Excursion Guide 4th PATA meeting Aachen

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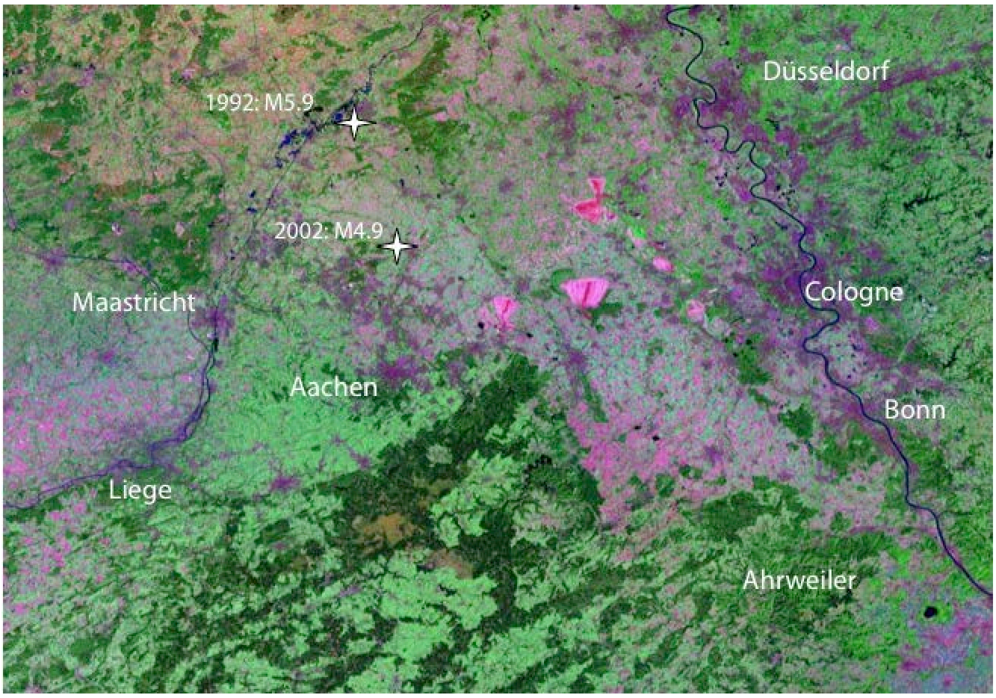

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10 October (THU) - Excursion to Cologne and the Lower Rhine Embayment – Archaeoseismology, Active Faults and Critical Facilities

Program: Flerzheim, Swist fault (guide: Martin Salomon); Roman and medieval Cologne (guide: Klaus Hinzen); the Inden open lignite pit mine.
9:30 Excursion to Cologne, starts at the Aachen Theatre, Theaterplatz 14, 52062 Aachen, (N50°46'19.52" E6° 5'15.38")
12:30 Time for individual sightseeing and short individual lunch etc.
14:30 Meeting at Cologne Hauptbahnhof (main station) (N50°56'34.87"E6°57'37.30")
19:00 End of excursion and arrival in Aachen

11 October (FRI) Ship cruise and Conference Dinner

Program: riverside-geology of the Rhine valley
(no explanations, only some figures and text provided)
Tour: Andernach – Bonn (river Rhine trip) – Ahrweiler

12 October (SAT) Wine tasting

Program: soil and geology of the Ahr valley
(no explanations, only some figures and text provided)
Tour: Ahrweiler downtown

13 October (SUN) Laacher See Volcanic Area

Program: Laacher See (Laacher Lake) Volcanic Area, excursion natural hazards and critical facilities
Tour: Ahrweiler – Maria Laach – Rursee/Simmerath

14 October (MON) - excursion to Aachen

Program: Aachen and surroundings
10:00 Excursion: Geology and archeoseismology in Aachen (guided cathedral tour)
12:00 Time for individual sightseeing, lunch etc.
14:00 Feldbiss-Fault in Aachen surroundings (bus trip, guide: Roland Walter)
18:00 Arrival in Rursee/Simmerath

Introduction (modified from Reicherter et al., 2008)

The Cenozoic tectonic evolution of Central Europe was governed over long periods of time by far-field stresses resulting from continent collision in the Alps, which is still ongoing, ridge push in the Atlantic Ocean, and other sources. Such far-field stresses interfered with more local stresses related to processes such as the rise of mantle plumes, leading to the Cenozoic volcanism of Central Europe, and glaciation. Alpine tectonics north of the Alps began with the effects of Late Cretaceous-Early Paleogene continent collision in the Pyrenees on the European crust. During Tertiary times, the stress field was unstable and repeatedly changed both in terms of magnitude and orientation. Notably, an episode of ESE-WNW to E-W directed extension during the late Eocene to Oligocene created the European Cenozoic Rift System (Rhône-Bresse Graben, Upper Rhine Graben, Lower Rhine Basin, and others; Fig.1) which up to the present is the tectonically most active zone of Central Europe. Flexural basins formed in the southernmost part of the Alpine-Carpathian foreland. The Jura Mountains also form part of the Alpine foreland, although they could, from a tectonic point of view, also be regarded as part of the Alps. They represent the most external foreland fold-and-thrust belt of the Alps. Folding and thrusting in the Jura Mountains took place during the Middle Miocene to Pliocene, and the thrust front presently propagates northward into the Upper Rhine Graben. The Alpine tectonics of southern Germany may best be described in terms of reactivation of older inherited, mainly Variscan, basement structures. This is also the case for the central Leine Graben, the Harz Mountains and parts of the North German Basin. Because of the frequent reactivation of faults, the following sections include also some remarks on the pre-Alpine deformation and sedimentation history.

The general episodes of Alpine deformation N of the Alps can be subdivided into three main phases, including (1) the period of Late Cretaceous-Early Paleogene inversion tectonics, when far-field effects of continental collision and the formation of the Pyrenees resulted in deformation extending as far to the N as the Danish North Sea and including the large-scale uplift of the Harz Mountains; (2) Eocene to Miocene extensional tectonics with the formation of the large graben systems, for example the Upper Rhine Graben; and, (3) the phase of tectonics related to the reorganization of the stress field during the Late Miocene, which coincides with the initiation of the "neotectonic period" and the present-day stress field in Central Europe, which is characterized by SE-NW compression and NE-SW extension.

