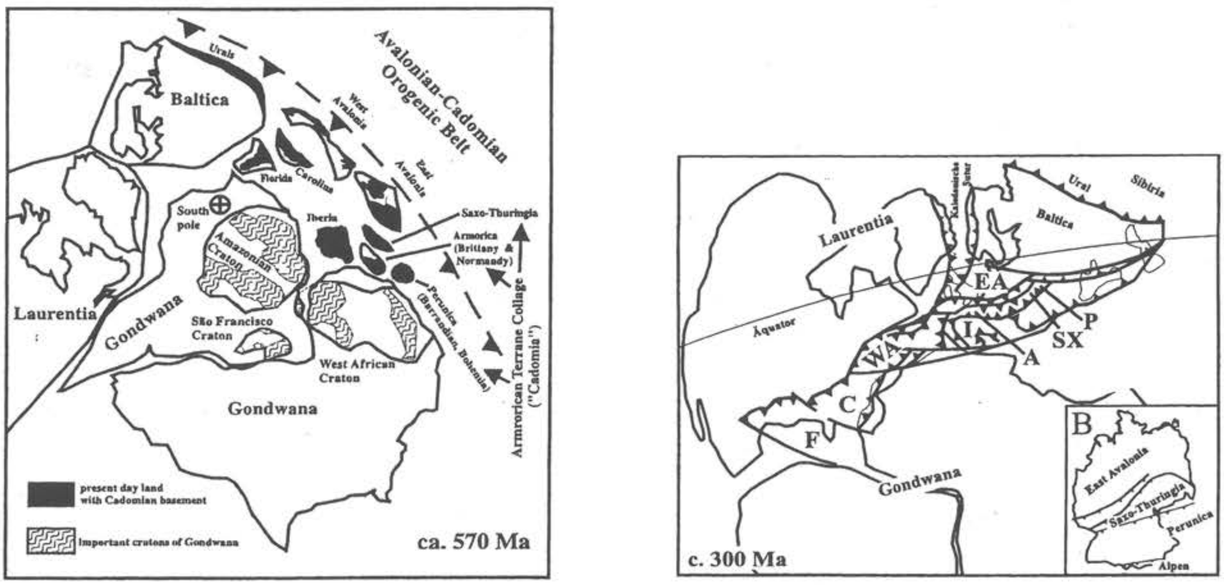


Fig. 5: The tectono-stratigraphic units of the (German) Variscides (from LINNEMANN et al., 2000). Left: Before the Variscan orogeny as parts of the Cadomian belt. Right: After the Variscan orogeny; EA = East Avalonia (the southern part of which is the Rheno-Hercynian), SX = Saxo-Thuringian, P = Perunica (≈Maldanubian).

The Sub-Variscan Foredeep represents the (northern) molasse basin of the Variscan Orogen, contains the coal measures of the Ruhr district and extends from Ireland in the west through Great Britain, northern France and Belgium, the Ruhr district, and, under cover, the area of Berlin southeast-wards to Upper Silesia. The rocks of this unit belong mainly to the Upper Carboniferous.

The Rheno-Hercynian comprises - as indicated by its name - mainly the area of the Rheinisches Schiefergebirge (i.e. the slate belt between Cologne and Frankfurt/M.) and the Harz Mountains. The main rock types are very low-grade metamorphosed slates and grey-wackes of Devonian to Lower Carboniferous age forming a fold-and-thrust belt.

The Mid-German Crystalline Rise consists of high to medium grade metamorphic and magmatic rocks (mainly gneisses and granitoids), forming parts of the Odenwald, the Spessart and the Thüringer Wald. The granitoids are arc-related and of Cadomian and Variscan age. The age of the protoliths of the metamorphic rocks is under discussion. The Mid-German Crystalline Rise is regarded as active margin south of the Rheno-Hercynian or north of the Bohemian Massif (RÖBER et al. 1997, FRANKE 2000).

The Saxo-Thuringian forms the main areas of northeastern Bavaria (Frankenwald), southern Thuringia (Thüringer Wald) and Saxony (Erzgebirge) and continues eastward to the Sudetes and westward to the northern tips of the Vosges and of the Schwarzwald (Black Forest). The unit shows a wide variety of rock types and ages of "formation" (sedimentation, metamorphism, plutonism, deformations). The northern Schwarzwald consists of phyllites and schists (greenschist facies) of possibly Devonian age. Southern Thuringia and northeast Bavaria are dominated by (very) low-grade rocks: slates, greywackes, and quartzites of Proterozoic to Ordovician age. Especially remarkable are Ashgillian diamictites. Other rock types in these areas include limestones and slates of Silurian, Devonian and Lower Carboniferous age. The Erzgebirge consists mainly of medium to high-grade metamorphic rocks. The bulk is made up of paragneisses and orthogneisses accompanied by mica-schists, small bodies of eclogites, and last, but not least "granulites" at the northwest-margin called Granulitgebirge (Granulite Mountains), the type locality of granulite. The metamorphic rocks are intruded by granites, three intrusive phases can be recognized: ~550 Ma (Cadomian, present orthogneisses), less common ~480 Ma, and ~330 to 290 Ma (discordant granites). There are corresponding metamorphic events. Relictic components with Archean and Proterozoic shrimp ages are also present (KRÖNER et al. 1997).

The Neo-Proterozoic and Cambro-Ordovician rock units of the Saxo-Thuringian are derived from the margin of Gondwana, all showing effects of the Cadomian orogeny. Their separation from Gondwana started around 450 Ma and was completed during the Ashgillian, coinciding with the Ordovician glaciation (Fig. 4).

Many details of the Saxo-Thuringian are controversial. During the last decade, large-scale nappe tectonics have become generally accepted.

The Moldanubian, named after the rivers Moldova in Bohemia and Danube, recently also termed "Perunica" (after a Slavic god) extends from the Massif Central (France) through Vosges and Schwarzwald to the main part of the Bohemian massif (mainly Czech Republic). The southernmost parts of this unit have been incorporated in the alpine fold belt (Gotthard and Aare massifs).

The southern section of the Massif Central and the southernmost part of the Black Forest can be regarded as a distinct unit separated from the other Variscan zones by the "Massif Central" ocean (LOESCHKE et al. 1988). As the Moldanubian has been, like the Saxo-Thuringian, a splinter at the northern margin of Gondwana, there are certain similarities between these units.

The Moldanubian consists, apart from granitoids, chiefly of medium to high-grade metamorphic rocks, mainly gneisses and migmatites which have suffered two metamorphic events, the Cadomian and Variscan. The protoliths of the metamorphic rocks are regarded as greywackes of Proterozoic, Cambrian, Ordovician, and Silurian age. Within the Bohemian massif, there are also nearly unmetamorphosed sediments of Cambrian to Middle Devonian age resting on a Cadomian basement. The granites are Cadomian (510–500 Ma) and Variscan (330-315 Ma), concordant as well as post-tectonically discordant.

Mesozoic Sedimentary Cover Rocks

The post-Variscan cover rocks in Germany start with Permian grabens, which are filled with red terrestrial Rotliegend sediments and porphyritic volcanic rocks. In North Germany these local depressions were then covered by the Zechstein Sea, which contains evaporites and most of the North German, salt deposits. In South Germany this marine ingression is not present.

In the Lower Triassic, a fairly uniform sedimentary blanket covered the whole of Germany, from the Island of Helgoland in the north to the Schwarzwald in the south. These Triassic

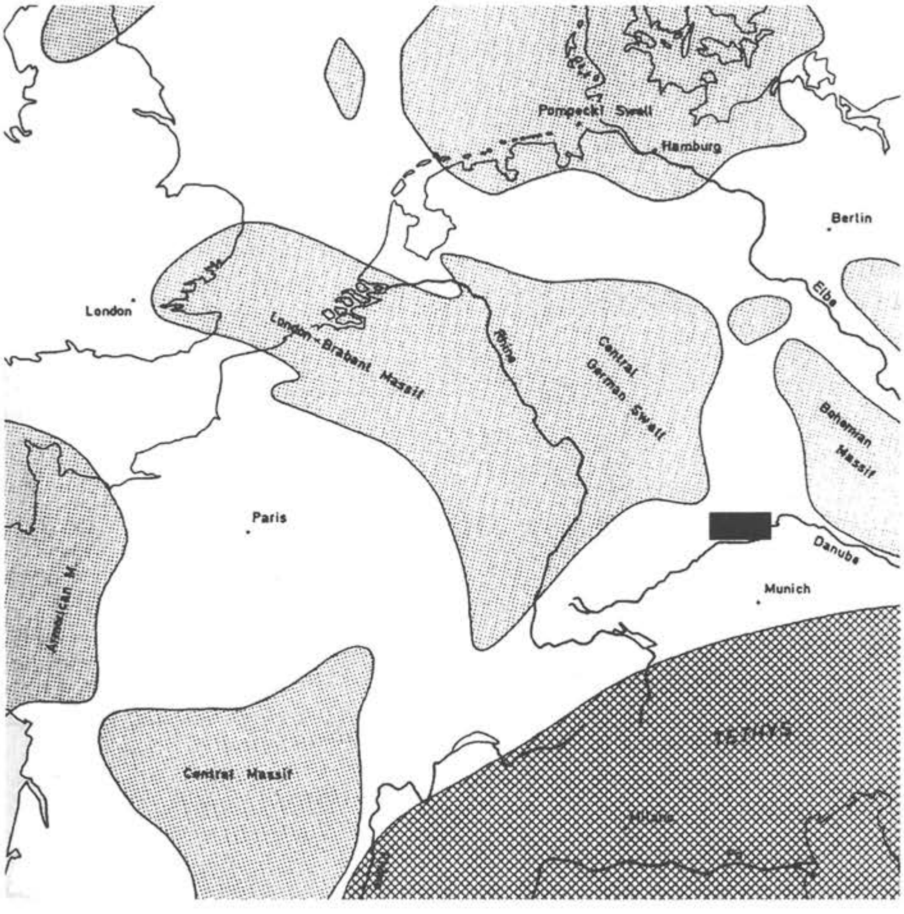


Fig. 6: Paleogeographic map of Middle Europe during the early Jurassic (OSCHMANN).

sediments show a threefold development: a lower terrestrial phase (Buntsandstein) is followed by a middle Triassic marine ingression producing the Muschelkalk limestone before terrestrial conditions re-appeared in the upper Triassic with the sedimentation of the red marly and shaly, sometimes gypsiferous Keuper sediments.

Marine conditions prevailed during the whole Jurassic period (Figs. 6, 7). The sediments in Germany are again divided into three, rather distinct subunits, this time by their colour. The lower Jurassic (Liassic), largely shaly sediments are also called Black Jurassic (Schwarzjura), the middle Jurassic (Dogger) marls and shales are called Brown Jurassic (Braunjura) and the upper Jurassic light-coloured limestones White Jurassic (Weissjura). The latter form the backbone of the Franconian and Suebian Alb mountains. These mountains are the highest part of a scarp and vale topography, which marks the area between the rivers Main and Danube. The whole sedimentary pile dips with 1-2° to the south-east. The shoulder uplift of Black Forest and Odenwald may be the motor for this tilting process.

The Danube River marks the boundary where the Upper Jurassic limestone platform of the Alb disappears under the Tertiary molasse sediments of the alpine regime. Cretaceous sediments are not represented in SW Germany.

In late Jurassic times the southern Franconian Alb was part of a carbonate platform extending south to the Tethys (in the present Alps). The platform was built up by the growth of sponge-microbial bioherms (Fig. 8) on submarine highs from the Oxfordian on. Progressive shallowing of the sea led to further spreading of these bioherms in the middle Kimmerdigian. Eventually, a whole network was formed with numerous small and often completely closed basins with restricted water exchange. High evaporation rates under a semi-arid climate led to a salinity-density stratification. No benthic organisms could exist in the hyper saline bottom water and therefore there were no bottom scavengers and no bioturbation. Life was possible, however in the surface layer. Organisms in the surface layer were killed by mixing with the saline layer during storms and sank down to the hyper saline bottom. They were rapidly covered there by fine carbonate debris and thus preserved as fossils. The Solnhofen Formation was formed under these conditions in the early Tithonian. The "Plattenkalk" is a pure micrite and relatively poor in organic matter.

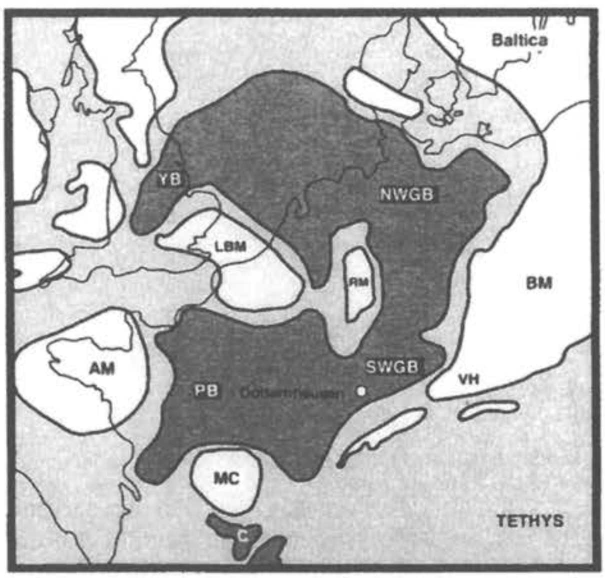


Fig. 7: Distribution of land and sea in Middle Europe during the late Jurassic (VIOHL 1996).

emerged areas:
LBM: London-Brabant Massif, RM: Rhenish Massif, BM: Bohemian Massif, VH: Videlician High, AM: Amoricanian Massif, MC: Massif Central.

distribution of the bitumimous facies:
YB: Yorkshire Basin, NWGB: NW German Basin, SWGB: SW German Basin, PB: Paris Basin, C: Chalhac.

shallow water

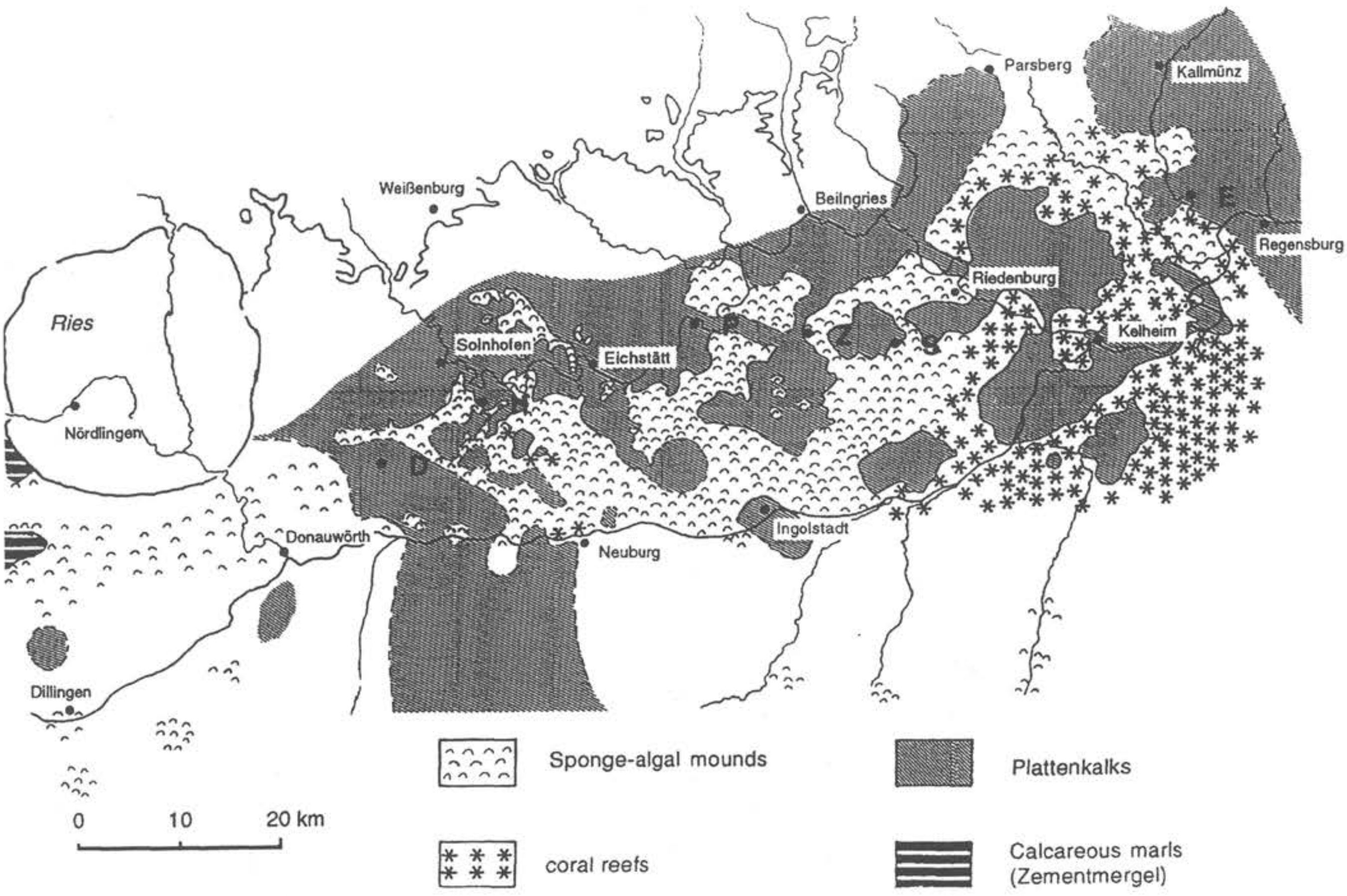


Fig. 8: Facies distribution in the Solnhofen area during the uppermost Jurassic (from VIOHL 1996).

Ries Meteorite Impact Structure

Roughly at the boundary between the Suebian and Franconian Alb (Alb = local term for the high Jurassic limestone plateaus extending diagonally across South Germany for a couple of 100 km), there is a peculiar circular depression the formation of which has been the subject of speculations for more than 100 years (Fig. 9). The similarity of a rock called suevite with some volcanic rocks have been the main argument for a volcanic origin of the Ries feature. The meteorite impact hypothesis was introduced in 1960 (CHAO 1977) and supported by the discovery of extreme high-pressure and temperature minerals in the suevite, which cannot be formed by the forces of the earth's interior. Today the impact origin is well established.

About 15 my ago a km-sized stone-meteorite hit the earth near the present town of Nördlingen (Fig. 10). It penetrated the locally exposed Jurassic limestones, the underlying Triassic sediments and finally the Variscan crystalline basement down to a depth of about 1000 m. About 150 km^3 of material were moved. The energy of the impact formed a 12 km wide inner crater. The meteorite and the rock matter directly hit by the impact were vaporized by the

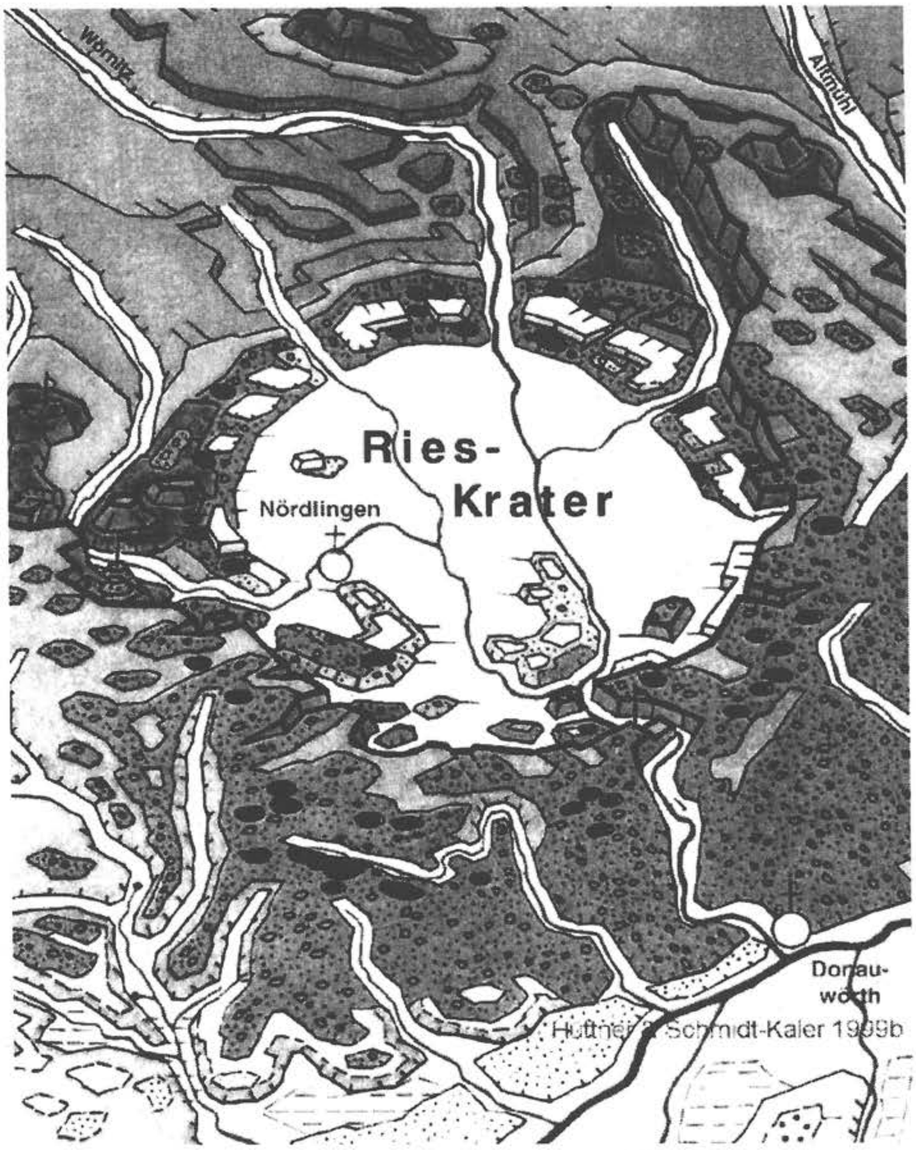


Fig. 9: Block model of the Ries impact structure (from HÜTTNER & SCHMIDT-KALER 1999).

enormous heat. Rocks in the immediate vicinity of the impact melted, more distant rocks became shattered and brecciated and thrown outwards from the centre of the crater. This material formed a 25 km wide complex crater with an internal ring wall.

A typical new rock type, the "suevite" (named after the local region of Suebia) formed in direct relation to the impact. It is a mixture of about 98 % of molten and solid crystalline rocks and about 2 % of sediments and contains abundant mineralogical evidence for extremely high pressures, e.g. coesite, quartz with a cleavage and plagioclase with isotropic sets of lamellae. Outside of the inner crater the rocks show commonly an inverted sequence: multicoloured breccia on top of Upper Jurassic limestones and in turn covered by suevite. A scientific drill

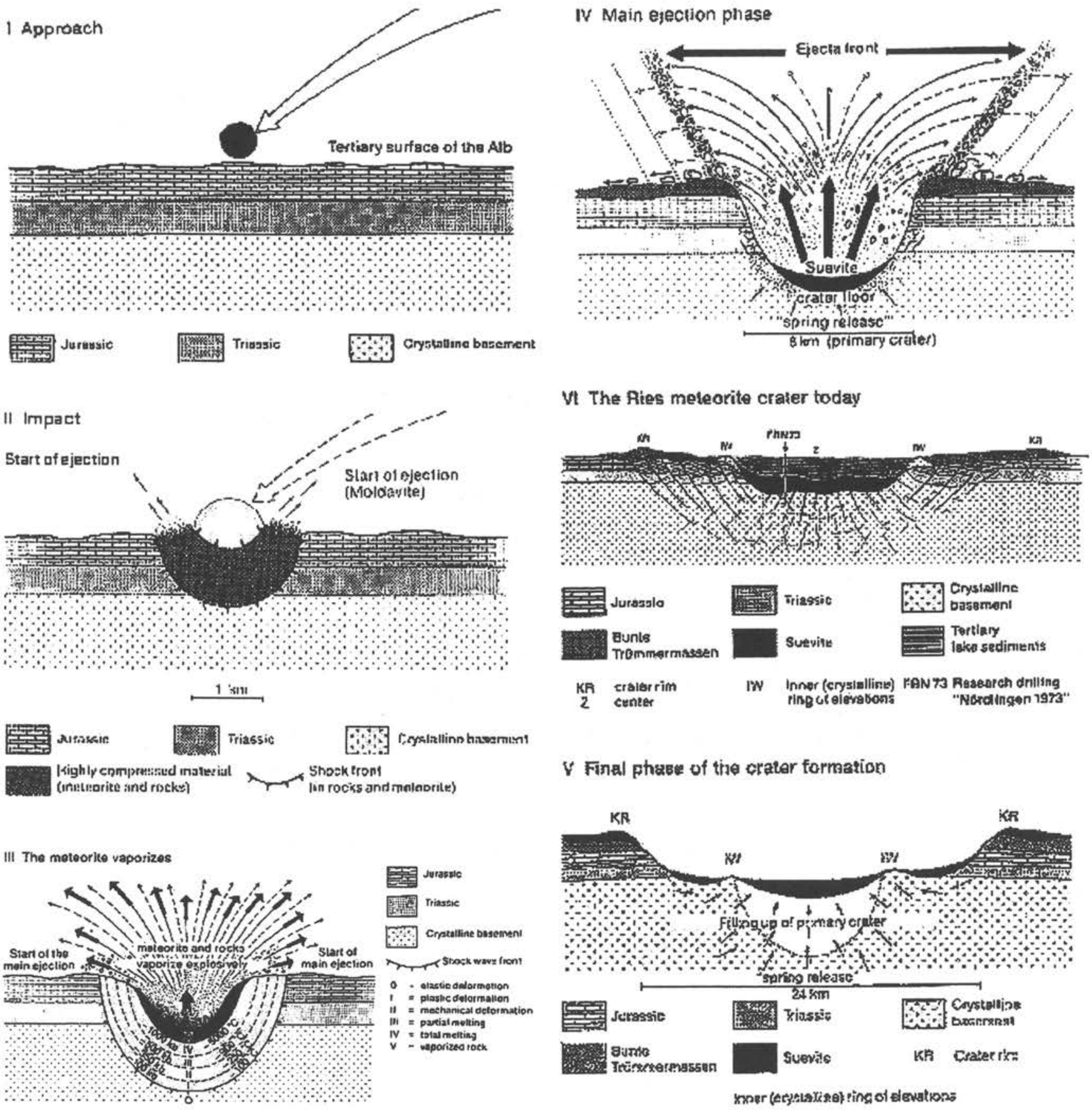


Fig. 10: Impact event in six steps (from KAWASCH 1986): I Approach; II Impact; III The meteorite vaporizes; IV Main ejection phase; V Final phase of crater formation; VI The Ries meteorite crater today.

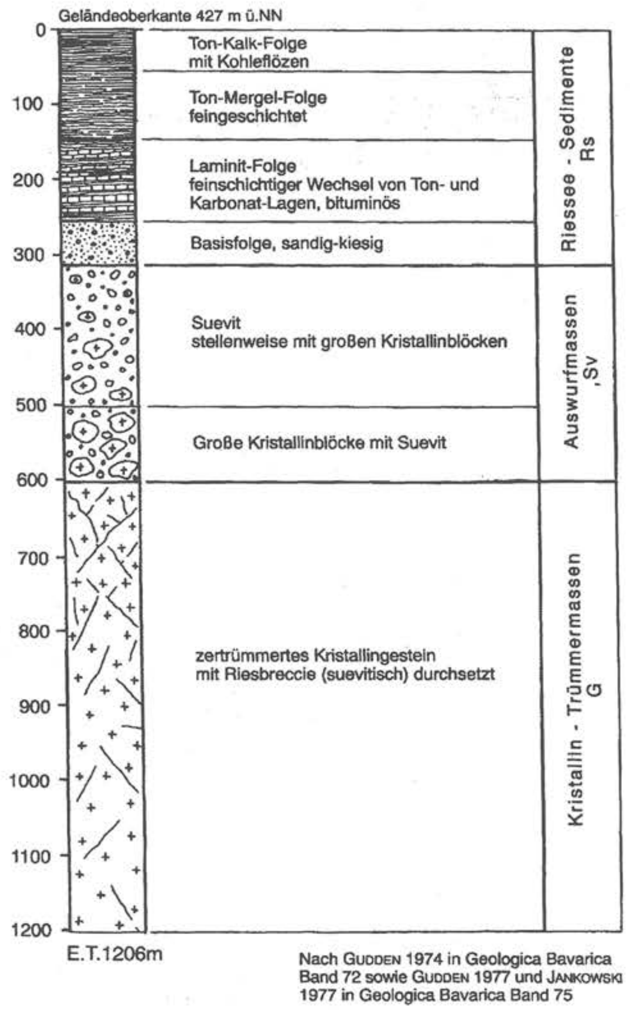


Fig. 11: Scientific well drilled in the Ries Crater in 1973 after HÜTTNER & SCHMIDT-KALER (1999).

hole with a depth of 1000 m gives additional evidence for the meteorite hypothesis (Fig. 11).

After the impact, which wiped out all live in the surrounding area, the crater was eventually filled by a shallow lake of about 400 km^2 size. This lake was in existence for about 2 Ma in the Miocene and the lake sediments provide freshwater fossils. During the Pleistocene the remaining depression was filled by fertile loess, which forms the base for the present agricultural use of the area.

Rhinegraben Continental Rift

Continental rifts are characterized by elongated deep sedimentary troughs, crustal thinning, high heat flow and associated alkali volcanism. The Rhinegraben is among the classical and most intensely studied cases on the planet. The Upper Rhinegraben is part of a system, which traverses Western Europe from the North Sea to the Mediterranean (Fig. 12).

Rifting started in the Middle Eocene in the form of graben subsidence along normal faults. Contemporaneous shoulder-uplift and tilting led to the exhumation of the Variscan basement rocks in Black Forest and Odenwald in the east and the Vosges in the west (Fig. 13). Both processes are still active today as shown by the seismicity. Within the graben, the Mesozoic cover of the Variscan basement is still preserved, starting from the Triassic and terminating with the Middle Jurassic (Dogger). Relics of these rocks units occur in tilted blocks along both graben margins (Vorbergzone; Fig. 16).

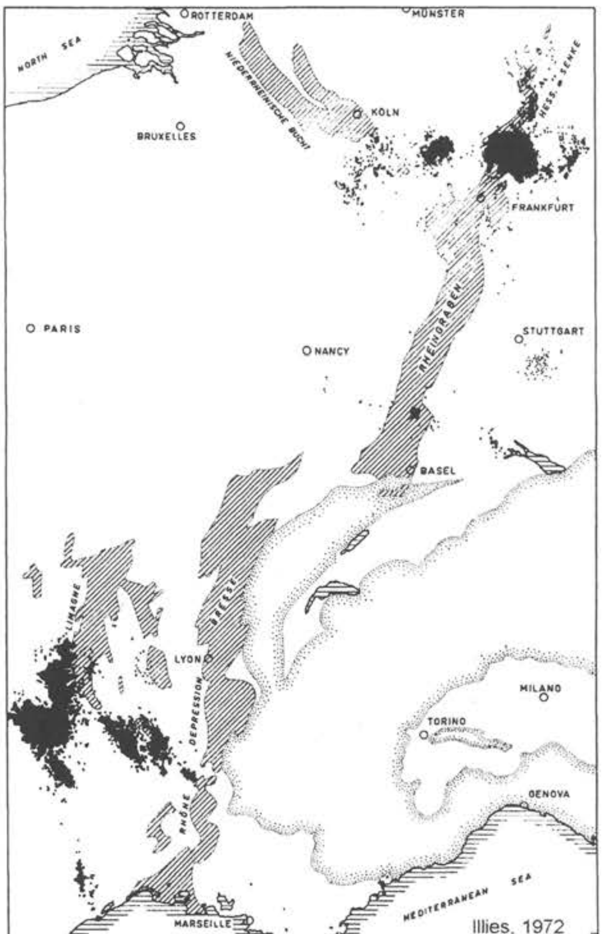


Fig. 12: The Rhinegraben as part of a rift system between North Sea and Mediterranean.

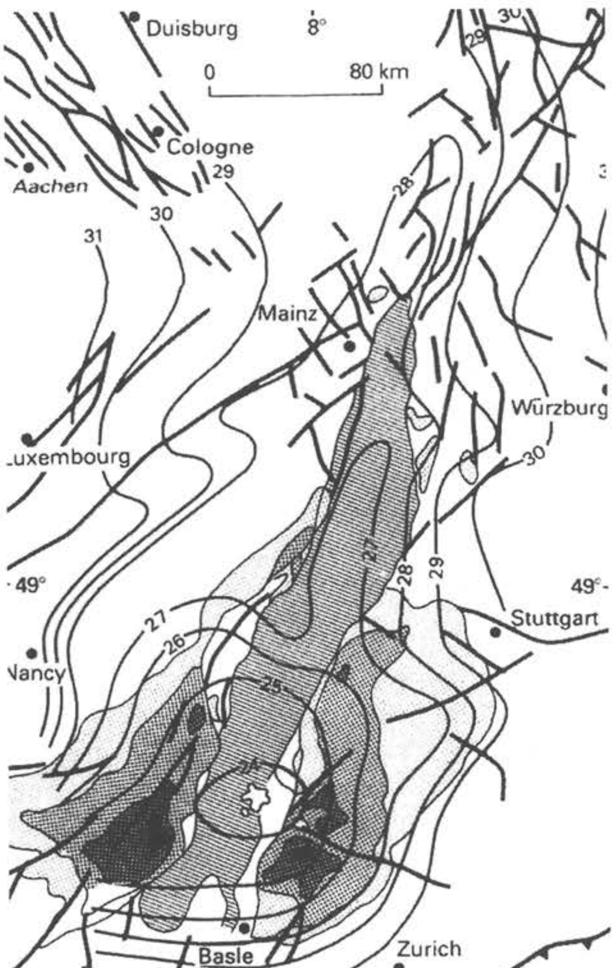


Fig. 13: Crustal thickness (with minimum of 24 km under the graben) and amount of shoulder-uplift (after Illies 1977).

The direction of extension was E-W in the south of the graben and NE-SW in the north. The Rhinegraben has a rather sharp termination in the north against the Taunus Mountains near Frankfurt and a more diffuse end in the south. The structural inventory indicates the existence of major transfer faults in both cases, in the north as a distinct fault against Variscan sediments, in the south more diffuse with the main faults at depth. The crust under the graben is about 24 km thick (Fig. 13).

Magmatism is strongly alkaline in character and, in the Kaiserstuhl in the south, comprises intrusive dike rocks and carbonatites as well as extrusive volcanic products of Miocene age.

The centre of maximum subsidence shifted from south to north through time, the thickest sediments occur in the northern part of the graben (3500 m; Fig. 15).

Most of the Tertiary sediments are terrestrial in character, but at one stage in the Oligocene the sea intruded the depression. Evaporites were formed at the end of this period in the southernmost part of the graben (Fig. 14). Most surface rocks in the graben are Pleistocene in age and the river Rhine entered the depression at a rather late stage (Fig. 15).

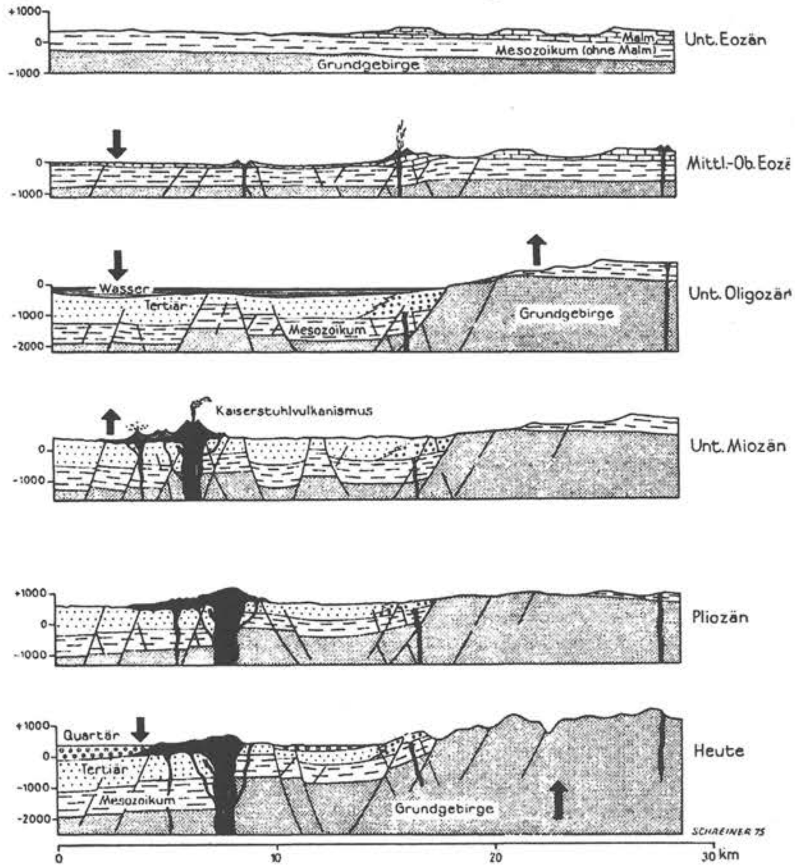


Fig. 14: Tectonic development of the Rhinegraben through the Tertiary (GROSCHOPF et al. 1981).

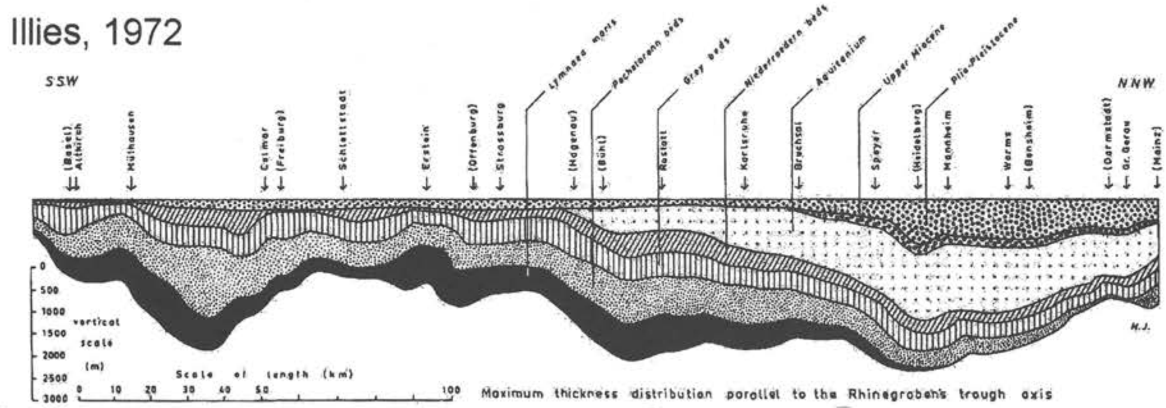


Fig. 15: Longitudinal section showing S-N shift of centre of subsidence through time.

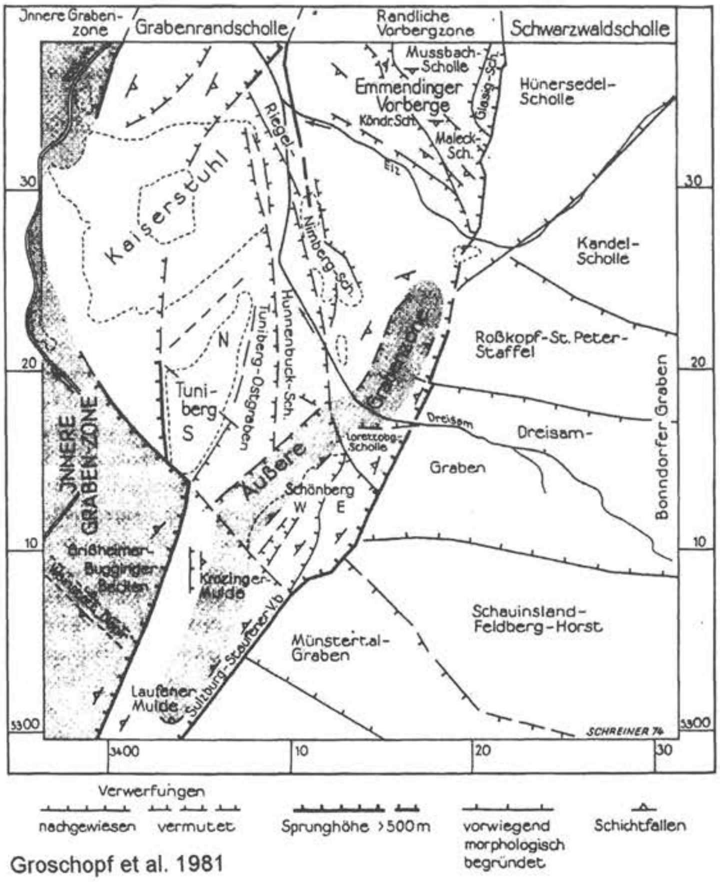


Fig. 16: Tectonic blocks of the original Mesozoic cover preserved along graben margin (Vorberg-Zone).

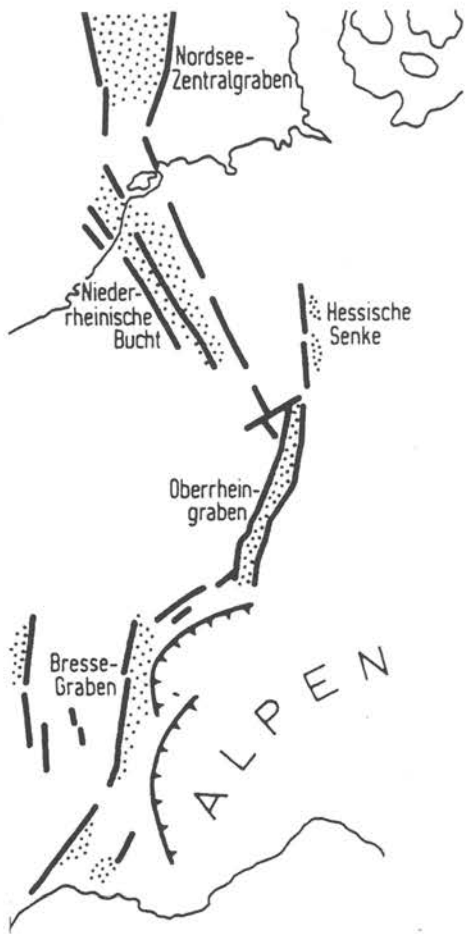


Fig. 17: Juxtaposition of extensive Rhine graben system and compressive collisional orogen of the Alps (after GEYER & GWINNER 1991).

The simultaneous extensional graben formation and compressional orogeny of the adjacent Alps pose a serious structural problem (Fig. 17).

Excursion Programme

On most days, the excursion programme comprises the combination of outcrops and local museum. The museums, mostly arranged according to modern self-explanatory didactic concepts, will add additional information in area and time on the subject of each day.

Day 1: Monday, September 15, 2003 Travel Berlin – Leipzig – Freiberg (overnight)

Freiberg - the oldest and most famous of the Saxonian mining centres – is one of the oldest mining towns in Europe (WAGENBRETH & WÄCHTLER 1985). It is situated on the northern slope of the Erzgebirge (Ore Mountains). Over centuries, the history of the town was closely connected with the development of mining and metallurgy and science. At present, the town counts around 50,000 inhabitants, is only of minor industrial significance (metallurgy, microelectronics, engineering, brewery) and hosts the smallest German technical university – the mining academy Freiberg (TU Bergakademie Freiberg).

The Erzgebirge was rich in hydrothermal ore deposits. Their discovery between the 12th and the 16th centuries led to the foundation of famous mining towns like Freiberg, Marienberg, Annaberg, Johanngeorgenstadt, Schneeberg and Joachimsthal (now Czech Republic). Due to their production of silver, lead, copper, tin and iron, these towns played an important role in the history of Saxony between the 12th and the 19th century. They made Saxony one of the wealthiest regions of Germany despite a history full of devastating wars.

Amongst the above-mentioned mining towns Freiberg played an outstanding role due to the enormous output of the mines. According to computer-estimates, the total production between 1168 and 1969 added up to 5.695 to of silver and 185.187 to of lead. Consequently, the mining activity led to the accumulation of extended empiric knowledge in mining and metallurgy and to a rapid development of the so-called montanistic sciences like mining technology, metallurgy, mineralogy, petrography, and geology of ore deposits.

Important events in the history of Freiberg are:

- 1168, discovery of silver-bearing ores and connected with native silver.
- 1170, first settlements of miners, and
- 1210/1218, the foundation of the town itself.
- In 1269, Abertus Magnus mentioned the silver from Freiberg in "De re mineralibus et rebus metallicis",
- in 1500, Ulrich Rühlein von Calw, mayor from Freiberg, published "Ein nützlich Bergbüchlein" (A useful booklet about mining),
- followed in 1556 by "De re metallica" from Georgius Agricola, mayor of the nearby town Chemnitz.
- In 1702, during the government of king Friedrich August of Saxony, a mining school was founded in Freiberg to raise the mining production with the target to secure the monetary base of Saxony.
- In 1765, the complicated economic situation in Saxony after the seven-year-war (1756-1763), accompanied by technological problems in mining and metallurgy, forced the government to establish a Mining Academy for a higher qualification of Saxonian mining officials. One of the first professors was Gottlob Abraham Werner (1749-1817),

the father of the modern mineralogy and the central figure of the neptunistic concept, lecturing about metallurgy, mineralogy, geology and palaeontology. The academy started with 19 students (at present 4,100). Amongst the first students were famous names like Leopold von Buch (1790), the creator of the elevation hypothesis, Alexander von Humboldt (1791), Carl Friedrich Mohs (1798), the poets Friedrich von Hardenberg (Novalis, 1797) and Theodor Körner (1808).

- Until World War II, the academy never had more than 350, most of the time less than 150 students. The unique educational system, combining practical instructions in montanistic professions and mining management with an academic education, attracted also foreign students. Temporarily, up to 30 or even 50 percent of the students came from European countries and from overseas. R. Samoilovitsch (1881-1940), known for the rescue of the Arctic Nobile-Expedition in 1929, was also a student of the Academy. Between 1765 and the end of the 19th century, the worldwide development of mining and metallurgy and the related natural and technical sciences was strongly influenced by the Freiberg Mining Academy.

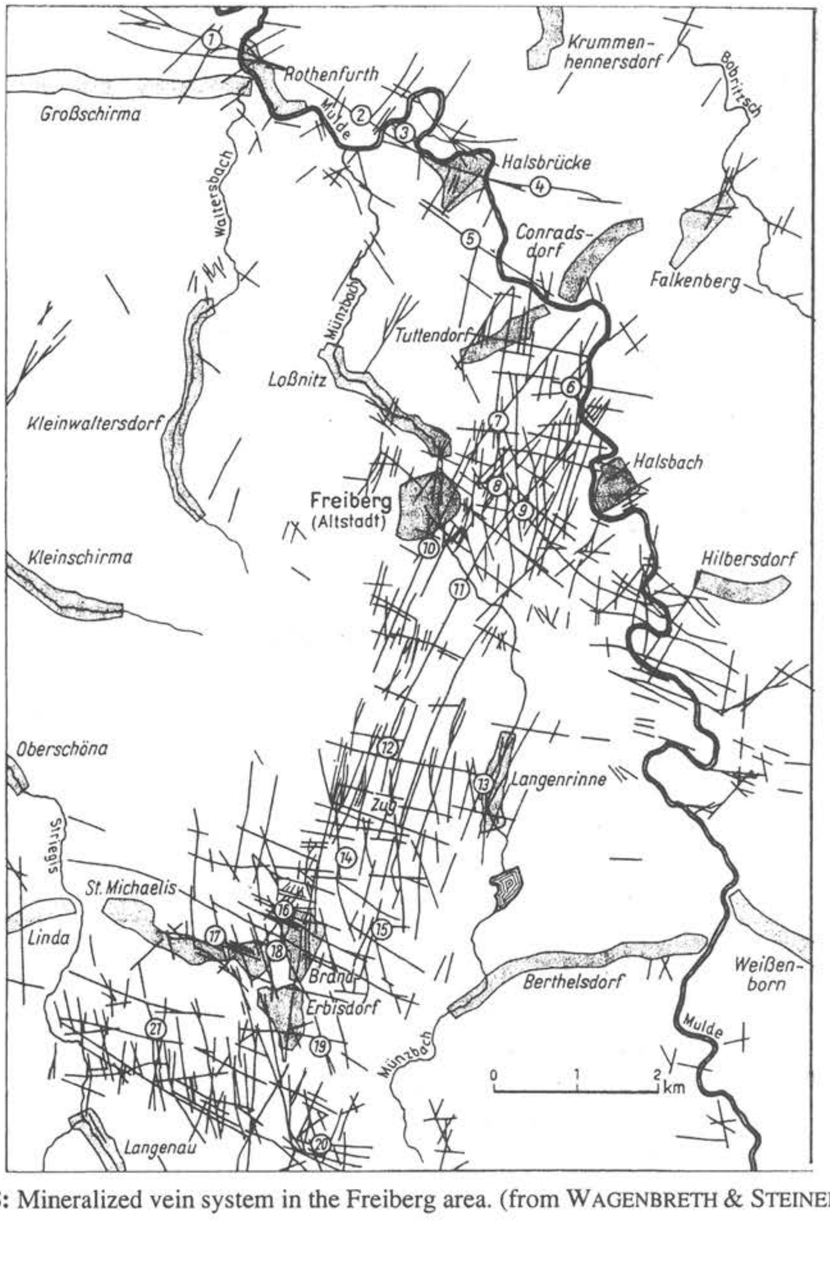


Fig. 18: Mineralized vein system in the Freiberg area. (from WAGENBRETH & STEINER 1985).

To demonstrate some highlights in the history of Freiberg, the excursion will touch three points of interest - one of the oldest mines, the mineral collection of the Freiberg Mining Academy and the historic centre of the town. More detailed informations will be given during the stay in Freiberg.

The entire Freiberg ore field (Fig. 18; ~100 km^2) shows a pattern of NNE-SSW trending (older) and ESE-WNW trending (younger) hydrothermal veins (shear systems). The older veins contain sulfides like galena, sphalerite, pyrite and arsenopyrite in connection with silver minerals (including native silver) accompanied by quartz, fluorite and carbonates. They are genetically related to a late Hercynian granitic intrusion. The younger veins contain pyrite, chalkopyrite and Bi-Co-Ni-Ag-minerals together with fluorite and baryte. The age of this system is Cretaceous to early Tertiary (100-60 m.y.). The host rocks of the veins are granodioritic gneisses and supracrustal metamorphics belonging to a Cadomian terrane, overprinted during the Hercynian orogeny.

Stop 1: Silvermine Himmelfahrt Fundgrube ("Ascension Mine"), Freiberg

The mine is situated at the eastern margin of Freiberg in the northern part of the ore field and accessible by two shafts - the "Reiche Zeche" (1584) and the "Alte Elisabeth" (1534), enabling at present access to levels 230 m below surface and to more than 14 km of galleries in which 600 years of mining history are displayed. The entire length of galleries in the Freiberg ore field comprehends 1620 km and plus 58 km of vertical and inclined shafts. The deepest level reached a depth of nearly 800 m in 1985.