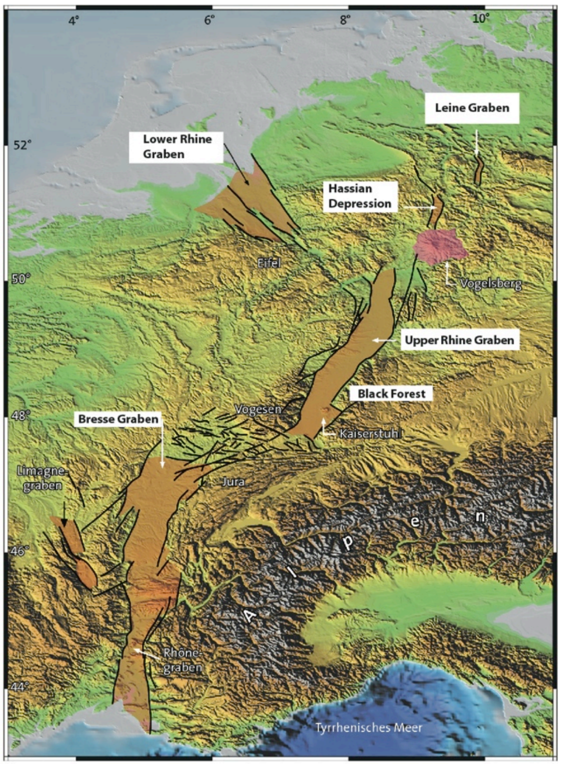


Fig. 1. Active rift system in Central Europe (modified from Frisch & Meschede, 2005).

Major basement faults within the intra-cratonic Central Eurpean Basin System are oriented NW-SE, while minor faults trend NE-SW and NNE-SSW, and are clearly visible in shaded relief and satellite images (Fig. 2; Reicherter et al. 2005). The northern rim of the Central European Basin System is bounded by the Tornquist Zone, which consists of the Teisseyre-Tornquist-Zone from Poland to Bornholm Island, and the Sorgenfrei-Tornquist Zone from southern Sweden to Denmark. Furthermore, the drainage pattern and the distribution of lakes in northern Germany parallel the block boundaries and, hence, mark zones of present-day subsidence (Mörner 1979; Stackebrandt 2004; Reicherter et al. 2005). A broad zone of subsidence extends from Hamburg over Berlin to Wroclaw (Poland) which is delineated by the delevation to the base of the Rupelian Clay (Oligocene; Garetzky et al. 2001).

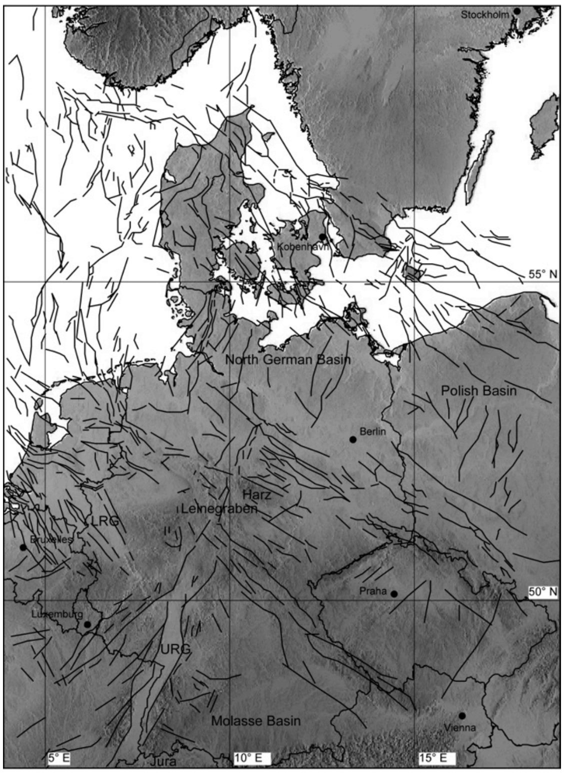


Fig. 2. Shaded relief map of Central Europe, with the North German Basin and the Polish Basin.

Western Central Europe: Upper Rhine – Lower Rhine Rift System, and Rhenish Massif

Cenozoic tectonic activity in Western Central Europe is concentrated in the Upper Rhine – Lower Rhine rift system. The Upper Rhine Graben is kinematically connected with the Lower Rhine Basin through the Rhenish massif. The Jura Mountains represent the most external foreland fold-and-thrust belt of the Alps. Their thrust front presently propagates northward into the Upper Rhine Graben.

The Lower Rhine Basin (or Graben) is a rift system active from Tertiary times to the present day and comprising several fault-bounded, SE-NW elongate blocks (Fig. 3). The southeastern part of the Lower Rhine Basin is morphologically expressed by the Lower Rhine Embayment (Niederrheinische Bucht), an area of low relief surrounded to the E, S and W by the uplifted plateau of the Rhenish Massif. The northwestern part of the Tertiary rift system is beneath the Dutch – North German plain. Many authors refer to the Lower Rhine Basin as the Roer Valley Rift System (e.g. Michon et al. 2003).

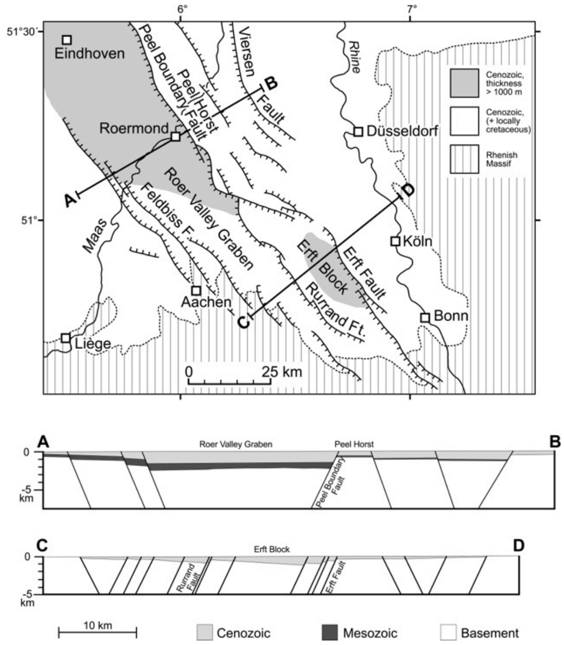


Fig. 3. Geologic sketch map with major active normal faults and two schematic cross sections (no vertical exaggeration) of the Lower Rhine Basin. After Ahorner (1994) and Schäfer (1994).

Evolution and architecture. The deepest graben structure of the Lower Rhine Basin is the Roer Valley Graben (Fig. 3). It was initiated in Late Permian-Early Triassic times and again active in the Middle Jurassic (Zijerveld et al. 1992). During the Late Cretaceous and Early Paleocene, this graben was inverted (Michon et al. 2003). Two periods of subsidence, in the Late Paleocene and in the Oligocene to recent, followed and these were separated by a further inversion phase in the Late Eocene (Michon et al. 2003). The present-day architecture and sediment fill of the Lower Rhine Basin developed mainly during the Late Oligocene to recent (Schäfer et al. 2005). Along the margins of the Lower Rhine Embayment, the Oligocene sediments rest unconformably on Paleozoic and Mesozoic strata.

During the Quaternary, the subsidence rates in the Lower Rhine Basin significantly increased (Houtgast & Van Balen 2000) as did the rate of displacement along the main block-bounding normal faults. In the inner part of the Lower Rhine Embayment, the main faults are clearly expressed morphologically. The southernmost part of the Lower Rhine embayment has been uplifted since the Pleistocene together with the Rhenish Massif (Meyer & Stets 2002).

The faults of the Lower Rhine Basin are generally almost pure dip-slip (see below) normal faults and follow two trends, the predominant SE to SSE

(135°-160°) trend and the subordinate ESE (110°-120°) trend (Fig. 3). The intersection of these faults in map view leads to the formation of lozenge-shaped blocks which are mostly elongate in a NW-SE direction. In the Lower Rhine embayment, most tectonic blocks are half grabens tilted to the NE, and the main normal faults accordingly dip to the SW (Fig. 3, section C-D).The maximum thickness of Cenozoic sediments, up to 2000 m, is found in the 20 km wide and 130 km long, NW-SE striking Roer Valley graben. Within this graben, the thickness of the Cenozoic sediments decreases to the SE as well as to the NW. To the SE, the decrease in thickness is partly compensated by a thickness increase on the Erft Block which becomes the deepest half graben in the inner part of the Lower Rhine Embayment (Fig. 3).

Seismicity and present-day deformation. The Lower Rhine Basin is seismically active and earthquakes of estimated magnitudes > 5 have repeatedly occurred. The strongest historical event was the Düren earthquake of 1756 with an estimated magnitude M_L of 6.1 (Ahorner 1994). The last major event, the 1992 Roermond earthquake with a local magnitude of 5.9 (Ms 5.4), occurred at a depth of 14 to 18 km on or close to the Peel Boundary normal fault (i.e. the NE boundary fault of the Roer Valley Graben). This was an almost pure dip-slip earthquake; the ruptured fault plane trended NW-SE (124°) and dipped to the SW, towards the graben, at an angle of 68° (Ahorner 1994; Camelbeeck & van Eck 1994).

The present-day stress field in the shallow crust, as determined from earthquake focal mechanisms, is characterized by a subvertical σ_1 and a subhorizontal σ_3 oriented SW-NE (42°; Hinzen 2003). This probably grades into a strike-slip stress regime (σ_1 horizontal SE-NW) in the lower crust (Hinzen 2003). Results from a regional GPS net in the southern part of the LRB suggest ongoing E-W-directed separation of the basin shoulders (Campbell et al. 2002). An extensional regime in the Lower Rhine Basin is also indicated by analysis of GPS data in western and central Europe on a larger scale (Tesauro et al. 2005).

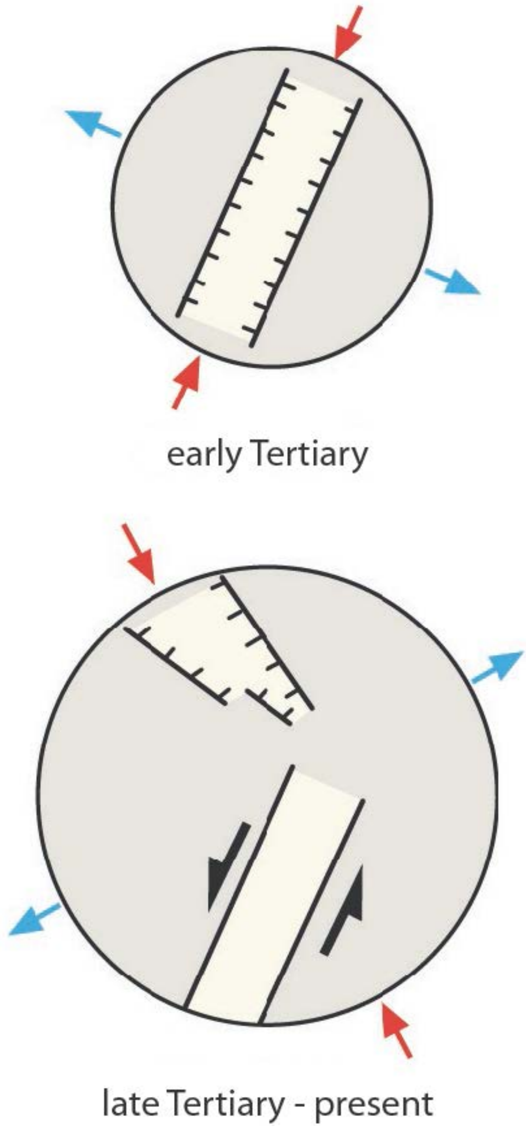


Fig. 4. Stress field changes in Tertiary in Central Europe, with associated reactivation of faults and basin formation.

Evolution of the stress field in the Lower Rhine Basin. During the Late Eocene, the Lower Rhine Basin and the Upper Rhine Graben evolved in different ways. While rifting and subsidence shaped the Upper Rhine Graben, the Lower Rhine Basin was inverted and eroded. In the western part of the Lower Rhine Basin, 200 to 600 m of Late Eocene uplift have been estimated from apatite fission track studies (Van Balen et al. 2002a). This inversion is consistent with the stress field assumed by Villemin & Bergerat (1987) for the Late Eocene in the area of the Upper Rhine Graben, a strike-slip regime with σ_1 oriented horizontal and N-S. (However, the timing of this stress field is uncertain; see above; Fig. 4). For the Oligocene, Michon et al. (2003) assumed a WNW-ESE direction of extension. This is strongly oblique to the main faults, which trend NW-SE, and would have resulted in dextrally transtensive opening. The late Oligocene-Early Miocene phase of strike-slip tectonics with NE-SW oriented σ_1, identified by Villemin & Bergerat (1987) for the Upper Rhine Graben (but doubted by Larroque & Laurent 1988), is not seen in the Lower Rhine Basin. Such a stress field would have reactivated the Lower Rhine Basin faults in compression, for which there is little evidence. Instead, strong subsidence occurred in the Late Oligocene. From Early Miocene times, the stress field was probably similar to the present-day stress field as determined from earthquake focal mechanisms, characterized by a steep σ_1 and a shallow σ_3 oriented SW-NE (42°; Hinzen 2003). Continuity between the Miocene and the present day is suggested by the presence of down-dip slickensides on normal fault planes and by offset of marker lines across normal faults in lignite open pit mines (Knufinke & Kothen 1997) which both indicate pure SW-NE dip-slip movement.