The mine visited belongs the TU Bergakademie Freiberg since 1919, interrupted by the last mining period between 1937 to 1969. After extended technical reconstructions, the mine is used since 1981 for practical exercises, scientific research and as a technical museum (BAYER 1999). The excursion is a guided tour through the mine and will last 3-4 hours. The participants will be supplied with special clothes. The mine is dry and well ventilated. The natural radioactivity does not exceed the normal level.

Stop 2: Mineralogical Museum of the TU Bergakademie Freiberg

The mineral collection, displayed in the Institute of Mineralogy/Geochemistry and Ore Deposits (Werner-Building) is comparable with the university collections of Padova, Lund, Uppsala and Madrid and with museums of London, Moscow and Vienna. It belongs to the oldest ten mineralogical collections in the world.

The first pieces of the collection - minerals from the Erzgebirge – go back to 1766, provided by C.F. Gellert (1713-1795). F.A. v. Heynitz (1725-1802), F.W. v. Oppel (1720-1769) and J.W.F. v. Charpentier (1738-1805) extended the collection. A.G. Werner (1749-1617) donated his own collection demonstrating his mineralogical system (8000 pieces). The Werner-collection is displayed in the museum in original form. Among the later professors responsible for the museum, one can find C.F. Mohs (1773-1839), F.A. Breithaupt (1791-1873) who described 46 new minerals and F.L.W. Kolbeck (1860-1943), the father of the soldering-pipe analysis of minerals.

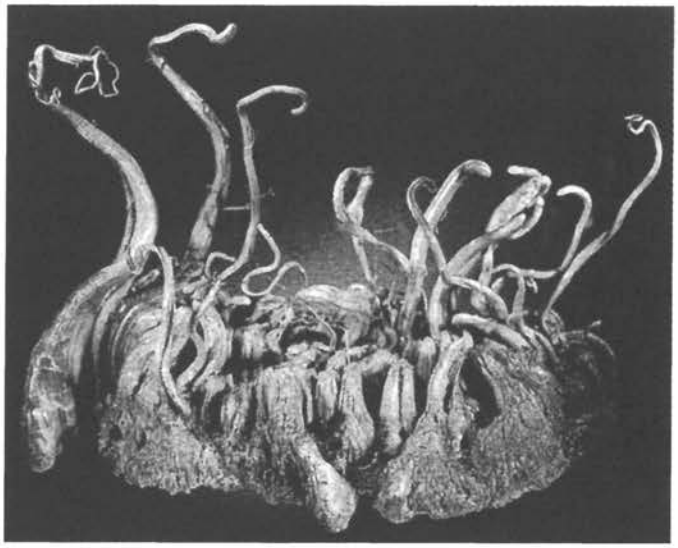
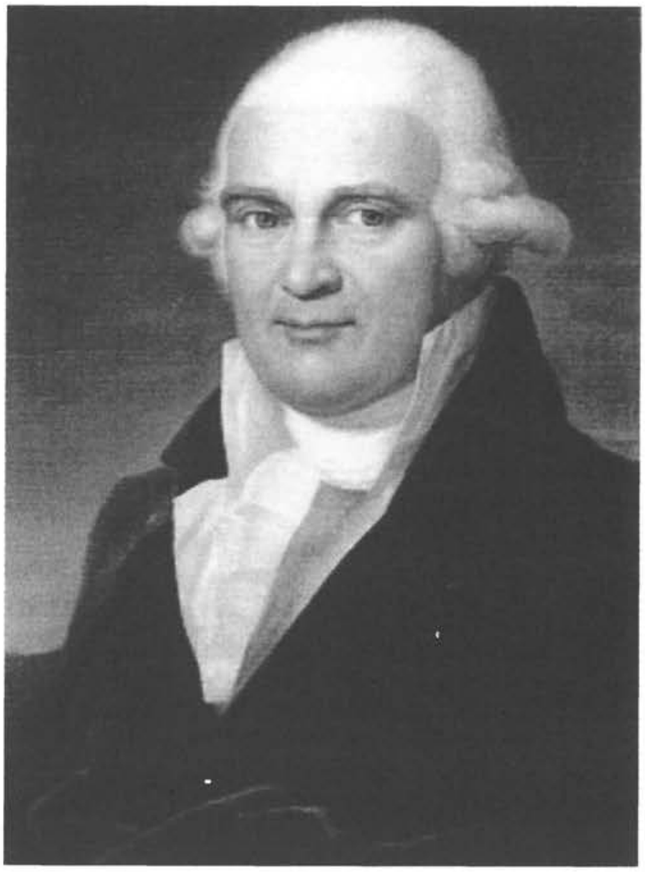


Fig. 19: Native silver from the Freiberg area (from BAUMANN et al. 1997).

The museum is in a process of constant growth. Actually, it contains several collections: the systematic collection (78,000 registered pieces), the Werner-Collection, the Collection of Ore Deposits, a collection of uranium ore deposits of the Erzgebirge (for scientific research only and in a separate building) and a petrographic collection. An extended stock in the magazines enables exchanges and the supply of interested scientists and collectors with material for scientific research (Fig. 19).

Stop 3: Historic centre of Freiberg.



A guided tour through the centre of Freiberg touches places of historic interest: fortifications of the town, the gothic cathedral (organ from the 18^{th} century), old houses with gothic and renaissance style, the first buildings of the Mining Academy, Museum of the Mining Academy, the house and the tomb of A. G. Werner (Fig. 20). An organ concerto in the cathedral at the end of the day is being organized. Special informations will be given during the tour.

Fig. 20: Abraham Gottlieb Werner was among the first professors at the mining academy of Freiberg founded in 1765. He was a proponent of the neptunist theory and the founder of the mineralogical science (from BAUMANN et al. 1997).

Day 2: Tuesday, September 16, 2003 Travel Freiberg – Chemnitz

Stop 4: Abandoned quarry at Röhrsdorf or Taura near Chemnitz

Granulite of the Granulitgebirge
The term "granulite" was originally defined and scientifically used by WEISS (1803). But the word "granulite" is older, it was invented by VON GOETHE (1785): *"Merkwürdiges Gestein aus dem Budetal der Suseburg schief gegenüber, das ich mir weder zum Granit, noch zum Porphyr zu rechnen getraue, und für welches ich den Namen Granulit, wegen der in solchen befindlichen rundlichen Quarzkörner in Vorschlag bringe"* (= "Strange rock type form the Budetal opposite the Suseburg [Harz Mountains], which I do not dare to classify either as granite or as porphyry and for which I propose the name granulite because of its content of round quartz grains"). [Comment: Goethe's "granulite" is a micrograinte and the localities in the Harz Mountains are nowadays called "Bodetal" and "Susenburg"].

The main granulite type of the Granulitgebirge is a quartzo-feldspathic granulite as exposed in the Röhrsdorf and Taura quarries. The granulite from the Röhrsdorf quarry has the following mineral composition: platy quartz + fine-grained recrystallised quartz, kyanite, garnet (-15 % pyrope), perthite, plagioclase, biotite (and chlorite) replacing garnet, round zircon. The granulite from the Taura quarry is slightly different: quartz I+II, hercynite, plagioclase, mesoperthite, biotite replacing garnet (Alm55 Pyr35 Gross10 – Alm60 Pyr37 Gross3), prehnite, round (!) zircon. Another granulitic rock type ~20 km to the NE contains kornerupine (GREW 1986, 1989) and mafic types ~5 km to the north contain orthopyroxene.

There are two textural types of quartzofeldspathic granulites: one is strongly foliated due to planar quartz disks (Röhrsdorf), the other one is rather massive (Taura). The foliated types are mylonites formed by simple and/or pure shear. Their fabric has been studied for the orientation of quartz-c-axes (e.g. BEHR 1961, HOFMANN 1975).
The metamorphic PT conditions of the granulites from the Granulitgebirge have been estimated

(1) by GREW (1986) as changing from >10 kb/-800°C to 4 kb/-800°C (anatexis) to 2-4 kb/550-600°C;
(2) by RÖTZLER (1992) as 780-850°C/11.5 kb;
(3) by Hagen et al. (1997) as Tmax = 900°C for the quartzo-feldspathic types and Tmax = 1030°C for the mafic types;
(4) by RÖTZLER et al. (1998) as 1060°C/20-25 kb ("ultra-high temperature/ultra-high-pressure granulite facies ");
(5) by O'BRIEN (2002) as 900-1000°C/>15 kb.

The granulites of the Granulitgebirge form a ~45 km long and ~18 km wide elliptic dome-like structure at the NW margin of the Saxo-Thuringian (Fig. 21), surrounded by a schist mantle of 2 km thickness. The schists are separated from the granulites by a detachment with southward-directed sense of shear (Fig. 22).

The problem of emplacement and exhumation of the Saxonian granulite complex depends to a large extent on the genetic classification and on the age of the quartzo-feldspathic granulites.

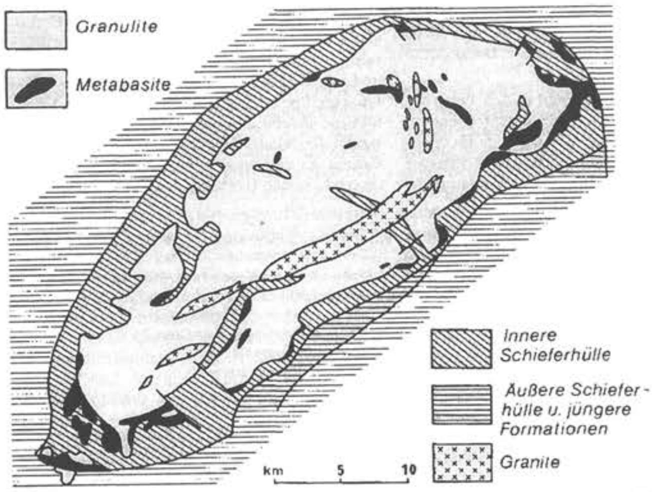


Fig. 21: Map of the Granulite Mountains near Chemnitz (after BEHR 1961). A granulite core is surrounded by an envelop of slate rocks.

In the 19th century, the granulites have first been interpreted as intrusive rocks forming a contact aureole in the schist mantle, later as strongly metamorphosed and deformed rocks. Even today the actual nature of these rocks is under discussion. Their protoliths are regarded as sedimentary arkoses or pelitic psammites (GREW 1986, 1989) or as magmatic rocks (O'BRIEN 2002), although the well-rounded zircons are an argument against the latter.

Up to 15 years ago, the granulites have been taken to be amongst the oldest rocks of Central Europe (Palaeoproterozoic?). Based on recent SHRIMP data (e.g. BAUMANN et al.1998) the timing of the Granulitgebirge might be as follows:

- Neoproterozoic to Cambrian sedimentation,
- earlier metamorphic event around ~500 Ma,
- peak metamorphism ~340 Ma,
- exhumation ~340 to ~330 Ma.

Different ideas of emplacement and exhumation of the Granulitgebirge and its granulites are illustrated in Figure 22). The following ideas have been proposed:

- diapiric implacement without or during compression,
- plastic flow due to hydrolytic weakening,
- a nappe unit (klippe?) derived from the southern Moldanubian or Saxo-Thuringian tectonic zones,

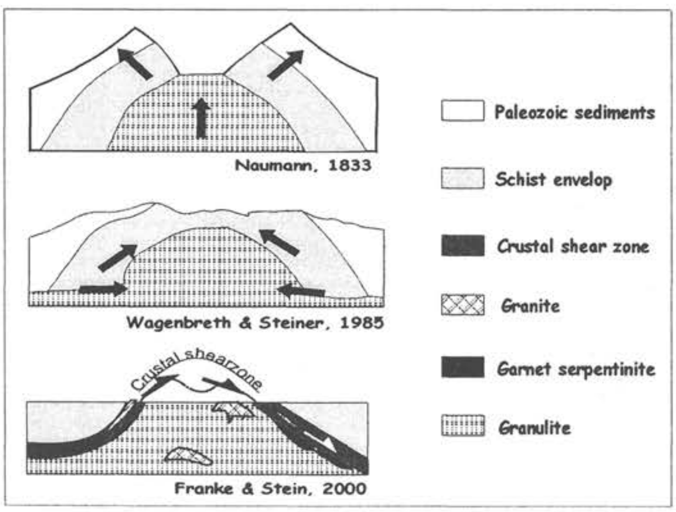


Fig. 22: Different genetic models of the Granulite Mountains from NAUMANN (1833), WAGENBRETH & STEINER (1985) and FRANKE & STEIN (2000).

- a ± liquid, hot body squeezed into a fore arc situation (e.g. FRANKE & STEIN 2000),
- a core complex / collapse structure, the main exhuming process of which is the detachment on top, comprising the entire schist mantle, and - as the emplacement took place under high temperatures - causing a kind of contact metamorphism in the schist mantle (e.g. KRÖNER 1995).

Finally, O'BRIEN (2002) stated that the granulite from the type locality is not a granulite, as its PT conditions are not of granulite facies but of HT eclogite facies!

Travel Chemnitz – Nürnberg - Eichstätt

Stop 5: Jura Museum Eichstätt

The Jura Museum is housed in the historic building of Willibald's castle, founded in 1355 and overlooking the town of Eichstätt. The Museum displays the geological development of the southern Franconian Alb. Highlights of the displays are the fossils from the famous Upper Jurassic Solnhofen limestone quarried in the entire area. Arthropods, insects, large and small fish, crocodiles, pterosaurs and one specimen of the archetype bird Archaeopteryx (Figs. 23, 24).

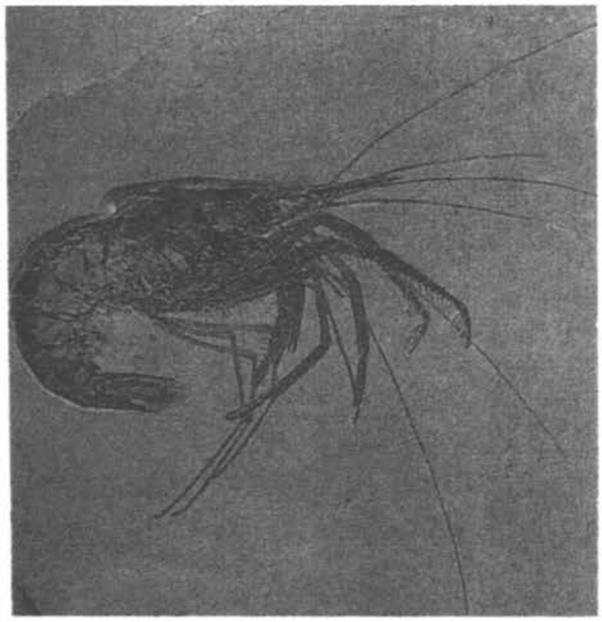


Fig. 23: Well preserved fossils from the Solnhofen area, a shrimp.

Fig. 24: Archaeopteryx from the Solnhofen limestone.

Stop 6: Quarries of the Langenaltheimer Hardt

The Romans already used Solnhofen limestone slabs as floor material for a military bath in Bavaria. In medieval time the rock was used as interior decorating material. The main boom for quarrying in the Solnhofen area occurred after the lithographic printing method had been invented in 1798 (Fig. 25). The Solnhofen limestones is unique in having all the necessary qualities needed for this method: a fine grain, a dense (pore-free) surface and a high pressure resistance. Numerous fossils were found during the quarrying activities of two centuries, among them seven specimens of archaeopteryx. Today, the limestones are quarried for the cement production.We will see exposures of the Solnhofen facies in one of the numerous and big quarries on the Langenaltheimer Hard west of Solnhofen.

Fig. 25: Solnhofen quarry in the last century (from VIOHL 1996). The limestone was mainly used for lithographic printing.

Travel Eichstätt – Nördlingen (overnight)

Day 3: Wednesday, September 17, 2003 Day trip through the Ries impact structure

Stop 7: Riescrater – Museum Nördlingen

The Museum is situated in a large 16th century barn. It is one of the most modern and instructive geology museums of Germany. Main subject of the exposures is the meteorite impact mechanism in general and the Ries event in particular. The museum forms an ideal introduction to the Ries excursion later in the same day.

Stop 8: Wallerstein

Viewpoint on Tertiary limestones (Sarmatian): From the top of the cliff the whole crater rim is visible in a 360° view. Numerous fossil finds have been recorded in past literature, but unfortunately nowadays almost all have disappeared into obscurity.

Stop 9: Small quarry north of Wengenhausen (Fig. 26)

This outcrop is about 5 km distant from the western rim of the crater. Limestones of the crater lake overlying rocks of the crystalline basement wall. The basement consists of garnet-cordierite gneiss-amphibolite and two-mica granite, and kersantite veins. The crystalline rocks show shatter cones.

Fig. 26: Limestones of the crater lake overly ejected basement rocks.

Stop 10: Quarry south of Unter-Wilflingen

Outcrop is about 2 km away from crater rim. Ejected crystalline rocks, polymict crystalline breccia containing glass and coloured breccia. In this outcrop, the polymict crystalline breccia containing glass is covered by coloured breccia (in the northern wall) and therefore not part of the normally overlying ejected suevite but a relic of the suevite formation in place in the basement rocks.

The basement in this outcrop has been ejected by at least 470 m. Note pre-Ries shear plane in eastern wall.

Stop 11: Quarry Aumühle 2.5 km NE of Oettingen (Fig. 27)

Suevite overlying coloured breccia. At the entrance to the quarry, shales and marls of the middle Jurassic are overlain by white sandstones of the upper Triassic and covered by the big mass of suevite which is exposed in the main part of the quarry. The outcrop shows the roll-slide mechanism of the suevite deposition out of a turbulent gas-cloud (CHAO 1977). Diffuse vertical tube-like features are interpreted as post depositional degassing structures. Best outcrop for hand specimens of suevite.

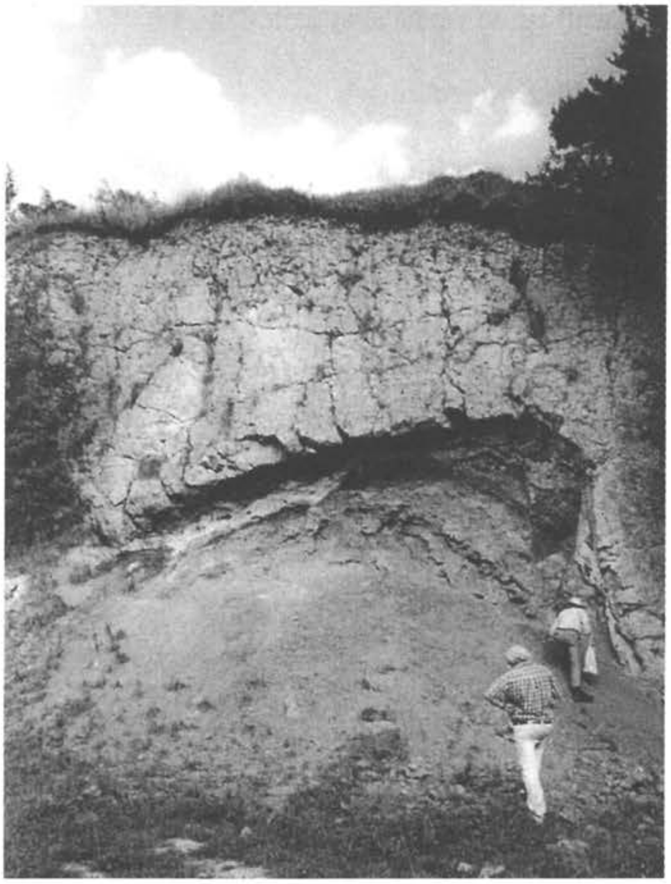


Fig. 27: Suevite overlying coloured breccia in the Oettingen quarry where Chao and Shoemaker found proof for their impact hypothesis.

Stop 12: Ronheim Quarry, 1 km east of Ronheim

This outcrop is located just outside the southeast-rim of the crater. It consists of autochthonous thick beds of Malm δ limestones grading laterally and vertically into reef structures. The upper surface of the limestone beds shows characteristic striations, caused by the forceful deposition of the overlying coloured breccia. The latter is about 20 m thick and contains almost all components of the Triassic and Jurassic sedimentary sequence.

Stop 13: Gosheim, old quarry east of Gosheim

The outcrop is located in the SW crater slope and displays well-bedded limestones of the Malm β and γ. The stratigraphy indicates that the beds are overturned. The overturned beds of this allochthonous block show a characteristic narrow joint system caused by the impact.

Return to Nördlingen, stay overnight

Day 4: Thursday, September 18, 2003

Travel Nördlingen to Dotternhausen via Neckar valley

Stop 13: Museum of Rohrbach Cement Plant in Dotternhausen

For the cement production, the Dotternhausen plant uses a combination of raw materials. A rather pure upper Jurassic limestone (Malm δ) and bituminous shale of the lower Jurassic (Lias ε) are mixed. The latter does not only provide the necessary shale component, but also part of the energy (15 %) for the process. During World War II, there had already been experiments to free the fossil energy from the oil shale, but with only minor success.

The museum has a typical section of the Lias ε on display with explanations on the sedimentation process and on the living conditions of the fossils which are mainly found as imprints on the shale surfaces. Excellently preserved examples of fish (Fig. 28), ichthyosaurs and crocodiles are exposed as well as belemnites, typical ammonoids as index fossils and complete specimens of crinoids (Seirocrinus) attached to driftwood.

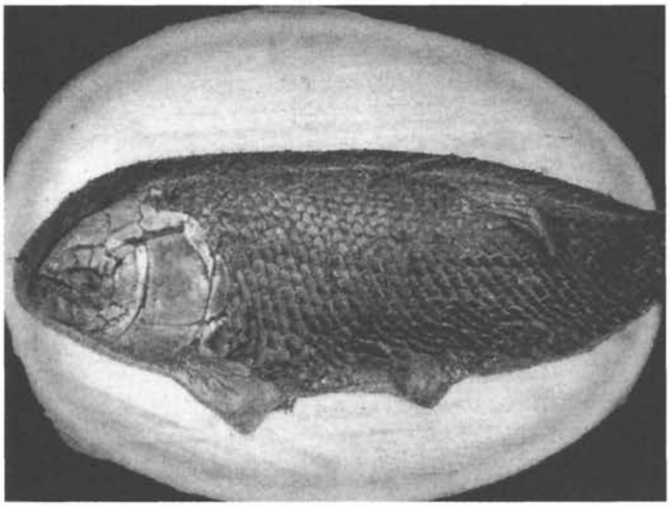


Fig. 28: Well-preserved fish from the lower Jurassic oil shale sequence of Dotternhausen, exposed in the local museum (from JANSEN et al. 2002).

The rocks of the Posidonia shales consist of fine-grained mixed siliciclastic and carbonate components. Most common are clay and silt particles with a certain amount of derived from the hard parts of calcareous phytoplancton (Coccolithophorids). The depositional conditions in the Posidonia shale must have been very calm for most of the time resulting in a micro-laminated fabric of the sediment. The periodic variation in the proportion of clay and carbonate resulted in a distinct alternation of white and dark layers. Microscopic views of thin and polished sections commonly indicate a deposition of the calcareous nannoplankton as tiny pellets.

Compared to the micro-lamination, bioturbation occurs only sparsely. Chondrites and less common Thalassinoides burrows occasionally occur within the section and indicate that bioturbation in general took place only during short time intervals.

A very characteristic feature of the Posidonia Shales is the remarkable quantity (up to 20 %) of particulate organic matter, which derived mainly from organic-walled phytoplankton protists (particularly prasinophytes and dinoflagellates). The type and amount of organic

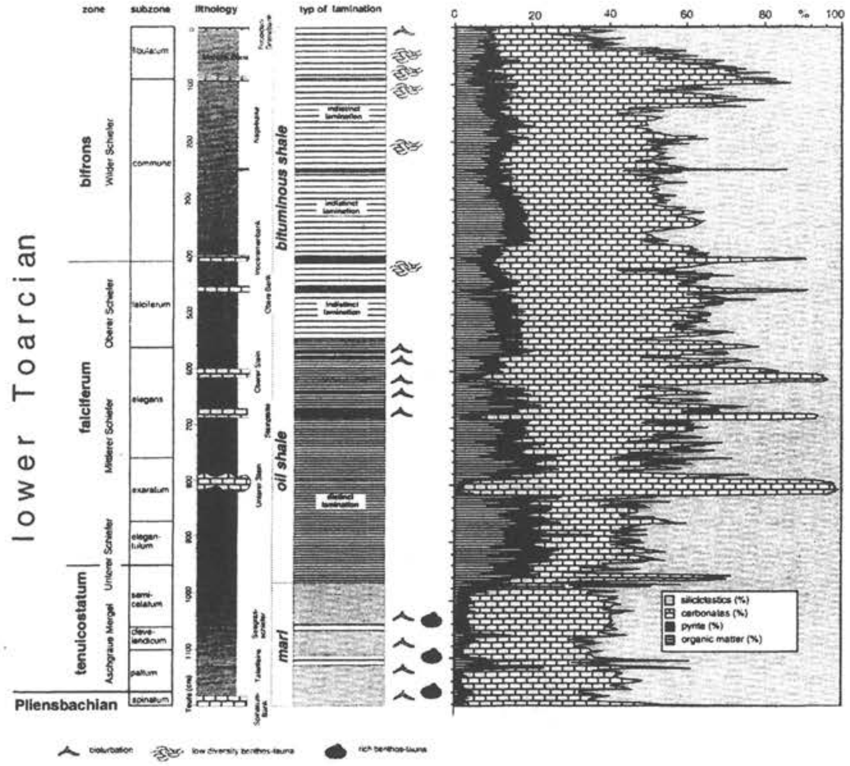


Fig. 29: Stratigraphic interval and rock features of the lower Toarcian rocks of Dotternhausen.

matter has the potential for oil generation, which however has not become mature, and is classified as type ll-kerogen in terms of organic geochemists.

Microbial activity within the substrate and the bottom water took place. Among others heterotrophic anaerobic bacteria (sulphate reducers) used the accumulated organic matter as nutrients and sulphates from seawater as a source of oxygen for respiration and produced toxic H_2S, which was precipitated as very fine dispersed sulphides (mainly pyrite, Fig. 29).

During early diagenesis, precipitation of calcareous concretions and concretionary layers (the so-called "Laibsteine" = loaves of bread) result from the high alkalinity caused by sulphate reduction.

The benthic macro fauna consists of seven associations and was used, in combination with geochemical data, to reconstruct the fluctuations in oxygen availability with time. In general anoxic conditions prevailed during the deposition of the Toarcian black shales. Anoxia, however, were punctuated by various short periods (weeks to years) with oxygenated bottom water conditions.

Stop 14: Dotternhausen Quarry

The Lias ε oil shales are exposed in the quarry west of the plant. The shales used also to be called Posidonia-shales after an earlier name for the clam Buchia found in the sediments. The shales contain a fauna of ammonoids, fish and crinoids, which lived nektonic in the water above and were then preserved by the anoxid bottom conditions. A few limestone beds indicate short intervals with better oxygen supply. These frequently contain well-preserved examples of fossil fish.

Travel Dotternhausen - Titisee

Stop 15: Quarry near Lake Tititsee, Schwarzwald (Black Forest)

The outcrop is situated within the Cadomian Central Schwarzwald Gneiss Complex (CSGC) of the Moldanubian tectonic zone of the Variscan basement. Exposed is a top-to-the-south-directed shear zone of Variscan age (Fig. 30) affecting rocks originally metamorphosed during the Cadomian orogeny. Ductile thrusting is supposed to be related to subduction of an ocean immediately to the south (see section in Fig. 31, Loeschke et al. 1999). This ocean can be correlated with the "Central Massif" ocean further to the west (Fig. 4, ZULAUF unpublished).

The migmatitic paragneiss from the quarry has the following composition: quartz, feldspar, biotite, fibrolite, cordierite/pinite, ± white mica, round zircon. The texture is partly mylonitic.

Fig. 30: S-directed reverse shear planes in gneiss, outcrop at Stop 15, Titisee (Photo Thomas Agricola).

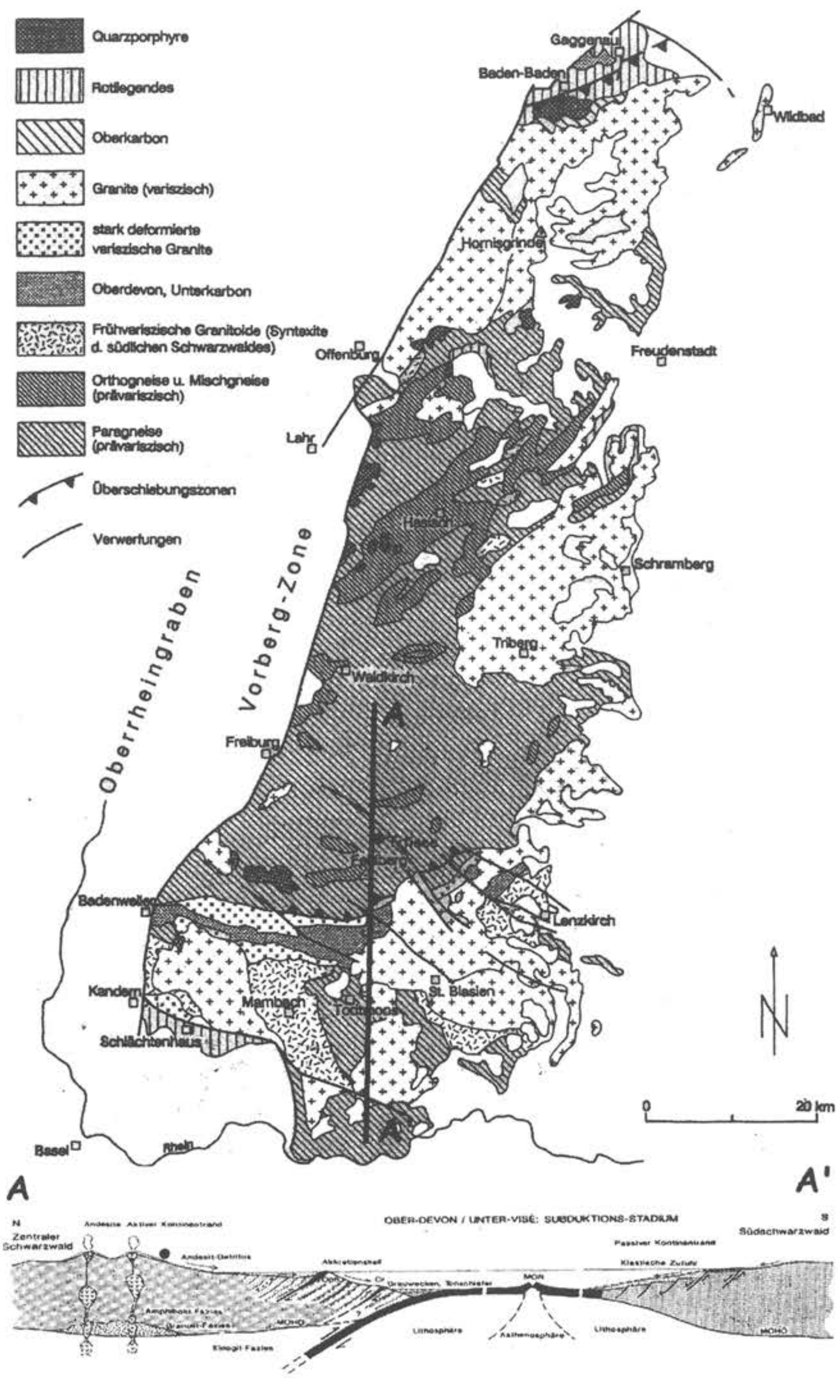


Fig. 31: Geological map of the Black Forest (after WALTER 1995) and genetic model (LOESCHKE et al. 1998). A-A' Line of model section. Black dot: Approximate location of excursion Stop 15 at lake Titisee.

Travel Titisee - Freiburg in the Rhine Valley.

Stop 16: Schönberg south of Freiburg

The excursion stop is a viewpoint in the Vorberg Zone adjacent to the eastern master fault of the Rhinegraben (Fig. 32, behind Kaiserstuhl). In good weather conditions we can see the rift shoulder of the Schwarzwald (Black Forest), the Kaiserstuhl volcano, the small horst of the Tuniberg and the surrounding hills of Mesozoic rocks of the Schönberg block. The master fault (arrow on Fig. 33) of the Rhinegraben was exposed during construction of a railway tunnel in the Loretto Mountain in Freiburg (CLOOS 1947). It formed a 15-m-wide zone of intensely sheared gneiss dipping 55° to the WNW.

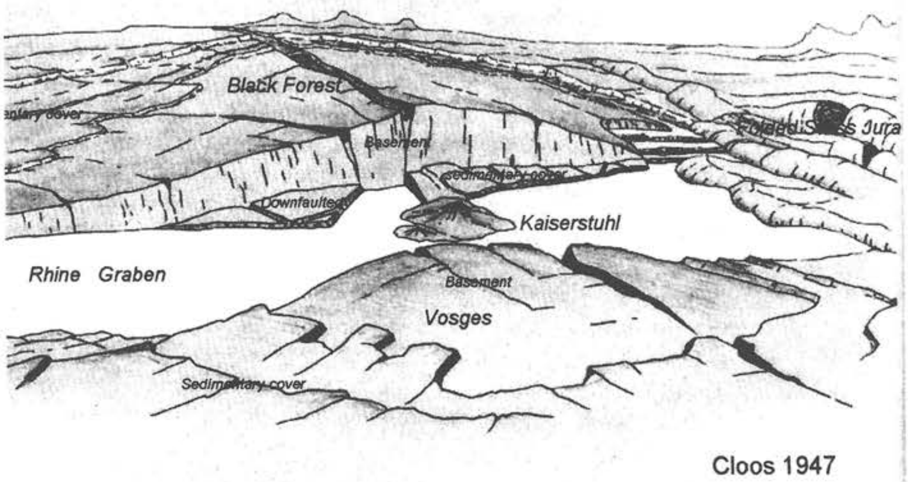


Fig. 32: Block model of the Rhinegraben near Freiburg viewed from the west (from CLOOS 1947). The rift shoulders of Black Forest and the Vosges both contain a core of basement rocks. The Kaiserstuhl is a rift-related Miocene volcano.

The Schönberg block contains a W-dipping rather complete sequence of the pre-rift Mesozoic cover, spanning the period from lower Triassic to middle Jurassic (Fig. 33). This sequence is capped by a Tertiary conglomerate on the top of the Schönberg in a small transverse graben.

We will see the Bajocien (bj3) Rogenstein (oolitic limestone) in small exposures. This limestone dips under the Tertiary and Quaternary cover of the Rhine valley plain, but reappears in the small Tuniberg horst (Stop 18). Tertiary conglomerates are found near the church of Ebringen and a small tuffitic feeder piper is exposed near the old chapel.

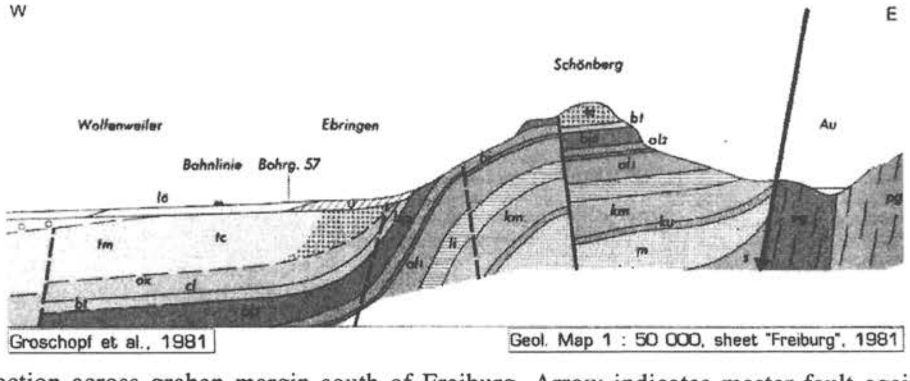


Fig. 33: Section across graben margin south of Freiburg. Arrow indicates master fault against Black Forest basement. Down faulted block (Vorberg) of the Schönberg contains sedimentary sequence from the Triassic through to the Middle Jurassic, covered by Tertiary conglomerate (from GROSCHOPF et al. 1981). Legend: og orthogneiss; pg paragneiss, s Buntsandstein (lower Triassic); m Muschelkalk (middle Triassic; ku and km Keuper (upper Triassic); li Lias (lower Jurassic), al1 and al2 Aalenian; bj Bajocian; bj3 Hauptrogenstein (middle Jurassic); bt Bathonian; cl Callovian; ox Oxfordian; tm Tertiary marls; tc Tertiary conglomerates.

Travel to Breisach on the Rhine River (overnight)

The city of Breisach, our destination for this day, was founded around 1185 by the Staufer King Heinrich IV on a rocky promontory overlooking an important ford across the Rhine river. This crossing had already been used in Roman times. The three main components of the foundation are the castle in the north, the central city and the cathedral in the south. The construction of the cathedral of the Breisach Münster was begun around 1200 in Romanesque style. The choir and the wings were then added in gothic style. The western wing houses the wall painting "The last judgement" from 1488, created by the famous painter Martin Schongauer who is represented with other works in Colmar across the Rhine River. The wood carving of the altar in the choir, made between 1523 and 1526, is the masterwork of an unknown artist "H.L.".

Day 5: Friday, September 19, 2003 Day trip through the Kaiserstuhl (Fig. 34).

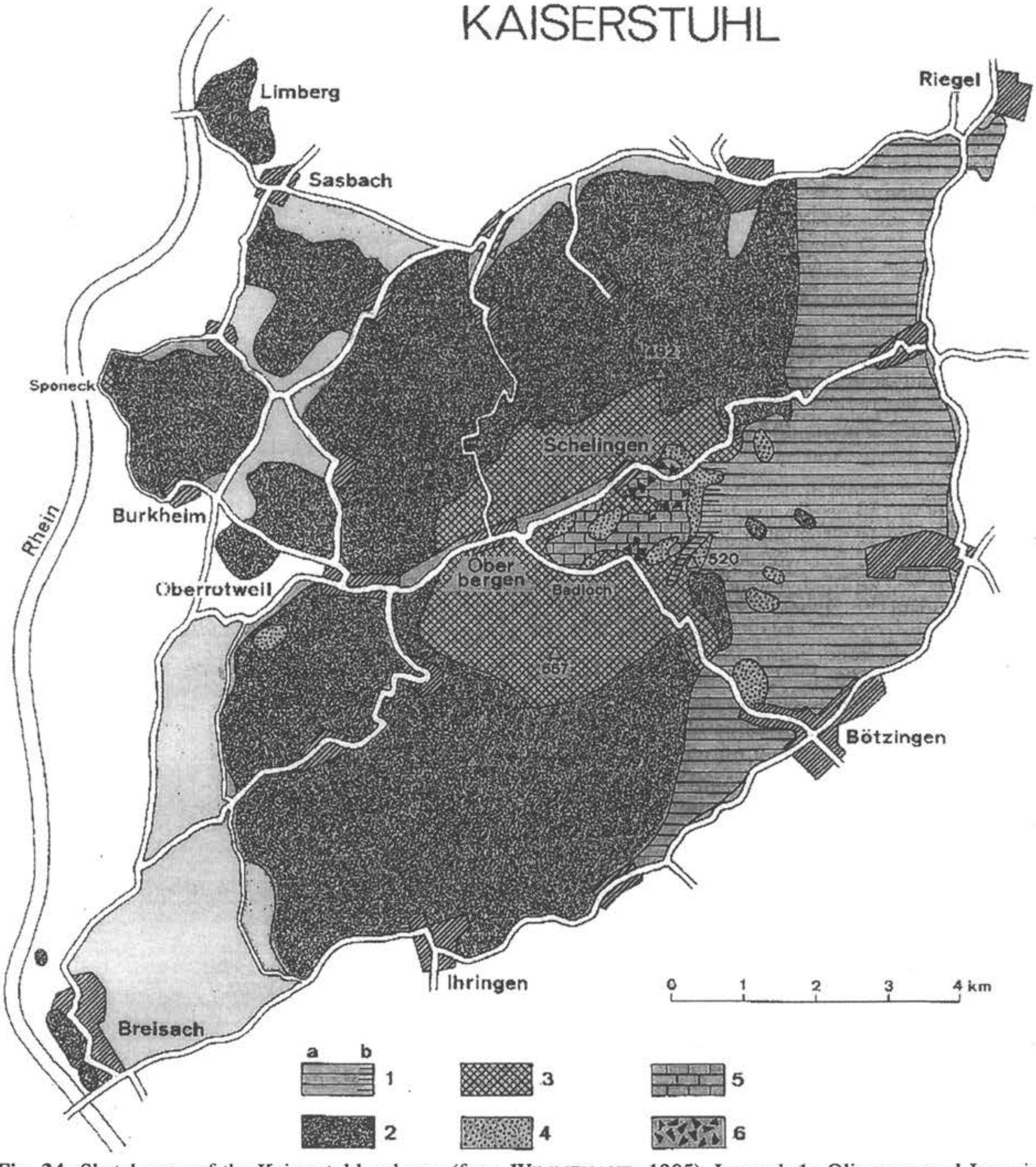


Fig. 34: Sketch map of the Kaiserstuhl volcano (from WIMMENAUEr 1985). Legend: 1a Oligocene and Jurassic sediments; 1b Oligocene, contact-metamorphic; 2 lavas and pyroclastites; 3 intrusive alkaline rocks of the centre; 4 phonolite plugs, 5 carbonatites; 6 sub-volcanic breccias.

Stop 17: Breisach, Münsterberg

On the southern slope of the rock foundation of the Breisach Cathedral, a tuff and an overlying breccia are exposed. Both rock types contain tephritic and olivine-bearing tephrite components. In the breccia at the top of the outcrop, these components form meter-sized blocks, partly dense and partly vesicular.

Stop 18: Tuniberg near Merdingen (Fig. 35)

The Tuniberg, far out in the gravel plains of the Rhine valley, is a horst-like relic of the pre-rift Mesozoic cover rocks. The exposed mid-Jurassic limestones quarried near Merdingen expose some of the fault structures associated with the rifting process (Fig. 36). The limestones and their cover of glacial loess form the soil for some good red wines

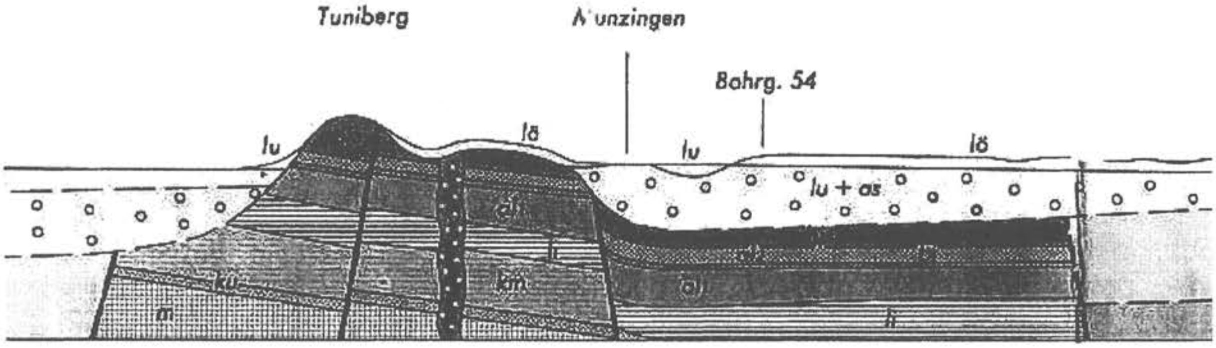


Fig. 35: E-W section across Tuniberg south of the Kaiserstuhl. The mountain consists of Mid-Jurassic limestones and forms the highest part of a horst-like relic of the pre-rift Mesozoic sedimentary cover. Nach GROSCHOPF et al. 1981).

Fig. 36: Quarry in middle Jurassic limestones of the Tuniberg displaying a number of normal faults.

Stop 19: Kirchberg quarry in Niederrotweil

This large quarry (Fig. 37) was worked in a massive phonolite stock (430 by 200 m). It has an intrusive contact against tephritic lavas and is itself traversed by a monchiquite dike. The phonolite shows a pronounced N-S striking vertical joint system and E-W striking steeply N-dipping slickensides.

Petrographically, the rock contains phenocrysts of feldspar, melanite, aegirine-augite and hauyn-sodalite. The latter are weathered brick red in the Kirchberg quarry. Hydrothermal alteration is common in all Kaiserstuhl phonolite stocks.

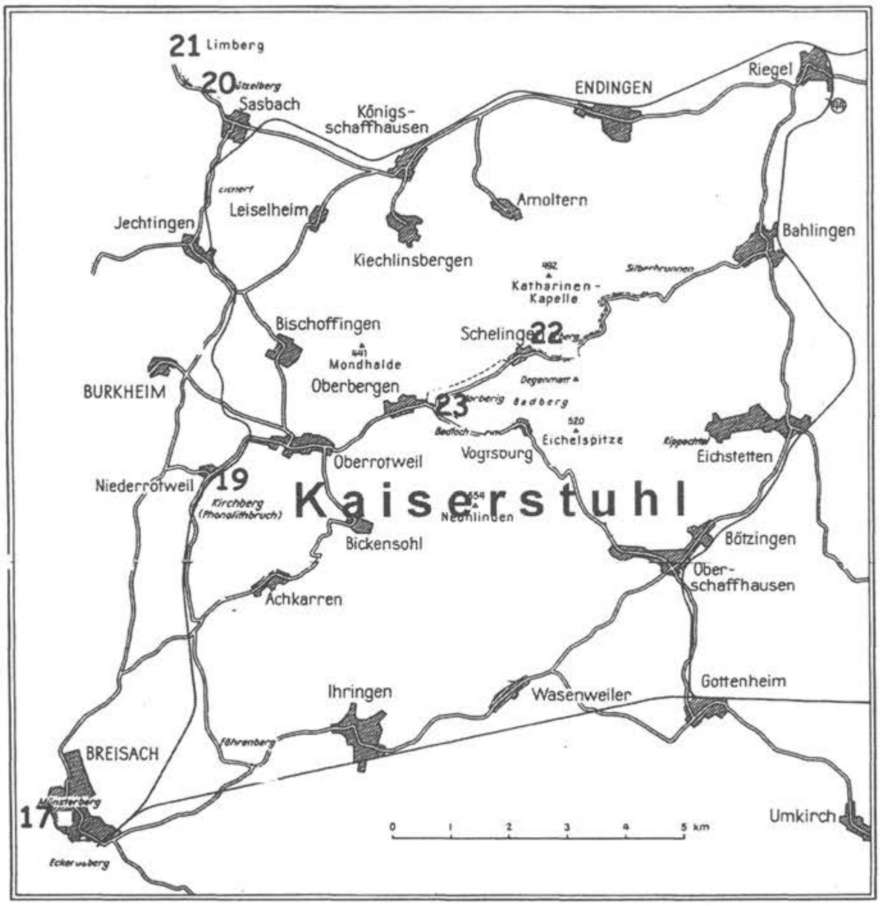


Fig. 37: Sketch map of Kaiserstuhl showing the location of outcrops visited.

Stop 20: Road cut between Sasbach and Limburg

400 m south of Sasbach (Fig. 37), the road to Limburg (Fig. 38, arrow)exposes olivine-nephelinites containing many (weathered) olivine-inclusions. Many other outcrops on the Limberg (7 old quarries) are overgrown in the meantime and mostly inaccessible. The Limberg is the main locality in the Kaiserstuhl, where tephritic lavas are interbedded with Miocene sediments.

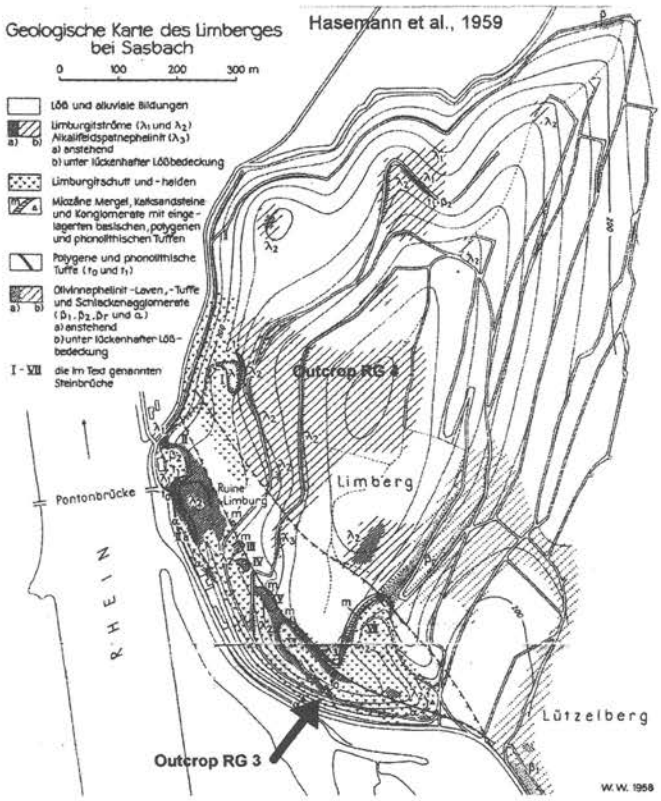


Fig. 38: Topographic map of outcrops on Limberg near Sasbach. A fast-growing vegetation has formed thorny thickets over several of the former outcrops. We are therefore forced to restrict our visit to the road cut near the Rhine River and to quarry No. 1 in the north.

Stop 21: Quarry No. I north of Limburg

In this old quarry (Fig. 39), two Limburgite lavas are separated by a small yellowish tuff band. In fresh hand specimen the lower Limburgite is a black rock. The compact lava shows columnar jointing. Phenocrysts of black augite and altered olivine as well as gas bubbles filled with secondary minerals can be seen with the naked eye. On the weathered surface of the lava flow the groundmass is altered and the crystal faces of the augite phenocrysts are exposed.

Fresh specimens of the upper Limburgite lava are of a dark reddish-brown colour. This lava is vesicular and contains phenocrysts of augite and olivine. The flow shows a blocky texture.
The tuff contains components of limburgite, olivine-nephelinite and phonolite as well as limestone concretions and wood.