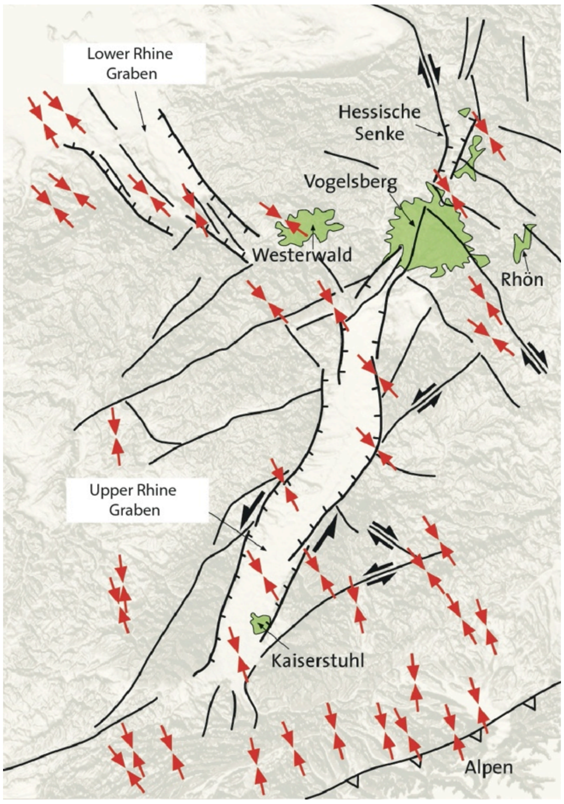


Fig. 5. Present day maximum horizontal stresses in Central Europe (red arrows). Green: Tertiary volcanics. Kinematics of major faults.

The Miocene to present-day stress field in the Lower Rhine Basin is thus similar to the one in the Upper Rhine Graben, the different style of deformation (strike slip in the Upper Rhine Graben, extension in the Lower Rhine Basin) resulting from the different orientations of the main graben-bounding faults, which were inherited from earlier stages (Fig. 5).

Rhenish Massif

The Rhenish Massif is an uplifted area where Paleozoic (mainly Devonian) rocks crop out. Although the uplift responsible for the present-day reflief occurred during the Cenozoic, the NW and SE boundaries of the Rhenish Massif are partly inherited from Variscan tectonics. The NW boundary roughly corresponds to the NW limit of intense Variscan deformation, and the SE boundary to the boundary between the Rhenohercynian fold-and-thrust belt and the Mid German Crystalline Zone. Towards SW, the Rhenish Massif plunges beneath the Mesozoic sediments of the Paris Basin, and towards NE, beneath the Mesozoic of the Hessian Depression.

Uplift. Oligocene rifting of the Lower Rhine Basin probably also affected the central part of the Rhenish Massif, because the normal faults of the Lower Rhine Basin continue towards the SE into the Rhenish Massif. However, the distribution of coastal facies in the adjacent basins indicates that the Rhenish Massif was an uplifted area between the Lower Rhine Basin and the Upper Rhine Graben throughout most of the Oligocene and Miocene. The area was only flooded by the sea for a short period in mid-Oligocene times and possibly a second time in the Early Miocene (Murawski et al. 1983; Sissingh 2003b). The Rhenish Massif has been undergoing uplift from the Miocene up to the present day. Analysis of fluvial terraces of the Lower Maas River indicates that the uplift of the Ardennes area strongly accelerated at c. 3 Ma (Van den Berg 1994). The uplift rate at the southwestern flank of the Roer Valley Graben was 0.003 mm/a from 14 to 3 Ma, and on average 0.06 mm/a from 3 Ma to the present day (Van den Berg 1994). An episode of particularly strong uplift occurred in the early Middle Pleistocene at c. 0.7 Ma contemporaneously with the onset of the youngest phase of volcanism in the Eifel (Van Balen et al. 2002b). Uplift of up to >250 m over 800,000 years (>0.31 mm/a) in the central part of the Rhenish Massif was determined from the analysis of fluvial terraces along the Rhine, Lahn,

and Mosel rivers and their tributaries (Meyer & Stets 1998, 2002). The maximum of this young uplift is located between the West and East Eifel volcanic districts, suggesting a relationship between uplift and volcanism (Meyer & Stets 2002). A ridge of marked uplift (> 200 m over the last 800,000 years) extends from the Eifel volcanic region towards the WNW into the Hohes Venn area. Present-day uplift rates determined from precision levelling are c. 0.6 mm/a in the Eifel volcanic region and up to c. 1.6 mm/a at the northern margin of the Rhenish Massif in the area of the Hohes Venn (Mälzer et al. 1983). Pleistocene vertical displacement between the northern end of the Upper Rhine Graben and the uplifted Rhenish Massif was mainly localised along the southern boundary fault of the Rhenish Massif (Peters & van Balen 2007).
The Rhenish Massif was not uplifted as a single block or plateau but rather as several blocks with marked differences in the rate of uplift. Whereas the Pleistocene uplift maximum in the Eifel volcanic region can be related to volcanism, the zone of marked uplift in the Hohes Venn area is devoid of Cenozoic volcanics and uplift here may be related to crustal shortening, as suggested by the occurrence of thrust earthquakes in this area (see below).

Seismicity and stress field. The distribution of historical and present-day earthquakes forms a continuous belt of seismicity from the Lower Rhine Basin through the Rhenish Massif to the northern end of the Upper Rhine Graben (e.g. Ahorner 1983). Branching off from this belt towards the W is a zone of seismicity that follows approximately the northern margin of the Rhenish Massif (Stavelot-Venn Massif). In the Middle Rhine Zone (between Lower Rhine Basin and Upper Rhine Graben), fault-plane solutions suggest a stress regime of normal-faulting character with σ_3 oriented NE-SW, as in the Lower Rhine Basin (Ahorner 1983; Hinzen 2003). The Middle Rhine Zone is today a NW-SE-striking rift forming a continuation of the Lower Rhine Basin. The rift has no Cenozoic sediment fill, except in the Neuwied Basin, because rifting occurs contemporaneously with regional uplift.

For the Stavelot-Venn Massif, a strike-slip stress regime is indicated with σ_1 oriented subhorizontal and NW-SE (316°), and σ_3 subhorizontal and SW-NE (225°) (Hinzen 2003). Some earthquakes in the Hohes Venn area have compressional (reverse) dip-slip focal mechanisms. For these, one of the two possible fault planes dips shallowly towards the SSE, as does the Variscan Aachen Thrust, the frontal thrust of the Rhenohercynian fold-and-thrust belt which underlies the Hohes Venn area. For this reason, Ahorner (1983) suggested a reactivation of the Aachen Thrust by SE-NW compression. This may explain the relatively strong present-day uplift of the area, and also the rough coincidence, in this area, of the NW margin of the Rhenish Massif with the NW front of Variscan deformation.