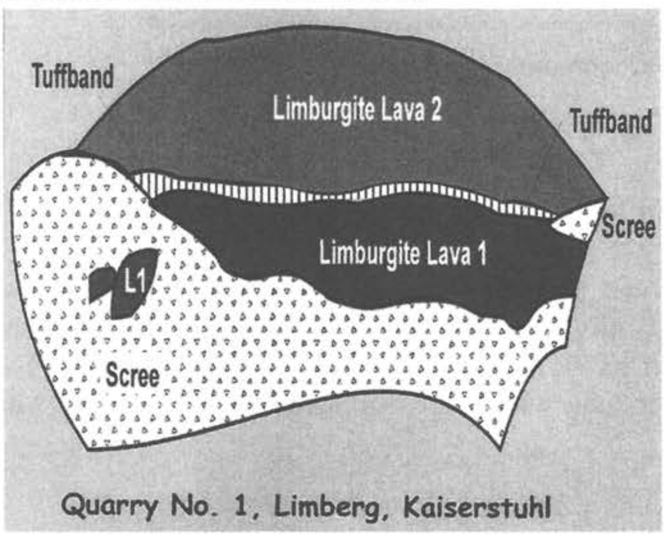


Fig. 39: Outcrop sketch of quarry no. 1 north of Limburg; 200 m across. A tuff band containing components of limburgite, olivine-nephelinite and phonolite as well as limestone concretions and wood separates two lava flows of Limburgite.

Stop 22: Orberg east of Schelingen

The outcrop (Fig. 40) exposes a carbonatite belonging to the central area of the Kaiserstuhl, which is characterized by the occurrence of strongly alkaline intrusive rocks. The main occurrences of carbonatite are the Badberg to the south and the Orberg to the east of Schelingen. The carbonatites are supposed to be younger then the essexite dikes and the phonolite stocks of the area. They contain small quantities of minerals of Niobium and rare earth elements. Uranium-bearing coppice and dysanalyte have been reported.

In the outcrop the carbonatites are inhomogeneous medium to coarse-grained rocks in the form of layers and schlieren (NW-wall). The fresh carbonatite in the outcrop is of a light bluish-grey colour; the weathered varieties become iron stained and porous. The size of the carbonate crystals may be rather large, 30 cm long crystals have been reported from this outcrop. Dark components are magnoferrite (octahedra up to 3 mm), forsterite (turbid grey-yellow grains) and koppite (red-brown octahedra up to 2 mm). The Niobium content of the koppite is 56 %; the content of the whole rock is less than 0.5 % to a maximum of 1.3 %.

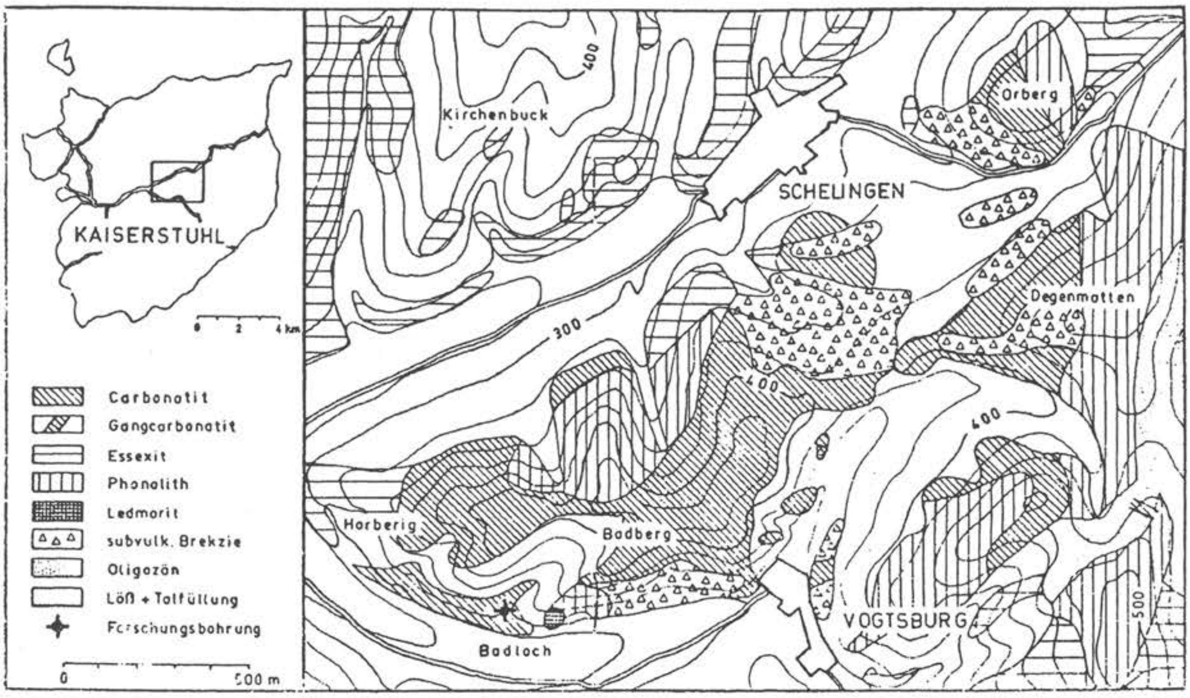


Fig. 40: Geological sketch map of carbonatites in the central Kaiserstuhl near Schelingen (after WIMMENAUER 1966).

Stop 23: Horberig north of Oberbergen (Fig. 41)

The outcrop at the western spur of Badberg (Fig. 37) shows the greatest variety of intrusive rock types, mainly in the form of dykes. The rocks comprise essexite, theralite, monchiquite, phonolite, tinguaite, mondhaldeite, shonkinite. The outcrop has also been used to work out a relative sequence of the intrusive events.

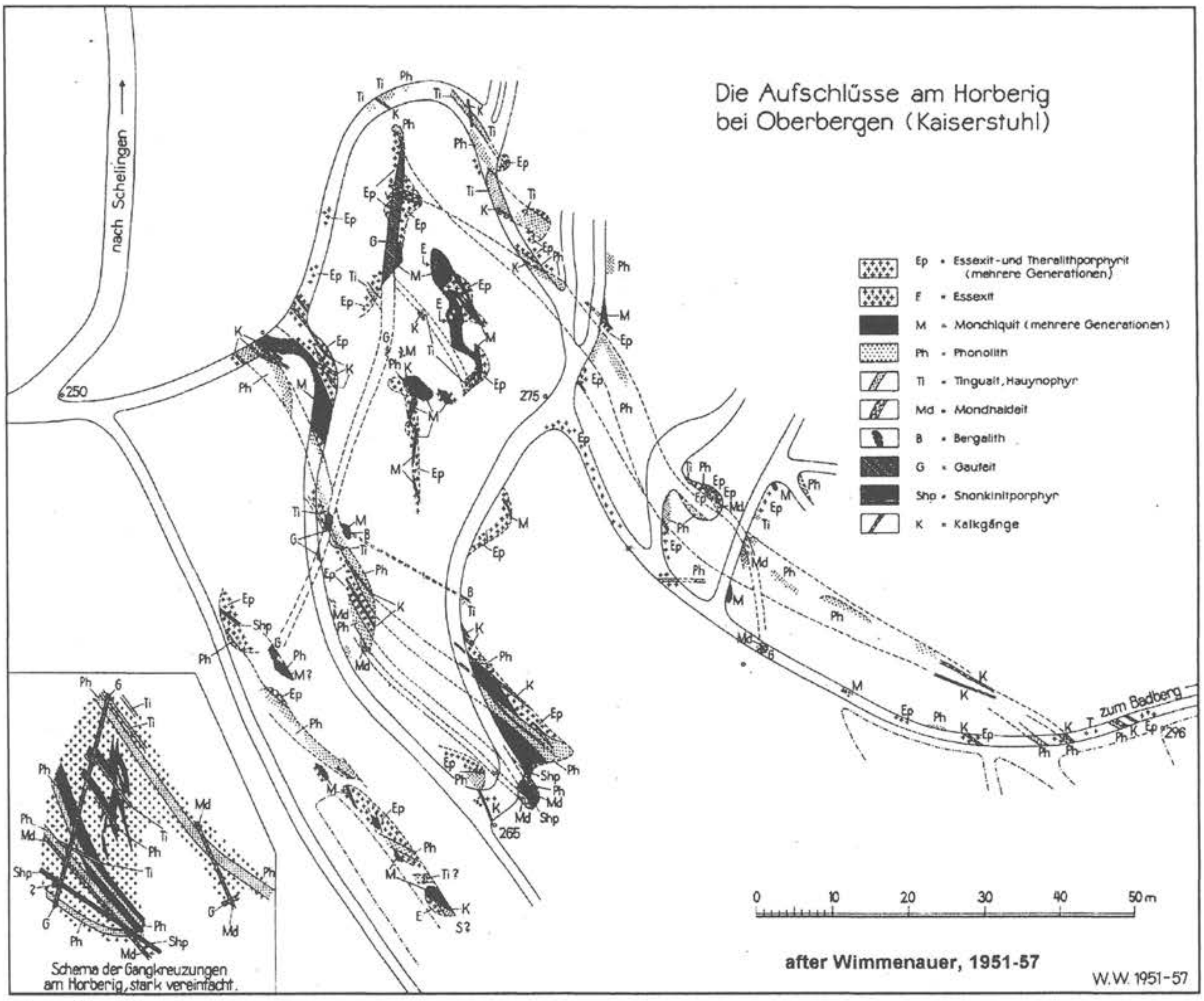


Fig. 41: Sketch map of intrusive alkaline rock types on Horberig Mountain, central Kaiserstuhl (after HASEMANN et al. 1959).

Return to Breisach (overnight)

Day 6: Saturday, September 20, 2003

Travel from Breisach north through the Rhinegraben to Darmstadt

The UNESCO World Heritage site of the Messel pit south of Frankfurt.

From 1875 to 1885 a kerogene-rich "oil shale" was quarried as brown coal (lignite), from 1885 to 1971 for the production of different hydrocarbon derivatives. A total of about 25 million m^3 of "oil shale" was quarried. During these mining operations a unique fossil collection was recovered in an extraordinary state of preservation. When the mining operations were closed down, the deep pit seemed ideal as a central waste disposal site for the State of Hessen. However, these plans were dropped after local people and scientists all around the world had protested. The pit was bought by the State of Hessen in 1991 and designated as a protected palaeontology site. In 1995, the Messel pit was included in the

UNESCO World Heritage list of sites. Since 1992 the research institute and nature museum Senckenberg in Frankfurt is responsible for the management of the site. This is done by the newly founded Messel Research Department of Senckenberg. Seismic section and drill core are explained under Stop 26.

Stop 24: Rhinegraben from Black Forest to Odenwald

A large part of the scientific knowledge of the Rhinegraben is the result of the (in Germany unsuccessful) search for oil, mainly by seismic investigations and drilling. The mentioned estimates of sediment type and thickness (Fig. 15) are largely based on these results. The seismic results, together with surface investigations, have also been used to work out the structural pattern. An excellent example is the map of the area around Karlsruhe which clearly shows two sets of faults, one set parallel to the graben margins, the other one at a high angle.

Stop 25: Messel Pit

The Messel pit is situated about 20 km southeast of Frankfurt/Main and 8 km northeast of Darmstadt. Geologically it is located on the Sprendlinger Horst, a northward continuing ridge of the Odenwald. To the west, the Sprendlinger Horst is bordered by the upper Rhine rift valley, downthrown by 1500 m in Tertiary times and to the east by another Tertiary basin.

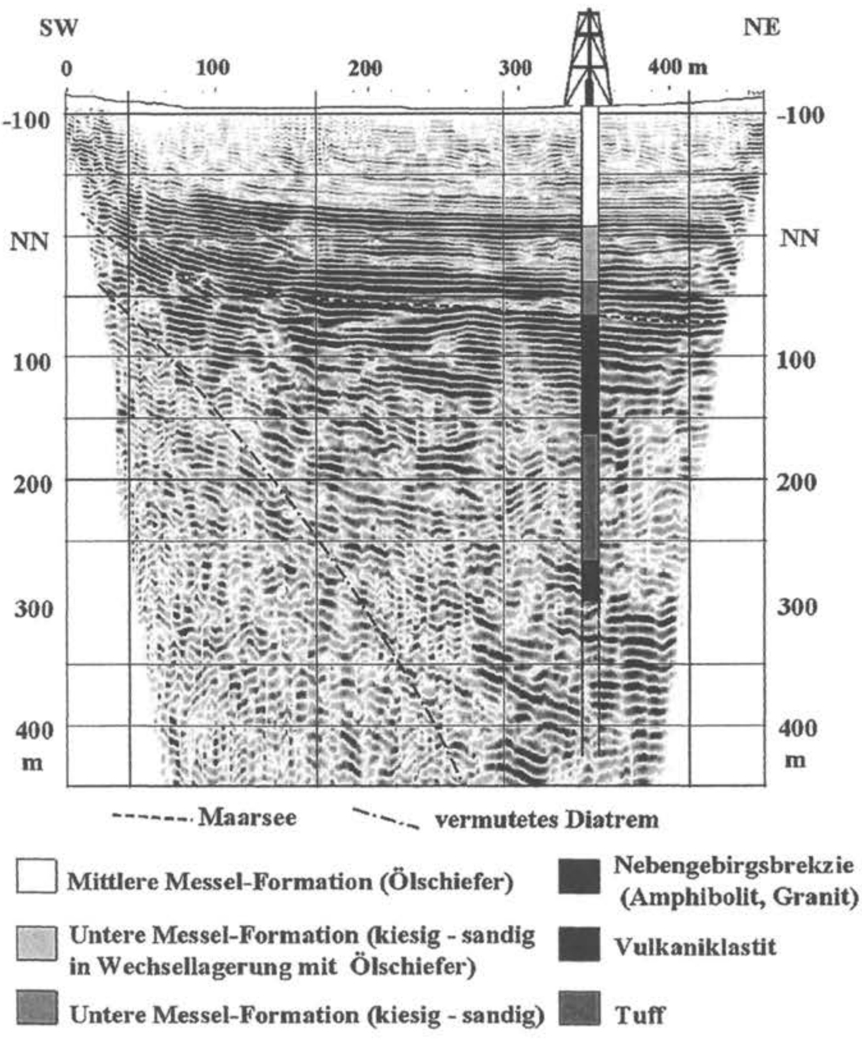


Fig. 42: Seismic section of the Messel pit (from BUNESS et al. 2000), a 49 Ma old Mid-Eocene fossil site, UNESCO World Heritage.

The core of the horst consists of Odenwald crystalline rocks overlain by Permian sediments ("Rotliegendes"). Cretaceous to Late Tertiary volcanic rocks penetrate these units. The entire structure is cut by SW-NE trending fractures.

The mining operations left us with a pit which is which is about 1 km long, 700 m wide and at the deepest point about 70 m deep.

The visible part of the Messel-Formation forms a very finely laminated algae-laminite. The clays contain about 40 % water, 35 % clay minerals (mainly smectite) and 25 % organic substances (kerogen). The majority of the kerogen in the clay (about 80 %) originates from algae, in particular from the cell walls of a green alga (*Tetraedron minimum*). The laminae of the clay are in average one tenth of a mm thick, with a characteristic colour banding with lighter (mostly orange) laminae and darker (mostly brownish) laminae. The latter consist predominantly of clay particles and the lighter laminae of the organic relics of green algae. This alternation may indicate a seasonal algae growth in the Messel Lake, which caused this light/dark sediment layering. If one couplet of these laminae represents the sedimentation of one year, 1 cm of sediment would represent approximately 100 years. Since the finely laminated upper part of the Messel-Formation is about 200 m thick, this sediment package could represent a duration of sedimentation of 1 to 1.5 Ma.

Episodically intercalated several-mm-thick, yellowish layers consist of sideritic material. These layers originated perhaps from the activity of bacterial mats covering the anoxygenated lake bottom. A double layered about 2 cm thick mica-horizon points to the activity of nearby volcanoes.

The Messel freshwater lake had a relatively small surface, steep lake banks and walls, and was relatively deep, around 70-150 m. This situation caused two distinct water bodies, an oxygenated upper water body and a deoxygenated deeper water body. Water movement was obviously so slight, that there was no intermixing of these two water bodies. Consequently, conditions on the bottom of this lake were anaerobic. Due to the lack of oxygen, animal carcasses or plant remains deposited on the lake bottom could not be scavenged by other animals or decomposed by microorganisms. The preservation of the fine lamination without any bioturbation is also due to lack of bottom dwellers and bottom currents. Most of the Messel animal carcasses are preserved complete and the skeletons are joined together (even in frogs, bats, snakes and birds). The fine and unoxygenated mud preserved also skin, hair, fur, feathers and soft parts (e.g. tadpoles) in detail, as well as the stomach content of nearly all the vertebrates.

Stop 26: The Messel drill core

Extensive geophysical surveys (Fig. 42) and a deep scientific well (Fig. 43) drilled at the centre of the pit and finished in 2001, provided new data for the interpretation of the site. The drill hole reached a depth of 433 meters and the down hole section is made up by various lake sediments (Messel-Formation) and volcanogenic pyroclastic rocks. This sediment sequence indicates, that a phreatomagmatic explosion generated the crater. A maar-like lake filled the depression afterwards. Other similar diatremes have recently been reported from surrounding areas.

	Messel-Formation:
0 to 100 m	fine to very fine layered clays ("oil shale")
100 to 110 m	rather sandy clays
110 to 140 m	fine to very fine layered clays ("oil shale")
140 to 170 m	tuffitic sands and gravels
170 to 180 m	volcanic breccia
180 to 240 m	tuffitic sands with intercalations of gravels and clay
	Pyroclastics:
240 to 375 m	pyroclastic lapilli-tuffs
	Diatrem-filling
375 to 433 m	layered breccias with amphibolite, granite, granodiorite and sandstone

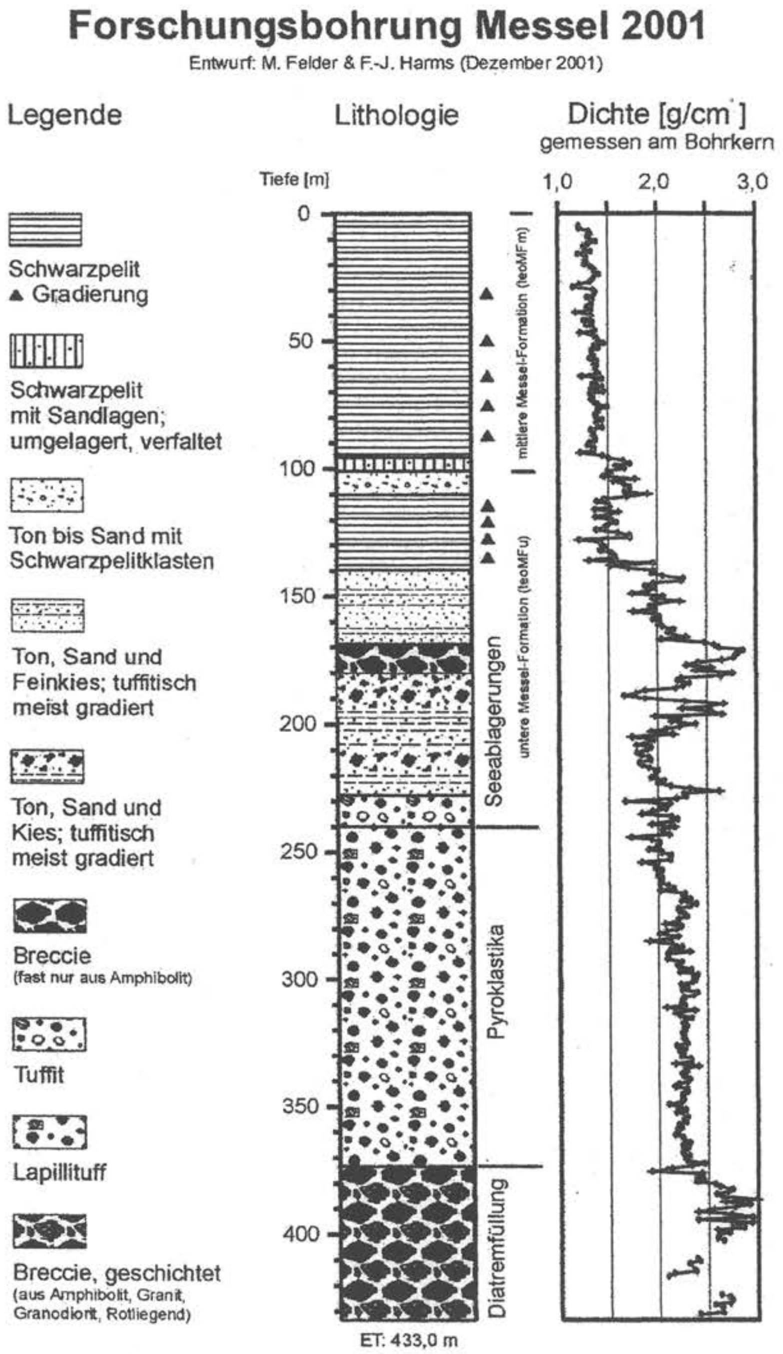


Fig. 43: 433 m long drill core recovered from the Messel pit in 2001. The oils shales are underlain by volcanic breccia and pyroclastics, which provides strong arguments for a diatreme explosion mechanism for the formation of the Messel hole. The drill core will be on display for the excursion.

Stop 27: Museum-Senckenberg / Frankfurt city centre

In 1817 Goethe initiated the foundation of the Senckenberg Society in Frankfurt aimed at the study of nature. The society immediately started with large collections of materials and soon founded a nature museum. The collections today comprise 25 million objects and the research institution, which in 1914 was among the founders of Frankfurt University, has now research stations in Wilhelmshaven, Hamburg, Weimar, Biebergemünd and Messel. Famous among the Senckenberg fossils from Messel is the large collection of fossil bats, the earliest record of this animal community.

The Messel mammal fauna is of special interest because here we still find some of the more archaic types from the Mesozoic (e.g. original marsupials and insectivores) and a high diversity of faunal elements from the basic radiation of modern mammals of today (e.g. rodents, bats, prosimians, primitive carnivores, ancient even-toed to odd toed ungulates like the "Messel horses" Propalaeotherium. There is also a highly diverse and modern snake fauna and a flora with about 60 families of flowering plants only.

The continental Eocene is subdivided in several Mammal biozones and so-called Mammal ages; both zonations are based on the evolution of mammals. Only the quarried upper part of the Messel-Formation, which yielded the famous Messel fauna and flora can be biostratigraphically correlated by its mammal fauna to Mammal Biozone MP 11, the oldest biozone of the so-called Geiseltalian Mammal Age. By radiometric ages and marine intercalations with continental mammal bearing sediments elsewhere (e.g. North America) this mammal biozone and age can be correlated with the lowermost part of the Lutetian, respectively the lowermost Middle Eocene of the existing chronostratigraphic scale. By this correlation an age of 48 to 49 million years can be derived.

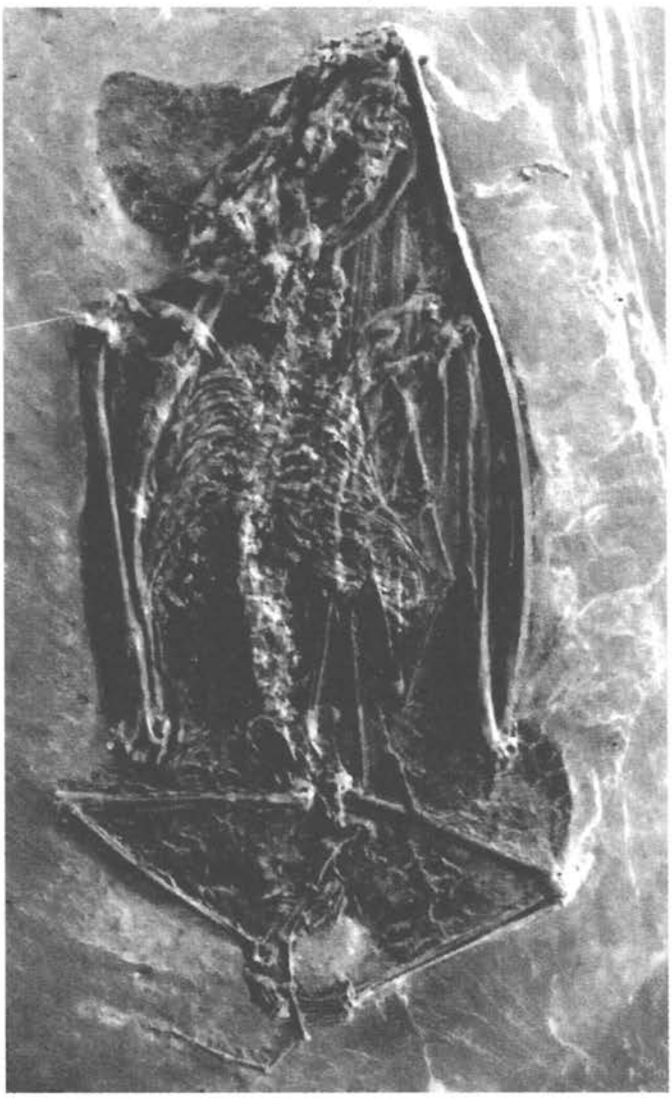


Fig. 44: Fossil bat from the Messel collection of the Senckenberg museum in Frankfurt (from JANSEN et al. 2002).

From some other fossils we even can derive behavioral facts like the mating position in turtles (e.g. Allaeochelys), the sonar hunting of bats, beetles loaded with pollen grains and leaves damaged by herbivorous organisms. There are pregnant bats and horses and the total ontogeny can be studied in some reptiles (turtles, crocodiles) and mammals and from several insects larva and larva cases are known. There is detailed information on the last meal of most of the land living vertebrates by preservation of the stomach, respectively gastrointestinal tract content and in addition also coprolites from fishes and crocodiles are frequently found. In total we can reconstruct the lake situated in a paragneisses tropical warm and densely wooded rain forest environment, which is proven by various plants (e.g. palm trees, ginger plants, mulberry bushes, moonseed- and aroid-plants) and animals (e.g. different groups of crocodilians and freshwater turtles like the genus Trionyx). Geophysical results place the lake in Eocene times at a latitude of about 38 degrees North approximately on the latitude of Sicily of today (the latitude of today is 50 degrees North).

Scientists have been excavating and working on Messel fossils for more than a hundred years now. However, there is still no consensus on what the Messel Lake itself and its surrounding areas might have looked like in detail. In general two different environments with their faunal and floral elements are recorded (1) the aquatic environment of the oyxgenated water body of the lake and aquatic organisms washed into the lake from river environments and (2) the continental environment, where we find organisms from different habitats, from near shore till to the hinterland. We assume that most of the remains and carcasses from these continental environments were washed into the lake by river transport too. It is interesting that we miss typical remains of fossils, which you would expect to be deposited in an Eocene freshwater lake and on the other hand we record some fossils (e.g. bats, snakes, birds), which are generally considered to be very rare, and are usually know by fragments only. Some of these rare organisms are discovered even frequently in well-preserved specimens and are often recorded with several different species. Finally there are some "exotic" and world wide very rare preserved animals and plants like a sweet water eel (Anguilla), the anteater (Eurotamandua), a pangolin (Eomanis), ostrich, ibises and flamingo like birds, lots of rare insects (e.g. termites), spiders and a crustacean and the cob-palm (Cylanthacea) to give some examples.

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Field Trip B
Traverse through the Eastern Alps

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Introduction

The Eastern Alps are a complex orogen. Complex, because two great orogenies, the Hercynian and the Alpine, are involved, and much more complex, because most of their elements are rootless nappe units, deriving from up to 800 km away. We will see only some few of these elements, and reduced to an only 200 km wide section. In a short overview the situation can be described as follows (see Figs. 1 and 2):

- The central European basement was formed by the accretion of probably allochthonous, Gondwanide terranes (Armorica, East Avalonia) in the Early Palaeozoic. This subcontinent was folded, metamorphosed, intruded by granitoids and stabilised in the Hercynian orogeny mainly during the Carboniferous. Famous regions of this orogen are e.g. the Black Forest and the Bohemian Massif with the ranges around. It extended south at least to the today's Central Alps of Tyrol and Salzburg, where it is exposed as part of the Tauern window.

- In all these regions small grabens had developed which were filled with Permian sediments and volcanics. In Central Europe great part of the continent was covered with sediments in the Mesozoic: the genuine Triassic (Buntsandstein, Muschelkalk, Keuper), the threefold Jurassic (Lias, Dogger, Malm) and, above all in the northern parts, with Cretaceous. To the south, most of this sedimentary cover terminates at a line that coincides more or less with the Danube river. The southern landmass carrying only thin or no Mesozoic, is called "Vindelician Land". Rarely Mesozoic calcareous and clayey sediments were deposited until the great Late Jurassic transgression covered the whole area with limestones.

- Only south of this landmass beginning in the Permian a trough began to form, which was filled firstly with clastic sediments and carbonates. From the Late Triassic rifting extended to build a true ocean basin filled with marls, basalts and other ocean floor magmatic rocks, including ultrabasic intrusives. This trough is called Penninicum; it may have been about 200 to 300 km wide. From the Late Cretaceous the Penninic trough closed again, most of it was subducted, part of it, the now observable rocks, were overthrust to the north covering the old continent. This is the lowermost great nappe system of the Alps.

- During the same time, much more southerly, in the Palaeozoic great areas were filled partly by clastic sediments, partly by fossil-rich carbonates. After the Hercynian orogenic event they were covered with thick Triassic, Jurassic and Cretaceous sediments. This region must have had the position of today's Adriatic Sea and part of Italy. It is, therefore,

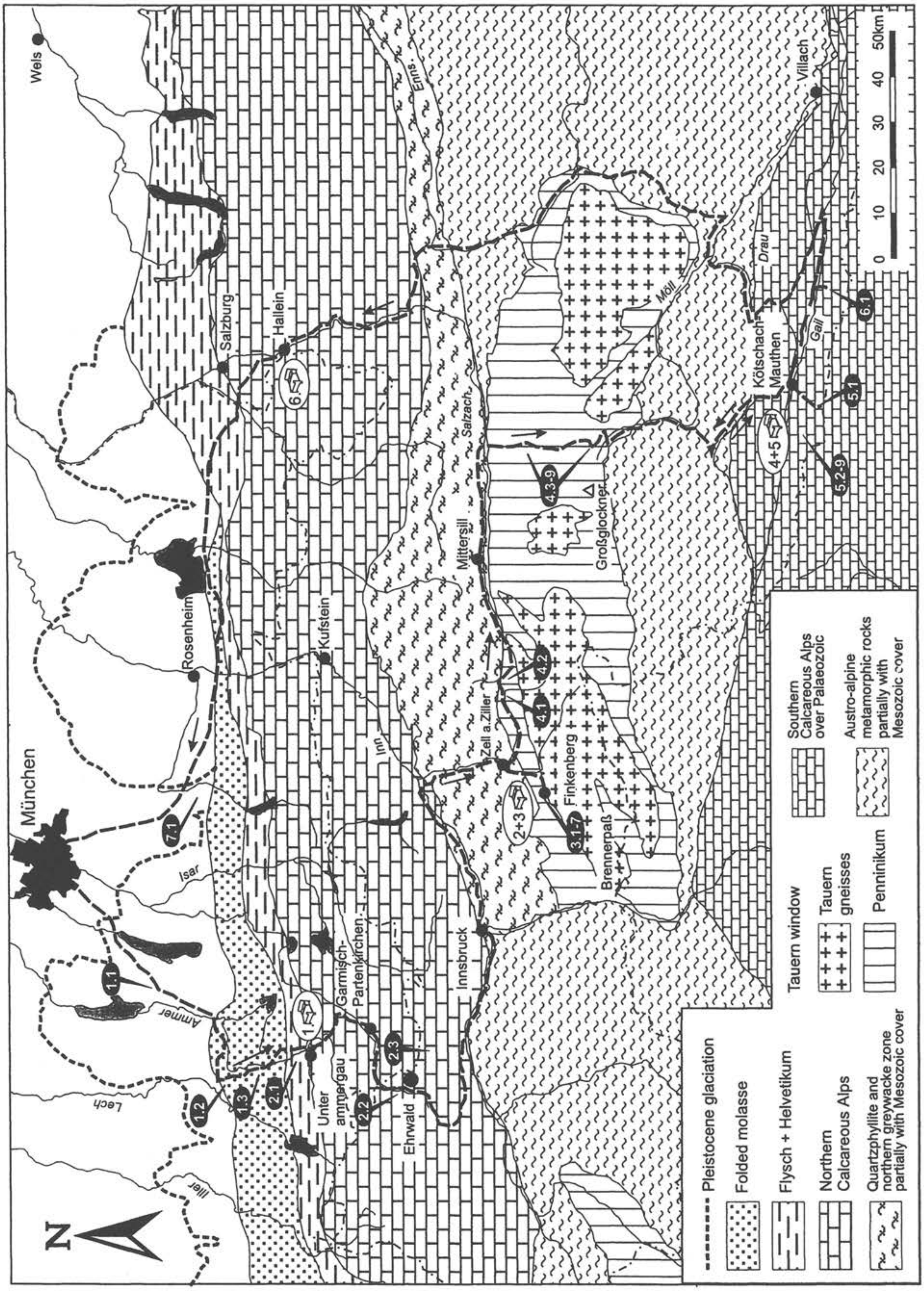


Fig. 1: Geological sketch map of the western part of the Eastern Alps with the field trip route.

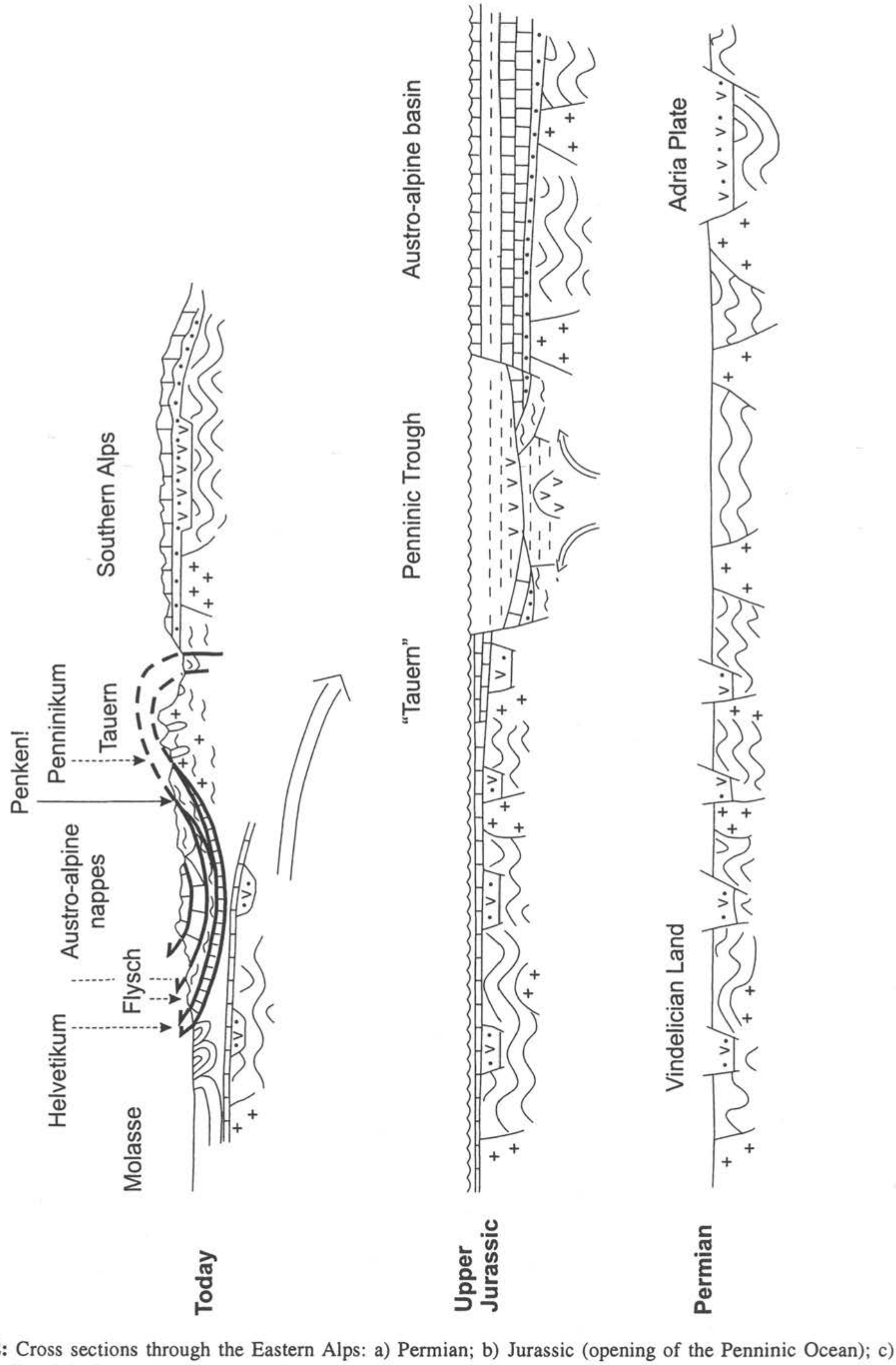


Fig. 2: Cross sections through the Eastern Alps: a) Permian; b) Jurassic (opening of the Penninic Ocean); c) Today (Penninic Ocean closed, Austro-alpine nappes thrust to the north).

called Adria Plate, forming part of the Tethys Ocean. Part of this micro-continent remained south of the autochthonous continental land mass, seen in the Carnian Alps (Palaeozoic and Mesozoic) and Dolomites (Mesozoic above metamorphic Palaeozoic). Part of the Adria Plate's upper crust split off from the lower crust and was transported to the north covering the edge of the European Plate and additionally the Penninic nappe system, getting as north as Bavaria. As, contrary to the situation in the Western Alps, these units are widespread in the Austrian Eastern Alps, they are called East Alpine or Austro-alpine nappes. So, the uppermost nappes are the most far transported ones.

• Additionally to these three great units: Old continent, Penninikum, and Austro-alpine, three more units will be crossed by the field trip: Firstly the Molasse trough, which is easily understood as the sediment-filled foredeep of the rising Alps. Secondly the Helvetikum. This zone plays a major role in Switzerland (therefore the name), where it contains a complete pile of sediments from Permian up to Eocene, in a facies which remembers the Central European one. In the Eastern Alps it begins only in the uppermost Jurassic. The unit is rootless. The provenance is unknown; in comparison with the Swiss situation it possibly was deposited south of the Central (Tauern) Alps. Thirdly the Cretaceous to Lower Tertiary flysch trough, called Rheno-Danubian flysch in our section. It is evidently a nappe system, because it lies on the before mentioned Helvetikum of Cretaceous to Early Tertiary age. The pile is composed of sandstones and marls, partly typical turbidites. Most people consider it to form part of the Penninic trough.

Some more details will be given in the particular descriptions of the days. For a detailed study the books of TOLLMANN (1977, 1985; in German) are recommended. There is no overview book in English, but detailed papers are commonly written in English in various journals since the eighties.

Day 1: Sunday, August 31

Route: Munich – A95 – B2 – Weilheim – Peiting – Saulgrub – Oberammergau (overnight)

We cross the Würm-Glacial outwash plain (Münchener Schotterebene) for the Würm moraines round the Starnberger (or Würm) Lake. Overview of the Ammersee basin. Mid Tertiary clastic sedimentary rocks and coal measures of the folded molasse basin of the Alpine foreland.

Stop 1-1: Hirschberg-Alm near Pähl. P 685.

The moraines of the last glaciation (Fig. 3) reach 760 m to the east of our look-out. The recent Ammersee surface is at 540, the lake bottom at 451 m a.s.l.. Thus, the interglacial and glacial erosion reaches c 300 m. Landscape is formed by moraines, which overlie fluvioglacial gravels of Günz and Mindel glaciation (Fig. 4). Below about 600 m a.s.l. continental and marine sands, gravels and marls of Oligocene to Miocene age, up to 3000 m thick, build the main flat lying sedimentary pile (molasse trough) above a very thin Mesozoic cover and the

Fig. 3: The moraines of the last (Würm) glaciation surround the basins of the Ammersee and Würmsee. Locations of stops 1-1, 1-2, and 1-3 are indicated. Map after ROTHPLETZ (1917).

crystalline basement. Due to the scarcity of Mesozoic sediments above the Palaeozoic metamorphic and magmatic basement this area is known as "Vindelizisches Land". East of our look-out some coniform hills are called "tumuli". Probably they formed from landslide material fallen upon the glacier crossing the northern calcareous Alps. To the west, the sedimentary filling of the Ammersee trough is seen. The lake was about twice as long when it formed immediately after the glacier melted. The Ammer river brought much gravel from the mountains, filling up the basin after glacial retreat.

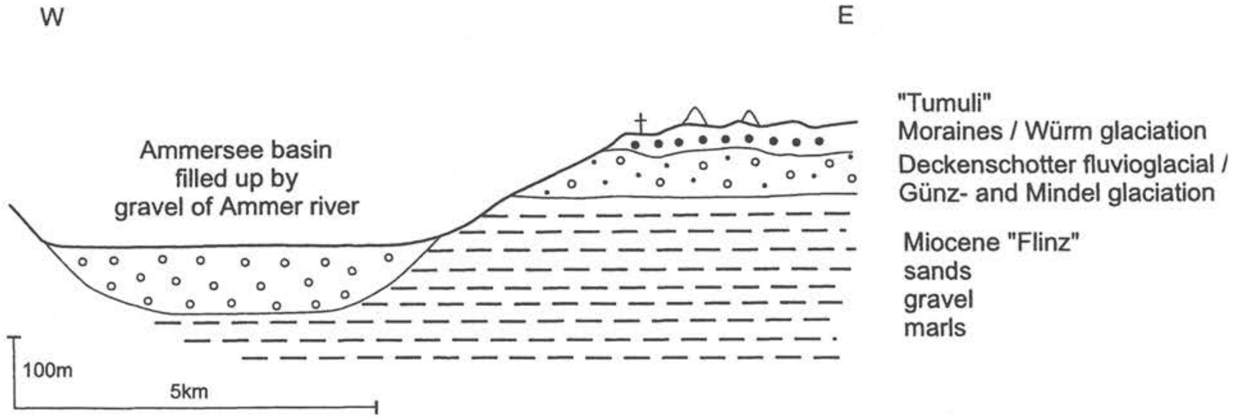


Fig. 4: Cross section through the Ammersee basin. The cross is the location of Stop 1-1. Not to scale.

Stop 1-2: Road outcrop south of Peiting.

At the immediate front of the Alps the Tertiary molasse sediments are folded and thrusted. Four units are distinguished referring to the facies conditions: beginning with the Lower Marine Molasse and Lower Freshwater Molasse, and continuing with the Upper Marine Molasse and the Upper Freshwater Molasse (Fig. 5, 6). From east to west the continental part and the grain size increase, the molasse forming hills and mountain ranges in south-west Bavaria and Switzerland. Whenever the facies changed from marine to continental or vice versa, swamps formed, which were transformed to coal measures. These were worked until the late sixties in several mines. One of them was crossed at Peißenberg. Stop 1-2 is situated on top of the most westerly mine, Peiting.

In the outcrop two small coal measures can be observed (mined by many field trip participants). Host rocks are sandstones and marls, partially full of the pelecypod Cyrena, typical for brackish waters. The Tertiary is overlain by moraines of the Würm glaciation, to be studied following the road about 30 m to the west.

Remarks to the landscape history: The Ammer river leaves the Alps in north-north-west direction through a deep gorge, turning abruptly to the east just front of this stop. The plain, where the bus is parking, is an old broad Ammer valley from a time this part of the Alpine foreland was already free of ice, whereas the Ammersee glacier was still occupying its basin. The Ammer at that time fell into the Lech river north of Peiting. After retreat of the Ammersee glacier, a creak falling into its deep basin reached the Ammer by backward directed erosion and got the river to turn east into the deeper situated valley eroded by the ice.

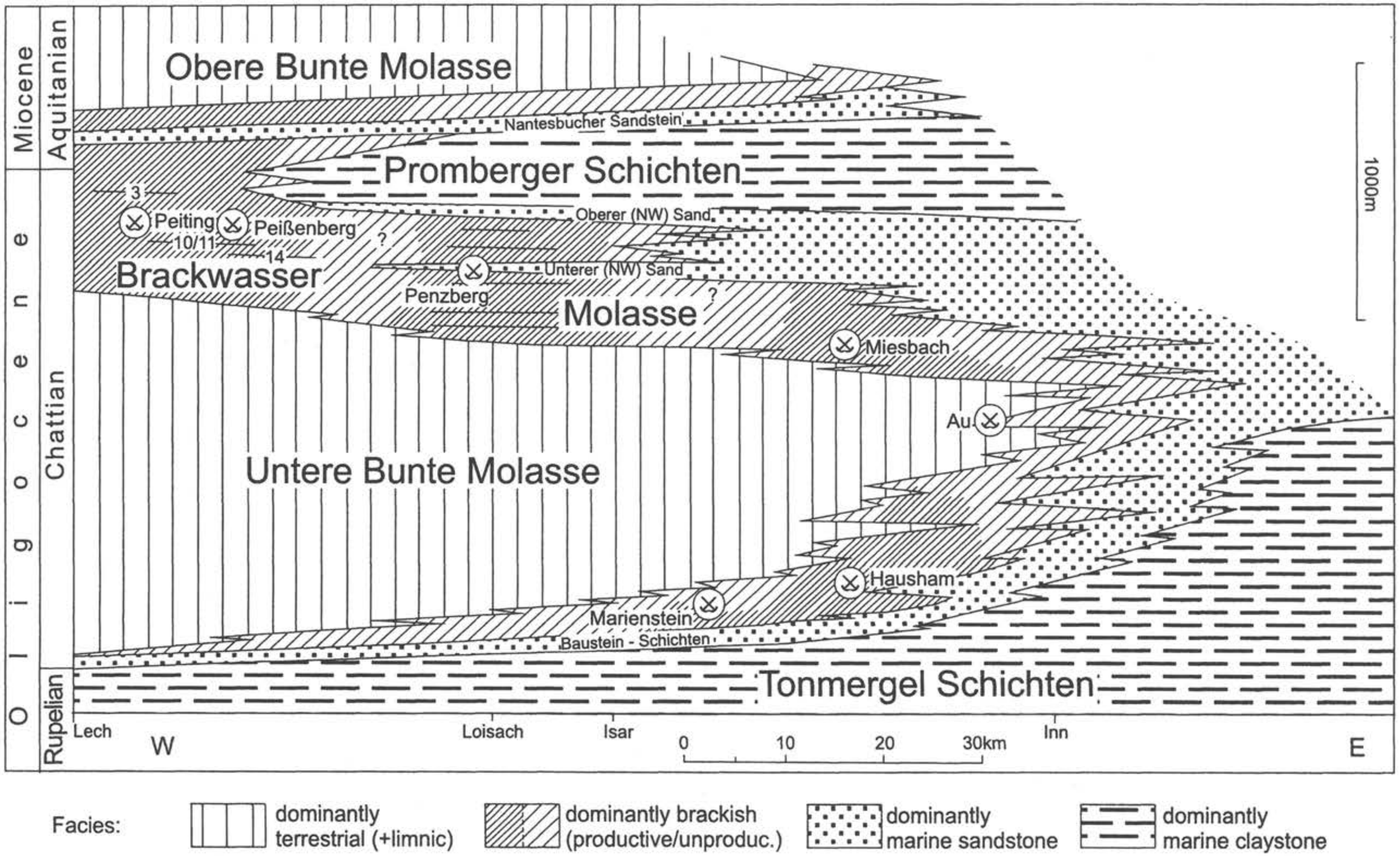


Fig. 5: Facies pattern of the folded molasse zone in Bavaria. Note the location of the abandoned coal mines in the transitions of marine to terrestrial facies and viceversa (after GEISSLER 1975).

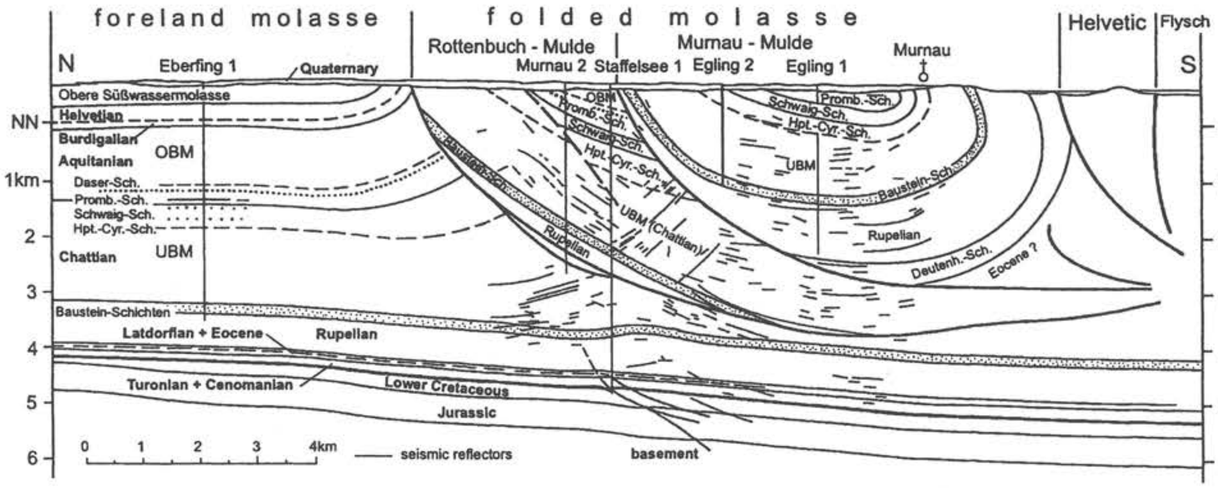


Fig. 6: Tectonic style of the folded molasse. The synclines are fairly allochthonous, thrust to the north over the autochthonous Tertiary cover of the basement and thin Mesozoic rocks (after MÜLLER 1970).

We continue to the south until Saulgrub, across the "Echelsbacher bridge", a famous construction that allowed traffic to avoid difficult crossing of the Ammer gorge.

Stop 1-3. "Scheibum" (means "overturn" in Bavarian)

From Saulgrub we turn to the west on a small road which accompanies the great peat region of the "Murnauer Moos", to reach the Ammer gorge at an old power plant.

a) A few metres north of the bridge claystones of the Murnau formation (mid Oligocene, Lower Marine Molasse) crop out at the river side.

b) Walking to the north, where the path begins to rise we cross the uppermost parts of the Murnau marls, here with some sandstone beds. Further north sandstones of the Baustein-Schichten (means "Building stone beds"; mid Oligocene, marine). We climb down to the river bed and cross a small cross bedded sandstone bank (overturned!) to reach the conglomerates of the Weißach-Schichten (Upper Oligocene, Lower Freshwater Molasse). These coarse grained conglomerates are typical for the western facies of the molasse, whereas in East Bavaria most of the foreland Tertiary is built of sandstones and claystones alone. Approximately 10 m south of the red conglomerates a small coal bed within the Baustein-Schichten is formed by allochthonous plant remains.

The site is called "overturn" because canoeists often do so entering the small gorge formed by the conglomerate beds.

Day 2: Monday, September 1, 2003

Route: Oberammergau – Halbammer valley – Ettal monastery – Garmisch-Partenkirchen – Ehrwald – Innsbruck – Finkenberg

Stop 2-4: Halbammer valley (means: "half Ammer")

Rheno-Danubian flysch. Mostly turbidites overlying the "Helveticum" and overthrusted by the Northern Calcareous Alps. Allochthonous, provenance not clearly known.

a) Rockslide warning sign
Front of the creek: Typical outcrop of Piesenkopf-Schichten. Intercalation of sandstone and pelite beds.
b) Some 200 m farther south on western side of the creek: Landslide typical for most Flysch zone sedimentary rocks.

At the road side outcrop of Piesenkopf-Schichten (Lower Turonian – Coniacian). Thin bedded pelite/sandstone sequence. Rich on traces of *Chondrites.*

We return to Oberammergau for Garmisch-Partenkirchen/Wettersteingebirge and Ehrwald / Tyrol. If time allows, the baroque monastery of Ettal will be visited.

Stop 2-5: Ehrwald, 100 m NW of railway bridge, road to Duftl Alm.

Outcrop of Plattenkalk ("Platy limestone"). Upper Norian grey limestone, bituminous smelling when fresh, mm to m banking. Thickness variable from 0 to 600 m. Interesting sequence stratigraphy, not yet investigated in detail. Taking the place of and interfingering with the uppermost Hauptdolomit ("Main dolomite"), which besides the Wettersteinkalk is the thickest formation of the Northern Calcareous Alps.

Strata are dipping to the south. They form the northern limb of a great syncline with the Early to Mid Jurassic Allgäu Formation in the core. Mind the beautiful N-dipping normal faults.

View to the east (Fig.7):
Western slope of the Wetterstein-Gebirge. The Schneefernerkopf forms the core of a great syncline. To the left (not visible) the Zugspitze (2962 m), the highest peak of Germany. Main peak forming rock is the Wettersteinkalk, Ladinian, built of reefs (corals, sponges) and back reef lagoonal limestones with *Diplopora annulata* and other algae (Dasycladaceae). The darker, well stratified rocks beneath the Wettersteinkalk are "Alpiner Muschelkalk", mostly shallow water limestones and marls. It contains several layers of tuff, probably wind transported from the southern Alps.

Beneath it, on the left side (second cable car mast), Reichenhaller Schichten (upper Scythian - Lower Anisian): dolomites, limestones, porous limestones ("Rauhwacken"). They serve as slide horizons for inverse faults frequently. Beneath the massif limestone complex, Jurassic

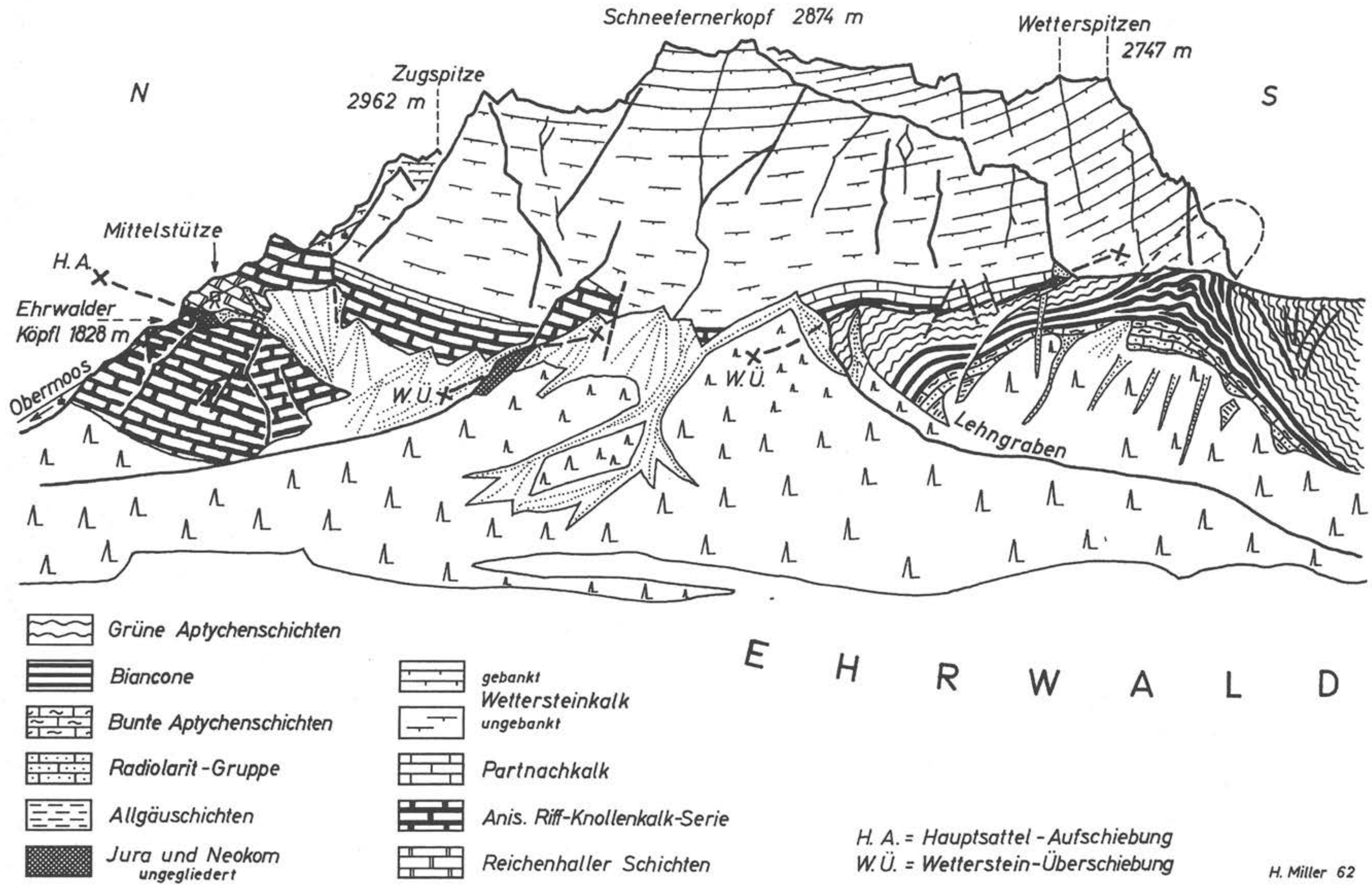


Fig. 7: Western slope of the Wetterstein Range. The 1000 m thick Ladinian reef limestones have been squeezed out to the north and south, where during the same time clays were deposited between the reefs.

and Lower Cretaceous limestones, marls and cherts crop out. They are forming an anticline, overturned to the south. This demonstrates that relative movement of the Wetterstein Massif has been to the south, not to the north as common in the northern Calcareous Alps, nor to the west as for a long time had been supposed due to the N-S striking of the outcrops of the strata.

Applied geology:
During the sixties, control of the erosion problem by sewing grass, planting trees, and some works on the steep creeks was tried to be effective. As one can see, many of the steep slopes are free of vegetation once more, and blank water rills show that erosion and transport are going on.

To the southeast: The Mieminger Mountains are built of several anticlines and synclines of mid Triassic limestones. On their western slope several mining dumps are visible. They document the frequent mining on galena and sphalerite ores occurring in the upper Wetterstein-Kalk. These ore bearing levels were producing small quantities of ores in the northern Alps nearly everywhere, mostly during the 19^{th} century. In the southern Calcareous Alps, e.g. Bleiberg, Mesiza, Raibl, Gorno, these levels and the overlying Raibler Schichten produced large quantities of ores up to the end of the 20^{th} century.

Whereas the Wetterstein Block was moved over the Jurassic/Cretaceous "Jungschichtenzone" ("young strata zone") to the south, the Mieminger Block moved to the north over the younger strata. In the afternoon, we shall see the Jurassic rocks in a window through the Triassic nappe.

The Ehrwald Basin was a large lake after the Pleistocene glacier retreated. It is now filled with lakustrine sediments. The hills within are partly outcrops of Jurassic marls, partly (the sharp cones) they are remnants of an immense late glacial landslide that also builds the Fernpass which will guide us to the south in the late afternoon.

Stop 2-6: Feldern-Alm creek, 1700 m.

Triassic limestones (Raibl Group, Carnian) overlying Jurassic cherts (Radiolarit-Gruppe) and Lower Cretaceous marly limestones (Aptychen-Schichten), see Figure 8. The overridden rocks are strongly deformed. Structurally, the Triassic belongs to the Mieminger Block.

If time remains, we will have a look to the Upper Wettersteinkalk close to "Alpenglühen"-Inn) when returning to the cable car. Well stratified limestones crop out on a small road, called "Knappensteig" ("miners' track"), which served as an access to the sulphide mines in past centuries.

In the late afternoon continuation to the south. We will cross the Fern Pass. It lies in a depression of the Triassic carbonate rocks covered with thick land slide deposits of late Pleistocene age. In Nassereith we turn to the left, going east along the southern limb of the Mieminger anticline, the high peaks built by Ladinian Wetterstein limestone and the rise built by Norian Hauptdolomit (Main Dolomite). We reach the Inn valley at Telfs and take the highway further

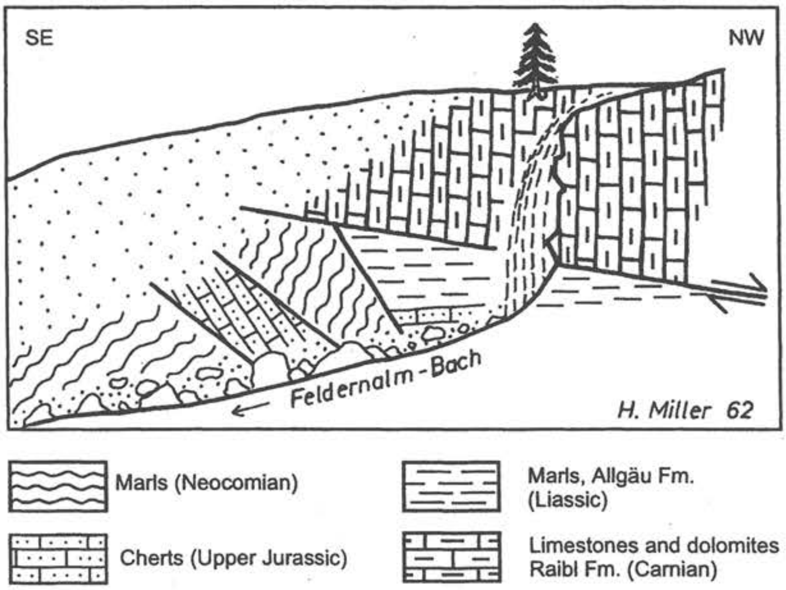


Fig. 8: Outcrop at Feldern-Alm creek. Upper Triassic limestones (Raibler Kalk) of the Mieminger Massif thrust to the north, overlying Jurassic and Lower Cretaceous marls and cherts.

eastwards passing Innsbruck, capital of Tyrol, at its southern margin. The highway follows the Inn river to the north-east. We pass Schwaz, an old mining city. The southern slope of the valley is full of adits and dumps. Principal ore was silver rich grey copper (tetraedrite). The mines were one of the sources of fortune of the Fugger dynasty in the 16^{th} century. The geological situation south of Schwaz is fairly complicated. Devonian limestones and dolomites, Lower Palaeozoic quartz phyllites and partly mylonitic gneisses occur.

A few kilometres east of Schwaz we turn to the south, entering the Ziller valley. Where at Mayrhofen the broad valley terminates abruptly, we turn to the west entering the Tux valley to stay overnight at Finkenberg.

Day 3: Tuesday, September 2, 2003

The village of Finkenberg lies at the outermost part of the glacier shaped Tux valley. It is the best starting point to recognise the geological units from the parautochthonous "Central gneiss" of the Tauern window, through its parautochthonous sedimentary cover rocks, to the marls of the Penninic Ocean, and finally crossing the principal nappe boundary of the Eastern Alps from the Penninic zone to the Lower Austroalpine nappe. All these units can be seen easily on one only day (Figs. 9, 10).

After the accretion of several Gondwana derived micro-continents in the Early Palaeozoic, the European continent was affected by folding, metamorphism and granitoid magmatism during the Hercynian orogeny. The consolidated continent extended far to the south into the location of the modern Alps. From northern Germany to the core of the recent Tauern Mountains many post-orogenic extensional troughs were built on the continent from the Late Carboniferous to the Early Triassic. They were filled firstly with mostly acidic volcanic rocks and clastic sedimentary series, later partly saline facies developed up to the Early Triassic. About south of the today's Danube river, sedimentation outside these troughs was very scarce and if any, extremely thin, before in the Late Jurassic a continuous shallow limestone layer covered the whole continent.

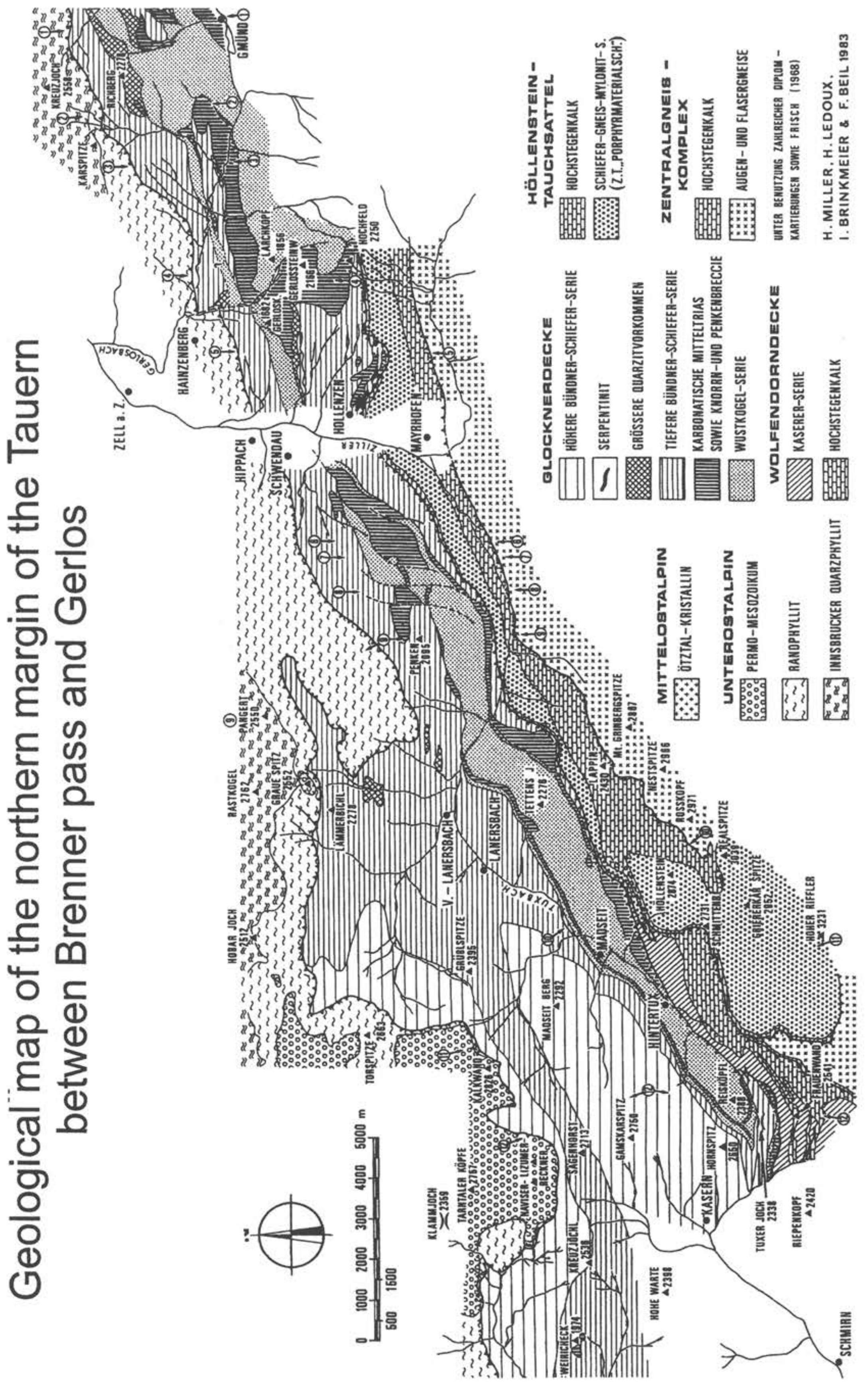


Fig. 9: Geological map of the northern Tauern margin at the surroundings of Finkenberg. The central part is composed of several small thrust sheets of former local Permian basins on top of the Central Gneiss group and of schists of Penninic realms. In the south, the parautochthonous gneiss, in the north the far transported Lower Austro-Alpine Innsbruck Quartz phyllite accompany this manifold zone.

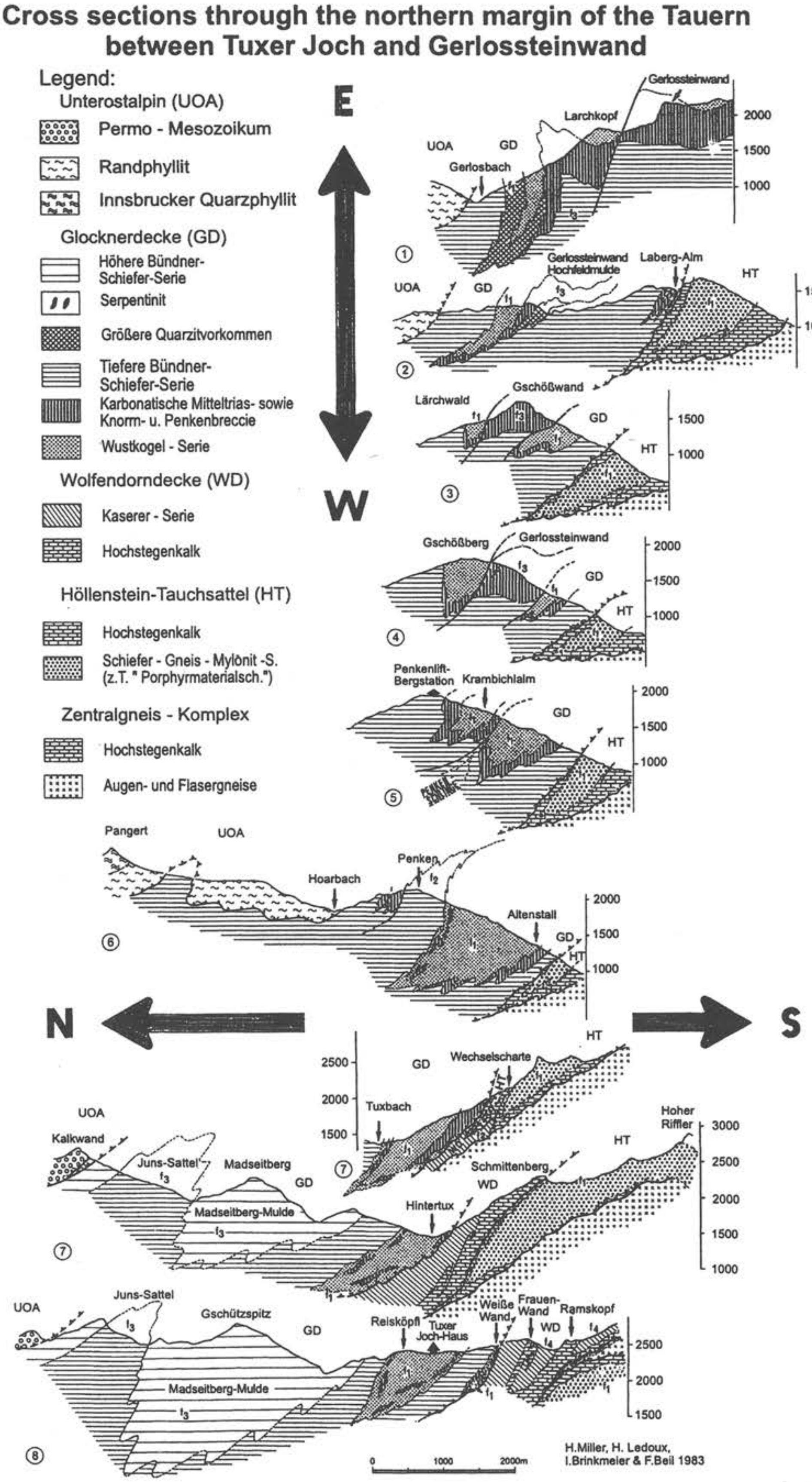


Fig. 10: Cross sections through the northern margin of the Tauern in the area shown in Figure 9.

From the Late Triassic, the continent broke up to form a some hundred kilometres broad ocean that at least in its central part was underlain by real oceanic crust. This short-lived intra-continental ocean basin is called "Penninic Zone"; it is most widespread in the Western Alps. The basin filling begins with the Permoscythian Wustkogelserie, composed of meta-sandstones of variable feldspar and carbonate content and acidic volcanic rocks. Mid to Upper (?)Triassic dolomites and limestones follow, the so-called Seidlwinkel-Serie. The most typical rocks of the Penninikum are the Jurassic to Lower Cretaceous marls of variable carbonate/clay relation, the "Bündner-Schiefer-Serie". Some sandstones, volcanic and subvolcanic rocks as well as micro- and megabreccias of Mesozoic carbonate and clastic rocks are intercalated. The whole complex is metamorphic to variable degrees.

From Mid Cretaceous on, the Penninic ocean was closed by subduction, and part of the basin fill was thrust to the north over the continental margin, covering the former continent. The Permo-Triassic extensional basins jointly with the overall existing Upper Jurassic limestones participated in this thrusting, squeezed in between and north of the basement granitoids as small meta-clastic and -volcanic stripes. All rocks have undergone weak to intermediate metamorphism (south of the Tauern up to high grade). Additionally to the basin filling, the units built south of the Penninikum were thrust over the Tauern gneisses, over their meta-sedimentary cover and the Penninic rocks themselves.

The area of provenance of these southern units is called "Adria plate". They are composed of manifold greater and smaller nappe units, called "Austro-Alpine" or "East Alpine" nappes. In the area of Tux valley, we observe the basement of the lowermost unit, the "Innsbrucker quartz phyllite" of the Unterostalpin (Lower East Alpine) nappe complex. It is covered with the Triassic and Jurassic strata of the Tarntaler Berge, seen from far from Stop 3-8.

Stops may be re-arranged depending on weather conditions.

Stop 3-7: Road cut near hotel Stock.

Hochstegenkalk. Age recognised in 1940 as Upper Jurassic by an ammonite found in a block of a road wall far off. Later reconfirmed by sponge needles and radiolaria found in outcrop (KIEßLING & MILLER 1991). Deposition was probably bound to a deep shelf environment. The observable banking of the marble at Stop 3-7 is due to cleavage, not to sedimentary stratification. This is well documented by numerous syn-diagenetic chert nodules which trace the former bedding (e.g. Fig. 11, close to the northern end of the outcrop, 5 m to the right of the red arrow). Structurally this Hochstegenkalk forms part of the cover of the Zentralgneis of the Tuxer Hauptkamm (see Stop 3-12, Fig. 13).

We take the cable car to the Penken plateau. The first section of the cable car crosses the Permian Wustkogel Serie, well recognisable by the blocks of greenish gneisses.

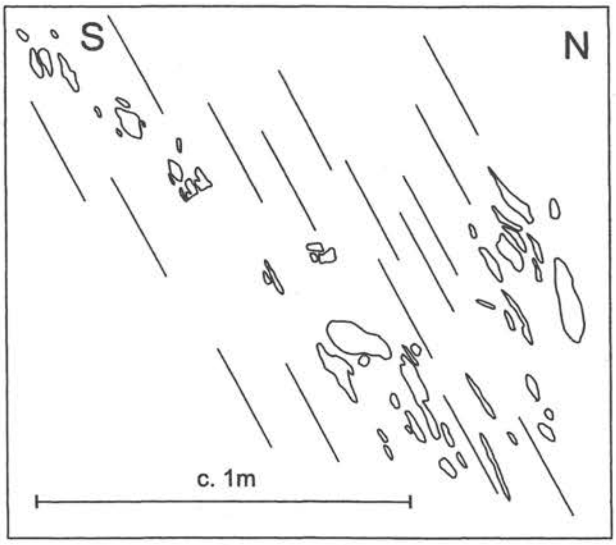


Fig. 11: Syndiagenetic chert nodules tracing the original bedding planes of the Upper Jurassic Hochstegenkalk, transformed to marble. Road cut near hotel Stock, Finkenberg.

Stop 3-8: Penken summit, look-out

We stay on Liassic carbonate quartzites and quartzites of the Penninic realm, small, but morphologically prominent beds in between the dominant marls of the "Bündner Schiefer Serie". The Penkenjoch (2095 m a.s.l.) forms part of an old (Pliocene?) broad valley system in the western prolongation of the Salzach valley.

To the south, the granitoids and gneisses of the Tux Main Range are front of us. To the south-east, in the background, the Zillertal Main Range of similar composition. Not well visible from far, Permian metasedimentary and metavolcanic series are squeezed into the magmatic and metamagmatic rocks. To the east, manifold Permian and Mesozoic schists are accompanying the Tauern Ranges in the north, similar to the area we are considering this day. To the south-west, Triassic carbonate rocks overlie the Lower Palaeozoic Innsbrucker Quartz phyllite, both belonging to the Lower East Alpine nappe unit, thrust over the carbonate phyllites of the Penninic realm.

Applied geology.
The hydro-electrical power plant system of the Zillertal Alps is the largest of Austria. From the Penken summit only one of the reservoirs is seen: the Stillup week storage lake. It works in combination with the much bigger year storage lakes of Zillergründl and Schlegeis. Additionally to the storage of spring and summer water surplus, both also serve as pumping reservoirs in times of national and international surplus of electrical energy as well as for highwater regulation. A further power plant system of the same company will be observed the next day.

Stop 3-9: (sequence of outcrops).

We walk about half an hour to the north-west, crossing several lithologies of the Bündner Schiefer sequence. This is the most characteristic part of the Penninic basin filling, mainly composed of meta-marls with intercalations of greenschists, quartzites and carbonate breccias.

Stop 3-10: Top of ski course running downhill to the north.

Innsbruck quartz phyllite, marginal facies.
We crossed the most important Alpine nappe boundary, the thrust of the Lower East Alpine Palaeozoic quartzphyllite over the Mesozoic Penninic Bündner Schiefer Serie. Lithologies are very similar, so that the famous Bruno Sander did not distinguish them in the map, but called both jointly Tuxer phyllites. One of the very rare exposures of the boundary was destroyed recently by the construction of the ski course.

The rocks are greyish phyllites and quartz phyllites containing typical rounded reddish brown quartz nodules (quartz nodules in the Bündner Schiefer Serie are white and more planar). An early Devonian age has been determined for one conodont sample close to our position. These Lower Palaeozoic meta-clastic rocks are very widespread covering most of the area to the north and west down to the Inn valley and Innsbruck. Within this unit a few kilometres to the west magnesite has been mined until about 20 years ago. The product was transported by cable car crossing the Penken plane some hundreds meters west of us, going downhill to the Ziller valley for loading on trains. As a particularity, within the Lower Devonian phyllites, close to the magnesite, scheelite ($CaWO_4$) has been found and mined for several years in the sixties of the 20th century.

Stop 3-11: Penken summit region, about 300 m NE of the cable car terminal

Penken breccia.
Mostly carbonate, more rarely quartzite clasts of varying size are widespread in the northern marginal zone of the Tauern. They range between mm sized single isolated grains up to several hundreds of meters long and tens of meters wide blocks. The Penken breccia is of particularly easy reach, and therefore the best known. The facies of the carbonates is similar to the Mid Triassic of the Lower East Alpine Mesozoic rocks, the scarce fossil content indicates Triassic age. KRISTAN-TOLLMANN (1962) who firstly described the outcrops of the Penken in detail, assigned them to the Lower East Alpine nappe system and assumed a tectonic transport to the Penninic realm of the Penken. This assumption was understandable

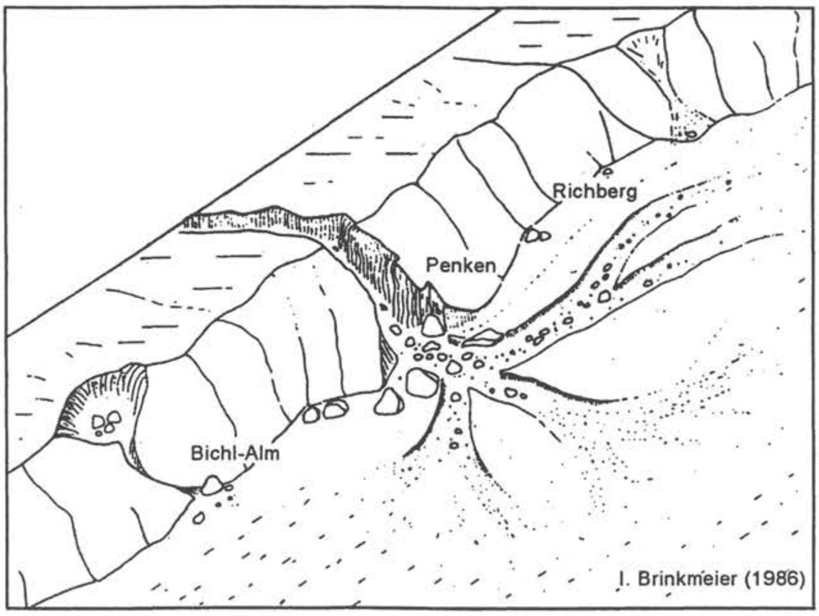


Fig. 12: Some typical examples of sedimentary incorporation of blocks of Triassic quartzites and carbonates into the Penninic ocean at its margin (BRINKMEIER 1986).

due to the close vicinity to the Lower East Alpine carbonate rocks of the Tarntal Alps to the west, and the similarity of facies. Actually, carbonate and partially quartzite breccias are found everywhere within marls of the Bündner Schiefer Serie north of the Tauern massif. Following the thesis of BRINKMEIER (1986), it is most probable that the Penken Breccia is only one typical example of olisthostroms and olistholiths which broke up and run down into the Penninic trough from the carbonate shelf at the margin of the Penninic realm (not distinguishable from the neighbouring Lower East Alpine shelf of the same age) (Fig. 12). Thus the provenance of the components of the breccia is similar in both hypotheses. Only the way of transport is different (tectonic vs. sedimentary).

The visited outcrop shows mostly carbonate, rarely quartzite and micaceous quartzite boulders in a phyllitic and quartzitic matrix. The irregularly rounded boulders range between centimetres and several decimetres. The age of the boulders is Permoscythian (quartzites) to Mid and Upper Triassic (the limestones and dolostones). The age of deposition into the Penninic ocean probably corresponds to the beginning of opening of the Penninic Ocean, maybe uppermost Triassic or Liassic.

Stop 3-12: Inn "Zur schönen Aussicht" ("Pleasant out-look")

We cross the Tuxbach (Tux creek) at the site of an old wooden bridge (traffic now on a new one). The creek runs in a several tens of metres deep gorge eroded and polished in Upper Jurassic Hochstegenkalk. A short walk brings us to the contact between the Jurassic meta-sedimentary rocks and the Tuxer gneiss (Fig. 13).

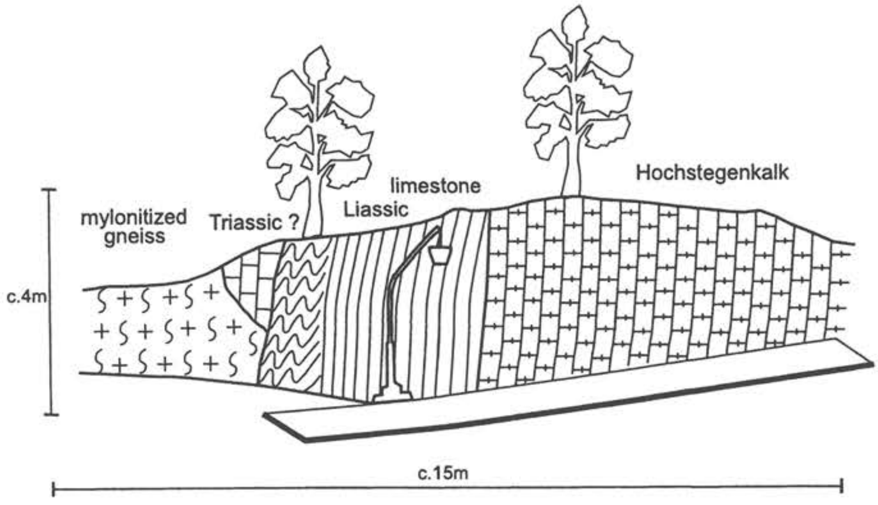


Fig. 13: Inn "Zur Schönen Aussicht". Cross section from the basement of the Alpine edifice (Tuxer Augengneiss) to its sedimentary cover (mid Triassic (?) limestones, black Liassic phyllites and Upper Jurassic Hochstegenkalk).

We are at the lowermost part of the Alpine edifice. The Tuxer gneiss is probably the southern continuation of the South German basement, exposed there in the Black Forest and Bavarian Forest, forming part of the European Plate and called locally "Vindelician Land" due to the scarceness or lack of Mesozoic sedimentary cover. The exposed Augengneiss is covered by about 2 m of black phyllites, probably Liassic, and Hochstegenkalk, a light gray marble of Upper Jurassic age. The Augengneiss is mylonitised, as stronger as closer to the contact. The

Liassic phyllites are strongly folded. Between both a fragment of carbonate rock is intercalated that may be a slice of Mid Triassic or of Hochstegenkalk.

For hammering we go back some meters to the road where on a little fault the sequence is repeated. Returning to the village, we observe diminishing mylonitisation of the Augengneiss on the road cut.

Stop 3-13: Road to Astegg, north of the village of Finkenberg.

a) Narrow turn at the end of built up area. At both sides of the turn Hochstegenkalk crops out. But: why the morphological depression? Probably there is a fault separating two different stripes of Hochstegenkalk. Further east, at the eastern side of the Ziller valley, an increasingly thick meta-clastic unit, the so-called Kirchspitz-Kristallin, intercalated between two discernible Hochstegenkalk members, clearly verifies this idea.

b) Following the road (pay attention to fast running Tyrolian drivers), the Hochstegenkalk is overlain by dark calcareous phyllites with boulders of massive carbonates and once more Hochstegenkalk. The phyllites probably belong to a marginal facies of the Bündner Schiefer Serie (called Kaserer Serie in the literature). The contact to the lower Hochstegenkalk is probably concordant, whereas the higher Hochstegenkalk layer belongs to the next unit, the so-called "Porphyrmaterialschiefer-Serie" (porphyr material schist series).

c) The Porphyrmaterialschiefer is composed of mylonitic gneisses, platy mylonites, green phyllites and quartzites. More rarely greenschists (former tholeiitic, continental intra-plate basalts) and acidic meta-volcanics occur. The Porphyrmaterialschiefer is allochthonous, a Permian graben filling on top of the Central gneiss, squeezed out and transported to the north during the Alpine orogeny. The Hochstegenkalk at its side is its primary cover. So every part of the Permian/Triassic continent has got its own Hochstegenkalk cover: The Augengneiss of Stop 3-12, the Kirchspitzkritallin (outcropping east of the Zillertal), and the Porphyrmaterialschiefer Serie. While the Triassic is widely lacking, and Lower (and Mid?) Jurassic only rarely occurs, the Hochstegenkalk sea was covering the whole continent, grabens and horsts of the southern tip of the continent, the south Bavarian Vindelician Land and, naturally the central Bavarian site of the Jura mountains.

   Just some metres before crossing the cable car cables, on the road cut σ- and δ-clasts are exposed on north dipping schist plains, showing movements north-block down (be careful and observe individually, not crowded!).

d) "Haus Bergland". Outcrop of an acidic meta-volcanic rock of the Porphyrmaterialschiefer-Serie. Crystallisation of this rock has been dated as 284 (+2/-3) Ma by SÖLLNER et al. (1991), proving the Early Permian age of this series.

Day 4: Wednesday, September 3, 2003.

We go eastwards, along the Tauern northern margin, using the longitudinal valley of Gerlos and Salzach. Main proposal is the cross section through the Tauern Window along the Großglockner Hochalpenstraße.

During the Alpine nappe tectonics the (par)autochthonous Tauern gneisses were covered entirely with the Penninic rocks. Uprising of the gneisses produced erosion of this cover, and it remained only at the margins and within a zone of strong transversal downwarping. The tourist road close to the highest peak of Austria, the Großglockner, offers an outstanding opportunity for studying the lithology of the Penninikum.

Stop 4-14: Am Seeblick, close to the Gerlos Pass.

View to the Durlaßboden reservoir. This hydropower reservoir was finished in 1967. The lake is situated mostly in slaty phyllites of the Bündner Schiefer Serie. The dam, therefore, had to be built as a rubble dam with central sealing core. Another problem results from the land slide coming down slowly from the western slope.

To the south-east a similar cross section like in Finkenberg can be observed, being most of the units wider developed than there.

Stop 4-15: View to Krimml waterfall

The Salzach valley, where we are just arriving, is deeply eroded and widened by the Pleistocene glaciers. Consequently the tributary creeks coming from the Tauern fall to the Salzach or in deep gorges or in waterfalls. This one is famous for the amount of water and beauty.

For the next hour we will follow the Salzach river downward. To the left (north) the so-called Grauwackenzone (greywacke zone) of Cambrian to Devonian clastic sedimentary rocks and volcanics. Tectonically it forms part of the Upper East Alpine nappe system. To the right (south) diverse nuclei of gneisses and granitoids, surrounded by rare Upper Precambrian, partly Palaeozoic and mostly Mesozoic schists. These units form the so-called Tauern window, whose frame are the East Alpine (or "Austroalpine") nappe systems.

Stop 4-16: Piffkar.

In Bruck we left the Salzach, turning south for the Großglockner Hochalpenstraße. This road was constructed in the early thirties and inaugurated in 1935. In the last decades it was reconstructed and enlarged several times. The pass was an important mercantile and military route yet in the Romans' time. The Piffkar parking lot allows for a short overview.

As described in the introductory chapter for Tuesday, the Penninic trough is composed of

Top		
Bündner Schiefer Serie	Jurassic and Cretaceous	marls, phyllites, quartzites, basic volcanics
Seidlwinkel Serie	Mid to Upper Triassic	limestones, dolomites
Wustkogel Serie	Permian to Scythian	clastic sediments, volcanics
Base		

Within the central part of the ocean the older parts are lacking, basic volcanics are frequent and ultramafic rocks occur. The whole series is low grade to medium grade metamorphic, in the south of the Tauern up to eclogite facies grade. The various parts of the trough have been thrusted and transported to the north and piled up during the Alpine orogeny.

From the parking lot to the west, carbonate rocks of the Seidlwinkel Serie are observed, to the west, the high mountains (around 3400 m) are entirely composed of calcareous micaschists of the Bündner Schiefer Serie. Beautiful hanging glaciers correspond with the dark rocks and green pastures.

We will have lunch at Naßfeld and follow the road to

Stop 4-17: Hexenküche

We take an old mule-track for outcrops. The landslide blocks of feldspatic gneisses belong to the Permian Wustkogel Serie. Real outcrops are grey and black micaschists, black phyllites and thin layers of quartzites. Schistosity is flat. Finally we get to a swamp. To the right (west), possibly marmots can be observed. Return to the bus.

Stop 4-18: Rock exposition south of Fuscher Lacke (Lacke = pond).

Not all exposed rocks are from the surroundings.

Stop 4-19: North of Mittertor tunnel

Karst in carbonate rocks of the Seidlwinkel Serie. At the parking lot cellular limestones or dolomites ("rauhwacken", Carnian or tectonic origin?). Walk to an old quarry in marbles. In some boulders folds can be observed indicating that the rocks are strongly folded although this is not evident everywhere.

Stop 4-20: North of Hochtor ("high gateway")

See the exposition of historic road findings. If wanted, go to the north-east for outcrops of marbles of the Seidlwinkel Serie.

Stop 4-21: Schönwand (= "beautiful wall")

We leave the road to the west and enter the road to Franz Josefshöhe. Here ocean floor ultramafic rocks of the Penninic Ocean are exposed, transformed into serpentinites. Some secondary veinlets of serpentine are seen at the road cut close to the bus. You can also have a little walk upwards on a path and see other outcrops (do not harm the flowers!). Walking along the road to the northwest, you cross several rock types of the Penninikum: mica bearing marbles, garnet bearing micaschists, micaschists and another small piece of serpentinite. Take care of the traffic!

Front of us, the Großglockner (3798 m), highest peak of Austria. Composed of prasinite, an albite – epidote – chlorite – barroisite-schist, typical for the transition from greenschist to amphibolite facies. Protoliths were basalts or basaltic pyroclastic rocks.

Stop 4-22: (if time and weather allow) Franz-Josefshöhe

We continue through calcareous micaschists of the Bündner Schiefer Serie up to the final point of the Großglockner Hochalpenstraße. Look-out: In front the Großglockner Massiv, below us one of the largest glaciers of the Eastern Alps, the Pasterze, retreating like all Alpine glaciers since their high-stands in the midth of the 19th century. Downstream the Margaritze reservoir, which catches the melt water of the Pasterze for passing it to the great reservoirs north of the central ranges.
Rocks are prasinites like described in Stop 4-21.

We return to the main road and continue to the south for Kötschach-Mautern.

Carnic Alps

Introduction

The Carnic Alps are situated south of the Periadriatic Lineament – an Alpine plate boundary - which separates the allochthonous nappes of the Eastern Alps in the north from the relatively autochthonous Southern Alps. There, the pre-Late Carboniferous rocks were affected by the Hercynian deformation and very low grade to low grade metamorphism. The Carnic Alps are famous for their well preserved Palaeozoic and early Mesozoic rocks ranging from the Late Ordovician up to the Middle Triassic with only a short interruption during Late Carboniferous due to the Hercynian Orogeny. The area was studied since the second half of the 19th century by Stache, Frech, Gortani, Heritsch and von Gaertner, and recent investigations are still based on those outstanding works. The first reliable conodont stratigraphy was established by WALLISER (1964) in the Cellon section. Our modern knowledge of the Palaeozoic stratigraphy of the Carnic Alps is mainly due to the studies of H.P. Schönlaub, who mapped large areas, described many sections and studied the conodonts (e.g. SCHÖNLAUB 1980, 1988, 1998, SCHÖNLAUB & KREUTZER 1994, KREUTZER et al. 2000).

The basement of the Carnic Alps is not known. The Caradocian rocks are detached from their original basement and the Palaeozoic sediments are sliced and piled up to huge south dipping imbricates.

The oldest rocks are acidic volcanics and volcanoclastics interfingering with shales and sandstones (Himmelberg Sandstone). Dropstones indicate the vicinity of the Hirnantian glaciation of northern Gondwana during the latest Ordovician. A global drop of sea level as consequence of the glaciation resulted in erosion and subaerial exposure. Therefore, the Ordovician rocks are disconformably overlain by younger strata.

The sediment successions are characterised by different facies realms reaching from shallow water to deep basin environments at least since the Silurian. According to Kreutzer (1992) and Kreutzer et al. (2000), the Lower Devonian to Frasnian deposits of four different nappes belong to four main depositional environments (Fig. 14): Shallow water facies (Kellerwand nappe), transitional facies (Cellon nappe), pelagic carbonate facies (Rauchkofel nappe), and basinal facies (Bischofalm nappe). Deepening during Famennian resulted in wide spread deposition of pelagic carbonates (nodular limestones). Finally, mid-Visean to Namurian flyschoid sediments of the Hochwipfelschichten indicate the onset of the tectonism in this part of the Hercynian orogen.

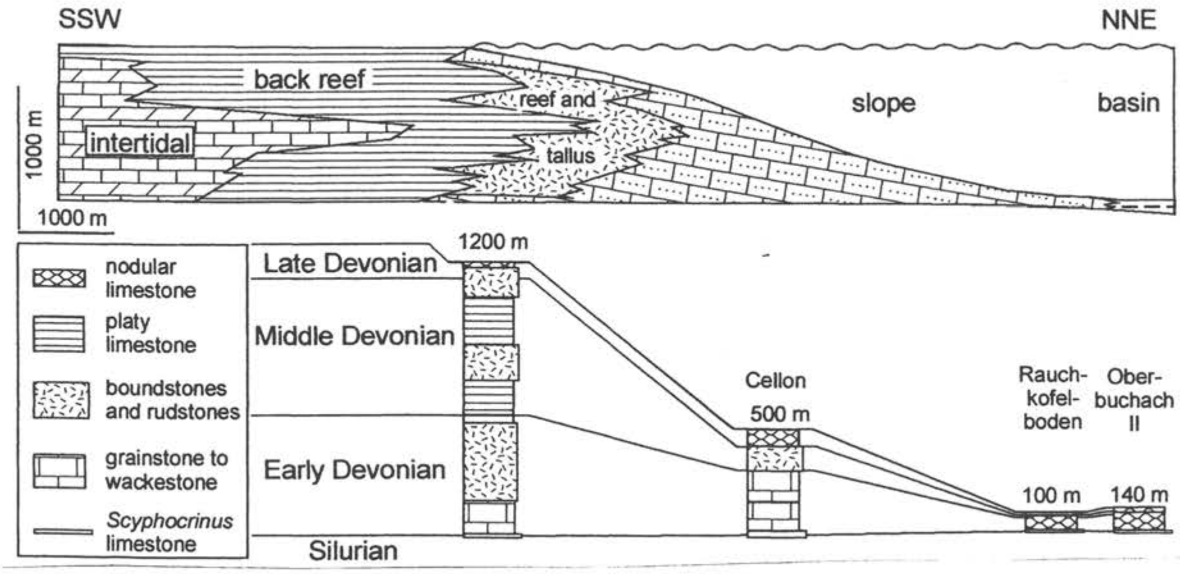


Fig. 14: Palinspastic reconstruction of the Devonian environments preserved in the different nappe units of the central Carnic Alps (modified from KREUTZER 1992).

The post-Hercynian sequences can be divided into several transgressive-regressive megacycles. Sedimentation started already during Moscovian with conglomerates, silty shales and thin limestone intercalations. Tectonically bound depot centres accumulated the highly cyclic thick Auernig Formation consisting of deltaic, paralic and marine deposits. The cyclicity is caused by the waxing and waning of the Permo-Carboniferous ice shield in Gondwana. The early Permian succession with the shallow marine Lower *Pseudoschwagerina* Limestone, the siliciclastic Grenzland beds, the Upper *Pseudoschwagerina* limestone and the Trogkofel carbonate mounds mirror the transition from inner shelf to outer shelf or platform margin environments (BUGGISCH et al.1976). Block tectonics at the Early/Middle Permian transition resulted in regression, erosion and deposition of continental red beds (Tarvis breccia and Gröden Formation). The following Late Permian transgression is documented in evaporites and restricted to open marine carbonates of the Bellerophon Formation (NOÉ 1987).

The Permo-Triassic boundary is situated within a few dm to m thick oolithic horizon (Tesero oolithe). The following Early Triassic Werfen Formation which corresponds to the transgression in the Eastern Alps again exhibits land derived siliciclastic input. Block faulting led to erosion and deposition of conglomerates during Anisian. Accompanying volcanic eruptions are evident in the green tuffs of the Anisian "Pietra verde". The Ladinian Schlern Formation – composed of bedded limestones and reef mound deposits – built up the youngest prominent mountain tops of the area visited during the excursion.

Day 5: Thursday, September 4, 2003

Overnight in Kötschach-Mauthen.

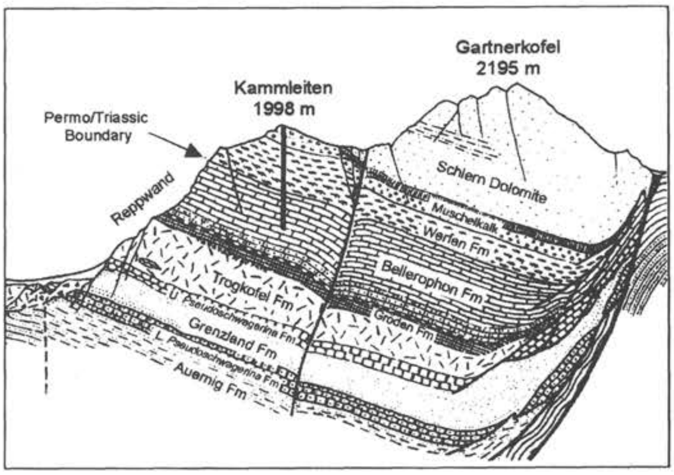
Drive southward to the Plöcken Pass (1360 m) at the Austrian/Italian border. From the pass we will climb up a small trail on the western slope towards the north and reach the Cellon avalanche ravine after about 30 min (Stop 5-23). Afterwards we will cross over into the Valentin Valley and climb about 1000 m up to the Valentin Törl (Pass 2238 m) which offers magnificent views (Stop 5-24). A short roundtrip enables us to reach outcrops exposing Ordovician to Carboniferous strata (black numbers 3 to 9 in Fig. 16). We will descend through the Valentin Valley to the Plöcken road or from Lake Wolay towards the north to the Hubertus Chapel and the village of Birnbaum.

Stop 5-23: Cellon

Stratigraphy (WALLISER 1964, KREUTZER 1992): An almost complete section spanning the Late Ordovician to Late Devonian is exposed in the avalanche ravine of the Cellon. We will visit only the basal part of the section up to the Pridolian – Lochkovian boundary, which is well defined within echinoderm grainstones. The following section is exposed:

Top	
Rauchkofel Limestones (80 m)	dark platy limestones with intercalated calcareous shales
Silurian/Devonian boundary	
Megaerella Limestone (8 m)	crinoidal to nautiloid limestones
Alticola Limestone (20 m)	grey to red crinoidal and nautiloid limestones
Cardiola Formation (3.5 m)	black bituminous limestones and intercalated black shales
Kok Formation (13 m)	calcareous shales at the base that pass into platy and nodular limestones
Plöcken Formation (4.8 m)	dark shales at the base overlain by crinoidal limestones and sandstones that dominate towards the top.
Uggwa Limestone (7.3 m)	argillaceous limestones with greenish siltstones
Base	

TRIASSIC	Ladinian	Schlern Formation
	Anisian	Muschelkalk Formation
	Scythian	Werfen Formation
PERMIAN	Tatarian	Bellerophon Formation
	Kazanian Kungurian	Gröden Formation Tarvis Breccia
	Artinskian	Treßdorf Limestone
	Sakmarian	Trogkofel Formation
	Asselian	Upper Pseudoschwagerina Limestone Grenzland Formation Lower Pseudoschwagerina Limestone
CARBONIFER.	Gzhelian Kasimovian	Auernig Formation
	Moscovian Bashkirian	
	Serpukhovian Visean	Hochwipfel Formation
	Tournaisian	Kronhof Limestone
DEVONIAN	Famennian Frasnian	Pal Limestone
	Givetian Eifelian	Cellon/ Valentin Limestone
	Emsian	Vinz Limestone
	Pragian	Kellerwand Limestone
	Lochkovian	Rauchkofel Limestone
SILURIAN	Pridolian	Megaerella-Alticola Limestone
	Ludlowian	Cardiola Formation Kok Formation
	Wenlockian	
	Llandoverian	
ORD.	Ashgillian	Plöcken Formation Wolayer Limestone/Uggwa Formation
	Caradocian	Himmelberg Sandstone/Uggwa Shale



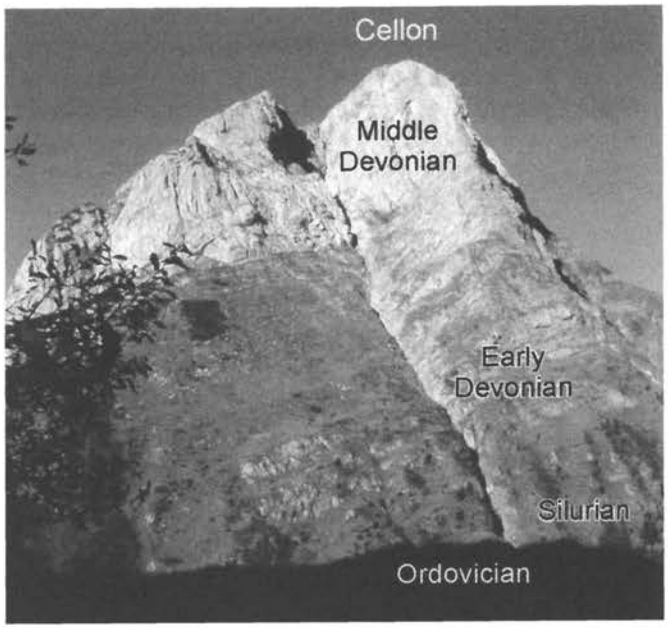


Fig. 15: Stratigraphy of the Palaeozoic rocks of the Carnic Alps (left), the Reppwand - Gartnerkofel section (upper right) [both simplified from SCHÖNLAUB & KREUTZER 1994] and the Cellon section (Photo Buggisch).