Eifel plume. P- and S-wave tomography revealed a low-velocity structure in the upper mantle beneath the Eifel volcanic field. This structure extends down to at least 400 km and interpreted as a plume (Eifel plume; Ritter et al. 2001; Keyser et al. 2002). This plume is most likely the cause of the Pleistocene to recent volcanism in the Eifel area. The geochemical similarity between Quaternary and Tertiary volcanism in the Rhenish Massif (e.g. Haase et al. 2004) suggests that a mantle plume may already have existed under the Rhenish Massif from Paleogene times onward.

Summary. The Miocene to recent tectonics of the Rhenish Massif were controlled by three processes: rifting in the Middle Rhine Zone (i.e. the prolongation of the Lower Rhine Basin), the rise of a mantle plume during the Pleistocene but probably also in Tertiary times, and regional NW-SE compression within the European plate. These three processes combined in a complex manner to produce the current situation.

10 October (THU) - Excursion to Cologne and the Lower Rhine Embayment – Archaeoseismology, Active Faults and Critical Facilities

Stop 1:

Swist Fault (or Swistsprung)

Flerzheim (guide: Dr. Martin Salomon)

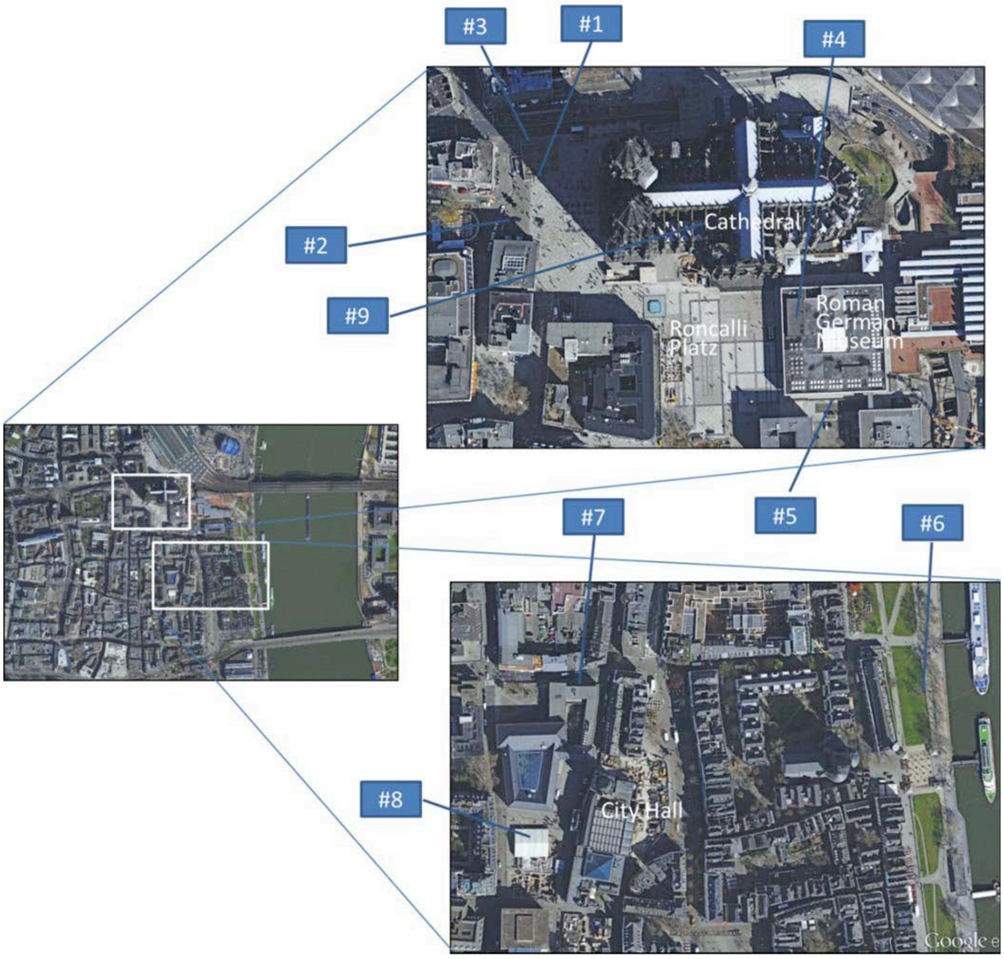
Stop 2:

Cologne

(guide and text by: Prof. Dr. **Klaus-G. Hinzen**, email: hinzen@uni-koeln.de)

This stop in Cologne consists of several sub-stops (9) and will be conducted in an area between Cologne Central station and the Heumarkt. Today, the area of interest is in the heart of Cologne city; but in Roman times, the area constituted the northeast corner of the Roman city fortification. Planned stops are (2-1) A pedestrian entrance to the North gate of the former Roman fortification wall, (2-2) A cement replica of the Kreuzblume of the south tower of the Cologne Cathedral, (2-3) the remains of northern section of Roman city wall in the Cathedral parking garage, (2-4) Dionysus mosaic of the Peristylhouse in its original setting within the Romano-Germanic Museum (RGM) of Cologne, (2-5) the remains of the Roman road leading to the harbor and a view of the morphology of the Lower Terrace, (2-6) a walk along the current Rhine River bank, (2-7) a tour of the Praetorium, the ruins of the former Roman governor's palace, (2-8) the Cologne city hall (with both modern and ancient parts) and the ongoing excavation of the Archaeological Zone Cologne, (2-9) finally, Cologne Cathedral and tour through the archaeological excavations underneath the Cathedral.

Fig. #: Stops in Cologne



Stop 2-1:

The northward extension of the Roman Empire in the last century BCE and the first century CE resulted in immense expenditures to create and fortify new Roman settlements. During the Roman period, building activity boomed and several well-preserved buildings from this period still exist in central Europe. Agrippina, the wife of the Emperor Claudius, made her birth town in 50 CE a colony with the name **Colonia Claudia Ara Agrippinensium (CCAA)**, and the inhabitants became Roman citizens. The name 'Claudia' goes back to the family of the ruling emperors, the Claudians; 'Ara' refers to Ara Ubiorum, the name of a Germanic stone altar of importance to the entire Germanic province, the germania inferior. The settlement was located on a plateau of 1 km2 of the Lower Terrace, ca. 14 m to 16 m above the Rhine River and safely above the level of flooding. To the east, an arm of the Rhine River bordered this settlement. The city walls of the Oppidum Ubiorum (Ubi settlement) were laid out in a rectangular pattern similar to Italian Roman town foundations, while the city walls of the second half of the first century CE followed the irregular pattern of the terrace edges. At the riverbank, the city wall did not follow the terrace edge but was placed right at the waterline in order to afford those approaching by boat an unobstructed view of the city's important and prominent structures. Among these waterfront buildings were the Mars temple and the Praetorium (s. #7).