Stop 5-24: Valentin Törl (Törl = little pass)

Magnificent view of landscape, stratigraphy, facies units and tectonic style of the Lake Wolay region (Figs. 15, 16).

Stops 5-25 to 5-27: Rauchkofelboden

Strata from the Late Ordovician to the Middle Devonian are continuously exposed in the Rauchkofelboden section. The oldest sediments are Ordovician shales and sandstones (Himmelberg Sandstone) overlain by about 8 m of massive limestones (Wolayer Limestone) with Cystoids (echinoderms). Due to the glacio-eustatic regression, Llandoverian beds are missing. Wenlockian and Ludlowian limestones are condensed. The Pridolian is represented

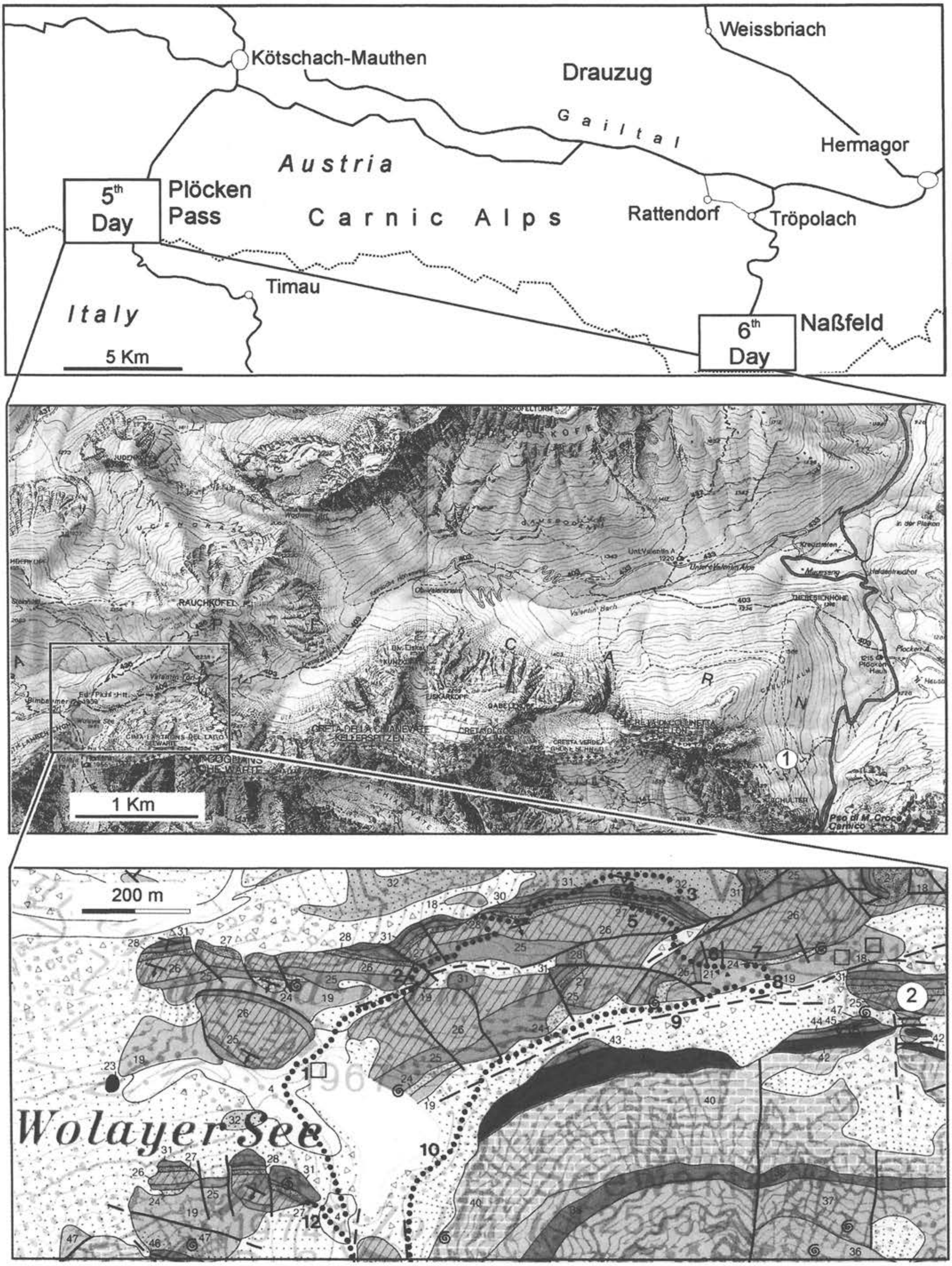


Fig. 16: Itinerary and maps for the 5th and 6th day: Central Carnic Alps; Area between Plöcken Pass and Lake Wolay, area between Valentin Törl and Lake Wolay (from SCHÖNLAUB 1988).

by dark nodular limestones of the Alticola Limestone. *Scyphocrinites* beds mark the Silurian – Devonian boundary. The basal Lochkovian limestone beds with shale intercalations (Rauchkofel Limestone) are extremely condensed. The Lochkovian – Pragian boundary is defined by the first appearance of *Nowakia* aff. *acuraria* and it is marked by a change in colour from grey to red (Findenig Limestone). The continuous Rauchkofelboden section is terminated by a fault.

Stops 5-28 and 5-29: Wolay valley west of Valentin Törl (2080 and 2100 m a.s.l.)

Frasnian deep water limestones with goniatites, stylinoids and conodonts overlain by intensely folded sandstones, breccias, and shales of the Hochwipfel Formation showing graded bedding, cross-beds and slump structures. Flysch facies of the rising Carnic Hercynian chains.

Stop 5-30: Large block of limestone at the margin of the "Wolay Glacier"

The block derived from the steep walls in the south. It consists of large crinoids and stromatoporids and represents the shallow water reef talus facies of probably late Middle Devonian age.

Stop 5-31: Wolayer Glacier (2040 m a.s.l.)

Emsian, Eifelian, Frasnian and Fammenian beds are exposed in the condensed Wolay Glacier section. Stylinoid-rich wackestones are exposed at the base of the section. Givetian rocks are almost missing – probably due to extreme condensation or omission. But mixed conodont faunas with Givetian and Early Frasnien elements are found in the phosphatic layer at the Middle/Late Devonian boundary. A 6 cm thick black shale unit is interpreted as equivalent of the Lower Kellwasser Limestone. Light-coloured bioturbated mudstones instead of black shales corresponding to the Upper Kellwasser Limestone are observed at the Frasnian/Famennian boundary. The youngest Famennian limestones (*crepida* conodont Zone) are disconformably overlain by Carboniferous flysch deposits (Hochwipfel Formation).

Day 6: Friday, September 5, 2003

Overnight in Kötschach-Mauthen.

Drive eastward to the Nassfeld Pass (1552 m) at the Austrian/Italian border. From the Watschinger Alm we will climb the "Reppwand Steig" with and without a trail to the Kammleiten (1998 m).

The Nassfeld area is famous for the post-Hercynian rocks of the Carnic Alps. All units will be seen from a distance. Along the hike we will have a close look to the Late Carboniferous

Auernig Formation and to the Middle Permian to Middle Triassic sequences from the Gröden Formation to the Schlern Dolomite (Fig. 15).

Day 7: Saturday, September 6, 2003

Mangfall valley. Drinking-water supply for the city of München.
80 % of the drinking-water for Munich is caught from springs and wells in the Mangfall valley 40 km SE of Munich. Source rocks are Pleistocene and Holocene gravel deposits. Aquiclude is the Tertiary Upper Freshwater molasse. More details will be given during the guided tour at Thalheim.

Return to Munich in the afternoon.

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Field Trip C
Glacial and Periglacial Phenomena in NE-Germany

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Introduction

This field trip focuses on glacial and periglacial phenomena in NE Germany, but it also supplies a little insight into the Tertiary paleoenvironments, the history of Quaternary research, modern coastal problems and neotectonic activity in the region (Tab. 1).

Date	Site	Exposure	Location	Stratigraphy
15. Sept. morning	Klieken	former diatomite pit	1.5 km W of Klieken, 2.5 km W of Autobahn A9, exit Coswig	• limnic diatomite sequence of the Holsteinian Interglacial
15. Sept. afternoon	Profen	opencast lignite mine	10 km N of Zeitz, 2 km W of road B2	• fluvial Eocene and marine Oligocene sequences, • Quaternary glacial and periglacial succession
16. Sept. morning	Hohburg	glacial striae, wind carvings	6 km NE of Wurzen, close to village Hohburg	• Permian porphyry • predominantly Weichselian glacial striae and wind carvings
16. Sept. afternoon	Rüdersdorf	quarry of Triassic limestone	25 km E of Berlin, 5 km E of Autobahn A11, exit Rüdersdorf	• salinar structures • Triassic limestones • Quaternary cover
17. Sept. morning	Schiffmühle/ Oderinsel	outcropping sediments on hill flank	15 km E of Eberswalde, at road B158, 6 km to Polish border at Oder R.	• push moraine of Weichselian ice margin, Pomeranian stage • periglacial sequences
17. Sept. morning	Rummelsberg	Inselberg	15 km NE of Eberswalde, at road B2, S of lake Parstein	• morphological view into a morainic arc
17. Sept. afternoon	Althüttendorf	sand pit	15 km N of Eberswalde, at Autobahn A11	• end moraine of Weichselian Pomeranian stage, • sander off Pomeranian ice margin
17. Sept. evening	Hohensaaten, Oder River	sand pit	20 km ENE of Eberswalde, at road B158, W shore of Oder River	• Late Weichselian melt-water sediments and terraces
18. Sept. morning	Fischland, Darß	cliff section, modern beach, modern dune	Peninsula at the coast of the the Baltic Sea, half way between Rostok and Stralsund	• Late Weichselian glacial and periglacial sediment formation • Holocene and modern coastal erosion and sedimentation

Tab. 1: Overview of sites to be visited during the field trip, with the dates, kind of exposure, location and stratigraphy.

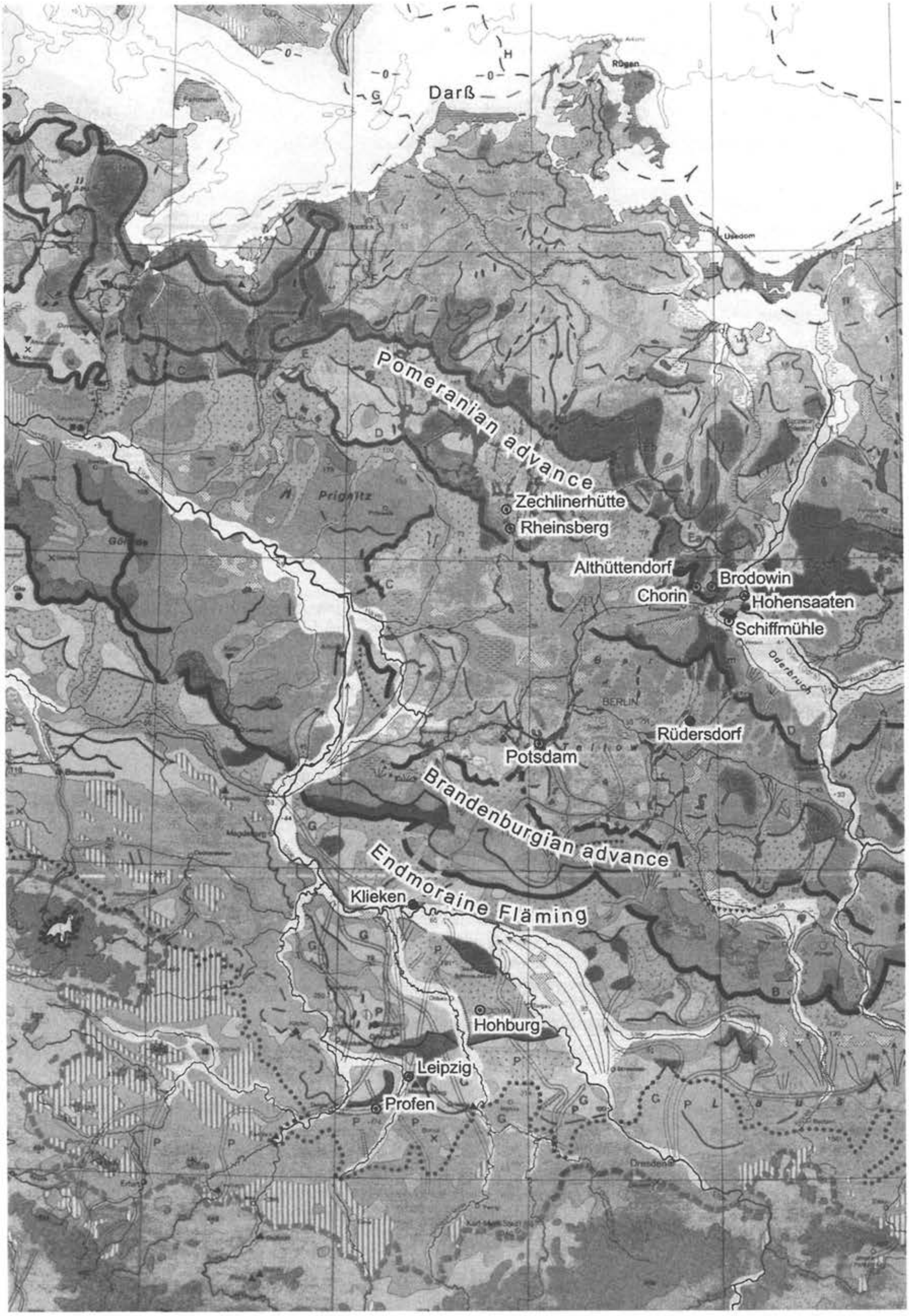


Fig. 1: Overview of the excursion route and distribution of quaternary sediments in northeastern Germany; base map after LIEDTKE 1981.

Northern Germany belongs to the southern part of the region inundated by Pleistocene glaciations from Scandinavia. The area was covered by ice sheets and glaciers during the Elsterian, Saalian and Weichselian glacials (names deduced from rivers in Germany and Poland), showing individual fluctuations in ice edge positions, respectively (Fig. 1, Tab. 2). The southernmost ice advance occurred during the Elsterian glaciation (475–370 ka BP). It extended from the Erzgebirge via Lower Saxony towards the Ruhr area. The north European ice cap was not in contact with the glaciers of the Alps. Therefore, the correlation of the glaciations in space, genesis and time is still only partly succeeded.

						ka BP
Quaternary	Holocene					10.2
Quaternary	Late Pleistocene	Weichselian Glaciation	Late Weichsel.	Dryas episode		13
			Main Weichsel.	Mecklenburgian advance Pomeranian advance Brandenburgian advance		24
			Early Weichsel.	*multiple alternation of cold and warm climates*		115
		Eemian Interglacial				128
	Middle Pleistocene	Saalian Glaciation	Late Saalian Glaciation			
			Main Saal.	Warthe advance		
				Drenthe advance		
			Early Saalian Glaciation *multiple alternation of cold and warm climates*		Holsteinian Complex	347
		Holsteinian Interglacial				370
		Elsterian Glaciation	Late Elsterian Glaciation			
			Main Elster.	2nd Elsterian advance		
				1st Elsterian advance		
			Early Elsterian Glaciation			475
		Cromerian Complex				780
	Early Pleistocene	*multiple alternation of cold and warm climates*				1800
Tertiary						

Tab. 2: Quaternary stratigraphy in northern Germany (simplified after LIPPSTREU 2002).

The geomorphology of northern Germany is mainly the result of the repeated overriding by inland ice attaining a few kilometres of maximum thickness. The processes associated with the glaciations formed sediments of about 80 m thickness, covering more than 95 % of northern Germany. The deposits comprise tills of different origin, glacial outwash sands in plains, fluvial sediments in valleys and lacustrine sediments in lakes. Exaration, erosion and glacitectonic movement has extensively modified the sedimentary sequences. The variable formation of push moraines and other end moraines, both arranged like festoons, was caused by changing glacier dynamics along the edge of the inland ice. The features in northern Germany can be compared with those of moraines formed by modern glacier and ice cap edges in Antarctica, Greenland and Spitsbergen, where ice velocities vary from several 100 m/year to almost stagnant ice in adjacent areas. Characteristic for the glaciation in northern Germany is the formation of deep channels, penetrating up to more than 500 m into pre-Quaternary deposits. These deep channels are probably created by subglacial glacio-fluvial erosion as the result of interaction between exogenic and endogenic factors of the landscape formation (STACKEBRANDT & MANHENKE 2002).

The Late Quaternary glacials in northern Germany are characterized by cold but variable climate, leading to distinct stadials and interstadials. Besides the Holocene, two interglacials with warm to moderate climate occurred: the Eemian and the Holsteinian. These interglacials had individual temperature and precipitation developments; mean temperatures partly increased to a level higher than those of today. During the interstadials and interglacials in northern Germany the ice masses thawed and retreated, and the vegetation redeveloped. The formation of the Quaternary landscape created two types of morphogenetic units, the glacial "uplands" and the (glacio)-fluvial "lowlands". To the latter the broad water cources (Urstromtal) in front of the ice sheet belong, which allowed discharge of glacial melt water carrying a high amount of debris.

Leipzig Lowland

The Leipzig Lowland (in German "Leipziger Tieflandsbucht"), constituting the southern part of the region visited during the field trip, is the type area of the Elsterian and Saalian glaciations in Europe (EISSMANN 2002). The area is delimited by the rivers Werra in the west and Neisse in the east, the Erzgebirge and the Lausitz mountain ranges in the south and the Fläming ridge in the north (Fig. 2). It includes lowlands, hills and subdued mountain regions, and is characterized by largely fertile soils developed upon thick deposits of loess and till. Aquifers are well developed, mainly within Quaternary gravel bodies. Rich mineral resources, exploited since pre-historic times, include tin, silver, lead, cobalt, copper and uranium. Many of these resources are now exhausted, though the Zechstein salt deposits remain important. Brown coal occurs over a region of more than 10.000 km^2 in the Leipzig Lowland and Niederlausitz. These deposits typically consist of two or three seams of Eocene, Oligocene and Miocene ages. Their presence led to intense and extensive opencast mining even before World War I. At various times since World War II, up to 59 opencast mines had been active in the area between the Harz Mountains and the river Neisse, reaching depths of up to 130 m. Following the German unification in 1989, most of these mines have successively been closed.

The characteristic feature of the Quaternary geology in the Leipzig Lowland is a sequence of more than 50 horizons and complexes of glacial (laminated clays, tills, glaciofluvial sediments) and periglacial facies such as (river gravels, gelifluction sheets, alluvium, loess (Eissmann 2002). In the period between the younger Tertiary and the first Elsterian continental glaciation, at least four gravel terraces were built up under cold climatic conditions (Fig. 3). The youngest of these gravel bodies lacks Scandinavian rocks and is interbedded with Elsterian glacio-lacustrine deposits. Pre-Elsterian temperate periods have been recorded at a number of places. Two major ice advances with additional minor oscillations have been identified, of Elsterian and Saalian ages. Consistently smaller extensions from one to another ice advance led to an inimitable preservation of the Elsterian and Saalian glacial series in Europe. Complete

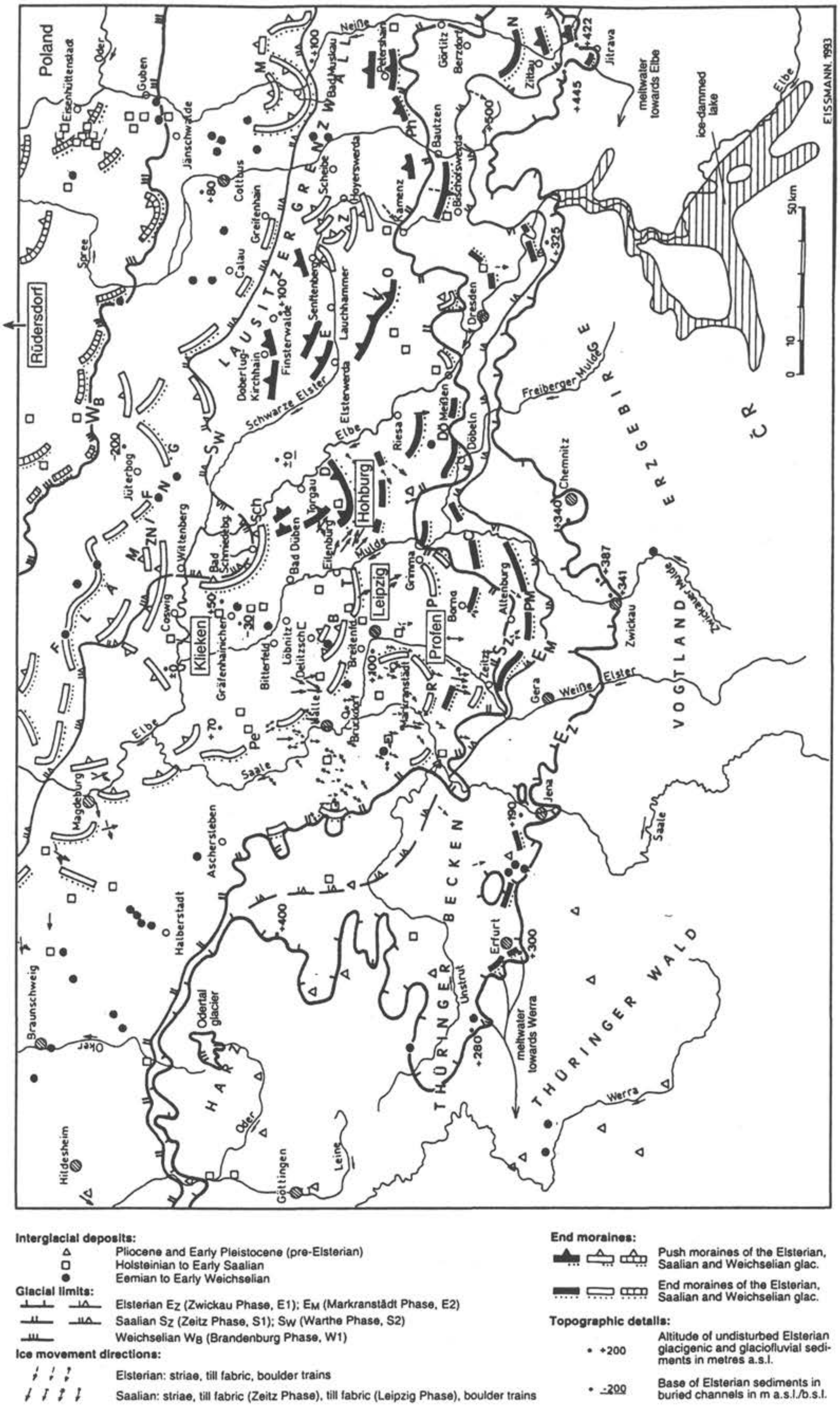


Fig. 2: Map of the Leipzig Lowland illustrating the glacial limits and flow directions of different Elsterian, Saalian and Weichselian phases, the locations of different interglacial deposits (after EISSMANN 2002), and the locations of exposures to be visited during the field trip (framed names). B = Breitenfeld, C = Colditz, D = Dahlen, Dö = Döbeln, E = Elsterwerda, F = Fläming, M = Muskau, N = Niederolderwitz, O = Ostrand, P = Pomßen, Pe = Petersberg, Ph = Petershain, PM = Pening-Meuselwitz, R = Rückmersdorf, Sch = Bad Schmiedeberg, T = Taucha, Z = Zeißholz-Liebegast, ZN = Zahna-Nudersdorf.

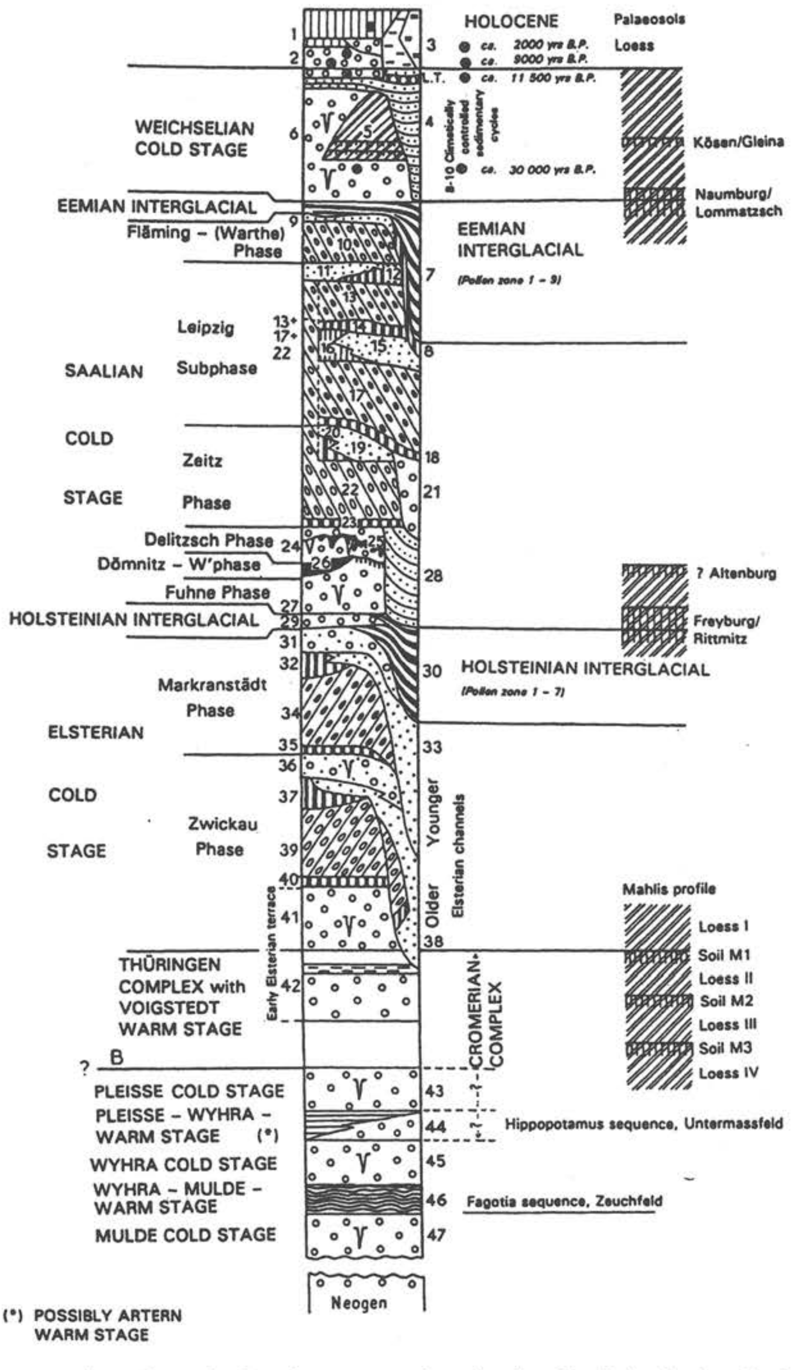


Fig. 3: Columnar section through the Quaternary deposits in the Leipzig Lowland (from EISSMANN 2002). Holocene: 1 - Younger and Older Floodloam; 2 Younger and Older Floodplain Gravel with dated wood fragments; 3 - silt, marl and peat (fills of small valleys and depressions); Weichselian: 4 - deluvial, deluvial-fluvial and limnic sand, silt and marl of minor valleys and depressions, with Laacher See Tephra (L.T.); 5 - loess complex with palaeosols; 6 - fluvial gravel (Lower Terrace) with dated plant remains; Eemian: 7 - limnic silt, mud, clay, locally peat; Saalian: 8 - Late Saalian warved clay; 9 - glaciofluvial and fluvial sand and gravel; 10 - till of the Fläming (Warthe) Phase; 11 and 12 - glaciofluvial or glaciolacustrine sediments; 13 - Second Saalian Till, upper unit of the Leipzig sub-Phase; 14 - Breitenfeld (advance) varved clay; 15 - glaciofluvial sand and gravel; 16 - Breitenfeld (retreat) warved clay; 17 - Second Saalian Till, lower unit; 18 - Bruckdorf (advance) varved clay; 19 - glaciofluvial sand and gravel; 20 - Bruckdorf (retreat) varved clay; 21 - Pomssen mixed gravel; 22 - First Saalian Till; 23 - Böhlen-Lochau (advance) varved clay; 24 - upper gravel; 25 - Markkleeberg Cryoturbation Horizon; 26 - limnic silt and fine sand with plant remains; 27 - Lower Gravel; 28 - deluvial, soliflual and limnic fine sand and silt; Holsteinian: 29 - mostly fine-grained fluvial gravel; 30 limnic silt, mud, marl, diatomite, peat; Elsterian: 31 - mixed gravel; 32 - varved clays and clays; 33 - glaciofluvial sand and gravel; 34 - Upper Elsterian Till; 35 - Miltitz (advance) varved clay; 36 - mixed gravel; 37 - Brösen varved clay; 38 - glaciofluvial sand and gravel; 39 - Lower Elsterian Till; 40 - Dehlitz-Leipzig (advance) varved clay; 41 and 42 - fluvial gravel of the Early Elsterian terrace; 43, 44 and 47 - fluvial gravel (Lower, Middle and Upper Early Pleistocene terraces); 45 - gravel, silt; 46 - silt, sand (limnic to fluvial); B/M - Brunhes-Matuyama Boundary (780 kyr BP); wedge symbol - ice-wedge pseudomorphs.

Eemian and Holsteinian sequences are represented showing vegetational development through each interglacial cycle (cool, temperate-warm, cool). The Weichselian glacial stage is represented by periglacial deposits, including gravels, gelifluction sheets, alluvium, debris covers and loess. Within these sediments a wide variety of glaciotectonic structures and periglacial soil structures occurs, including classical involutions and ice-wedge casts.

During the field trip in the Leipzig Lowland limnic diatomites of Holsteinian age are visited in the Klieken pit, about half way between Berlin and Leipzig (Tab. 1). Fluvial Eocene and marine Oligocene sequences, including thick lignite seams, and parts of the Quaternary glacial and periglacial succession, can be seen in the Proven open cast mine to the south of Leipzig. Back on the way north, another stop is made in the Hohburg Mountains, where glacial striae and wind carvings occur that have been interpreted as evidences for an inland glaciation already by MORLOT (1844) and NAUMANN (1848).

Stop 1: Klieken diatomites (after KNOTH et al. 1995)

The village Klieken is located in a glacial outwash plain in front of the Fläming end moraine that represents the "Warthe line" of the Saalian glacial. The diatomite sequence in the Klieken pit was formed during the previous interglacial, the Holsteinian. Deposition took place in an elongated, NW to SE trending basin of 1200-1500 m length and 300-400 m width (Fig. 4a). The basin follows an Elsterian subglacial stream channel linked to the Elbe depression, where the base of the Quaternary deposits is below sea level. As known from several boreholes, the Holsteinian lacustrine sequence is underlain by 40 to 50 m of Elsterian glaciofluvial, fine to medium grained sand of grey color and rich in reworked lignite (Fig. 4b). Outside the stream channel Elsterian till occurs.

The Holsteinian lacustrine sequence starts locally with a thin layer of peat, followed by 0.5 m to more than 2.0 m of lake marl and subsequent calcareous mud. The overlaying diatomite is calcareous in its lower part. In the upper part the diatomite is rich in organic matter and is termed "black glossy fuel peat" (or in German "Lebertorf"). The total thickness of the interglacial sediments reaches up to 17 m (Fig. 4a and b). One remarkable aspect is the presence of vivianite in nodes.

Palynological investigations of the Holsteinian diatomites were undertaken by MAJEWSKI (1961) and LENK (in KNOTH et al. 1969). The pollen diagram is dominated by *Alnus* and *Pinus* pollen (Fig. 5c), whose high portions complicate the interpretation. Nevertheless, the diagram clearly comprises the zones 3 to 7 after ERD & MÜLLER (1977), with the climate optimum represented by zones 5 and 6, characterized by maxima of *Carpinus*, *Abies* and *Tilia*. The diatom assemblage shows great diversity. Altogether 233 species belonging to 28 genera have been determined. The most frequent species are *Stephanodiscus astrea* var. *Minutula* (Kütz.) Grun., *Stephanodiscus dubius* (Fricke) Hust., *Cyclotella comta* (Ehr.) Kütz., *Cyclotella kuetzingiana* (Ehr.) Thaites, *Melosira granulata* (Ehr.) Ralfs, and *Melosira ambigua* (Grun.) Müller. Based on quantitative interpretation of the diatom assemblages, KRÜGER (1975) identified four sections reflecting increasing degrees of trophy in the lake. The water depth averaged 10-15 m and did not extent 20 m (DASSOW 1988).

The diatomites are overlaid by 6-12 m of predominantly Saalian sediments. They comprise laminated and cross-bedded glaciofluvial sands, partly containing reworked diatomite, and intercalations of glaciolacustrine silt and decalcified basal tills. During the Weichselian glacial, the region remained unglaciated. Permafrost conditions are evidenced by cryoturbate structures at the base of the modern soil, where a stone layer with wind-shaped pebbles, known as "Windkanter", occurs.

The Holsteinian lacustrine sequence and the overlaying Saalian sediments are folded and faulted. Some E-W striking ridges can be considered as ice-pushed folds formed by the inland

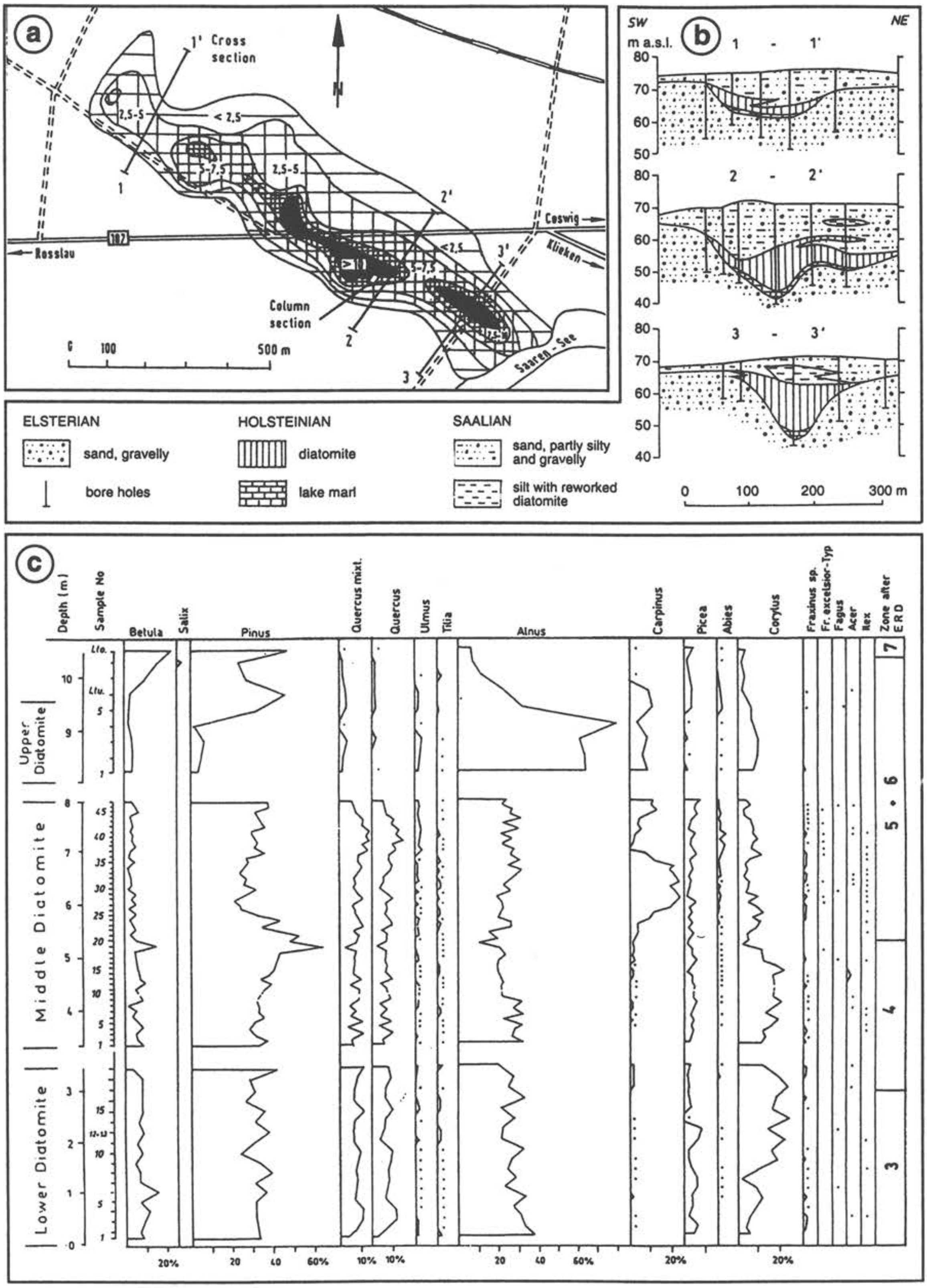


Fig. 4: Holsteinian diatomites near Klieken (after KNOTH et al. 1995). (a) Map showing the extension and thickness of the diatomites. (b) Cross-sections through the quaternary deposits close to Klieken. (c) Tree pollen diagram of the diatomites; dots indicate portions below 0.5 %. For locations of (b) and (c) see (a).

ice during the Saalian glacial. Faults in the glaciofluvial sand, in contrast, are the result of settlement processes, and slump marks, convolute bedding and glide planes within the diatomite, are probably caused by subaquatic slumps and slides from the slopes of the relatively narrow groove lake.

The diatomite was first mined in the 19th century. The pit was abandoned in 1993. According to its composition and petrophysical properties, the Klieken diatomite is impure and of relatively low quality. It was mainly used for heat insulation purposes in the form of light weight bricks. Small quantities of better quality have been used as a catalyst carrier for the production of sulphuric acid. The reserves are almost exhausted, with the exceptions of small blocks of material between the pit and the road running from Rosslau to Coswig and below the small road at the southeastern end of the deposit.

Stop 2: Profen opencast lignite mine (after JUNGE et al. 1995)

The Profen opencast mine is situated in the southwestern part of the Leipzig Lowland, to the northeast of the town Zeitz. Due to its peculiar pattern of sedimentation, which resulted in an especially high seam thickness (Fig. 5), the Profen mine is one of the two mines in central Germany where lignite extraction is set to continue for another several decades. The following description and interpretation of Pre-Tertiary, Tertiary and Quaternary deposits is mainly based on JUNGE et al. (1995).

The Pre-Tertiary substructure of the Profen mine is generally composed of Precambrian sediments of the north Saxon complex of greywackes as well as sediments from the marine Zechstein salt deposits. The subrosion processes of the salt deposits, which began in the Upper Cretaceous and persisted during several Tertiary and Quaternary periods together with epirogenic lowering, resulted in considerable lignite aggregation ("caldera"), dish-shaped subsidence of the layers ("holes") and collapsed sinks. Remains of the reduced Lower to Upper Eocene Geisel valley sequence are to be found in dolines, forming the oldest Tertiary deposits. The basis of the deepest seam, the Saxon–Thuringian under-seam (seam I) is formed by fluvial to limnic deposits ("Profen clay", "river sands"). Thickness of seam I usually is 2-4 m, while in syngenetic subrosion structures it rises to 25-35 m thickness, with a maximum of 75 m. The hanging topsoil clay ("Deckton") of seam I, which completes the Middle Eocene lignite formation, is overlaid by Upper Eocene fluvial sands ("Zeitz sands"). These are covered by the "Luckenau clay", which forms the basis of the "Thuringian main seam" (seam III). Between the Upper Eocene seam II and the Middle Oligocene seam IV ("Böhlen upper seam" are fluvial to limnic sediments ("Younger Zeitz sands", "Haselbach clay") and exposed marine-littoral-estuarine sediments ("Domsen sequence" with local silification zones, Tertiary quartzites). Marine Middle Oligocene sands and silts, which are only to be found in subrosion basins, complete the Tertiary sedimentation.

The oldest Quaternary sediments consist of gravelly deposits of the Early Pleistocene Saale and White Elster rivers. They are overlaid by deposits from the Elsterian glaciation. The classical order is: Dehlitz-Leipzig varved clay (up to 80 cm thick and with 60 varves), first Elsterian till, glacifluvial sands and gravels, and locally second Elsterian till. The second glaciation period, the Saalian, started with deposition of the Early Saalian gravel terrace of the White Elster. The transition zone from this fluvial facies to the overlaying, ca. 10 cm thick glaciolimnic sediment of the Böhlen-Lochau varved clay is formed by a littoral sediment ("Schlepp"). Peculiarities are shells found above the varved clay in gravitationally relocated sediments, and a thin layer of mosses (tundra vegetation) occurring directly beneath the varved clay. The Pleistocene sedimentation is completed by the first Saalian till, Weichselian loess on the flat upland area and thick muds and alluvial sediments in the Saalian valley side area of the White Elster.

In the Profen mine impressive dislocations of the seams in the form of diapiric upwedgings are exposed. This coal diapirism produced a picture of narrow, irregularly oriented coal crests of

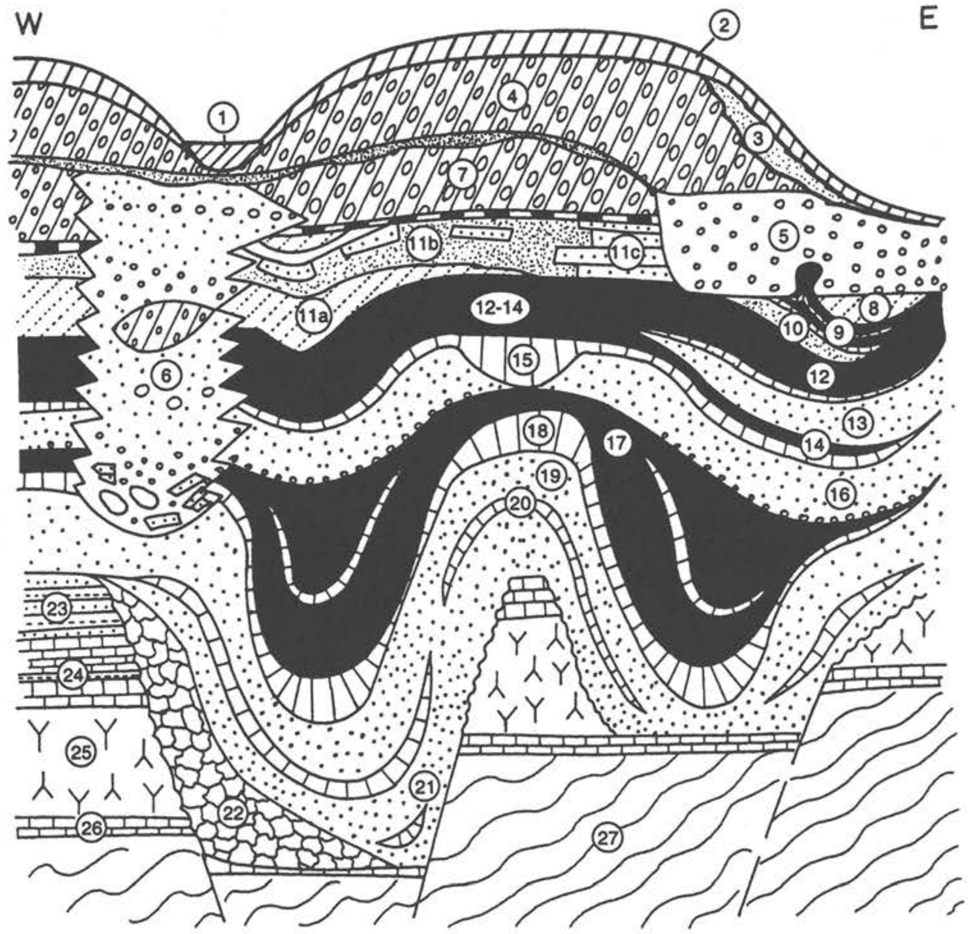


Fig. 5: Geological cross section through the Caenozoic and Pre-Caenozoic sequence in the Profen opencast lignite mine (after EISSMANN 1994). 1 - holocene fluvial sediments ("Auelehm"); 2 - Weichselian loess; 3 - late Saalian solifluction sediments; 4 - Saalian till; 5 - early Saalian fluvial sediments ("Hauptterrasse") of the river Weiße Elster; 6 - late Elsterian glaciofluvial sediments of the Döbris glacial channel; 7 - Elsterian till with Dehlitz-Leipzig varved clay at the basis and glaciofluvial sediments at the top; 8 - marine silts and sands from the middle Oligocene (Rupelian); 9 - Böhlen seam layer complex (upper, middle and lower bank); 10 - Haselbach clay and sand; 11 - marine to estuarine sediments of the Domsener Layers (a - silt, b - sand, c - silicious sands, Tertiary quartzites; 12 - upper bank with basal clay of the Thuringian main lignite horizon; 13 - fluvial sands (intermediate "Zeitz sands"); 14 lower bank of the Thuringian main lignite horizon; 15 - Luckenau clay; 16 - fluvial sands (older "Zeitz sands"); 17 - Saxon–Thuringian under-seam; 18 - Profen clay; 19 - fluvial sands; 20 - clay in the lowest groundwater layer complex; 21 - deeper Tertiary groundwater layers; 22 - subrosion features (karst); 23 - sediments from Lower Bunter and Zechstein ("Zechsteinletten"); 24 - carbonates of the Stassfurt and Leine evaporation cycles; 25 and 26 - anhydrite and carbonates from the Werra cycle; 27 - folded and deformed Palaeozoic and Proterozoic rocks.

more than 100 m length and over 10 m height, and of widely extending rim synclines with various fillings (fluvial gravel, tills, meltwater sediments). Apart from the areas, where diapirs frequently appear, there are also areas with undisturbed seam stratification. In general, the diapiric upwedging structures developed through autoplastic solicinetic processes (EISSMANN 1981). A gravitative displacement of water-saturated, highly mobile lignite by superposed, more heavy fluvial gravels and tills took place during times of permafrost ground degradation. Several diapirs evidence a multiphase genesis (EISSMANN 1987). Two phases of lignite ascending are indicated in the schematic geological cross section through the Profen mine (Fig. 5): an Early Saalian phase demonstrated by the thickness increase of the Early Saalian gravel terrace in the rim syncline, and an Early Weichselian phase demonstrated by the lignite intrusion into the Weichselian loess.

Stop 3: Hohburg Mountains (after EISSMANN & MÜLLER 1994)

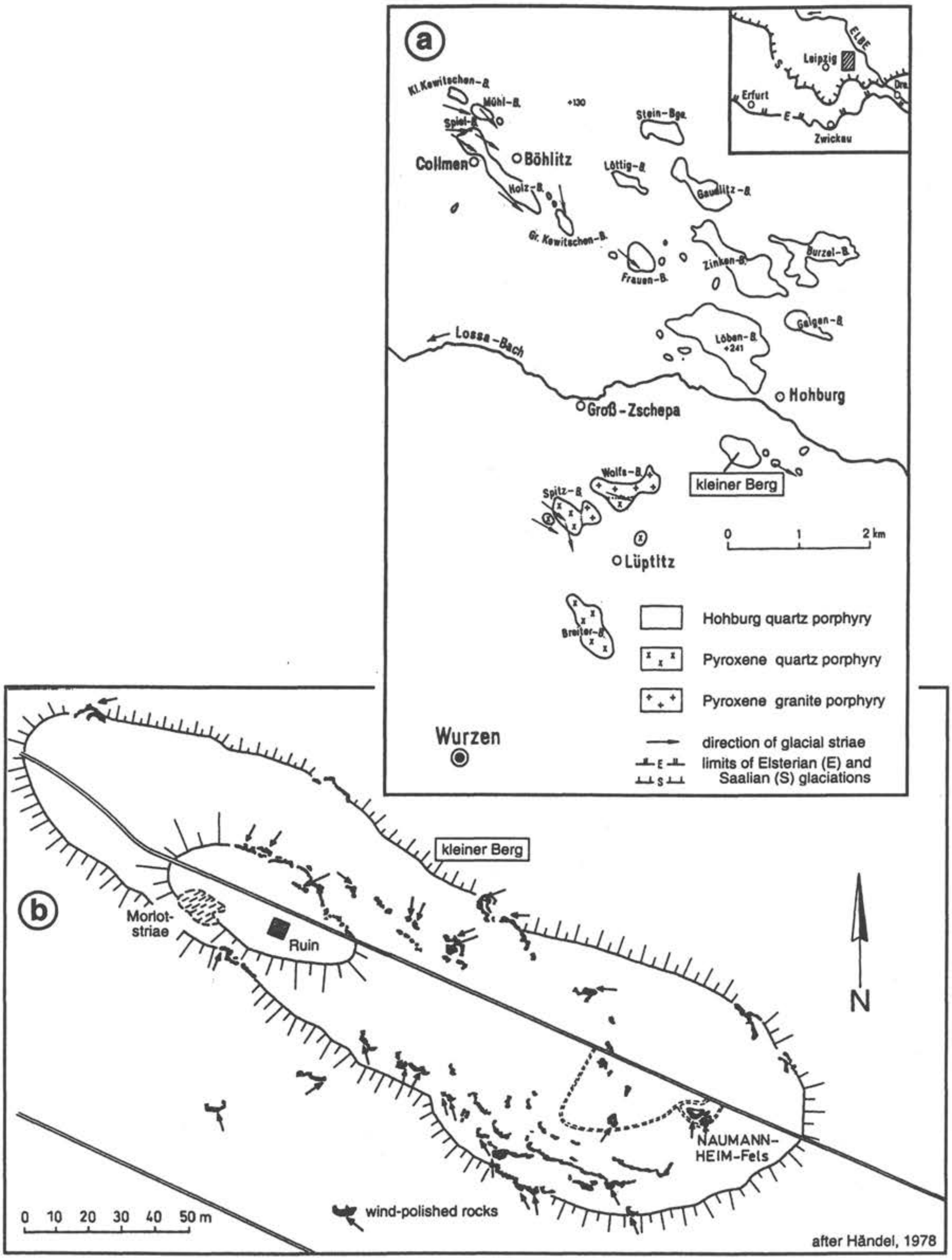


Fig. 6: Glacial striae and wind polish in the Hohburg Mountains, to the east of Leipzig (after EISSMANN & MÜLLER 1994). (a) Scetch map of eminences of porphyry rocks on the Hohburg Porphyry Hill Country near Wurzen (see inset for large-scale overview) showing directions of glacial striations. (b) Scetch map of the top of the "Kleiner Berg" ("Little Mountain") with the locations of Morlot-striae and wind-polished rocks.