The Roman city wall from the first century CE is roughly 4 km long and surrounds the area of the original Colonia. There is some justification in supposing that its length was not arbitrarily chosen. The city wall of Roma is 13200 passi. Converted to Roman measures, the 3911.8 m of the Cologne fortification comes to 13216 pes (5 pes á 0.296 m correspond to one passus of 1.48 m). The foundation of the wall was up to 3 m thick, on top of which we find a wall of 2.4 m width and at least 7.8 m height. Inside and outside a mantle of nicely formed Grauwacke-blocks was built and the gap filled with layers of opus caementitium. At 3-4 m distance a 3-4 m deep and up to 12 m wide moat was built. Of the total 9 gates, 3 are found on the west side, 3 in the east, 2 in the south, and only one in the north. The wall included 19 round towers of 9.2 m diameter. The northern gate was 30.5 m wide with two square-towers, 7.6 m wide. The side (pedestrian) and middle entrances were 1.9 m and 5.6 m wide, respectively. The arch above the main entrance shows the letters CCAA (currently in the RGM). The part preserved close to the Cathedral is not in situ; it was originally located 4 m deeper and a few meters to the west.

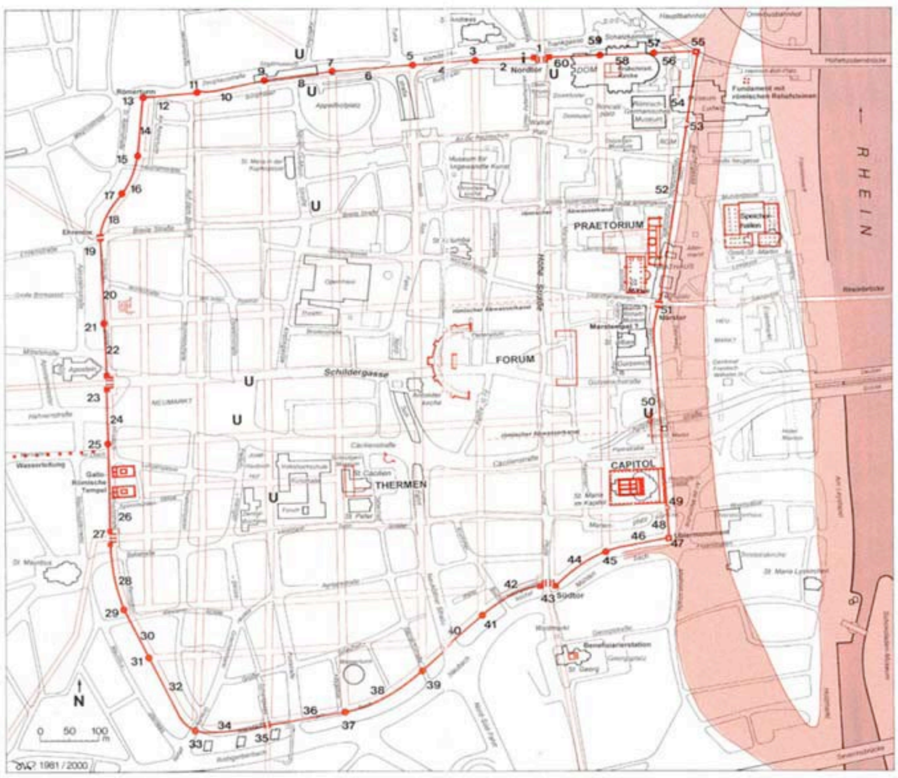


Fig. #. Main features of the Roman Cologne (red) on top of the current city layout. Starting withthe northern gate (1) all wall sections and towers are numbered with even and odd numbers, respectively in a counterclockwise sense. The two main roads *cardo maximus* between the north and south gate (today Hohestraße) and the *decumanus maximus* (today Neumarkt and Schildergasse) are still the dominant directions in the current city plan (from: Wolff, 2000)

Stop 2-2:

The **Kreuzblume** is a 1:1 replica of the original on top of the south tower. The concrete version has a mass of 35,000 kg, about half that of the original made from Oberkirchener Sandstein (Wealden sandstone, Berriasian, Early Cretaceous; also used in the Aachen cathedral, the Aachen and

Antwerp town hall, and even in the White House in Washington, D.C.). The connection to the top of the tower is interesting also from the seismic point of view. It can move relative to the tower top as it sits in a metal half-sphere. At the bottom a steel rod of 0.1 m diameter and 21 m length with a weight on its end is attached which acts as a counterweight.

Fig. #. View of the Kreuzblume of the north tower in 1881 (left) and the replica of 1991 (right), Photos from: Schmitz (1881) / VollwertBIT

Stop 2-3:
In the parking garage, the full width of the fortification wall is visible. On the field side, the upgoing wall starts with a sloped base block; on the town side we see three small steps. The foundation was built in a trench with wooden paling board. Wood grain and traces of rusted nails are still visible. The basement next to the wall was originally located southwest of the cathedral. Further on we see the so-called Annostollen. It is a 5.5 m deep shaft followed by a horizontal drift underneath the fortification wall. Supposedly, the Archbishop Anno used this secret passage to escape from insurgent Colognians in 1074. The well of the old cathedral (diameter 2.35 m, depth 15 m) was located in the yard of the former church. Now it is located immediately in front of the foundations of the current Cathedral.

Stop 2-4:
The Dionysus mosaic measures 7x10.6 m and is composed out of more than one million stones of 0.5 to 1.0 cm2. Details can be found in Wolf (1020). It is part of a representative villa at the Rhine River front and in situ. While the villa originates from the second half of the first century CE, the mosaic was added during major renovations in the second quarter of the third century. During the 1999 world economic summit, dinner was served on top of the mosaic to the G8 leaders. Next to the mosaic we see the reconstructed sepulcher of Poblicius (about 40 CE), which was found outside the city limits.

Stop 2-5:
Looking back to the Cathedral you might notice, that the eastern Kreuzblume of the southern transept has a lighter color than the western one. The original one (500 kg) fell (together with more than a dozen smaller ones) during the ML 6 Roermond earthquake in 1992. During the construction of the new Romano-Germanic Museum (RGM) a 65 m stretch of an eastward trending Roman road was discovered. The stones had to be temporarily removed during construction of the parking garage. During the excavation, a marvelous inscription in a large block was found, which describes in detail the decadence of Nero. The sewer section was found underneath the road.