As most of the northwestern Saxonian porphyry hills, also the "Kleiner Berg" ("Little Mountain") close to Hohburg exhibits an asymmetric shape and a smoothed surface formed by glacial erosion. Besides few real glacial striae (Morlot striae), various wind-polished rocks occur, being best preserved on steep to vertical surfaces at the edge of the hill top (Fig. 6).

The striae were first interpreted as being of glacial origin by MORLOT (1844) and NAUMANN (1848), remarkable three decades before the glaciation of northern Germany by Scandinavian ice masses became widely accepted. Even in the seventies of the 19th century, famous scientists such as HEIM (1874) and CREDNER (1874) disagreed with the glacial origin of the striae on the Saxonian porphyry hills. A few years later, however, CREDNER (1879) corrected himself. One reason for the inconsistent interpretation for such long time was found by DALMER (1883), who first recognised that only some of the features on the rock surfaces are glacial striae, whilst others are of different origin.

The eolian origin of various features on the Saxonian porphyry hills was deduced by GRAHMANN (1957) and HÄNDEL & HÄNSEL (1980). Some slickenside-like furrows, extending only a few centimetres to decimetres, may represent features that were originally produced by tectonic activity, rock cooling or glacial erosion, but later became polished by sediment-laden winds. The furrows are 2-3 mm wide and deep. On surfaces exposed to the S and W they gleam like varnish, and at some places they fade to circular impact marks.

The formation of the wind-polished features is believed to have taken place predominantly during the Weichselian glacial, though some features may bave been formed already during the Saalian glacial. At the "Kleiner Berg", HÄNDEL & HÄNSEL (1980) reconstructed highly variable wind directions, covering all but westerly winds, and assumed that the features were formed under an arid climate with restricted vegetation predominantly by easterly winds, which were ascending at the hill slope and at least periodically had high velocities (northeasterly storms in winter times).

Northeastern Germany

Northeastern Germany, visited during the second part of the field trip, comprises the states Brandenburg and Mecklenburg-Vorpommern. There, the southern and the northern upland belts, representing the Fläming end moraine in the south and the Pomeranian end moraine in the north, are the dominant landscape features. In between, broad melt-water courses occur. Their concentration in central Brandenburg and along the river Elbe towards the North Sea during glacials had formed the drainage zone for both melt water from the ice sheet and precipitation water from the mountainous regions to the south. In this zone neotectonic subsidence (dominantly along faults) took place during the past 35 Ma, visible from the North Sea via Hamburg and Berlin to southern Poland (STACKEBRANDT & LUDWIG 2002).

In Rüdersdorf, to the east of Berlin, a classical site of quaternary glacial geology is visited (Tab. 1). The finding of glacial striae on top of Triassic limestone in Rüdersdorf by the Swedish geologist Otto TORELL (1875) was the breakthrough for the theory of an inland glaciation in northern central Europe. A few years later, PENCK (1879) distinguished three glacial and two interglacial periods in the Quaternary (at that time called "Diluvium") sequences of the region based on fossil-bearing sediments. KEILHACK (1896) later inaugurated the terms Weichselian, Saalian and Elsterian for the three glacials.

Subsequently, the excursion proceeds northward to the Oder River and the Polish borderland. There, a moraine belt formed during the Pomeranian ice advance of the Weichselian glaciation is well developed, forming the most prominent morphological feature of the North-German Lowlands. The most important elements in glacial formation of the Pomerania advance are visited.

Finally, modern geological processes are visited in the Fischland and Darß areas (Fig. 1) at the coast of the Baltic Sea to the northeast of the seaport Rostock. There, intense sediment accumulation takes place in the Holocene between older Pleistocene complexes. Coast sedimentation, coast protection and influence of sea-level fluctuation are amongst the topics to be discussed.

Stop 4: Rüdersdorf (after JUBITZ et al. 2001)

The Rüdersdorf exposure of Triassic sediments within the North German Lowlands, covered by Tertiary and Quaternary sequences, is a unique geologic monument (Figs. 7 and 8). Already in the first half of the 13th century, the Middle Triassic limestones allowed access to their exploitation. Five centuries later first scientific descriptions were published. KLÖDEN (1828) dealt with stylolites (Säulenstein = columnar rocks), making Rüdersdorf the *locus typicus* for these compressive structures. Of historical interest is also the first measurement of the temperature in a bore hole in 1833. The observations of glacial striae on top of a pavement on Triassic limestone by TORELL (1875) brought the breakthrough of the inland ice theory for the Pleistocene glaciations in the scientific community.

Under the aspect of regional geology Rüdersdorf is only one of numerous salt structures (salt pillow, salt diapir, salt ridge) in the North German Lowlands. These structures form the saline and supra-saliniferous sequences in their tectonic shape. However, the Rüdersdorf exposure is a unique salt structure triggered by a pillow of Zechstein salt (Upper Permian) because it is offering deep outcrops of Triassic sequences. The sub-saliniferous sequences are represented by volcanic rocks of Late Carboniferous to Early Permian ages, overlain by Rotliegend sediments (Lower Permian).

In the geological structure Rüdersdorf the thickness of Zechstein salt is increased by salt movement (accumulation) to 2500 m and the top of the saliniferous sequence ascends to –500 m a.s.l. The salt accumulation in pillows is compensated by salt removing from primary marginal deeps where the salt thickness is reduced. Due to the extension on top of the salt structure the post-saliniferous sequences show extension structures as "Y"-like grabens. The northern part of the structure experienced the most intense uplift. Here, Upper Bunter (Röt) and Muschelkalk are exposed at the surface. Halokinetic activity is constrained in age: Early Kimmerian (Late Triassic) very weak, late Kimmerian (turn Jurassic/Wealden) and Subhercynian to Laramian (Cretaceous/Tertiary) as the main period, Early to Middle Miocene, Pleistocene and Holocene ages of completing activities.

The outcrops of Middle Triassic (Muschelkalk) sequences in Rüdersdorf and the results fom adjacent bore holes characterise the facies of the epicontinental (Germanic) Muschelkalk in the realm east of the Elbe river:

- continuous transition of the carbonatic sequences of the Upper Bunter to the Lower Muschelkalk;
- massif-type oolithic Schaumkalk (foam limestone) corresponding to the Oolith layer to foam limestone in Thuringia;
- Middle Muschelkalk being represented by dolomitic subordinately weak saliniferous sequences;
- increased thickness of Muschelkalk (about 130 m) in comparison to less than 100 m in adjacent areas;
- occurrence of thick-layered glauconite-bearing limestone of the lowermost Upper Muschelkalk substituting crinoidal (Trochiten) limestone of Middle Germany.

Of special paleontological and palaeogeographic interest is the fauna that migrated from the Alpine realm (ammonoidea).

Jurassic and Cretaceous sequences reflecting also the Albian transgression are known from bore holes at the slopes and in the secondary marginal deeps of the Rüdersdorf structure. Furthermore, Tertiary deposits are present, representing the Rupelian and the Miocene. Pleistocene

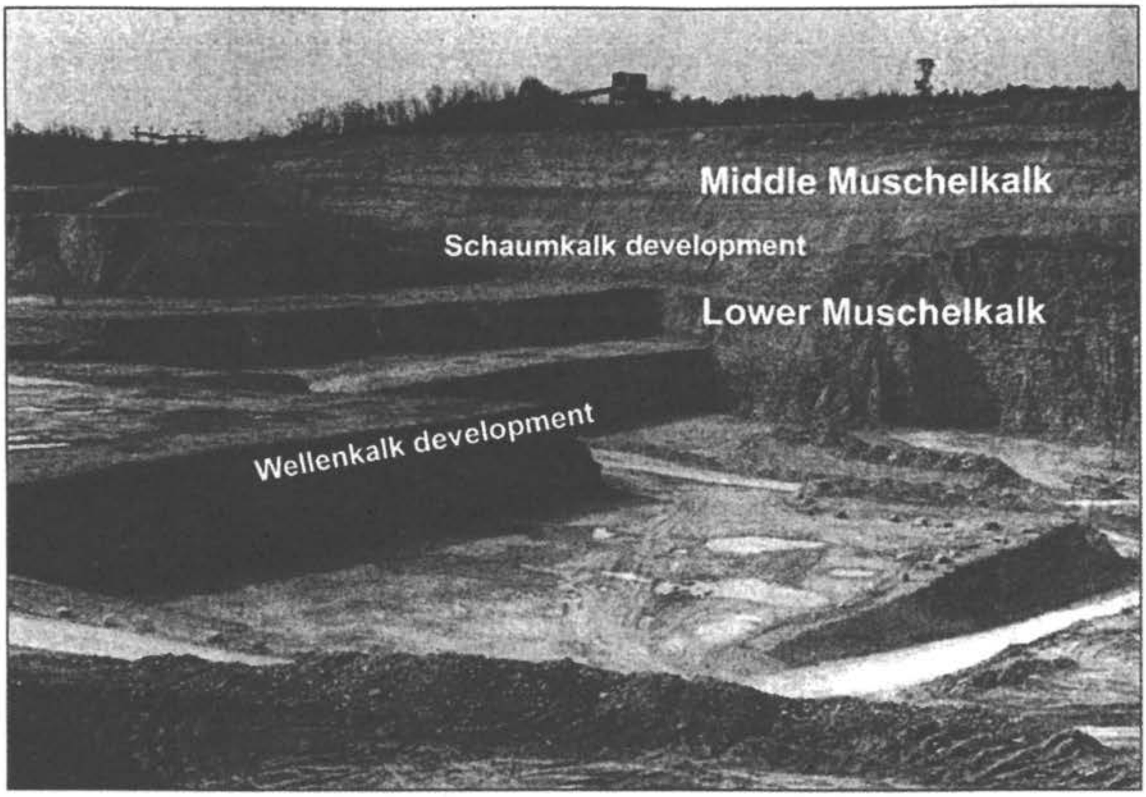


Fig. 7: Rüdersdorf, northward view into the Alvensleben quarry (Foto: K.B. Jubitz, 6. May 1996).

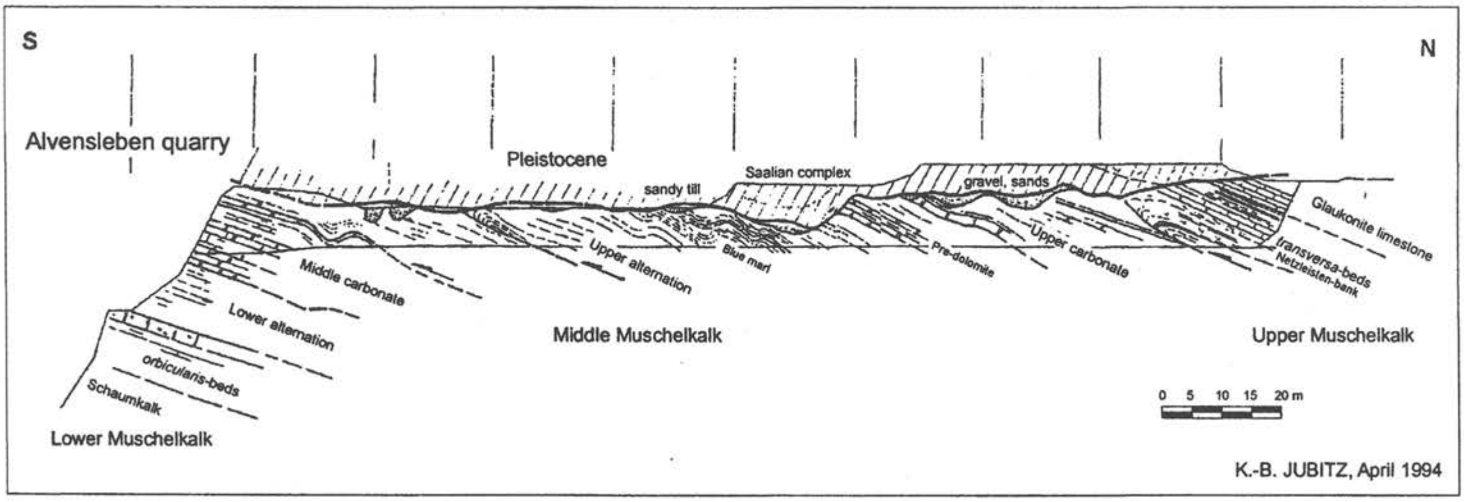


Fig. 8: Section of the Middle and Upper Muschelkalk and the Pleistocene sequence on the northern side of the Alvensleben quarry, Rüdersdorf (JUBITZ & WASTERNACK 1998).

deposits are wide-spread, represented by sediments of the Elsterian, Saalian and Weichselian glaciations, and the Holsteinian and Eemian interglacials. However, at the northern slope of the Rüdersdorf structure they are mostly removed or artificially covered by debris. Holocene sequences are built up by calcareous mud, silt and peat. In the peat layer the tuff of the Laacher See eruption (11,000 ^{14}C yrs BP) is present and functions as a reliable age marker.

The outcrops of the open-pit clearly reflect the tectonic structure and the facies/composition of the sequences of the uppermost Bunter to the Upper Muschelkalk, covered by Pleistocene sediments in a subglacial channel. The outcrops of the open pit are the result of economic exploration of the limestone/claystone deposits used for the production of cement. In a museum park of the "Rüdersdorf industry of constructing material" the history of the exploration, including the transport and the processing of the raw material, is shown in technical monuments. The modern production of burnt lime, cement, crashed limestone gravel, rock meal and fertilizer is performed in a modern cement factory.

In the open-pit the entire profile of the Muschelkalk is exposed: from the Lower Muschelkalk (Rüdersdorf Wellenkalk and foam limestone) in the southern and middle part of the quarry, via the Middle Muschelkalk (indicated by more light weathering colors) at the northern slope, to the Upper Muschelkalk (*Myophoria transversa* beds, glauconite-bearing limestone of Middle Germany) partly exposed beneath unconformly overlaying Pleistocene deposits (base moraine of the Saale Glaciation). In the area of a historical bridge Pleistocene sands crop out in an erosive subglacial channel that cuts the flank of the Rüdersdorf structure. The northward tectonic inclination of the Triassic sequences varies uniformly between 20° and 25°, only locally cut by normal faults of small amplitude and by crevasses due to the extension on the top of the structure.

Recent exploitation of the limestone is carried out along floor planes arranged in the strata trend, i.e. concentrically reflecting the top of the Rüdersdorf structure. Generally, the exploitation is directed towards the west, attaining a depth of 80 m below the level of superficial waters (34 m a.s.l.) at the northern part of the open-pit. Starting in the mid-50ties of the last century the blasting off bore holes has been applied. In the times before the exploitation technique was based on galleries chessboard-like drifted into the walls. Then the safety pilars remaining in the gallery system were blasted away and the walls collapsed. The exploitation needs extensive water pumping (20 m^3/min) from a drainage gallery at a level of –55 m a.s.l.

Of outstanding scientific interest is the interrelationship of the Rüdersdorf Quaternary sequences with the underlying lithified Muschelkalk limestones (local moraines, glaciodynamics, glacial striation, glacial mill, erosive channels, soil formation during interglacials and geologic pipes). Unfortunately, the classical monument of the glacial striae found and interpreted by TORELL (1875) and the glacial mills are removed.

Pomeranian ice advance (after MARCINEK et al. 1998)

The moraine belt formed during the Pomeranian ice advance of the Weichselian glaciation is the most prominent morphological feature of the North-German Lowlands. In the Brandenburg province the Pomeranian glaciers represented by the Oder glacier formed the Parstein arc in the east and the Joachimsthal arc in the west. Besides end rsp. push moraines the boulder occurrences reflect the quasi-stabile position of the ice edge. The glaciers were rich in sedimentary material, evidenced in outwash sediments accumulated in front of the ice edge. These sediments occur as outwash plain (forest Schorfheide), outwash channel (lakes Bugsinsee, Werbelinsee) and outwash cone (Althüttendorf). In consequence of the deglaciation, associated with younger ice margins (e.g. Angermünde), melt water courses returned into previous valleys and locally eroded them. Additionally, periglacial processes were active. The excursion reveals important elements in glacial formation of the Pomeranian advance.

Stop 5: Push moraine Schiffmühle/Oderinsel

Subsequent to the retreat to the Baltic Sea area and the thawing-off of the glaciers of the Brandenburgian advance colder climate conditions led to a new ice advance. In this Pomeranian advance (Figs. 1, 3; Tab. 2) large areas of northeast Germany again became covered by an ice shield that comprised the Oder glacier. Typical for the Oder glacier is the abundance of transported till, indicated in the relief of moraines. The result is a high variety of Pleistocene deposits already mapped by BERENDT & SCHRÖDER (1899) in the sheet Oderberg. Deposits comprise fluvial and glacio-fluvial sands in valleys, outwash deposits covering Tertiary sequences in the foreland, boulder concentrations in end moraines, as well as rhythmites and flat-lying glacial till in ground moraines of the hinterland. Ice-push processes attacked sequences ranging in age from the Miocene to the early Weichselian glacial down to a depth of -60 m a.s.l.

Stop 6: Brodowin, inselberg Rummelsberg

Under good weather conditions the Rummelsberg hill south of the lake Parsteiner See reveals an impressive overview of the hinterland of the Pomeranian ice advance: the end moraine arc in the south, and the glacial piedmont lake (Parsteinsee) associated with the end moraines of the younger Angermünde ice advance in the north. Besides an overview of the morpholopy the Quaternary sequences of this region will be explained on the base of geological sections. Furthermore, the Rummelsberg stop allows discussion on the formation of so-called inselbergs, characterized by its isolated position.

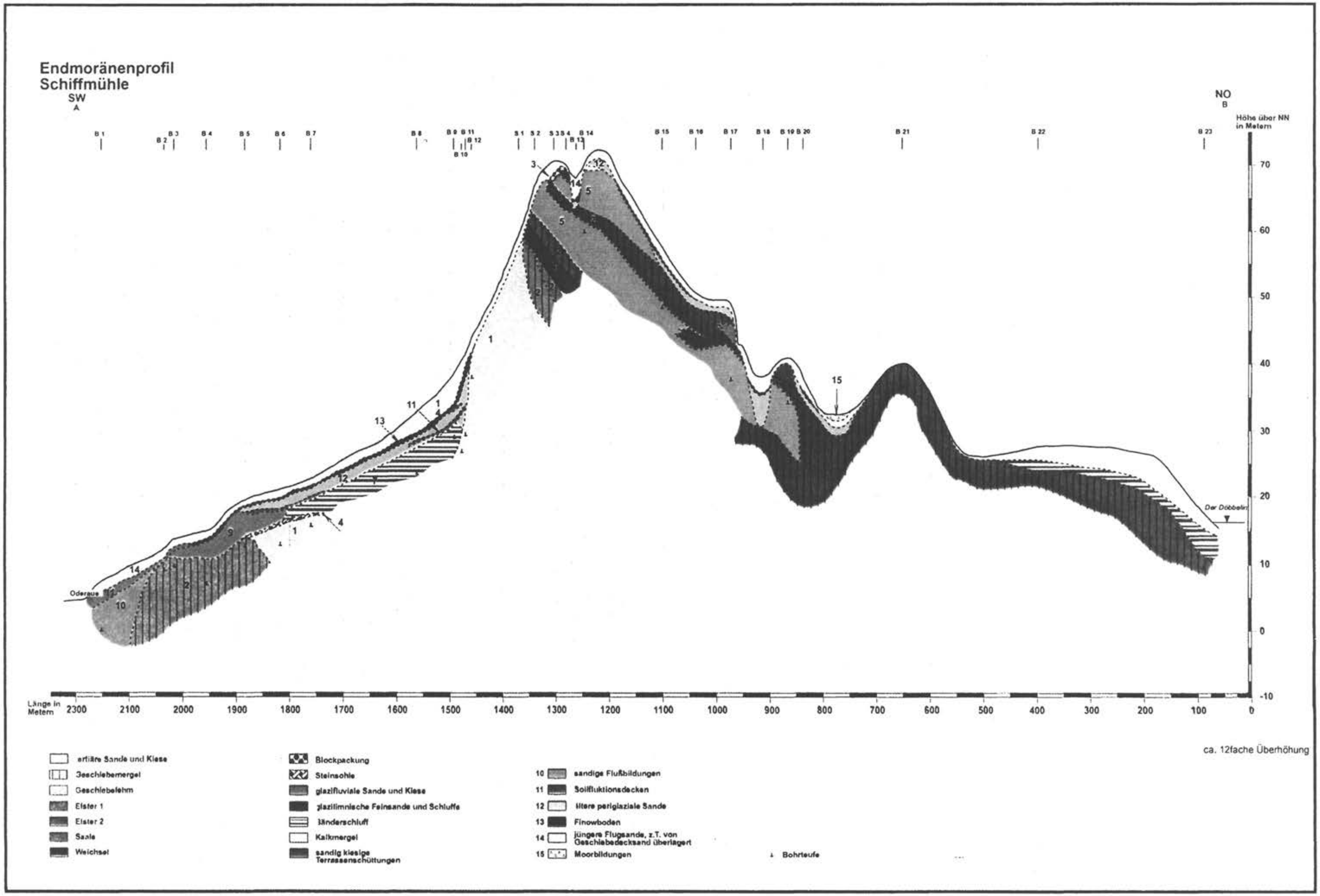
Stop 7: Althüttendorf end moraine, outwash plain

In the region of Joachimsthal-Althüttendorf the end moraines of the Pomeranian ice advance classically display various features of Quaternary geology. The part visited during the excursion belongs to the nature reserve "Schorfheide-Chorin". The end moraines of the Pomeranian advance form a ridge-like sedimentary complex of about 200 m width and 15 to 25 m altitude in relation to the adjacent area. They show the exterior margins of two wedge-like contacting moraine arcs of the Weichselian inland ice. The interior of the ridges is composed of clasts ranging in size between 10 cm and more than 1 m across. The pebbles/boulders are embedded in silty to silty-sandy matrix, partly revealing transition to boulder till. Clast composition is dominated by crystalline rocks, whilst sedimentary rocks are less abundant and flints are very rare. The predominance of crystalline, i.e. resistant clasts reflect the intense crushing of the till during glacial transport and accumulation. The boulder deposits are residual accumulations and reveal the outer margin of the glaciers of the Pomeranian advance.

Finer-grained components of the glacial debris were transported by melt water in front of the glaciers and accumulated in the convergence between the Joachimsthal and Parstein moraine arcs as conical outwash (Althüttendorf or Groß Ziethen outwash). The sequences of the outwash vary in thickness between 25 and 30 m. They reveal cross-bedded gravels alternating with fine- to coarse-grained sands. Transport direction was from NNE towards SSW. Syngenetic and epigenetic ice edges are widespread, demonstrating the permafrost conditions in the end moraines and their foreland.

Exploitation of the boulder deposits is known to have commenced at about 1850 A.D. Due to the poorness of bedrock exposures in the province Brandenburg, also boulders in the ridge along the margin of the Pomeranian advance eastwards were exploited. The till clasts were used in the construction of buildings, roads and canals. Furthermore, boulders and blocks were utilised for staircase steps, millstones and monuments. The excavations formed clear traces in the landscape, particularly in the area of Liepe-Oderberg and on the Oder island Neuenhagen.

Fig. 9: Geological section through the Pomeranian push moraine complex near Schiffmühle.


Endmoränenprofil
Schiffmühle
SW
A
NO
B
Höhe über NN in Metern
Länge in Metern
Oderaue
Der Döbbelin
ca. 12fache Überhöhung
ertiäre Sande und Kiese
Geschiebemergel
Geschiebelehm
Elster 1
Elster 2
Saale
Weichsel
Blockpackung
Steinsohle
glazifluviale Sande und Kiese
glazilimnische Feinsande und Schluffe
Bänderschluff
Kalkmergel
sandig kiesige Terrassenschüttungen
10 sandige Flußbildungen
11 Solifluktionsdecken
12 ältere periglaziale Sande
13 Finowboden
14 jüngere Flugsande, z.T. von Geschiebedecksand überlagert
15 Moorbildungen
Bohrteufe

Stop 8: Hohensaaten, Late Pleistocene terraces of melt water

The gravel/sand pit Hohensaaten is part of the traditional exploitation district of row material for constructing purposes in the area of the lower Oder River. The deposits are located in terraces to the west of the Oder River, between the Hohensaaten- Friedrichsthal canal and the margin of a morphological elevation to the west. Glacio-fluvial gravel and sand are excavated. The exploitation technology is: firstly excavation under dry conditions and subsequently by floating dredger. The thickness of the deposits varies between 15 and 25 m. A two-fold composition is visible in the exposure, with the lower part of the sequence being more coarse-grained than the upper part. The boundary between both is a disconformity which is characterised by coarser composition, forming a gravel layer.

In contrast to other authors grouping the lower part to the late Saalian glaciation, BROSE (1998) assign the entire sequence to glacio-fluvial environment of the late Weichselian glaciation. Probably, the maximum of erosion and accumulation processes was associated with the deepest erosive cut in the depression of the Baltic Sea during the Bölling Interstadial. This supports the short deepening of the drainage water courses. The erosion directed towards the Baltic Sea led to cut processes down to depths in the range of dekametres (BROSE et al 1987). In the southern and eastern excursion area deepening down to –30 m a.s.l. can be expected, proofed in southern Oderberg (small town at the flank of the Oder River). Subsequent gravel accumulation attains a depth of –7 m a.s.l. The deepening of the ancient Oder River (Ur-Oder) in the lower Oder area has occurred due to a stepwise retreat of the inland ice.

In combination with the stepwise ice retreat towards the north (into the actual Mecklenburg-Vorpommern province) a new water drainage system was opened. It was built up by a complex of five subsequent meltwater systems with terraces in the Randow-Welse river system. Four of the terraces are reflected in the recent morphology of the study area. The formation of the most recent terrace (Randow-Welse-System, Nr. IV) took place in an environment characterized by the presence of glacier ice. This is evidenced by the occurrence of block-like glacio-fluvial sequences with sharp boundaries, caused by erosive cutting and transportation along the edges of higher terraces under interaction of erosion and accumulation. The interpretation of terrace formation adjacent to the edge of ice bodies is supported by observations of periglacial transformations at least of the more ancient terraces.

The entire profile of the Pleistocene sequences of the outcrop can be divided into:

- Gravel/sand (qw3)
- Older clay (qsD-qsWA)
- Sand, silt, clay (qs//gl;b)
- Boulder clay (qsD)
- Sand, silt, clay (qe-qs//b)
- Rupelian clay (tolm) Tertiary

The sloping of the Weichselian sediments towards the Oder River valley and the deep erosion into the boulder clay of the Saalian glaciation display the erosive cutting of the melt waters through the moraines of the Pomeranian ice advance. This was a repetition of processes that had acted before during the Saalian glaciation.

Fischland and Darß

Geomorphologically, the Darß area at the Baltic Sea to the northeast of Rostock is classified into the following landscape units (see Hurtig 1954; Fig. 10):

- Foreland of the Fischland
- Fischland sensu stricto
- Old Darß (Altdarß)
- Pre-Darß (Vordarß)
- New Darß (Neudarß)

The narrow land barrier north of Dierhagen to Darß is called the Fischland, which represents a Pleistocene (Weichselian) moraine formation of ca. 3.2 km in length mainly between the villages of Wustrow and Ahrenshoop. Due to the steep slope and height (8-12 m) it is called the "high cliff", being affected by active coastal erosion. The top surface of the cliff dips towards the east to the Saaler Bodden. "Bodden" are characteristic types of coastal waters mainly along the Pomeranian coast. They are separated during the last millenia from the open Baltic Sea by

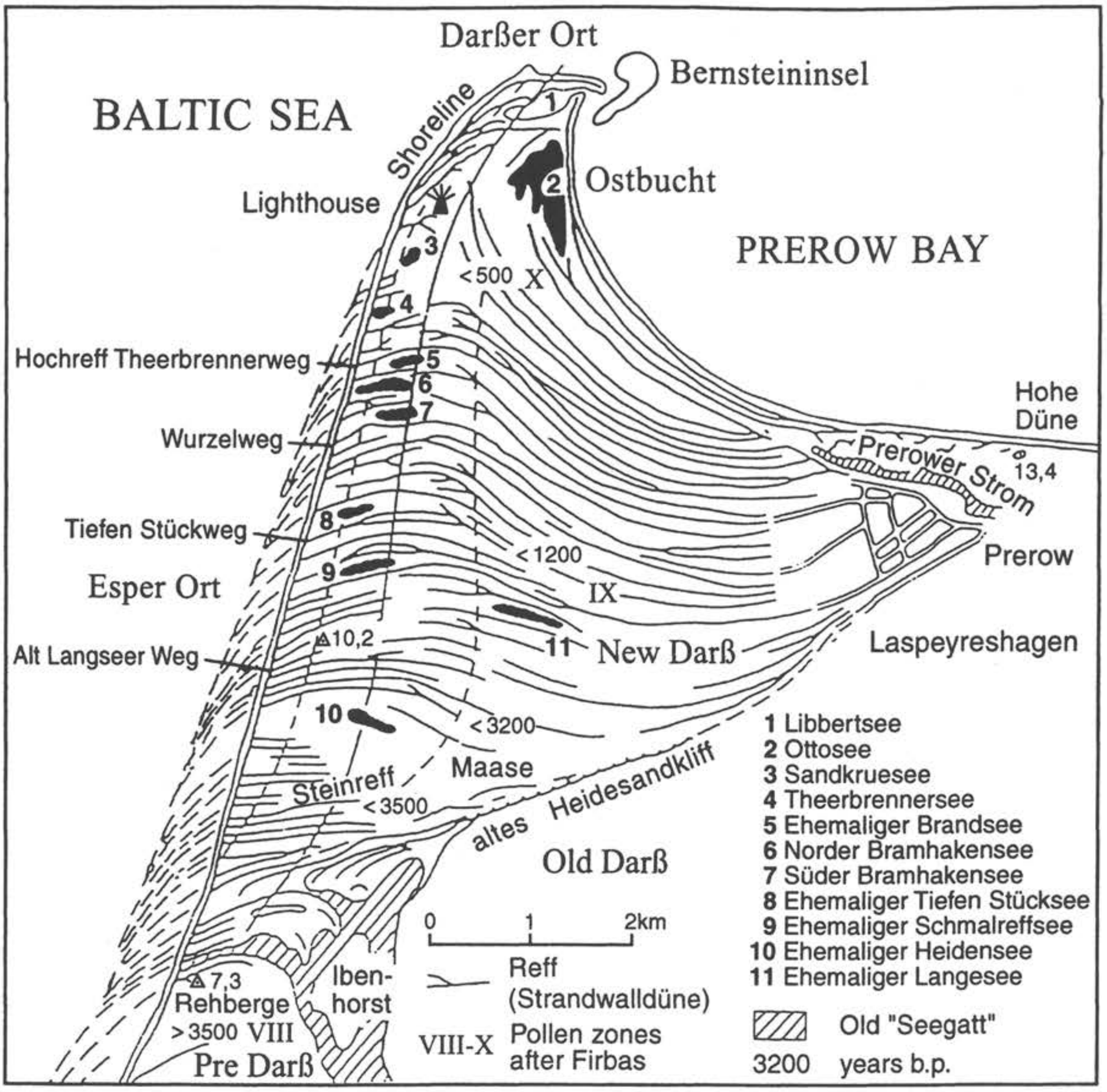


Fig. 10: Map showing landscape units and beach barrier systems along the Darß west coast (KOLP 1982).

longshore sand barriers. Sedimentologically, the cliff deposits consist of Weichselian tills intercalated with sands. On top Holocene eolian fine sands cover the older Pleistocene sediments. First investigated by GEINITZ (1910) it is common to classify the cliff section alongshore into 5 local units (DUPHORN et al. 1995):

- Northern Althäger sand depression ("Nördliche Althäger Sandmulde")
- Northern Althäger loam cliff ("Nördliches Althäger Lehmufer")
- Southern Althäger sand depression ("Südliche Althäger Sandmulde")
- Southern Althäger loam cliff ("Südliches Althäger Lehmufer")
- Niehäger sand hill ("Niehäger Sandberg").

Due to the high coastal wave energy, the steep shore slope and the cliff geology the Fischland area is strongly affected by erosion, leading to an average rate of cliff retreat of 0.46 m/year for the last 110 years. This exceeds the average value for the coastal retreat of all other Mecklenburg-Pomeranian cliff coast areas (0.34 m/year) by almost one quarter (GURWELL & WEISS 1989). Locally, the retreat amounts to 0.71 m/year.

The first comprehensive geomorphological description and genetical interpretation of the Darß was given by OTTO (1913) who stratigraphically classified this area into the Late Pleistocene Old Darß and the Holocene units of New Darß, Pre-Darß and the alluvial lowland of the Prerow stream. The thicknesses of the Late Pleistocene sands and silts of the Old Darß amount to > 20 m. Beneath this stratigraphical unit, indicated by boulder-size studies (statistics), a Weichselian till occurs. According to JANKE (1987) the sandy formations of the Old Darß, Barther and Rostocker Heide and Fischland were deposited within a glaciolimnic basin. The heights above sea level of the present surfaces of the sand units between Saaler Bodden, Bodstedter Bodden and Fischland vary between +9 m NN and +12 m NN. The differences probably are due to variations in Late Pleistocene ice thicknesses. Geomorphologically, the boundary between Old Darß and New Darß in the NW is formed by an older Holocene cliff along the Mecklenburger Weg (path). In east and south direction the Pleistocene sand deposits dip beneath the Holocene sediments of the bodden waters (e.g., Prerow stream). In the west, the boundary between Old Darß and Pre-Darß is formed by the east bank of a subrecent inlet ("Seegatt") which connected the open sea with the lagoonal waters (KOLP 1982).

Along the SSW-NNE running west coast of the New Darß (9 km in length) the beach barrier system consisting of generally west-east extending beach ridges ("Reffe") and peatified runnels ("Riegen") is cut by erosion. Since the New Darß grows towards north the beach ridges become younger in this direction, which earlier has been shown by pollen data (FUKAREK 1961). According to this author the entire New Darß should be no older than 3000 years. Due to later aeolian dunification of the beach ridges dune heights amount to 7 m (north of Langseer Weg, lighthouse). The peatified runnels between the dunified beach ridges predominantly represent former lagoonal beach lakes which - like the "Theerbrenner Lake" - are cut by coastal erosion.

The northernmost part of the New Darß is formed by an active modern beach barrier system called "Darßer Ort". The development of this beach barrier system suggested by KOLP (1978, 1982) is shown in Figure 10. Presumably, there is a climate-related (wind direction) cyclicity of about 200 years with regard to the formation of this youngermost beach ridge system. Recently it has been shown that the evolution of coastal spits and bars in the course of the last 3.5 ka was strongly sea-level controlled (SCHUMACHER 2000, Fig. 11). Sea-level change was the dominant impact on coastal dynamics during the past and will be in the future.

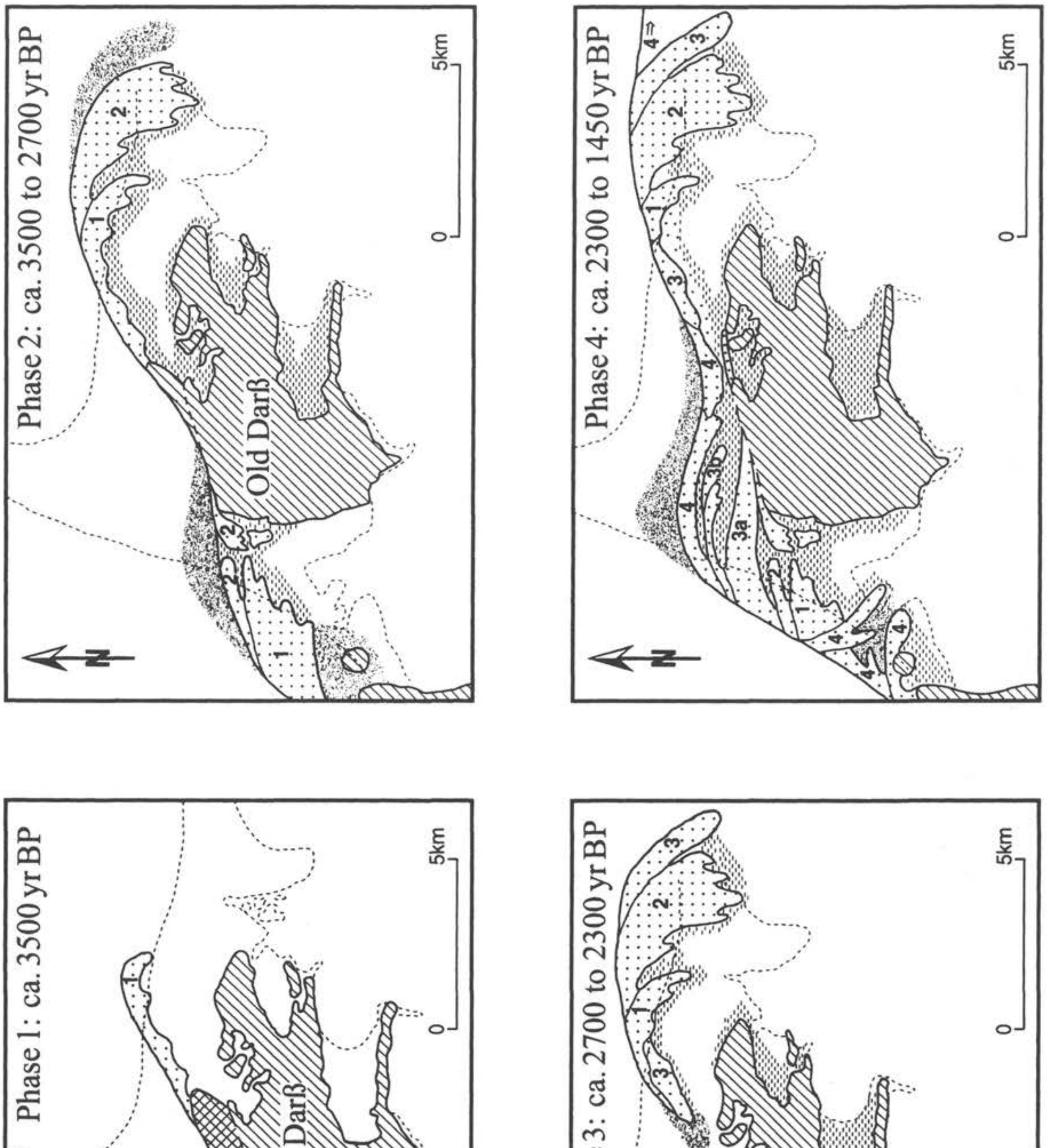
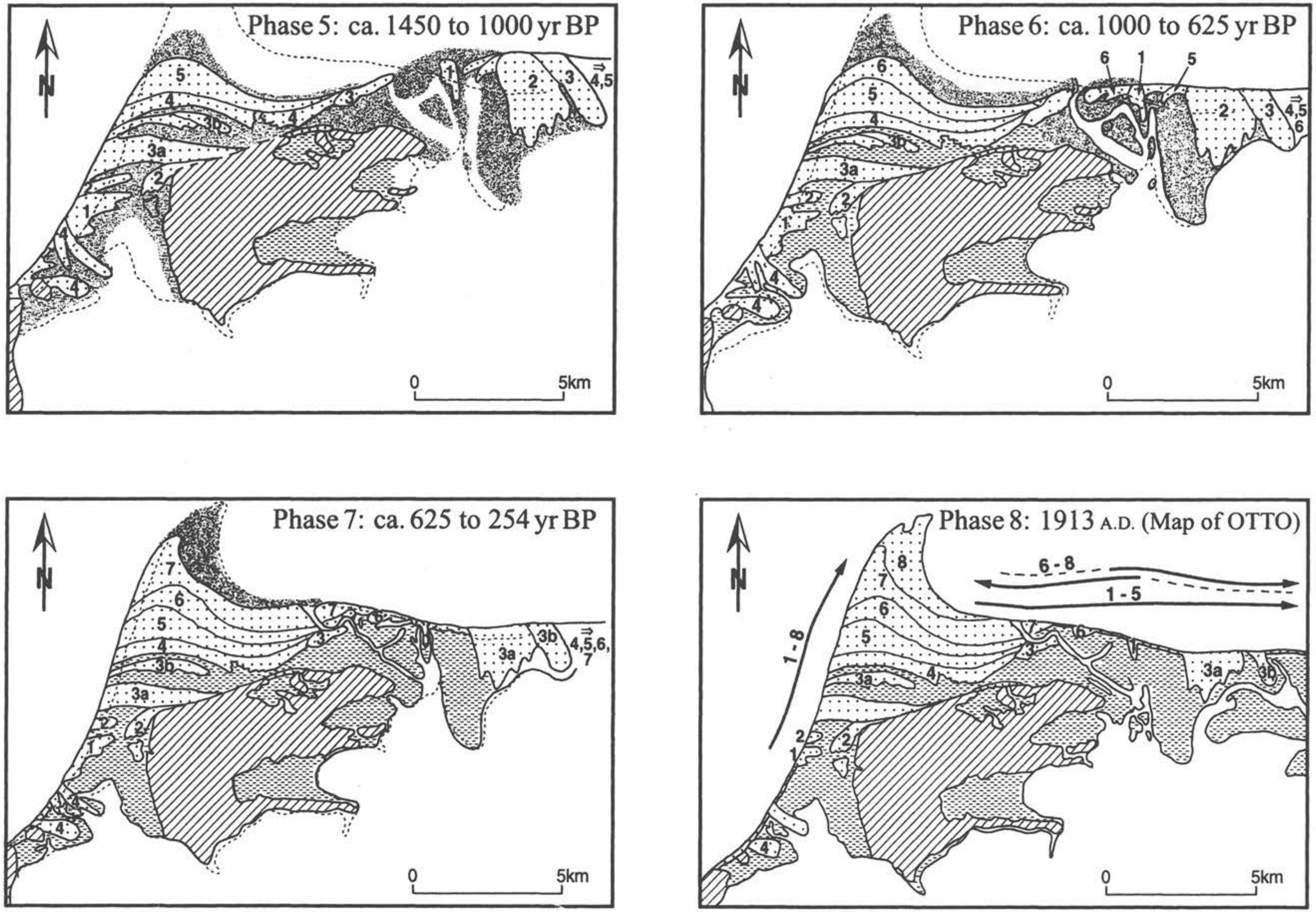


Fig. 11: Coastal formation of the Darß-Zingst Peninsula in ancient and modern times (SCHUMACHER 2000).


Phase 5: ca. 1450 to 1000 yr BP
N
5
4
3b
3a
2
1
4
3
1
2
3
4,5
0
5km
Phase 6: ca. 1000 to 625 yr BP
N
6
1
5
6
5
4
3b
3a
2
1
4
4
2
3
4,5
6
0
5km
Phase 7: ca. 625 to 254 yr BP
N
7
6
5
4
3b
3a
2
2
1
4
4
7
3
3a
3b
4,5,6,
7
0
5km
Phase 8: 1913 A.D. (Map of OTTO)
N
6 - 8
1 - 5
1 - 8
8
7
6
5
4
3a
3
7
6
3a
3b
2
2
1
4
0
5km

Stop 9: High cliff near Ahrenshoop ("Hohes Ufer")

In the course of the last decades this cliff section has been studied and described by several authors. According to the most recent work by PIETSCH (1991) the following sedimentary units from top to base exist: eolian dune sands, 6 m thick; paleosoil (leached podzol with layer of iron pan), 0.6 m; heath sand, 5 m; glacio-limnic sand, 12 m; upper till, 3.5 m; and lower till, 16 m.

The till horizons show differences in the boulder contents: the upper till (browngrey to lightbrown color, sandy, redbrown intercalations) has higher amounts of Paleozoic crystalline and sandstone components, the lower till (grey, more clayey) high contents of Cretaceous components. Compared with other Pleistocene tills in the neighbourhood of the Darß (e.g., Stoltera near Warnemünde) the upper till should be classified as Mecklenburgian Stage (W3) and the lower till as Pomeranian Stage (W2), both Main Weichselian. Locally, the glacio-limnic sands infill till depressions. Due to the decay of dead ice these sands might be related to creeping of soil (solifluction) and outwash (STEINICH 1992). According to paleontological findings the upper part of the sand unit may have been formed during the Late Pleistocene Allerød period (LUDWIG 1963). Obviously, these sediments were deposited in a cold and clear limnic stillwater environment of an open landscape (STEINICH 1992). There is a discordance between the glacio-limnic sand and the heath sand, whereas the latter unit is covered concordantly by a paleosoil (podzol) with iron pan ("Ortstein"). Locally, the top of the section is formed by outblown sands from the cliff which were transported upward (cliff dunes). Moreover, the aeolian sand bodies sometimes form Kupsten-dunes.

According to GURWELL & WEISS (1989), generally two factors control the cliff retreat: (1) hydrodynamics and abrasion resistance of the shoreface seems to be much more important than the cliff resistance (e.g., cliff geology), (2) the deposition of clastic sediments due to cliff retreat seems to restrain the velocity of retreat. Moreover, a cyclicity possibly occurs with regard to the cliff retreat, although full evidence from a 100 year record does not yet exist. Anyway, since more than 130 years coastal protection measures are done (1865: 9 groyne systems), especially following a catastrophic storm event in 1872 which lead to a coastal cut near Wustrow. Between 1875 and 1878 a grass-grown dike was erected which, however, could not prevent further strong coastal retreat by 0.5 m/year. During 1967-1970 a new 1.1 km long dike was built behind the older one. In order to renew destroyed coastal dunes, in 1974 a sand reservoir has been constructed between both dikes consisting of a sand volume of 230,000 m^3. Furthermore, 1974/75 the younger dike has been reinforced, and 1978/79 an artificial beach sand fill of 200,000 m^3 off Wustrow was built up. To complete the system of coastal protection, two large alongshore wave breakers were erected (each 150 m long, 120 m off beach), and the building of groynes is continuing.

Stop 10: modern beach ridge system "Darßer Ort"

This stop offers a wide range of beach sedimentation processes and actualistic sedimentological features. The sediment transport path runs along the Darß west coast towards north ends at Darßer Ort where in very shallow water a sand flat ("Schaar") is formed. This sand flat oriented in NE direction can be seen alongshore by surf breaking. The continuing sediment supply of this area from south (e.g., Fischland, Pre-Darß, New Darß) leads to sand accumulation and thickness growth of the sand flat. During low water level, due to offshore winds, great amounts of aeolian sand may be transported towards the sand flat. Moreover, this process may increase the thickness of the sand flat above sea level, especially around the so-called Amber Isle ("Bernstein-Insel"). Additionally, high water, due to NW storms, may also lead to sediment transport and some sand accumulation. On the other hand, during NE storms there is widespread erosion along the eastern flank of the sand flat and the eroded coastal sand moves south towards the Prerow lagoon.

About 1000 m southward of the Darß lighthouse along the western shore the Theerbrenner Lake ("Theerbrennersee") is located, representing a former beach lagoon. Due to erosion of a longshore coastal dune which, generally, protects the beach lakes like Theerbrenner, a dune cut occurred showing peat relicts of the lake bottom. The peat extends towards the shoreface and is covered by thin layers of modern beach sands.

Stop 11: "High Dune" near Prerow ("Hohe Düne")

With a height of +13,7 m a.s.l. the "High Dune" field east of Prerow is the highest dune complex of the entire Darß-Zingst Peninsula. According to GROBA (1954) the following preconditions may lead to such high dunes: (1) steady longshore transport in the vicinity of a cut/inlet through a beach barrier ("Seegatt"), and (2) longer periods of low water level as well of onshore winds. Such an old inlet existed east of the present "High Dune" and led to the formation. After closing of the mentioned inlet, due to changes in longshore wind and transport direction towards the east and opening of a new inlet cutting the beach barrier (Prerow stream/"Prerow-Strom"), another high dune complex ("Hagens Düne") has been formed to the northwest of Prerow. After a heavy storm flood event in 1872 this inlet was closed by men.

There is an excellent geomorphological view over the eastern Darß foreland, the alluvial low-land of the Prerow stream and the Zingst Peninsula in the east. The almost west-east extending shoreline suffers from strong coastal retreat. Therefore, measures of coastal protection (cf. WEISS 1979, 1989, GURWELL & WEISS 1989) have been carried out consisting of a system of groynes, dunes, forest and high water sea wall (1965-1974 reconstruction of the sea dike Prerow-Zingst) in order to prevent further damages by future flood events, which most recently affected the Pommerian coast like in November 1995. Now there is again much discussion on coastal protection.

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Field Trip D
Variscan Orogen in the Harz Mountains and Adjacent Regions

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Geological Framework

Plate kinematic evolution

The continental crust of Western and Central Europe was formed or at least modified by Variscan subduction and collision between c 400-300 Ma. After the levelling-out of the orogenic topography, the Variscan basement was covered by Late Carboniferous to Holocene sediments. Exhumation of basement outcrops was brought about by various uplift mechanisms, in Late Cretaceous to Holocene times. The Black Forest and Vosges Mts. on either side of the Rhine River were formed by Tertiary uplift of the graben shoulders. The Rhenish Massif straddles a Late Cretaceous to Holocene mantle plume. Other basement outcrops, such as the Harz Mts., the Flechtingen Block and the Bohemian Massif, were uplifted by dextral transpression associated with the formation of pull-apart basins in the foreland of the Alps. Uplift occurred in Late Cretaceous time, along NW-trending fault zones (STACKEBRANDT & FRANZKE 1989, see FRANKE 1997 for a summary of the geology of Germany, and FRANKE 2000 for a review of the Variscan evolution).