Stop 2-6:
The current bank of the Rhine River is ca. 80 m east of the slope of the Lower Terrace. During the first century CE, a sidearm of the river, probably only connected to the river at its northern end, served as a harbor. However, already during the first century it was successively covered with sediments and artificial fill. Step by step the former island – more accurately a peninsula – was

incorporated to the city. Warehouses and other buildings were built.

Fig. #. While the part of the modern city within the old Roman city limits is flood safe, the section east of the former city wall has a significant flooding hazard. (Photo taken from: Bundesarchiv B 422 Bild-0086, Köln, Rheinufer, Hochwasser.jpg)

Stop 2-7:

The Cologne Praetorium, the palace of the Roman governor of the province of germania inferior, was initially excavated and partially preserved in the 1950s. All modern buildings in this area had been destroyed during WWII aerial bombing. The Roman foundations were exposed during the construction of a new city hall. These foundations and remaining parts of the standing walls show severe structural damage, highly concentrated at the central octagonal part of the former building. The remains of the Praetorium include walls from four building phases (I to IV) between the first and the fourth century CE; damage is found in walls dating from phase I and IV.

The early excavators (Precht 1973) assumed slow static settlements due to a weak subsurface and inadequate building technique as the main cause of the breakdown of wall sections. Hinzen and Schütte (2003) argued for a more sudden event that affected the building ground and subsequently the integrity of the structure. They found arguments for secondary earthquake damage; however, they also pointed out the need to test for possible hydrologic causes.

In a comprehensive study Hinzen et al. (2012), which can be found on your data stick, produced a 3D laser scan model of the Praetorium and parts the excavations (>250 scans) which was used for a detailed damage analysis. Because almost all observed damage is due to unstable building ground static and dynamic slope stability was tested with site specific synthetic seismograms of earthquakes placed on the major active faults of the Lower Rhine Embayment. Seepage and subsurface erosion were tested as alternative causes for the ground movements in the area encompassing the Archaeological Zone Cologne.

Rekonstruktion Prätorium, Schütte, 2000

Fig. #. Reconstruction of the Praetorium (Schütte, 2000). The building was about 90 m long and the central octagonal tower 25-30 m high.

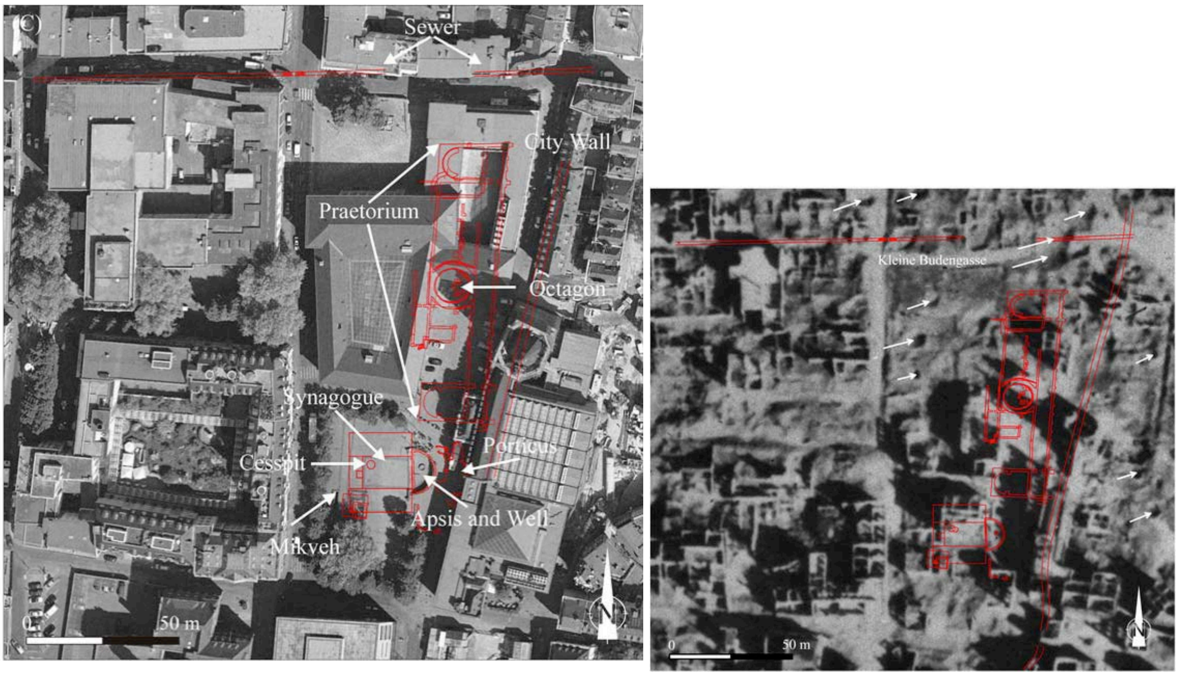
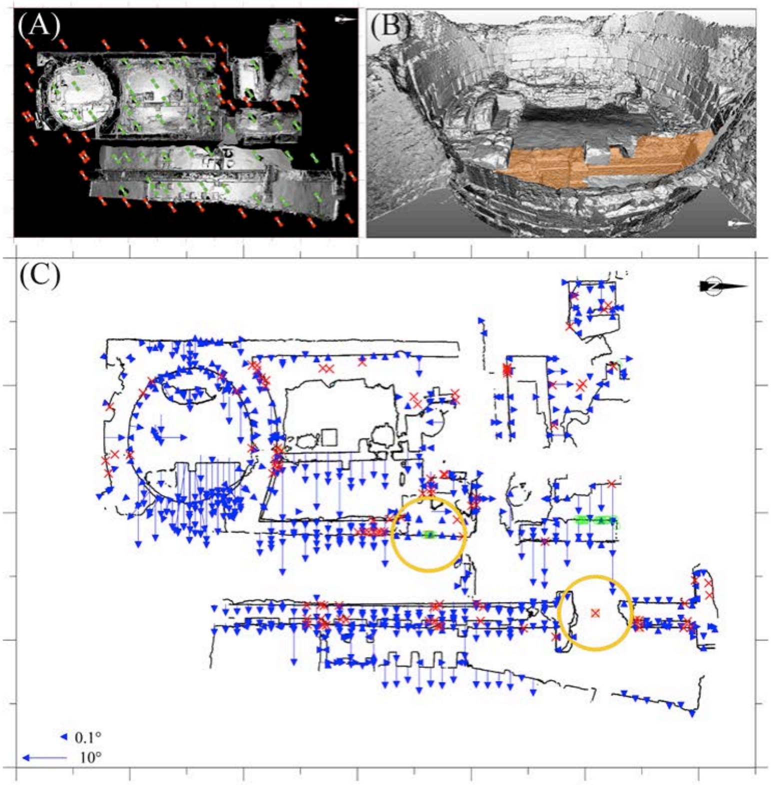