The Variscan Belt of Central Europe is a tectonic collage which comprises the north Gondwana margin, the Armorican Terrane Assemblage, Avalonia and Baltica. Collision of the major and minor plates resulted in at least three collisional belts: Rheno-Hercynian (collision of Avalonia with the Armorican Terrane Assemblage), Saxo-Thuringian (collision of the Armorican islands Saxothuringia and Bohemia) and Moldanubian (collision Bohemia / Moldanubia ? = north Gondwana). Field Trip D deals with the eastern part of the Rheno-Hercynian Belt exposed in the Harz Mts. and the Flechtingen Block (Fig. 1).

The evolution of the Rheno-Hercynian Belt is especially complex, since it comprises two plate tectonic cycles (Fig. 2):

- During the Late Ordovician through Early Devonian, the Rheic Ocean between Avalonia and the northern part of the Armorican Terrane Assemblage was being closed. Convergence was accommodated by intra-oceanic subduction, which produced a magmatic arc now preserved in fragments strung out along the southern margin of the Rheno-Hercynian Belt.
- Renewed extension from the late Early Devonian (Emsian) onwards produced a narrow Rheno-Hercynian Ocean, which can be traced from South Portugal via SW England, the Rhenish Massif, Harz Mts. and the Flechtingen Block as far as the Moravo-Silesian Belt on the SE flank of the Bohemian Massif. Although Devonian extension occurred grossly

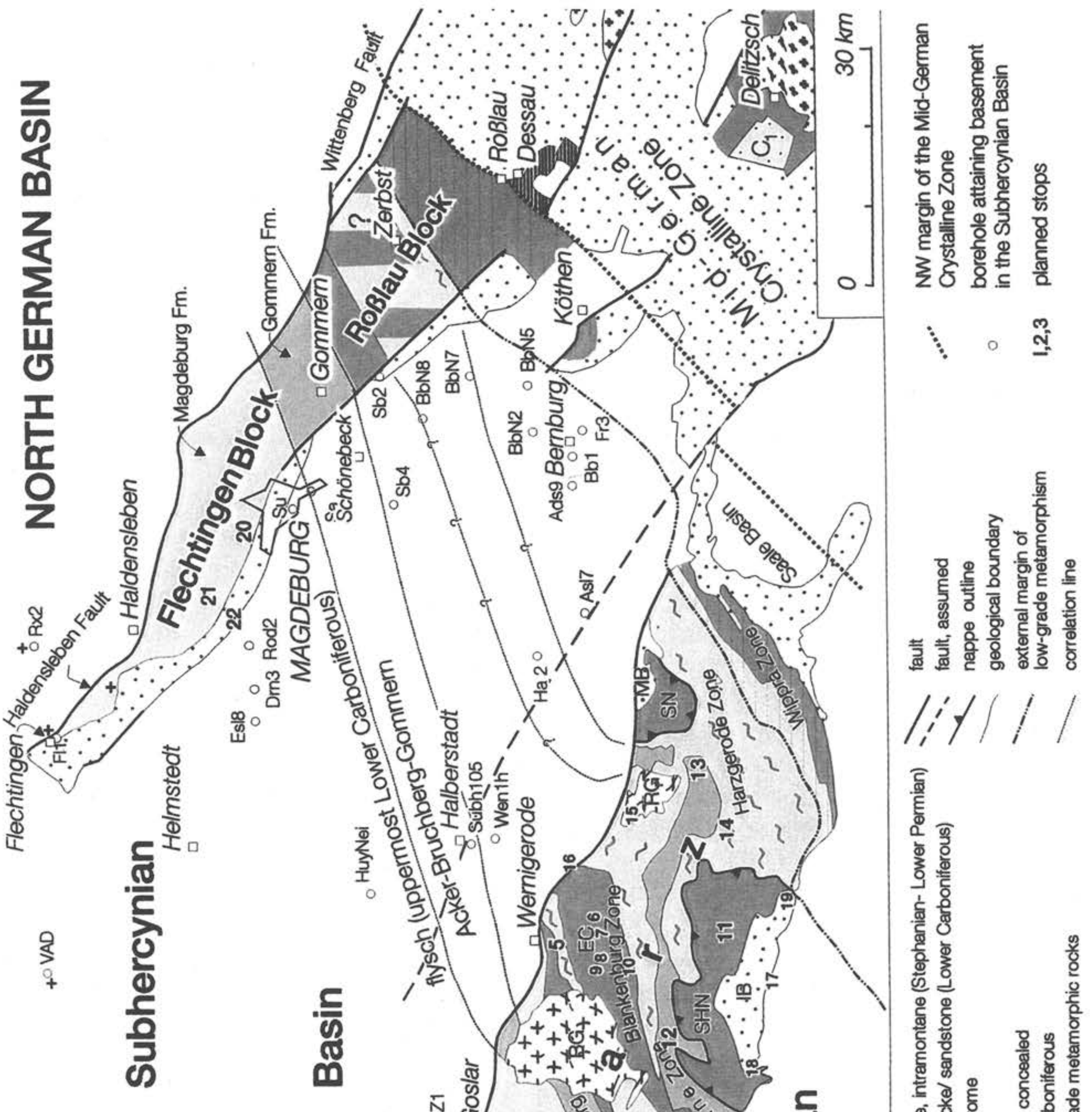

Fig. 1: Tectonic map of the Harz Mts. and Flechtingen Block. Nappes are represented in their minimal extent. BG = Brocken Granite, EC = Elbingerode Complex, I = Iberg Reef, IB = Ilfeld Basin, MB = Meisdorf Basin, RG = Ramberg Granite, SN = Selke Nappe, SHN = South Harz Nappe, UHA = Upper Harz Anticline (adopted from PAECH et al. 2002).

along the Avalonian/Armorican plate boundary, some Armorican fragments appear to have beenstranded on the N shore of the new Rheno-Hercynian ocean. From this position, they have been transported toward the NW over the Avalonian foreland (Fig. 3), and now occur as allochthonous fragments in chaotic sequences (e.g. Harzgerode Zone, Fig. 1).

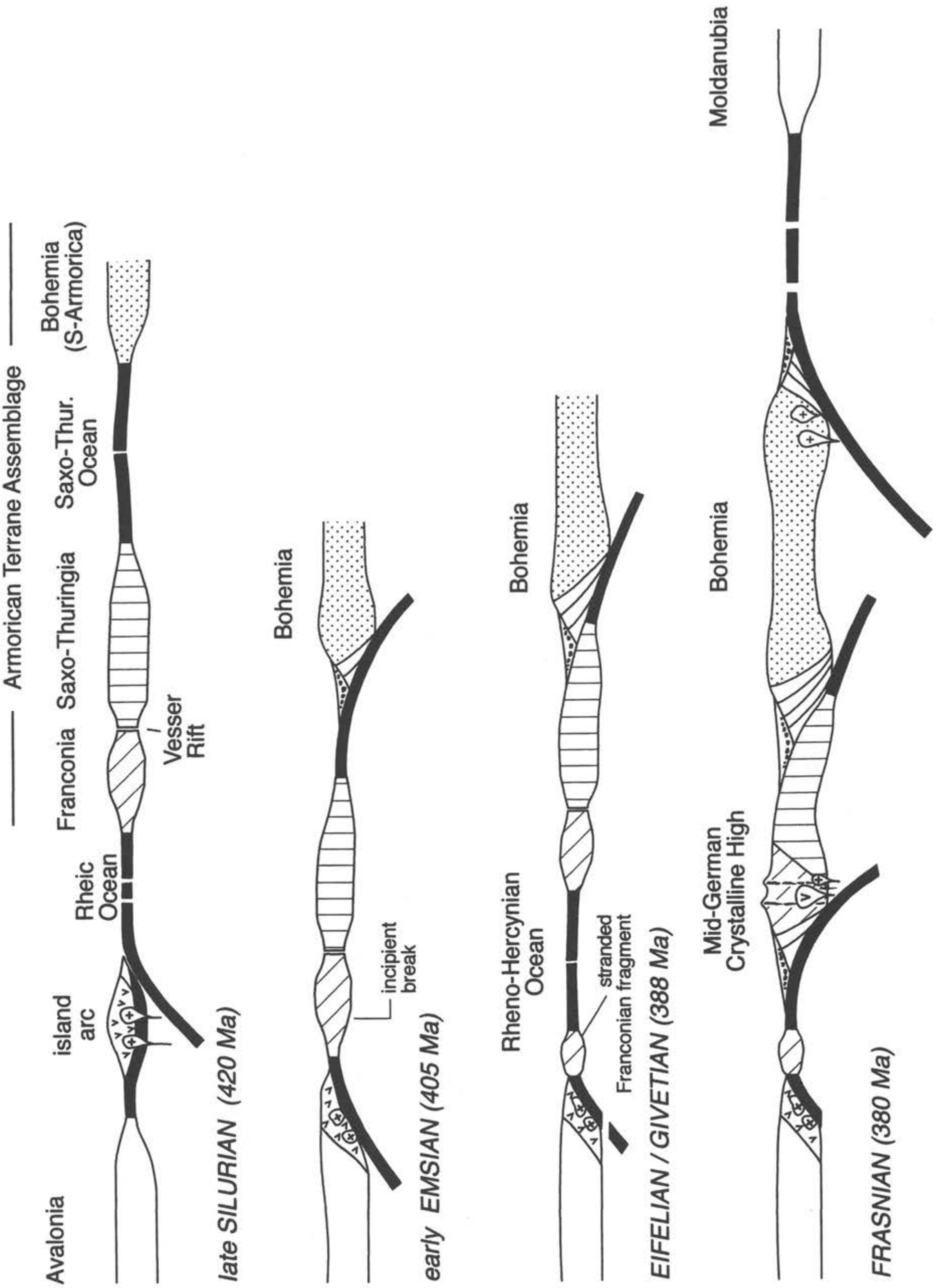

Fig. 2: Plate-tectonic cartoon for the assembly of microplates on the N flank of the Variscan Belt in central Europe (FRANKE 2000).

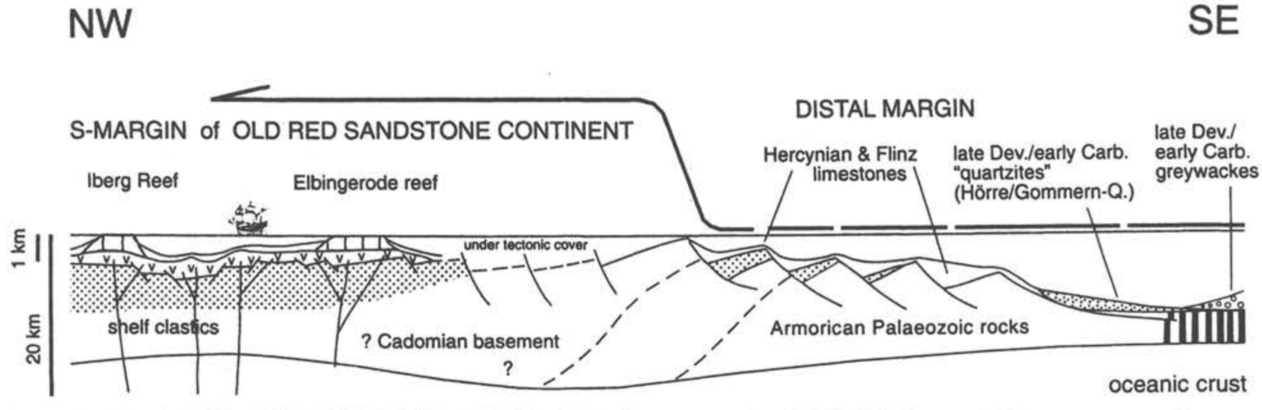

Fig. 3: Palaeogeographic reconstruction of the southeastern, distal margin of the Old Red Sandstone Continent. The Hörre-Gommern Qzt. is interpreted as allochthonous (after FRANKE 2000).

During the Late Devonian/Early Carboniferous convergence, the northern part of the Armorican Terrane Assemblage (Franconia, Fig. 2) was transformed into a magmatic arc (Mid-German Crystalline High) overriding the Rheno-Hercynian Ocean subducting towards the SE. The narrow Saxo-Thuringian ocean separating the Saxo-Thuringian and Bohemian members of the Armorican Terrane Assemblage was also subducted southeastwards. These events produced a tandem of NW-propagating fold and thrust belts with long distance thrusting over the forelands belts (Rheno-Hercynian, Saxo-Thuringian: Fig. 4).

The field trip concerns eastern segments of the Rheno-Hercynian Belt (Harz Mts., Flechtingen Block). The upper crust mainly consists of shelf sediments of the southern, passive margin of the "Old Red Sandstone Continent" (Figs. 2 and 4). Fragments of Rheno-Hercynian oceanic crust and its sedimentary cover have survived in thrust sheets, which cover the eastern part of the Rhenish Massif and large parts of the Harz Mts. (Figs. 3 and 4).

Sedimentary record

The Devonian to Carboniferous sediments which make up most of the Rheno-Hercynian autochthon were deposited on Neoproterozoic ("Cadomian") basement, which belongs to the Avalonia microplate. These rocks are only exposed in the Southern Hunsrück (W of the Rhine River). The infill of the Rheno-Hercynian Basin was largely provided by erosion of Caledonian source areas to the north ("Caledonian molasse" of FRANKE et al. 1978).

Devonian clastic sequences attain a thickness up to 10 km. In Early Devonian time, the clastic shelf sediments covered the entire width of the present-day Rhenish Massif and probably also of the Harz Mts. Continued extension and thermal subsidence during the Middle and Late Devonian brought about an encroachement of the pelagic facies towards the NW.

The youngest passive margin sediments occur in Hörre-Gommern Quartzite Zone, which can be traced from the eastern part of the Rhenish Massif via the Harz Mts. into the Flechtingen Block (Fig. 1), over a distance of c 300 km. The U/Pb systematics of detrital zircons and K/Ar mica ages of 440-410 Ma are indicative of Scandinavian sources (HAVERKAMP et al. 1992, HUCKRIEDE et al. 1998). The quartz arenites were probably transported by turbidity currents.

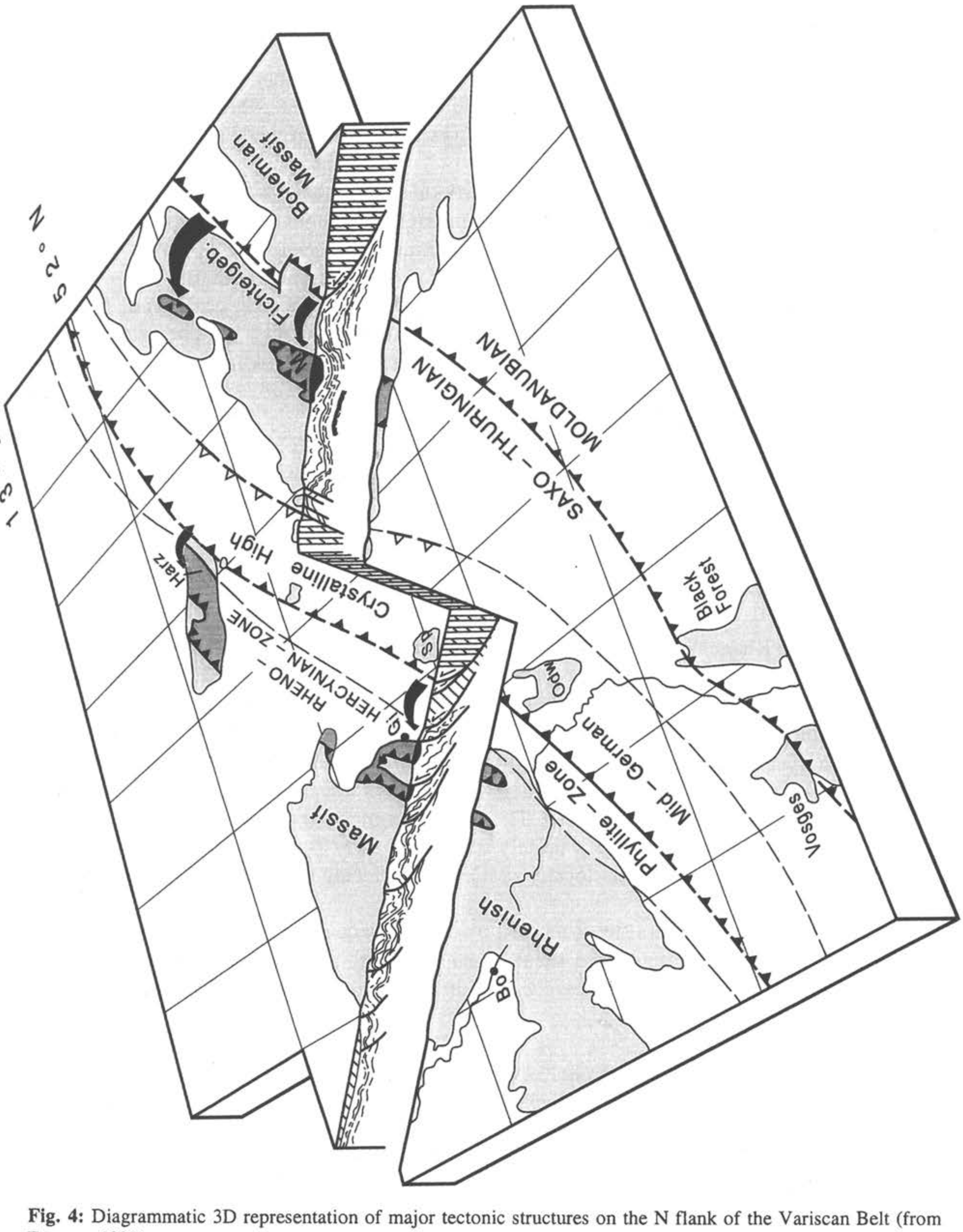

Fig. 4: Diagrammatic 3D representation of major tectonic structures on the N flank of the Variscan Belt (from FRANKE 1992).

In an allochthonous tectonic scenario (see below and Fig. 3), they were deposited at the distal passive margin of the Old Red Sandstone Continent (Laurussia and Avalonia) and then emplaced as a thrust sheet. Alternatively, they could have been deposited in a par-autochthonous sub-basin.

Crustal extension is also documented in widespread volcanism. A first volcanic episode in Emsian time is characterized by felsic rocks. The younger episodes (essentially Late Givetian / Frasnian and Tournaisian / Early Viséan) produced predominantly basaltic lavas and pyroclastic rocks. Basaltic volcanism is mainly localized in a belt which extends from the south-central Rhenish Massif into northwestern and central parts of the Harz Mts.

From the Late Devonian through to the Late Carboniferous, the Rheno-Hercynian Basin was closed by southward subduction. The active plate margin adjacent to the S, preserved in a belt of basement outcrops summarized as the "Mid-German Crystalline High", shed flysch-type clastic sediments (greywacke turbidites) towards the NW. Detailed goniatite and conodont stratigraphy documents NW-ward onlap first on the subducting ocean crust, and, from the earliest Carboniferous onwards, on the continental foreland (Tab. 1). The last stage of foreland sedimentation is characterized by Upper Carboniferous molasse-type fluvial and shallow marine (paralic) sandstones with coal seams, exposed and exploited at the northwestern margin of the Rhenish Massif.

The palinspastic restoration of the autochthonous and allochthonous units in the eastern Rheno-Hercynian Belt is shown in Fig. 3.

Tectonic evolution

The infill of the Rheno-Hercynian Basin was deformed into a thick-skinned fold-and-thrust belt (Fig. 4). As revealed by a reflection seismic profile in the eastern Rhenish Massif, the basal detachment does not correspond to the boundary between basement and cover, but was probably controlled by thermal and rheological gradients (DEKORP 1990, ONCKEN et al. 2000). In the par-autochthon, the main deformational event created NW-facing folds, with axial plane cleavage and thrusts. Strain increased towards the SE and amounts to c 50 % of the original width (ONCKEN et al. 2000). The par-autochthon was overthrust, at a later stage, by the Giessen-Harz Nappes, which largely consist of early flysch sediments underlain by condensed pelagic sequences and - locally - MORB-type metabasalts (e.g. FLOYD 1995).

The base of the allochthon is often occupied by chaotic sequences with blocks of competent clastic and carbonate sediments in a sheared shaly matrix. The relative importance of sedimentary re-deposition ("olistostromes") vs. tectonic mélange is a matter of controversy (see below).

The lateral extent of the allochthon is likewise controversial. FRANKE (in ENGEL et al. 1983, FRANKE 2000) suggests that the allochthon comprises not only the Südharz and Selke Greywacke Nappes (Fig. 1), but also the Tanne Zone and Sieber Syncline as well as the Hörre-Gommern Quartzite of the Acker-Bruchberg area (Fig. 1). Some authors (e.g. MEISCHNER 1991, SCHWAB 1979, WACHENDORF 1986) would limit the allochthon to more southerly parts of the Rheno-Hercynian Belt (Giessen Nappe of the Rhenish Massif, South Harz and Selke Nappes of the Harz Mts.).

Metamorphism in the Rheno-Hercynian Belt increases from diagenetic grade in the N to greenschist grade in a narrow belt of outcrop at its southern margin ("Northern Phyllite" or

"Wippra Zone", north of the Mid-German Crystalline High). The Wippra Zone comprises a complex association of protoliths (Tab. 1), from Devonian passive margin sediments, Silurian sediments and arc-related volcanic rocks, which remind association of the Harzgerode Zone, and Ordovician rocks with Armorican biogeographic affinities (FRANKE & ONCKEN 1995), ANDERLE et al. 1995, FRANKE 2000, REITZ et al. 1995, BURMANN 1973, SEHNERT 1991). Maximum temperatures of 300-350 °C combined with pressures of 3-6 kb indicate subduction-related metamorphism (MASSONNE 1995, SIEDEL & THEYE 1993).

Structure and Evolution of the Harz Mts. and the Flechtlingen Block

Variscan basement

The main difference between the Harz Mts. and the eastern Rhenish Massif lies in the large areal distribution of proven and suspected allochthonous units in the Harz Mountains. After FRANKE (2000), the par-autochthon is largely restricted to northwestern parts part of the Harz Mts. and the Flechtingen Block, to the NW of the Hörre-Gommern Quartzite Zone. In this northwestern part, the Oberharz Anticline exposes Lower Devonian shelf sandstones, overlain by hemipelagic shales, radiolarian cherts and carbonates (Middle Devonian to Tournaisian) (Tab. 1). Synsedimentary extension produced pelagic highs with condensed carbonates and basins with shales (STOPPEL & ZSCHEKED 1971). The lowermost Middle Devonian Wissenbach Slates (Tab. 1) contain a prime example of syn-sedimentary pyrite mineralization (Rammelsberg near Goslar, GUNDLACH & HANNAK 1968, SPERLING & WALCHER 1990, WERNER & WALTHER 1995). Crustal extension is also documented by basaltic volcanism prior to the Givetian/ Frasnian boundary, and in the Early Carboniferous. The Givetian/Frasnian Iberg Reef probably grew up on a volcanic mound (FRANKE 1973). Flysch sediments prograded across the exposed par-autochthon during the Late Viséan (RIBBERT 1975, ENGEL & FRANKE 1983, LUTZENS 1979, WACHENDORF 1986).

A more southerly part of the par-autochthon emerges in a tectonic window (Elbingerode Window). The Elbingerode Complex (Figs. 1 and 5) is characterized by thick Middle Devonian Schalstein (submarine basaltic products) probably forming an extended volcanic mound (10 km longest diameter in SW-NE direction) and an overlying Givetian to Frasnian (FUCHS 1987) reef formation (predominantly stromatopores and corals) in an atoll-like build-up attaining 600 m in thickness (JANSSEN & PAECH 1989). During the post-reef history the Elbingerode Complex preserved its morphological elevation allowing only pelagic sedimentation on top of the reef. Finally, in latest Viséan time the clastic flysch sedimentation (turbiditic greywackes) occupied also the top of Elbingerode reef build-up (Tab. 1, JANSSEN & PAECH 1989, FRIEDEL & JANSSEN 1988).

The main part of the Harz Mts. is occupied by a complex association of thrust-bounded slices. Its NW margin is marked by a segment of the Early Carboniferous Hörre-Gommern Quartzite Unit (in the Harz Mts.: "Acker-Bruchberg Quartzite", Fig. 1). South of the quartzite unit, there are thrust slices made up of Late Devonian Südharz and Selke Greywackes (SCHWAB 1976) through to Viséan turbidites (Tanne and Sieber Greywackes). In spite of tectonic dismembering, it is still possible to state that the onset of greywacke sedimentation, like in the NW part of the Harz Mts., tends to become younger towards the NW (Tab. 1).

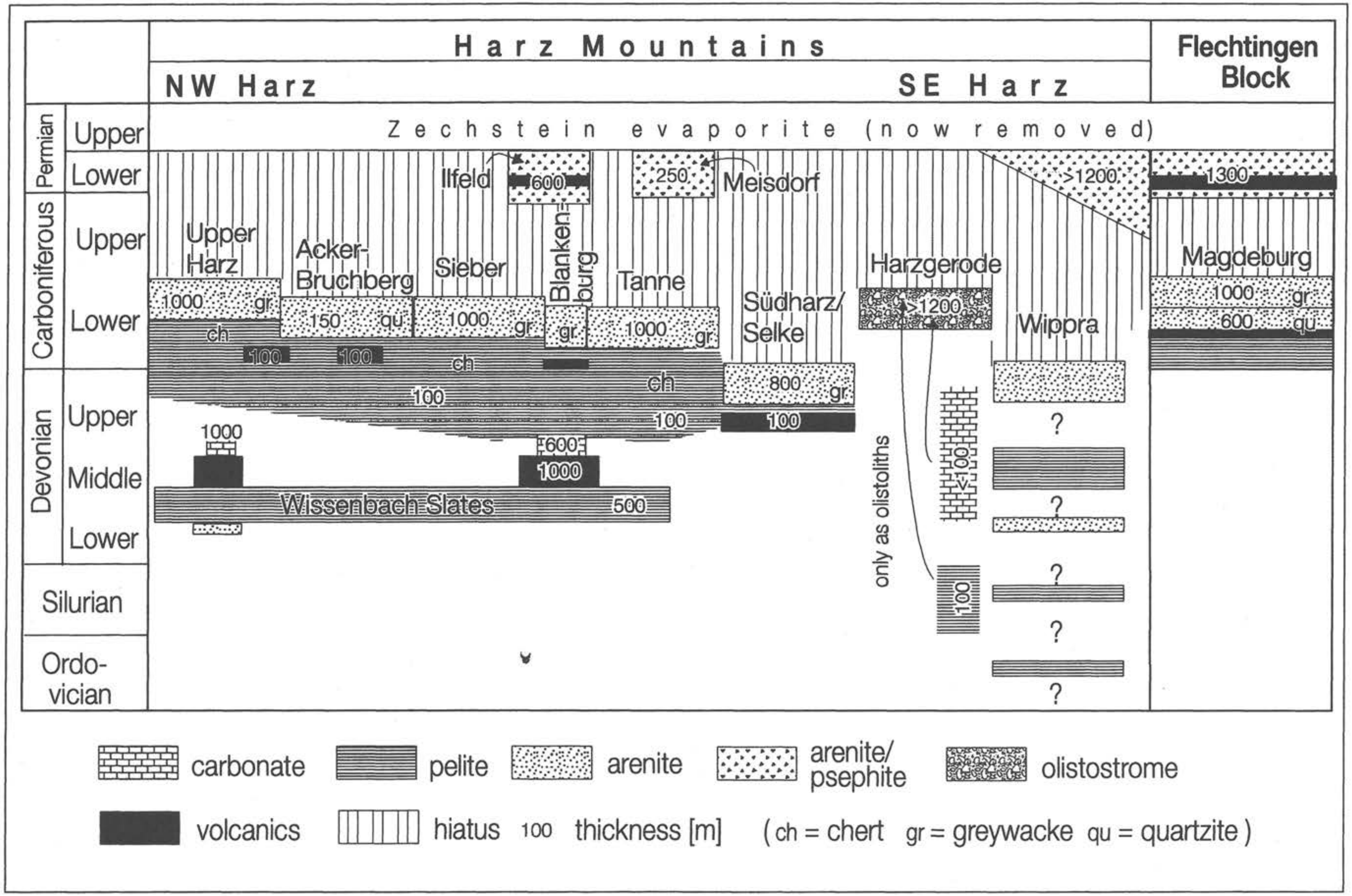

Table 1: Stratigraphic succession of the Harz Mountains and the Flechtingen Block

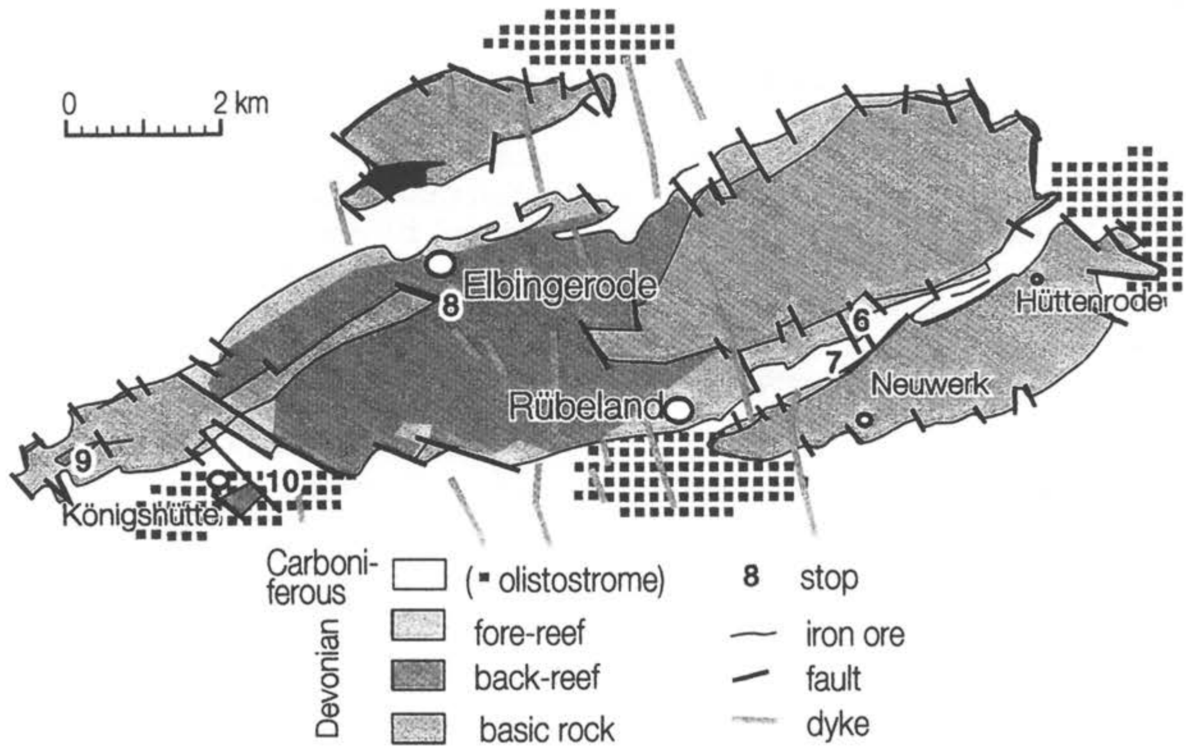

Fig. 5: Geological map of the Elbingerode Complex

The Late Devonian/Early Carboniferous flysch sediments are underlain by Givetian/Frasnian condensed shales and radiolarian cherts, which overly, in their turn, strongly sheared metabasalts. These comprise both MORB-type (PLATEN 1991) and within-plate lavas (GANßLOSER et al. 1995).

A deeper structural level ("Harzgerode Zone", Fig. 1) emerges from beneath the greywacke units. A chaotic sediment sequence with a matrix of sheared greywackes and shales contains fragments of Silurian cherts and shales, Devonian and Silurian neritic and pelagic limestones ("Hercynian limestones", e.g. HÜNEKE 1998), some mafic volcanic fragments and (locally) earliest Carboniferous conglomerates as the youngest component (BUCHHOLZ & LUPPOLD 1990). Bedded limestones ("Flinz") of Middle Devonian to Early Carboniferous age were sourced by the "Hercynian" carbonate realms and deposited by turbidity currents (LÜTKE 1976, BUCHHOLZ et al. 1991). From the Silurian through to the Early Emsian, the faunas of the Hercynian limestones exhibit some Armorican affinities. These rocks are probably derived from the Armorican fragment "stranded" on the northern shore of the opening Rheno-Hercynian Ocean (FRANKE & ONCKEN 1995, see Fig. 3).

The various fragments range in size from several centimetres to hundreds of metres. Some pelite olistoliths show indications of soft-sediment deformation. Several authors (REICHSTEIN 1965, LUTZENS 1973, SCHWAB 1979, GÜNTHER & HEIN 1999) interpret large parts of or even the entire Harzgerode Zone (Fig. 1), as a huge olistostrome, extending eastwards into into the Flechtingen Block (LUTZENS & PAECH 1975, PAECH et al. 2002). The olistostrome interpretation is backed up by a deep well in the Harzgerode Zone, which has penetrated a sequence with exotic fragments, which is more than 1.2 km thick and overlies a greywacke succession of unknown age. Alternatively, the dismembered lenses have been interpreted as tectonic slices in extensive shear zones (KOLL 1984, REICHSTEIN 1991, WACHENDORF 1986; discussion in BUCHHOLZ et al. 1991).

The tectonic structure of the Harz Mts. is still somehow controversial. KOSSMAT (1927) was the first to propose large-scale allochthonism. During a long time after, the existence of thrust nappes in the entire Variscan belt was banned. It was in the Harz Mts., that horizontal tectonic concepts were first revived (e.g. REICHSTEIN 1965, SCHWAB 1979). Today, the Südharz and Selke Greywackes with their pelagic/basaltic foundation are generally accepted as thrust sheets (SCHWAB 1976, 1979), while tectonic interpretation of the adjacent tectonic units remains controversial. KOSSMAT (1927, 1928), ENGEL et al. (1983), and FRANKE (1995, 2000) regard the Acker-Bruchberg Unit and all units adjacent to the SE as allochthonous, with the only exception of the Elbingerode Window. This view is backed up by the following observations:

- In the Rhenish Massif, tectonic klippen of Hörre-Gommern Quartzite also occur south of the main quartzite belt, on the par-autochthon of the Lahn-Dill area.
- In the Rhenish Massif, tectonic equivalents of the Acker-Bruchberg Quartzite and the Tanne Zone and Sieber Greywacke Unit reveal an inversion of low-grade metamorphism by comparison with the underlying par-autochthon, which suggests post-metamorphic thrusting.
- Contrastingly, deeper structural levels of the Harz Mts. (Devonian rocks in the Elbingerode area) show a higher grade of metamorphism than the overlying rocks, thus indicating a normal metamorphic gradient. Still, metamorphic pressures of 2-3 kb in Late Devonian rocks of the Elbingerode area (FRIEDEL 1996) require tectonic overburden, because the known stratigraphic thickness of the Late Devonian and Early Carboniferous has nowhere been found to exceed 3000 m.
- The raft of "Ecker Gneiss" encased in the Brocken Pluton adjacent to the Acker-Bruchberg Quartzite was metamorphosed in time after c 410 Ma (GEISLER et al. 2002), and cannot have been formed, therefore, in the Rheno-Hercynian Belt with its continuous subsidence and sedimentation throughout the Devonian and Early Carboniferous (see below). Instead, it must represent an allochthonous slice of rock emplaced at the base of the allochthon.

On the other hand, in the Harz Mts. the involvement of the Blankenburg Zone around the Elbingerode Complex and particularly the Harzgerode Zone and Acker-Bruchberg Unit in a the nappe complex is not compelling for some geologists (e.g. SCHWAB 1979, H.-J.Paech, this paper). Although many units are fault-bounded, the stratigraphic sequence is generally maintained, and the chaotic sequences overlying the Elbingerode Complex are more likely sedimentary formations (olistostromes) than tectonic mélange formed at the base of a nappe. In general, the wide-spread chaotic sequences of the Harz Mts. are olistostromes which attain the considerable thickness of more than 1,200 m (LUTZENS 1973, 1979) which argues against the interpretation as a shear zone.

All the proven and potential thrust sheets are taken to be derived from a root zone at the northwestern margin of the Mid-German Crystalline High (Fig. 4).

The southeasternmost part of the Harz Mts. belongs to the Northern Phyllite Zone (Wippra Zone), which intervenes between the very low-grade, external parts of the Rheno-Hercynian Belt and the high-grade Mid-German Crystalline High.
At the northeastern margin of the Harz Mts., the Palaeozoic basement is pierced by the Brocken and Ramberg Plutons. Similar granites (Roxförde, Flechtingen) occur in the northern part of the Flechtingen Block (Fig. 1). The granites were emplaced at c 295 Ma (latest Carboniferous; BAUMANN et al. 1991, STEDINGK et al 1991, 1997). The Brocken granite is underlain, to the NW, by the cogenetic Harzburg Gabbro. On top of the gabbroic portion, there is a roof pendant of granulite-facies Ecker Gneiss. SHRIMP dating of detrital zircons from meta-quartzites revealed ages of 0.9-1.2 Ga and 410 ±20 Ma (GEISLER et al. 2002).

Mafic dikes cogenetic with the Brocken and Ramberg Plutons (BENEK 1967) as well as geophysical evidence (GABRIEL et al. 2001) suggest that the intrusions followed NNE-trending fractures. This orientation probably corresponds to the direction of main horizontal compression and is ubiquitous in the Palaeozoic as well as in the Mesozoic/Alpine structural inventory of Central Europe (FRANKE 1997). Updoming above the NNE-trending Ramberg intrusion is responsible for the sigmoidal trend of tectonic units and for the separtation between the once coherent South Harz and Selke Nappes in the southeastern Harz Mts. (Fig. 1). The Brocken and Ramberg Plutons are not related to the Variscan orogeny, but reflect a late-Carboniferous/Permian magmatic event (mantle plume?), which has affected large parts of Europe, from northern England to the Southern Alps.

Post-Variscan evolution

While the Brocken and Ramberg Plutons and the Middle Harz Dyke Swarm intruded at shallow depths, intra-montane basins (Saale, Ilfeld and Meisdorf Basins) were formed at the surface in latest Carboniferous through Early Permian times. The Ilfeld Basin (Fig. 6) is situated at the southwestern margin of the Harz Mts. and exposes parts of a basin which extends further south beneath the Thuringian Basin (Fig. 1) on a distance of 50 km. The Ilfeld Group contains uppermost Carboniferous through Lower Permian molasse sediments and intercalations of volcanic sequences with a total thickness of about 600 m. Sedimentation started in the latest Carboniferous with coarse-grained proximal alluvial fan deposits, which are overlain by a coal-bearing sequence. Up-sequence, a local extrusion of latite is followed by redbeds with a thick (300 m) intercalation of rhyolite to rhyodacite (STEINER 1974, PAUL 1999). Step by step, the sedimentation of redbeds occupied areas further west and was topped by eolian sands covering the western flank of the basin. The Ilfeld Basin is interpreted as NS-trending graben associated with the Middle Harz Dyke Swarm. Further north in the Flechtingen Block and in the Northeast German Basin, the molasse sedimentation and the volcanic activity occupies large areas, which are apparantly unrelated with the small scale structures developed in the Harz area (e.g. BENEK et al. 1996).

In late Cretaceous time, the Adriatic promontory of Africa impinged upon Europe, and compressional stress was transmitted far into the foreland. Compression brought about important reverse faults, which exhumed the basement outcrops of the Teutoburger Wald, Harz Mts., Flechtingen Block, and the entire Bohemian Massif (ZIEGLER 1987, FRANKE 1997).

Uplift of the Harz Mts. occurred along a NW-trending, steeply SW-dipping fault (FRANZKE et al. 1992) and resulted in a SW-ward tilting of the upthrusted Harz block (Fig. 7 and below). Therefore, the Palaeozoic basement is framed, to the NW, SW and SE, by the sedimentary onlap of Late Permian carbonates and evaporites (Zechstein). These are overlain by the "Germanic" facies of the Triassic: fluvial to lacustrine redbeds (Bunter = Buntsandstein), shallow marine carbonates (Muschelkalk) and variegated, fluvial to hypersaline sediments (Keuper).

From the mid-Jurassic onwards, central and northern parts of Germany were part of a roughly E-W-trending land bridge, which separated a northern sea (an early precursor of the present-day North Sea and Baltic) from a southern, epeiric sea (the northern shelf of the Tethys Ocean. The northern sea invaded Germany during the global Cenomanian transgression. The shoreline was oriented EW, and was situated at the northern margins of the Palaeozoic outcrops of the Rhenish Massif and Harz Mts.

The Cretaceous and subsequent uplift history of the Harz Mts. as a tilted block is characterized by the Northern Harz Boundary Fault Zone, tectonic up-bending of the Mesozoic cover sequences along the northern Harz margin and contemporaneous sedimentation at least in Cretaceous times. The Northern Harz Boundary Fault Zone consists of a compressional growth fault, whose activity is recorded in the Cretaceous sediments. Drag along the fault plane caused progressive upward bending of bedding in the footwall (cross section Fig. 7). Older formations are overturned or steeply inclined, while bedding in younger deposits approaches the horizontal. The hanging wall block was detached along Permian evaporites.

NW of the Harz block, in the Subhercynian Cretaceous Basin, a thick pile of Cretaceous sediments was deposited from the Early Cretaceous onwards (STRATIGRAPHISCHE KOMMISSION DEUTSCHLANDS 2000, TRÖGER 1995). Shallow marine clastic sediments and marls attain more than 1 km in thickness. Sedimentation starts in Hauterivian and ends in Campanian times. This record is punctuated by sea-level fluctuations, which have produced angular unconformities formerly used by (STILLE 1910) for the definition of the "Subhercynian" orogenic "phases". However, the unconformities within the Cretaceous sediment pile are the result of the more or less continued uplift by upthrusting of the Harz block which ends not prior to Campanian: locally, still the Upper Santonian Heimburg Formation is steeply inclined. Upthrusting of the Harz Block and faulting in the basement of the Subhercynian Basin produced weak folding in the Mesozoic sediments to the NE. The structural pattern is partly controlled by narrow, NW-trending salt diapirs located above faults zones in the Variscan basement.The fold pattern is characterized by narrow anticlines (Fig. 7) and broad synclinal structures.

In contrast to the northeastern margin of the Harz Mts., its southwestern margin is characterized by a more or less normal onlap of the Permo-Carboniferous and Triassic on the the Thuringian Basin.

In our field guide, we describe a number of key outcrops (probably more than we will be able to visit), which are representative of the Palaeozoic and younger evolution of the area.

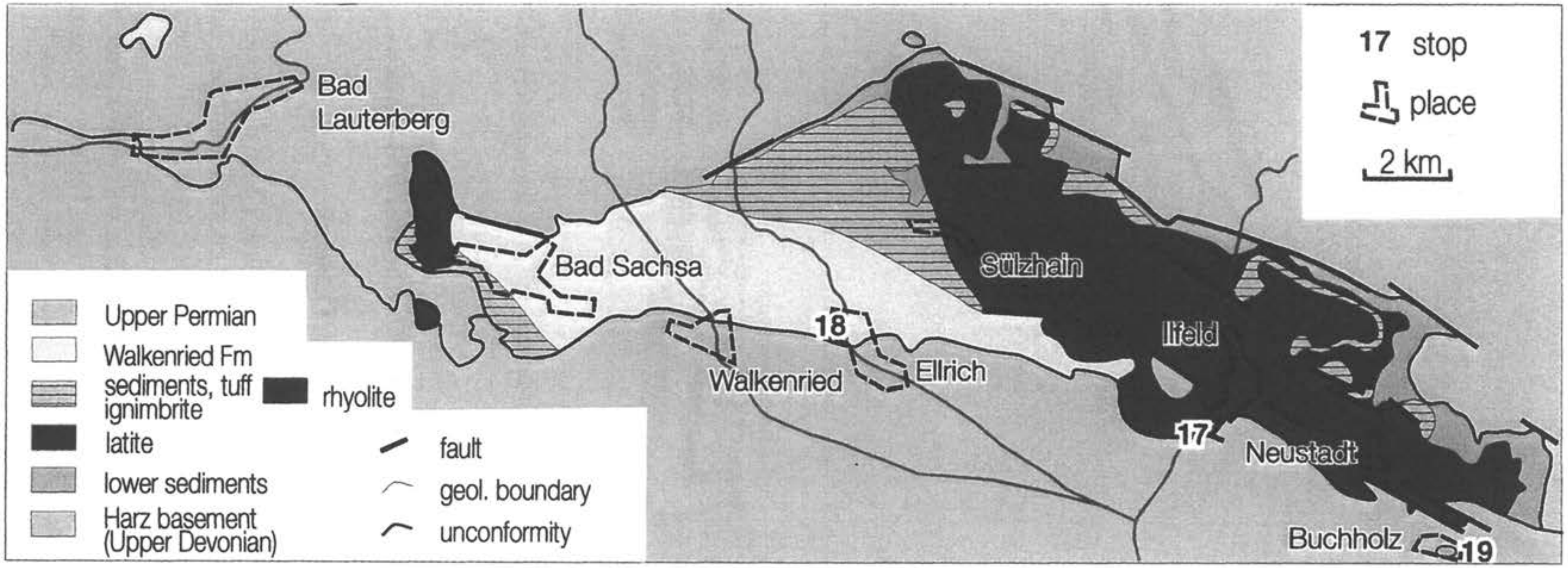

Fig. 6: Post-Variscan intramontane Ilfeld Basin (modified after PAUL 1999)

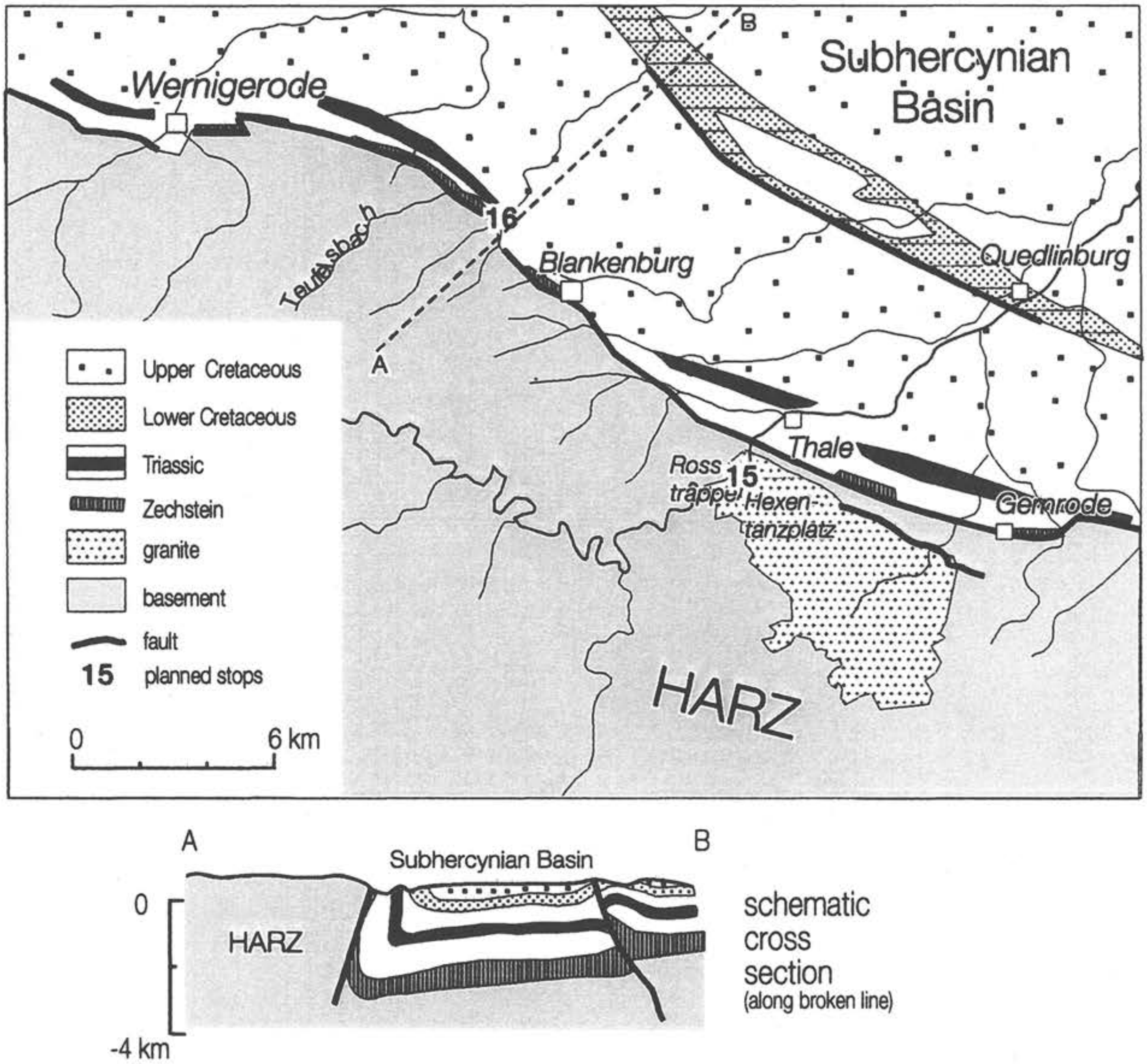

Fig. 7: Geological sketch map of the Harz Mts. and the adjacent Subhercynian Cretaceous Trough along the Northern Harz Boundary Fault Zone

Stops in the Basement of the Harz Mountains

Stop 1: Abandoned quarry at Fuchshalle, Osterode

The quarry exposes black radiolarian cherts of Late Tournaisian age. They represent a global black shale event (SIEGMUND et al. 2002). The cherts have been deformed into NW-facing folds. The Variscan basement is unconformably overlain by the Late Permian "Kupferschiefer" (Copper Shale), a metalliferous black shale which has since long been exploited for copper. In Poland, subsurface mining of this level is still active. Precipitation of metal sulfides (mainly Cu, Pb, Zn) has long been considered to be synsedimentary, but is now being interpreted as hydrothermal (JOWETT 1986, JOWETT et al. 1987). The Kupferschiefer is overlain by carbonates of the Zechstein (z1, the first of altogether 6 cycles of evaporites, whose deposition was probably controlled by eustatic changes of sea-level. The Late Permian deposits surrounding the Harz basement were deposited within a very short time span of 7 Ma (DEUTSCHE STRATIGRAPHISCHE KOMMISSION 2002), fill up a topographic relief of up to 70 m, which documents a rapid sea-level rise.

Stop 2: Iberg-Winterberg Reef north of Bad Grund

The Iberg and Winterberg Hills consist of Givetian through to Middle Frasnian reef limestones, which probably cap a concealed volcanic mound. Facies distribution reveals an atoll, which has been duplicated by a NW-dipping normal fault (FRANKE 1970, FRANKE 1973, Fig. 8).

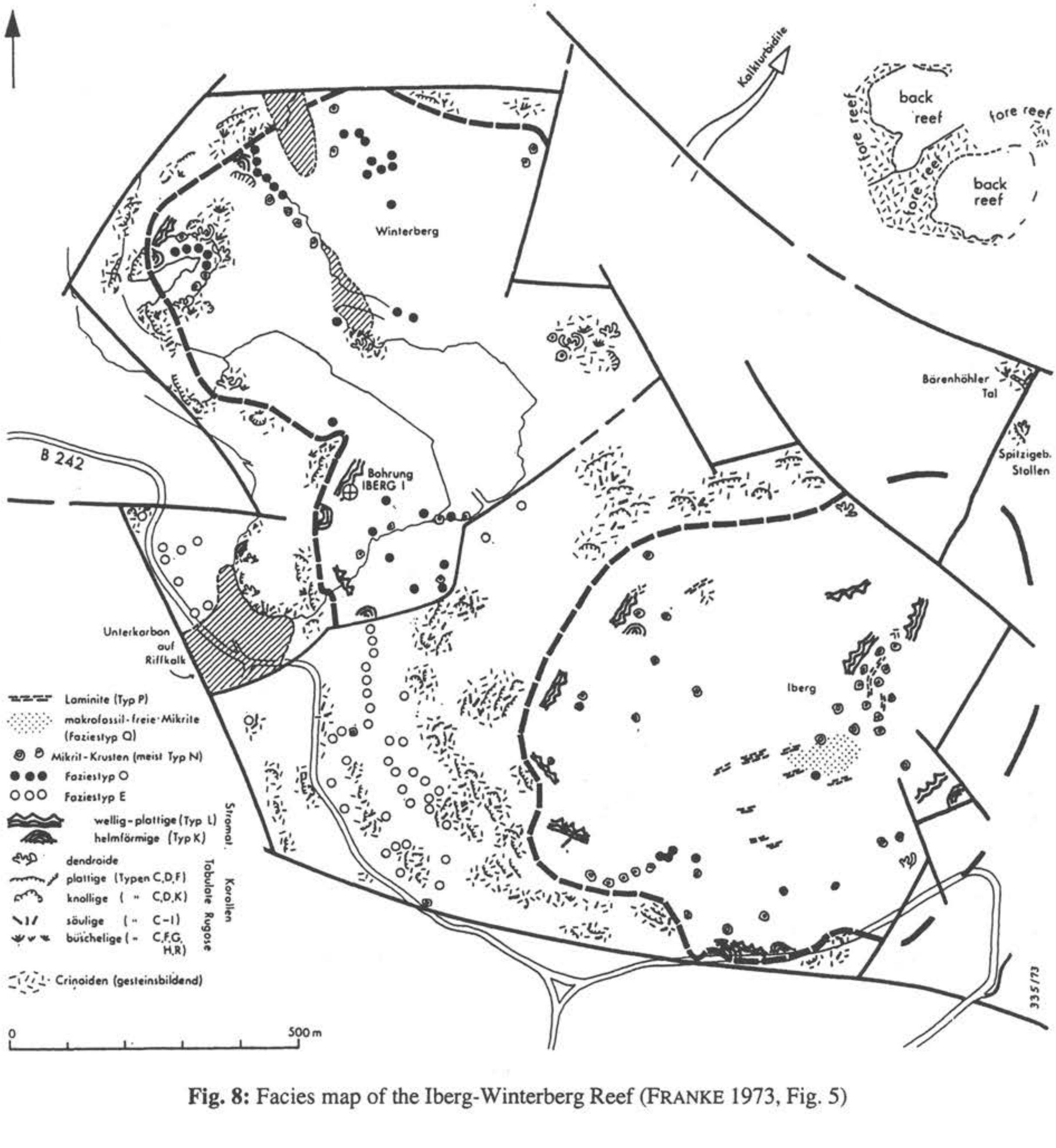

Fig. 8: Facies map of the Iberg-Winterberg Reef (FRANKE 1973, Fig. 5)

The northwestern hill (Winterberg) represents the younger, "decapitated" part of the reef structure. The normal fault might represent a Riedel shear zone relating to the overlying basal thrust of the Harz allochthon (now eroded, but closely adjacent to the SE). Reef growth was terminated at about the Frasnian/Famennian boundary by the global "Kellwasser Event" (e.g. BECKER & HOUSE 1994, JOACHIMSKI & BUGGISCH 1993).

Post-reef history has been described in detail by FRANKE (1973), GISCHLER (1992, 1996) and GISCHLER & KORN (1992). From the Late Frasnian due to the Late Viséan the reef top persisted as a submarine rise with extremely condensed sedimentation. Major parts of the stratigraphic record are only documented by redeposited conodonts in late Tournaisian limestones. A large part of the post-reef sediments is contained in NW-trending neptunian dykes. Other reef and post-reef sediments occur as tilted or overturned blocks. Fracturing and displacement occurred repeatedly in the early Famennian, early and late Viséan time, probably related with seismic activity and/or synsedimentary volcanism. $\delta^{13}C$ data from a late Viséan brachiopod community indicate formation above a methane seep (PECKMANN et al 2001). It was not before a late part of Late Viséan B (*sensu* KORN 1996) that the reef top was buried by synorogenic greywacke turbidites (Fig. 9). In the basinal areas around the reef, greywacke deposition begins significantly earlier (see Stop 3).

We shall visit a large quarry in the Winterberg hill (reef limestones), and roadside outcrops on the western flank of the Iberg (Carboniferous infill of neptunian dikes).

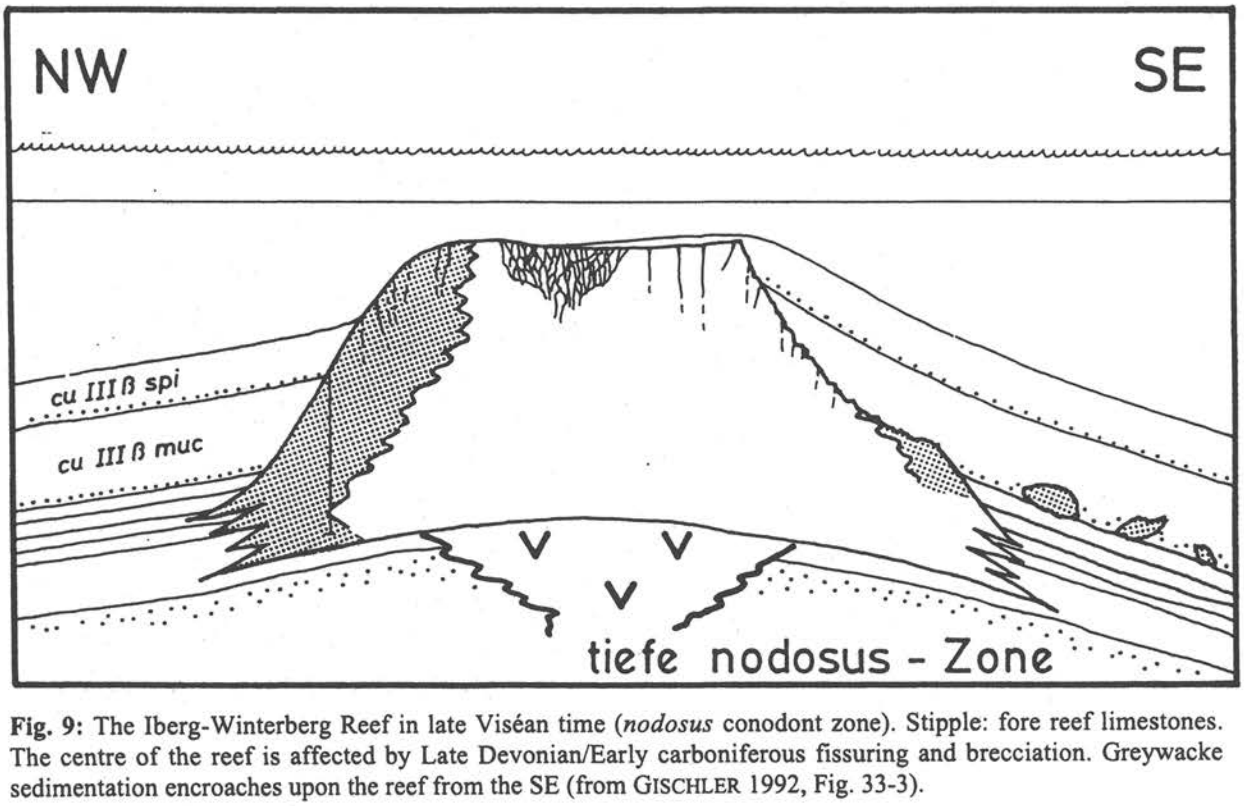

Fig. 9: The Iberg-Winterberg Reef in late Viséan time (*nodosus* conodont zone). Stipple: fore reef limestones. The centre of the reef is affected by Late Devonian/Early carboniferous fissuring and brecciation. Greywacke sedimentation encroaches upon the reef from the SE (from GISCHLER 1992, Fig. 33-3).

Stop 3: Abandoned quarry north of Wildemann, east of Iberg-Winterberg reef

The quarry exposes classical greywacke turbidites on the north flank of of a major anticline. Goniatites from shaly interbeds found by FRANKE (1970) indicate deposition during the *gracilis* and *spirale* stages of the Late Viséan B (*sensu* KORN 1996). On the reef 3 km to the west, this level is represented by condensed pelagic limestones.

Stop 4: Sparenberg NW Lautenthal

Cliffs along a foothpath expose pelagic shales and limestones of late Middle Devonian to middle Famennian age. At about the Givetian/Frasnian boundary, there is an intercalation of sedimentary breccia with limestone clasts in a shaly matrix. Redeposition occurred at the northwestern flank of a submarine rise. The outcrop is representative of the pelagic realm, which, during the Middle and Late Devonian, encroached upon the clastic shelf. Note that the central portion of the section is time equivalent with the Iberg reef limestones.

Stop 5: LOSSEN monument, about 2 km southwest of Wernigerode

K.A. LOSSEN (1841-1893) was a famous Harz geologist who mapped several sheets of the geological maps and compiled the first map covering the entire area of the Harz (LOSSEN 1881). In honour of LOSSEN this monument was erected 1896. Around the monument the main rock types of the Harz Mountains are represented by impressive samples.

Stop 6: Abandoned quarry "Garkenholz" c 2 km ENE Rübeland (Fig. 5)

The outcrop exposes reef limestones of Late Givetian age. The reef limestone is made up of coarse-grained debris (lithoclasts and bioclasts) and represents the fore-reef. Bedding is poorly developed, and obscured by ductile cleavage with considerable flattening of the clasts and intense recrystallization (Fig. 10). Neptunian dykes are filled with early Famennian tuffaceous sediments (SCHWAB & JACOB 1994).

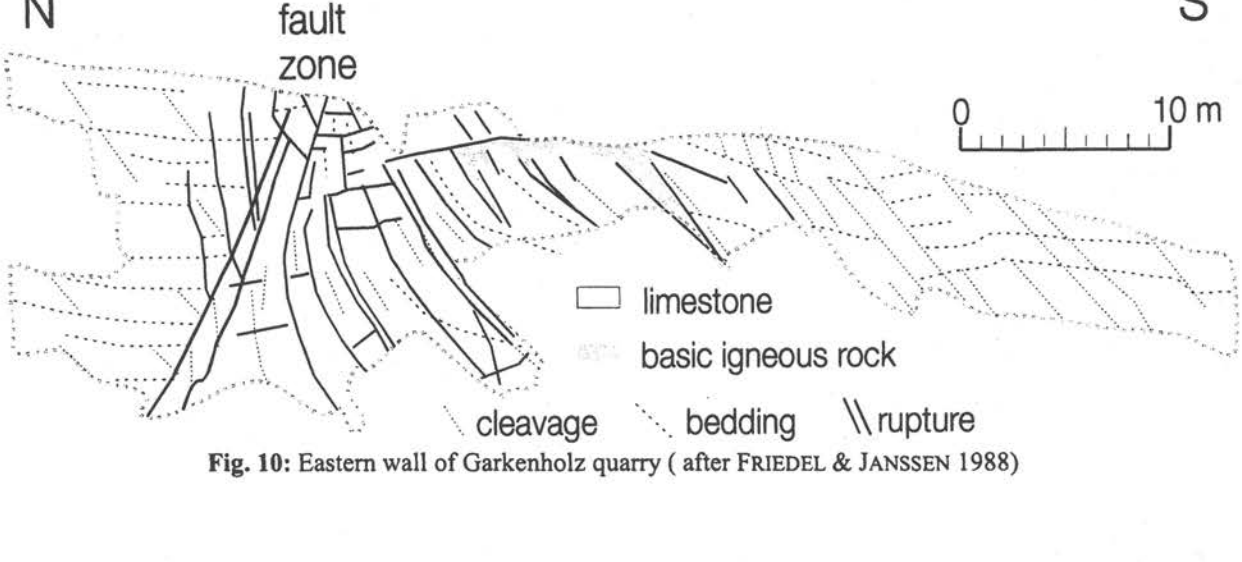

Fig. 10: Eastern wall of Garkenholz quarry (after FRIEDEL & JANSSEN 1988)

Stop 7: Abandoned quarry c 1 km east of Rübeland, opposite to turn-off to Neuwerk (Fig. 5)

A pelite-greywacke alternation of latest Early Carboniferous age shows features of turbiditic flysch sedimentation. It is represented by turbidites mostly from the distal environ (predominance of pelites). The sequence is intensely folded with a northerly vergence and shows a pervasive cleavage (JANSSEN et al. 1988).

Stop 8: Limestone quarry Elbingerode (Fig. 5)

In the extended limestone quarry (more than 1 km across) back-reef limestone is exposed (RUCHHOLZ & WELLER 1988). The limestone excavation started in 1973 and attains now 6 million tons a year (excavation is planned to go down to 100 m depth). We will have a view into the quarry and see the flat-lying sedimentary lamination in contrast to the massive fore-reef limestone.

Stop 9: Abandoned quarry at the western margin of Königshütte (Fig. 5)

In the small outcrop the transition of lower Givetian volcanic rocks (Schalstein) to Upper Givetian reef limestone is exposed. The reef facies is represented by a limestone/ shale sequence passing upwards into massive limestone. The entire sequence shows penetrative cleavage.

Stop 10: Rocks along the road in the Bode river, c 300 m east of the eastern margin of Königshütte (Fig. 5)

In the pelitic sequence steeply inclined (70° SE) some exotic blocks of clastic sediments are embedded which are interpreted as olistoliths. The sequence belongs to the Hüttenrode olistostrome flanking the Elbingerode Complex. At the northern flank of the Elbingerode Complex, the Hüttenrode olistostrome contains olistoliths which can be referred to the Elbingerode Complex. Alternatively, the Hüttenrode olistostrome might be interpreted as a tectonic mélange with slices detached from the footwall.

Stop 11:Outcrops along the road near the greywacke quarry Unterberg (c 4 km north of Ilfeld)

Roadside outcrops expose mostly fine-grained Famennian Südharz Greywacke. Since pelitic intercalations are lacking, bedding is scarcely discernible. The nearby quarry exposes an upright fold structure of about hundred metres width. The Devonian Südharz Greywacke belongs to the Südharz Nappe (Fig. 1), whose allochthonous position is evident from stratigraphic inversion with respect to the underlying Early Carboniferous olistostrome.

Stop 12: Abandoned greywacke quarry about 2 km northeast of Tanne

The Tanne Greywacke (Early Carboniferous) is represented by greywacke-dominated or shale-dominated sequences, both of which are intensely folded. The outcrop shows massive, structureless graywacke without shaly interbeds, possibly deposited by high density turbidity currents.

Stop 13: Rocks along the Selke River in Alexisbad

Along the river bed, the Lower Carboniferous Tanne Greywacke is represented by an alternation of fine-grained greywacke and pelitic intercalations. They show sedimentary structures characteristic of turbidites (graded bedding, convolute bedding, groove casts, load casts etc. Furthermore slumping structures are present. The Tanne Greywacke is intensely deformed into upright, ESE-trending axes.

Stop 14: Abandoned quarry near the railway in Güntersberge (Teichdamm = pond dam)

The concept of olistostromes in the Harz Mts. goes back to studies in this outcrop. A shaly matrix contains lenses of limestones, most of which are of pelagic origin and have been dated with conodonts (Emsian to latest Devonian in age, REICHSTEIN 1962). The limestones are known as "Herzynkalke" (Hercynian limestones) in the regional literature. They represent condensed sequences of pelagic origin. REICHSTEIN (1965) was the first to interpret the limestone blocks as olistoliths.

Stop 15: Rosstrappe 2 km southwest of Thale (Fig. 7)

The Rosstrappe rock provides a beautiful view over the NE margin of the Harz Mts. The Rosstrappe (403 m elevation) consists of Ramberg Granite dated at c 295 Ma (BENEK 1967). The granite is porphyric with feldspar porphyroblasts up to 2 cm in size. The wallrock is Middle Devonian Wissenbach Slate. The pluton shows a dome-like structure delineated by joints, aplite dikes and a fine-grained facies along the contact.

Stop 16: Escarpment along the road in the Teufelsbach Valley between Blankenburg and Heimburg (Fig. 7)

The outcrop exposes Ceratites Beds, the uppermost member of the Muschelkalk Formation (Middle Triassic), named after the special group of ammonoids (*Ceratites*). Ceratites evolved in a marginal sea ("Germanic Basin") north of the Alpine Tethys. The Ceratites Beds consist of an alternation of marls with bioclastic limestones (tempestites). Bedding is steeply inclined due to tilting along the northern boundary fault of the Harz Mts. (STACKEBRANDT 1986) The Muschelkalk Formation is unconformly overlain by the Lower Campanian Blankenburg Formation (Fig. 11).

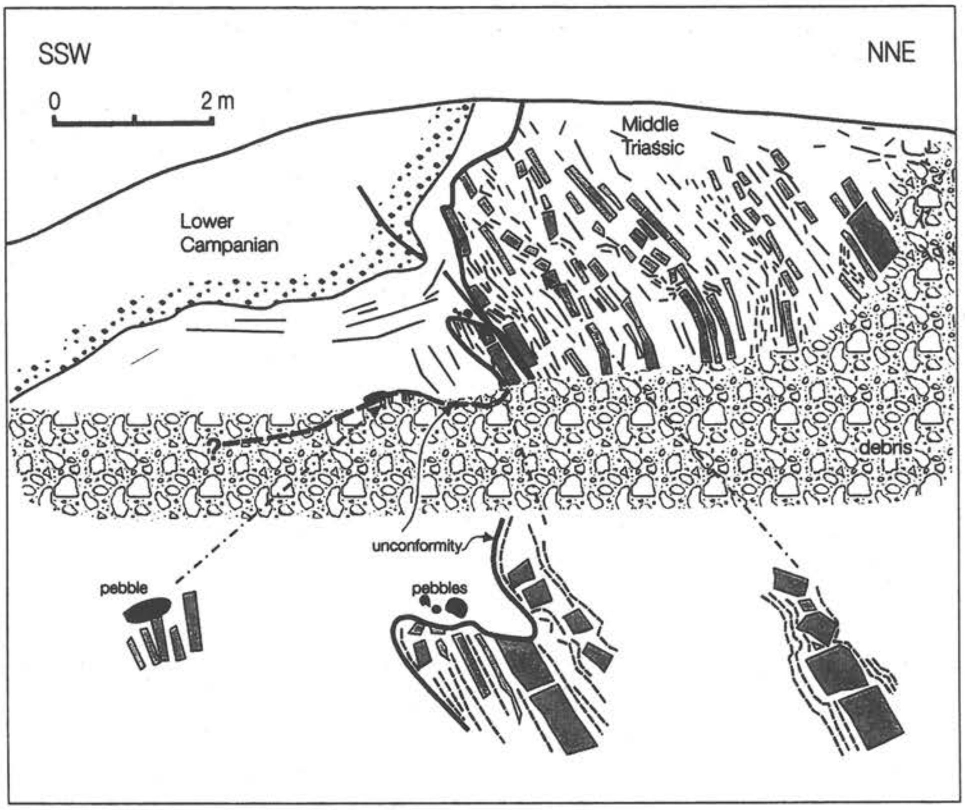

Fig. 11: Middle Triassic limestone (upper Muschelkalk) overlain by Lower Campanian marls of the Blankenburg Formation along an unconformity (adopted from STACKEBRANDT 1986)

It is the type locality of one of the "Subhercynian" tectonic "phases" of STILLE (1910), now recognized as a local feature (MORTIMER et al. 1996). Nevertheless, the outcrop shows clear evidence of the transgression of the Creatceous Blankenburg Formation. The pebbles derived from the underlying Middle Triassic are pierced by endolithic organisms. The limestone bedrock is likewise rounded by wave action of the invading Cretaceous sea.

Stop 17: Lange Wand near Ilfeld

Late Permian (Zechstein) unconformably overlies Early Permian rhyolithe. The top of the red rhyolithe is bleached due to weathering prior to the Zechstein sedimentation.

The Zechstein consists of a basal conglomerate (up to 1 m thick, with greywacke pebbles derived from the Harz basement), overlain up to 0.5 m of "Kupferschiefer" (Copper Shale). The Kupferschiefer is a black shale with economically important sulfide mineralization (mainly Cu, Pb, Zn). Part of the mineralization is synsedimentary, but there is also an influx of Late Permian/Triassic brines and possibly still younger processes (JOWETT et al. 1986, 1987, NAWROCKI 2000). Until some twenty years ago, it was extensively exploited at the northern margin of the Thuringian Basin). The Kupferschiefer is overlain by >3 m of Zechstein limestone. Bedding is gently inclined to the north, due to rotation along normal faults, which bring down increasingly younger beds toward the south. The normal faults have been overprinted by ?Cretaceous compression (Fig. 12).

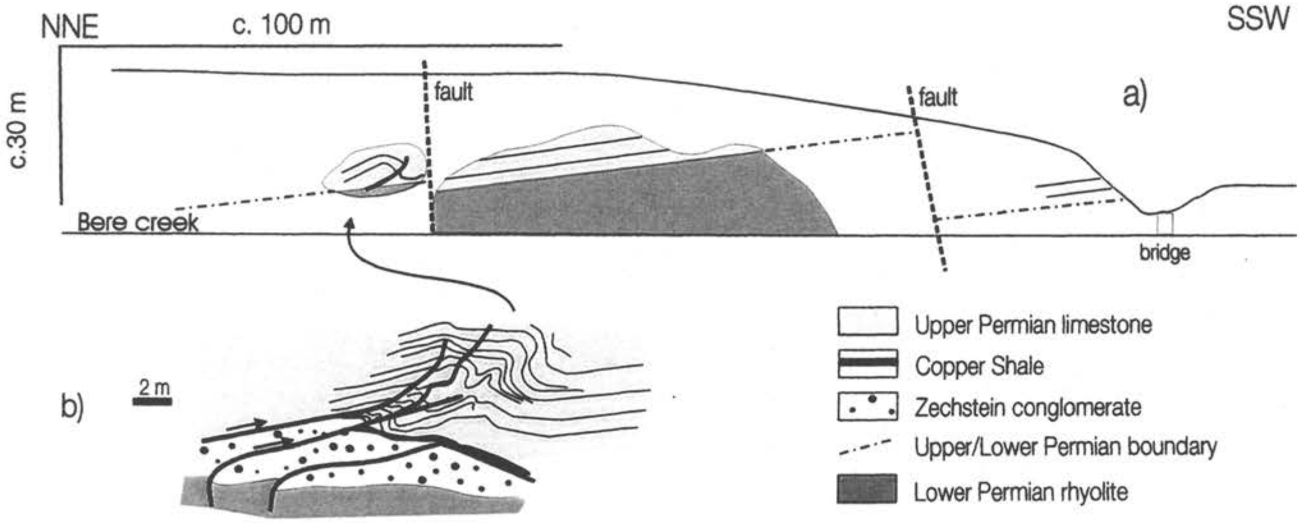

Fig. 12: Geological section along the Lange Wand (Long Wall) at the southern tip of Ilfeld (a) general sketch, b) detail according FRANZKE in BEUTLER et al. 1988)

Stop 18: Sand pit "Ellrich Sand (ELSA)" at the western margin of Ellrich

The sand pit exposes the contact between eolian Walkenried Sand Formation (Lower Permian) with the overlying Zechstein beds (Zechstein Conglomerate, Copper Shale and Zechstein Limestone). The red sands represent the uppermost part of the Ilfeld Group. They consist of well-sorted medium-grained sand with a large scale cross lamination characteristic of eolian origin. On the Flechtingen Block, the wind direction was from the northeast. Eolian sands have a wide distribution in the Permian sequences in the underground of the North-German Basin, and locally contain gas deposits.

Stop 19: Several outcrops in Buchholz (old waste tips, abandoned quarries)

An isolated occurrence of the Ilfeld Group at the eastern end of the Ilfeld Basin exposes coarse-grained alluvial fan sediments of reduced thickness. They overly a Devonian basalt of the Südharz Nappe and are overlain, in their turn, by a Zechstein sequence, whose Copper Shale was exploited in historical times. The belt of outcrop is still delineated by tips. The Zechstein Copper Shale and Limestone are overlain by evaporites which have been dissolved at the northern margin of the Thuringian Basin, leading to collapse depressions (dolinas) in the overlying beds.

Stops on the Flechtlingen Block

The Flechtingen Block comprises Lower Permian clastic molasse sediments with a thick (>1 km) intercalated volcanic sequence and basement made up of Lower Carboniferous turbidites (Magdeburg-Formation) attaining 1 km in thickness (PAECH et al. 2002, Tab. 1). The Early Carboniferous age of the Magdeburg Formation is constrained by rare findings of goniatites, trilobites, conodonts and other fossils occurring in thin pelagic inlayer (1 mm). The age ranges from Serpukhovian to Late Viséan. Sedimentologically, it is characterized by turbidites ranging from a proximal to a distal type. Transport was directed from East to West. The greywackes show small-scale folding along E-W axes. Fracture cleavage occurs but locally, and metamorphic alteration is only diagenetic to low anchizone. The Magdeburg Formation will be studied in two outcrops.

Stop 20: Former quarry near Ebendorf, north of Magdeburg

The basement of the Flechtingen Block is exposed at a depth of less than 2 m under Quaternary loess (Weichselian glaciation) of the "Magdeburger Börde". Here, the Flechtingen Formation is made up of thick greywacke beds (>1 m) with pebble layers and thin intercalations of siltstones. It can be interpreted as proximal flysch. The sequence is weakly folded into a syncline. There are no index fossils.

Stop 21: Former quarry near Hundisburg about 30 km northwest of Magdeburg

The Flechtingen Formation is represented by an alternation of greywackes and fine-grained sediments of typical flysch. Their age is constrained as Pendleian (uppermost Early Carboniferous) by pelagic fossils found in outcrops about 500 m to the south. The formation is represented by flysch sediments transitional between proximal and distal facies. The oucrop is located in the crest of an anticline in a set of folds with wavelength of about 600 m and northerly vergence. On top of the outcrop, glacial striae document the southeastward ice movement.

Stop 22: Cliff along the Bever Creek south of Bebertal

The outcrop shows c 10 m of Early Permian continental redbeds typical of the North German Basin. Fluvial deposits contain eolian intercalations and, up-section, deltaic sediments (ELLENBERG et al. 1976). The total thickness of the Early Permian attains 130 m.

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Field Trip E
Quaternary of Potsdam Area

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Introduction

The North-German Lowlands are mostly covered by glacial debris (boulder to clay size) transported by Pleistocene glaciers southwards from northern Europe (Scandinavia and intermitting regions). The Pleistocene sequences in this region mostly comprise sediments deposited during Elster, Saale and Weichsel Glaciations (Tab. 1). Beginning at 475 ka BP, the Elster glaciers advanced to the southernmost region marked by the so called "Feuerstein / firestone" i.e. flint line. This term refers to flint concretions formed in Cretaceous chalk, exposed at the southern coast of the Baltic Sea. Firestone pebbles within other debris are transported by glaciers southwards and their southernmost distribution indicates the maximum advance of Pleistocene glaciations. Subsequent glaciations terminated more in the north. The retreat of the last glacier was completed 13 ka BP (LIPPSTREU 2002a, b). The glacial periods were characterized by oscillating climate conditions which are reflected in interstadial sediments; the oscillating advance *versus* retreat of the glaciers is well documented in moraines of the Weichsel Glaciation. The Pleistocene glacier advance formed festoon-like arranged moraines that followed the N-S trending exaration (glacial denudation) channels that reached 300 m (at times in excess 500 m) in depth. This feature is particularly seen during the Elster Glaciation.

				ka BP
Holocene				10.2
Pleistocene	Weichsel Glaciation	Late Weichs.	Dryas episode	13
Pleistocene	Weichsel Glaciation	Main Weichsel	Mecklenburg advance Pomerania advance Brandenburg advance	24
Pleistocene	Weichsel Glaciation		(not represented in the study area)	115
Pleistocene	Eem Interglacial			128
Pleistocene	Saale Glaciation			347
Pleistocene	Holstein Interglacial			370
Pleistocene	Elster Glaciation			475
Pleistocene	Cromer Complex (not represented in the study area)			780
(not represented in the study area)				1800
Tertiary				

Tab. 1: Stratigraphic subdivision of Pleistocene deposits in the Potsdam area (simplified according to LIPPSTREU 2002a)

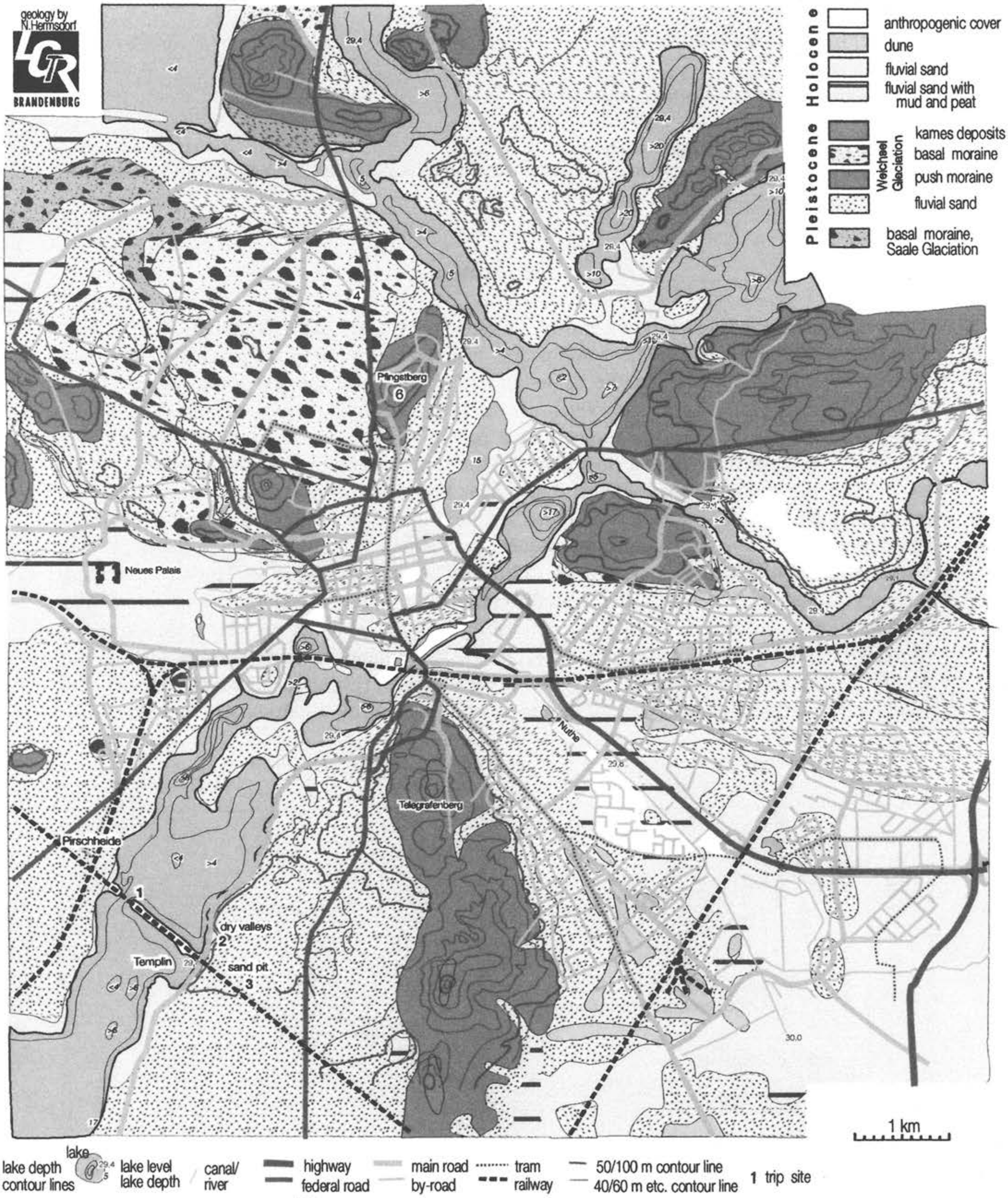
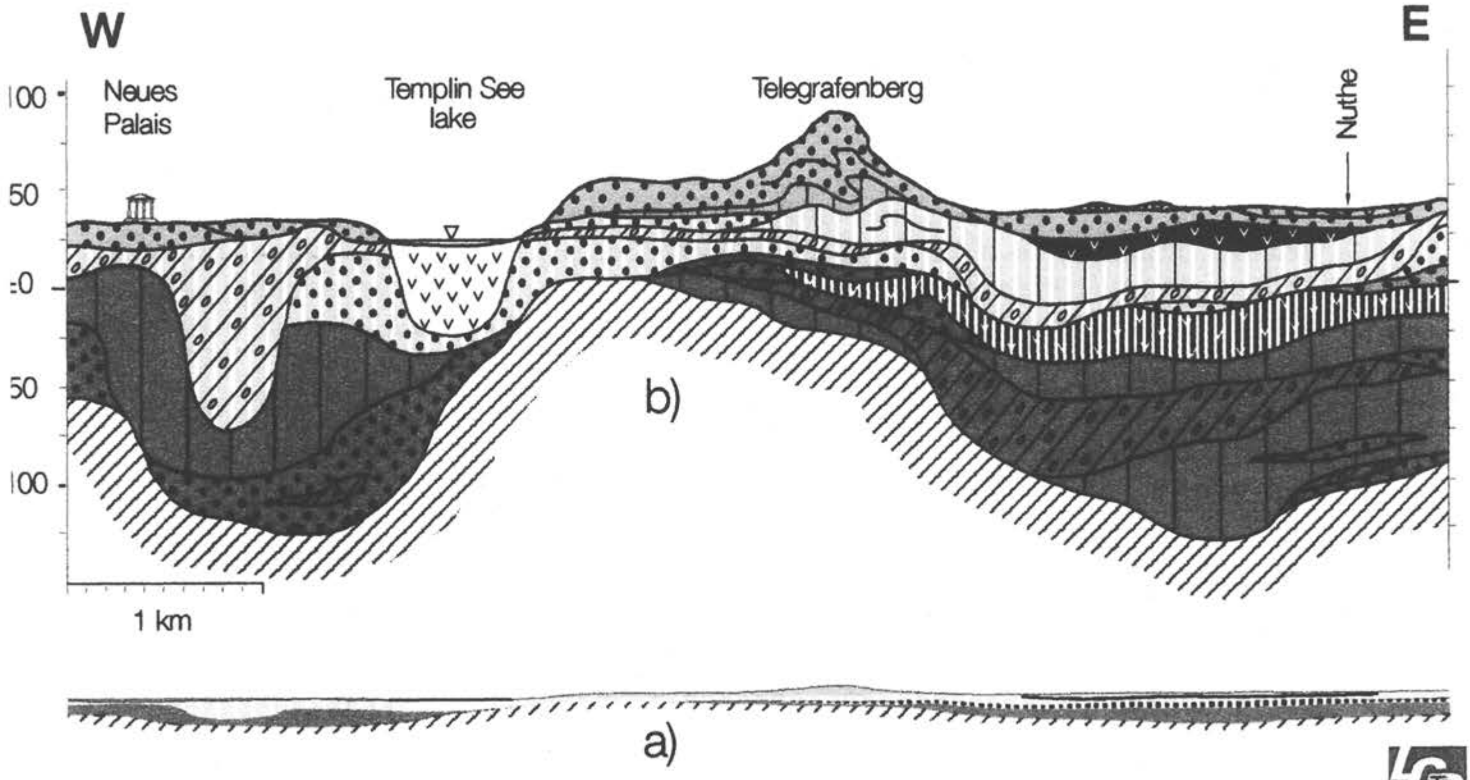


Fig. 1: Geographic and geologic sketch map of the Potsdam region. The field trip is planned as combined walking and bus tour. The pedestrian walk starts from the railway station "Pirschheide", crosses the Templin railway dam and the sand pit (field trip stops 1 to 3) and is completed at the Michendorfer Chaussee after a distance of about 3 km. Then, the bus brings the participants to the stops 4, 5? and 6, where after visiting the Belvedere palace at Pfingstberg, the field trip ends. The Stop 5 could not indicated on the map as it depends on the options to an available outcrop in September 2003.



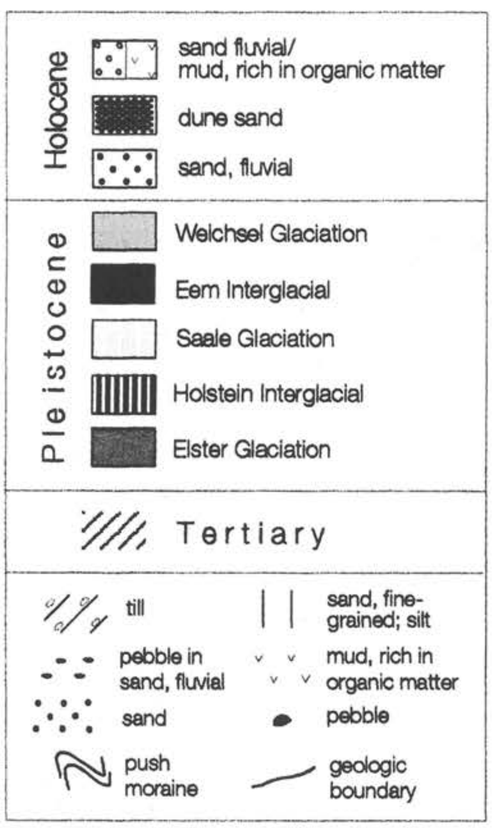


Fig. 2: Schematic cross section through the Quaternary sediments in the Potsdam region from the Neues Palais to East (simplified according to N. HERMSDORF, LGR Brandenburg, 2001); a) no vertical exaggeration and extremely generalized; b) exaggeration 10 times.

Typically the glaciations, under cold climate conditions, are interrupted by warm or at least moderate climate interglacial periods allowing the formation of fine-grained lacustrine sediments, mostly rich in organic matter. The Eem Interglacial was interrupted around 120 ka BP for 13 ka duration, and the Holstein Interglacial for about 23 ka duration around 360 ka BP (Tab. 1).

Predominantly, the landscape of Potsdam and its surroundings was formed during the Weichsel Glaciation (24-10 ka BP). The picturesque scenery and placement of the parks and palaces within the Pleistocene landscape by KNOBELSDORFF, GONTARD, UNGER, L ENNÉ, SCHINKEL and their students was the reason for the inclusion of Potsdam and its surroundings in the UNESCO list as Global Everlasting Heritage of Culture and Nature.

Geological setting of the Potsdam region

In the Potsdam region Pleistocene glacial deposits and minor Holocene sediments are exposed at the surface. The Pleistocene formations are composed almost completely of Weichsel deposits (possibly in minor degree Saale base moraine, Fig. 1). However, older Pleistocene formations are widespread beneath the Weichsel sequences (Fig. 2) and known from wells.

They are represented by Saale and Elster glacial tills and fluvio-glacial sands of cold stages, intercalated with interglacial deposits of the Holstein and Eem Interglacials. Only locally present (Fig. 2) are the sequences of the Eem Interglacial, comprising lacustrine calcareous muds (c 8 m in a borehole in the eastern part of Potsdam), and the Holstein Interglacial comprising clay mud (8 m with the leading gastropod *Viviparus diluvianus*, formerly known under the name *Paludina diluviana*) and calcareous sediments (1 m).

The total thickness of Pleistocene sediments varies considerably: in subglacial channels (trending NNE-SSW) it exceeds 200 m but in the intervening regions may be locally limited to a few meters. Often, the subglacial channels were filled by lacustrine sediments during the following interglacial. The Weichsel Glaciation was marked by oscillating advances of glaciers; these glacial deposits attain a maximum thickness of 50 m.

The oldest advance of the Weichsel Glaciation is the Brandenburg advance (Main Weichsel, Tab. 1) reaching towards regions south of Potsdam where the broad Baruth glacial spillway (Urstromtal) allowed the discharge of the huge amount of glacier melt waters transporting the fluvio-glacial debris. The subsequent Pomerania advance starts about 17 ka BP not reaching the Potsdam region and was stopped due to the reduction of ice formation north of Berlin where a glacial spillway discharged the ice melt water in northwestern direction. The glacial sequences of the Brandenburg advance in the region of Potsdam are often represented by fluvio-glacial sands, locally even fine-grained sand and silt, only to a minor degree by till. The fluvio-glacial sands occur in push moraines, in kames areas (i.e. their formation is associated with dead ice and its thawing-off), and in outwash plains more to the south of the study area. The moraines in Potsdam are end moraines and base moraines. The base moraines are composed of lodgement till and the end moraines mostly of fluvio-glacial sands. The later are compressed in push moraines which contain additionally also rafts of the pre-Weichsel

subcrop sequences. The Weichsel base moraine in northern Potsdam additionally shows structures (WEISSE 2001) which reflect glacial compression.
The subcrop of the Pleistocene sediments is composed of Tertiary sands containing lignite intercalations. It is disconformably underlain by Cretaceous sediments, which in turn are disconformably underlain by Jurassic sediments. The Mesozoic deposits are weakly deformed in an E-W trending anticline by halotectonic processes in regions where the Upper Permian salt deposits attain thickness of about 500 m. The underlying Lower Permian sequences comprise molasse sediments and subsequent volcanics which cover the Variscan unconformity now at depths of more than 3 km. The Variscan basement is made up of folded Namurian to Lower Carboniferous distal flysch.

Subsequently to the Pleistocene glaciations which played a major role in shaping the recent geomorphology of the Potsdam region, the Holocene processes, dominantly fluvial and to a smaller extent lacustrine, further modified the landscape. Two types of river systems can be distinguished. The Havel river follows a subglacial channel of the Brandenburg advance which was then filled by a thick southward advancing glacier tongue. These ice masses were concealed by younger glacial deposits and remained as dead ice in the channel. After the thawing of the dead ice, lakes formed and a river system flowed through the channel. The river lakes, aligned one after the other, form a picturesque landscape along the Havel river and its tributary rivers and creeks. The Havel river is characterized by slow water discharge in a broad valley composed of several lakes (mostly less than 10 m depth). During Holocene, the slow river flow regime allowed the sedimentation of fine-grained organic rich muds which filled the depression of the primary subglacial valley. These mud sequences attain 40 m in thickness and are indicative of the primary depth of the subglacial channel of the Brandenburg advance. The Havel valley is surrounded by numerous tributary subglacial creeks which are now filled by Holocene mud rich in organic matter, and peat layers. The channel infill has caused problems not only during the foundation of historical buildings in Potsdam but also in recent times. The channels were represented by swamp area, now artificially covered by piled up sand (some areas are indicated in Fig. 1).

The second type of fluvial system is associated with the compression of glacial sediments to push moraines. Downwards from the retreat point of the glacier, between the push moraine and the glacier front, a valley occurs which allows the discharge of the glacier melt waters. An example of this type is the Nuthe river (Fig. 1), east of the Telegrafenberg, which belongs to a hill range of a N-S trending push moraine with an extension of more than 10 km. Here the Holocene history (at least the last 10 ka BP) is characterized by a braided and meandering river system. The flow rate is higher than in the Havel river, extended fluvial sedimentation is restricted to overflow periods; in a separated meander valley lacustrine accumulation of mud and even peat is possible.

Composition of Pleistocene clastic deposits and their geological implications

The composition of the Pleistocene glacial to fluvio-glacial deposits can be deduced from studies of the coarse clasts ranging in size from gravel to boulders attaining 1 m and more across. In the Potsdam area the pebbles have different provenance: crystalline rocks (metamorphic and igneous) from the Baltic Shield, Neoproterozoic heavily lithified sediments and volcanic rocks, and Palaeozoic weakly lithified sediments (partly fossil-bearing) from the cover of the East-European Platform. Characteristic is the wide occurrence of Cretaceous flint (Feuerstein / "firestone"), evidence of the intense excavation of Cretaceous sediments in the region of Baltic Sea and North Germany. In several cases the source area is known (indicator pebble!).

The pebble content varies in the tills of different ages and, thus, can be applied for the age grouping of the tills. However, evidence of deposits with fauna or soil formations of an inter-glacial are more reliable.

Furthermore, the orientation of pebbles allows the reconstruction of the direction of ice flow. In the region of Potsdam no pavements of lithified sequences are known, on which the moving glacier can scratch striae. The striae on boulder surfaces are of minor value for the recontruction of the palaeoflow.

Geomorphology of the Potsdam region

Morphologically, the Potsdam region is characterized by moraines attaining elevations of more than 100 m a.s.l. (Fig. 1). The regions in between are mostly covered by fluvio-glacial sands with several gravel to pebble-bearing intercalations. Often the primary sedimentary morphology is modified by the primary dead ice inclusions, and subsequently, these kame formations experienced deformation due to the thawing-off processes. As a result caverns are formed and the fluvio-glacial sediments collapse under formation of normal faults. The result is a intensely undulated landscape with elevations ranging from 50 to 90 m a.s.l. The base moraines, ~40 m a.s.l. show a weakly undulating morphology. The compression within the base moraines finds no expression in the morphology.

The Holocene history following the completion of the deglaciation is characterized by the activity of surface waters as mentioned above. In Potsdam, the first river type, the Havel river, shows a water level ranging around 29.4 m a.s.l. and very slow discharge due the presence of several lakes through which it flows. The lakes mostly have low depth. However, the lakes not belonging to the river system attain depths of up to 34 m, i.e. the bottom of the lake is below sea level. On the other side, the Nuthe river shows higher velocities due to the higher gradient, decreasing in Potsdam from ~30 m to 29.4 m level at the mouth to the Havel river where a delta is formed (now Freundschaftsinsel).

Stop 1: Railway dam across the Templin See lake

Planned and partly built prior to the world wars, the railway ring around Berlin with a total length of 180 km, was finally finished in 1956 with the construction of the last 18 km stretch between Saarmund and Golm. The most complicated part, at that time, was traversing of the Templiner See (lake) which has a width of about 1250 m (Figs.1 and 2). It was achieved by constructing a sand dam with an elevation of 10 m above the lake level, a width of 10 m at the crest and 180 m at the base. The lake attains a depth of only 8 m; however, the lake bottom is made up of waterlogged Holocene mud attaining a thickness in excess 40 m. The expulsion of the mud was accomplished by continuous overburden during the construction, aided by additional weak explosions (KÖHLER 1957). The expelled mud formed small islands paralleling the sand dam. During the construction, these mud islands along the dam were removed. However, some remnants of islands are still preserved.

Stop 2: Escarpment near the Templin See lake ("dry valleys")

Along the eastern margin of the Templin See the fluvio-glacial sands form a steep escarpment. Its origin is explained by the presence of glacier ice infill (with a sharp ice edge to the east) in the river valley (formed subsequently) against which the sands lean, forming a steep "escarpment". This escarpment is cut by "dry valleys" of considerable length (Fig. 1) likely formed by periglacial processes.

Stop 3: Sand pit near Michendorfer Chaussee

In GDR times the sand pit near the Michendorfer Chaussee was a moneyspinner, selling construction sand to West Berlin. Until 1983 the excavations were carried out in a pit in the northeast which has now been abandoned. Recent excavations that began in 1983 are in the southwest. The latter has an area of approximately 700 x 400 m while the former had an area of 800 x 250 m. The high wall escarpments attain heights of 20 m.

In a vertically continuous profile, about 40 m sand is visible in the SW pit. Now access is restricted only to certain parts of the profile:

- Uppermost ~2 m are not exposed. However, the sequence now excavated by caterpillar contains sand with pebbles, probably of colluvial or periglacial origin. The pebbles are mostly crystalline rocks. Other components are (in order of priority): heavily lithified sediments, Cretaceous flint (Feuerstein / "firestone"), unknown soft pebbles that disintegregating during handling, some limestones and small fragments of lignite.

- Lower 38 m contains mostly fine-grained sand, light-coloured, medium grained sand, (coarse grained sand is rare), poorly calcareous admixture. Cross-bedding in middle- to coarse grained sequences shows transport towards west (ZIERMANN 1974, WEISSE 2001). The fine-grained sand show parallel-bedding. During the recent exposure in wells, fine-grained lacustrine sediments rich in organic matter were discovered below the profile described. They represent the Eem Interglacial (ZIERMANN 1974).

- The attitude of the bedding in sands is horizontal; no normal faults or compressive structures are seen. In contrast, from the abandoned pit to the SE WEISSE (2001) described normal faults and inclined bedding indicating the past presence of dead ice. In the nearby railway cut, rafts of lignite-bearing sediments some meters across have been found (DIENER 1961, KÖHLER 1957).

The fossil content is poor though findings of vertebrata from the 70ties are known: woolly rhinoceros (*Coelodonta antiqutatis),* mammoth (*Mammuthus primigenius*), reindeer (*Rangifer* *tarandus*), wild horse (*Equus cf.caballus*), bison and aurochs (same as European bison, *Bos*) (HERMSDORF 2001). In a silt layer, rich in organic matter at the base of this outcrop, sporomorpha from the earliest Weichsel Glaciation have been found. These sediments are from the transition period to the Eem sediments in boreholes, as mentioned earlier.

Stop 4: Glacial boulders near the Red Barracks (erected 1893-1897) in Potsdam

A short stop allows a view on the glacial boulders transported from the Baltic Shield over a distance of more than 1000 km.

Stop 5: Outcrop of lodgement till

Visit to an outcrop of the Weichsel lodgement till depends on access to a temporary cut opened in Potsdam. In January 2003 there was no exposure of lodgement till.

Stop 6: Pfingstberg and its surroundings

The field trip will be completed by a geomorphological overview from the Pfingstberg, an elevation of 76 m a.s.l., onto the picturesque Potsdam landscape with the push moraines, weakly undulated base moraines, outwash plains and lakes mostly in former subglacial valleys. It will be combined with sightseeing of the Belvedere (construction in two periods around 1850 and 1860), the Russian Colony (1826) with the Russian Church, and the Jewish cemetery (founded in 1743). The naming of Pfingstberg has an interesting history. It was called Eichberg (Oak hill) in times of Elector the Great (1680); after removal of the oaks that were needed for the construction of buildings in the city, it was called the place of mills. With the founding of the Jewish cemetery, it was named Judenberg (Jewish hill). Simultaneously, the southern slope was called the Oberweinberg (Upper vineyard). In 1817, during the reign of Frederick William III, the name Pfingstberg (Whitsun hill) was given in honour of the visit by a member of royal family (Queen Luise or King Frederick William III) on the day of Whitsun.

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