Fig. #. Left: Main Roman and Medieval constructions (red) overlaid on an aerial view of the current city. Right: The same area in 1945. Arrows point to major bomb craters. (after Hinzen et al., 2012)



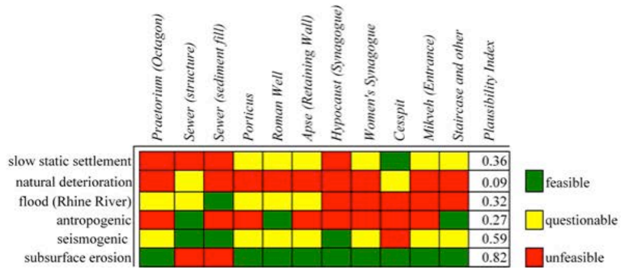


Fig. #. (A) Orthographic view from above to the virtual model of the northern section of the Cologne Praetorium, the Octagon is located in the southwest corner of the figure. Red and green symbols indicate the position of 94 scanner measurement locations from a higher and lower level, respectively. (B) Perspective view of the virtual model of the foundations of the Octagon. The colored wall section is from the third II/ III building period, while the Octagon was built in period IV. (C) Result of the damage analysis of the northern section of the Praetorium. Blue arrows indicate inclination of walls or wall sections, red crosses mark the location of major cracks, green circles are horizontal gap openings, and the yellow circles include areas affected by WWII bomb explosions. A distance of 10 m separates major tick marks (after Hinzen at al., 2012).

Fig. #. Plausibility matrix linking seven damage scenarios (rows) with 12 damage patterns in the study area in the city center of Cologne.

Based on the data acquired by Hinzen et al. (2012) (including a comprehensive virtual model and a subsurface model) and the current status of the excavation, a seismogenic cause of all the damage is less probable than previously hypothesized. In particular, the results of the slope stability tests indicate a subsurface stable even under significant dynamic loading. Barring new data with a clear suggestion of earthquake damage from the planned excavations of the southern part of the Praetorium, we favor the interpretation of seepage effects and subsurface erosion as explanation for the settlement-induced building failures in more than one event and WWII bombing in case of the broken sewer roof.

Stop 2-8:

Since 2007, extensive excavations immediately south of the Praetorium and a newly excavated section of a Roman sewer north of the Praetorium provided an opportunity to collect data from a hitherto inaccessible section of the subsurface. The current excavation area (Schütte and Gechter 2011) includes the medieval Jewish quarter of Cologne, which hosted one of the earliest Jewish communities in Europe. (**Tour guided by AZC archaeologists**)

Stop 2-9:
Since 1946 archaeological investigations have been carried out underneath the current floor of Cologne Cathedral. Here was the originating center of the early Christian communities in the no rthern part of the Roman Empire. (**Tour guided by archaeologists of the Dombauverwaltung**)

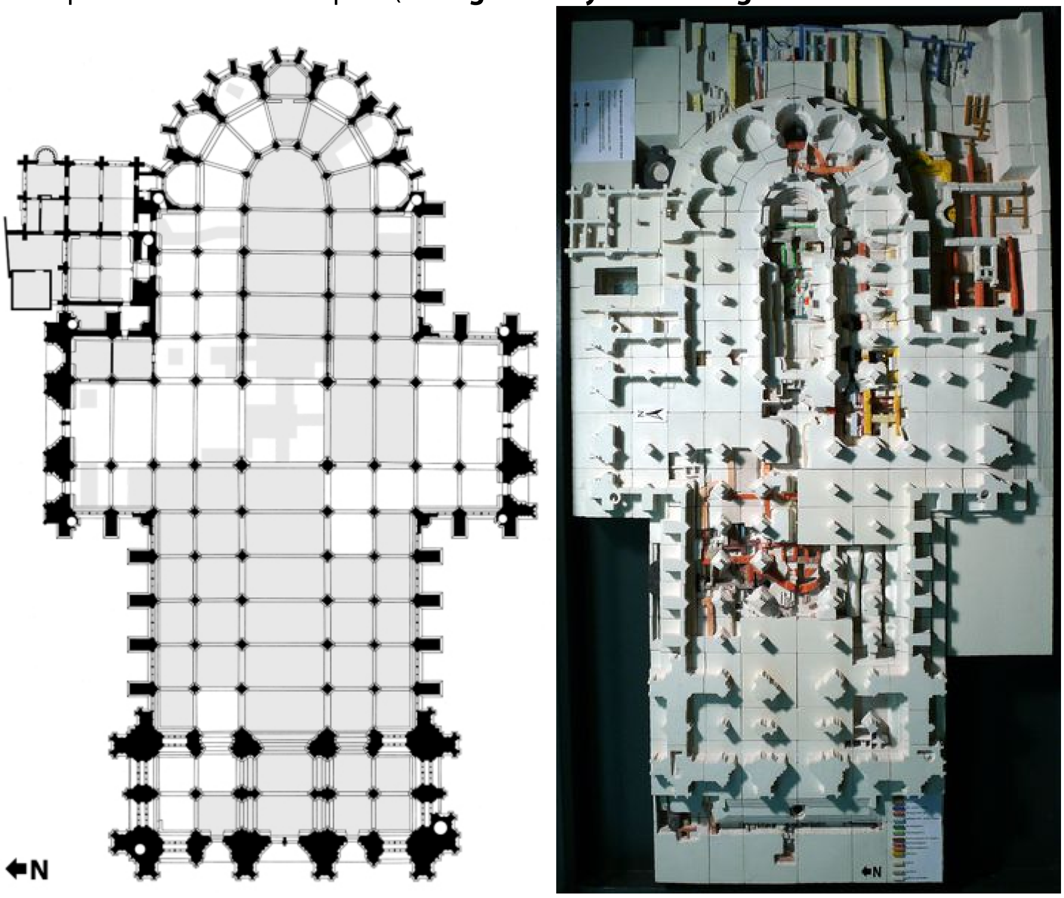


Fig. #. A plan of the cathedral, B: 3D plaster model of the findings in the excavation underneath Cologne Cathedral. Colors indicate the historic epochs of the findings. (more www.koelner-dom.de)

Seismic Surveillance of Cologne Cathedral
Cologne Cathedral belongs to the UNECO World Heritage. In cooperation with the Dombauverwaltung Köln, the University of Cologne maintains and operates the five strong motion stations in the Cathedral that were installed since 2006. During the tour we will be able to see one of the stations installed close to the foundation of the north-tower. The eigenfrequencies of the structure have been studied in detail; movements of the tower have been correlated with wind speed, the effect of swinging bells has been studied. Recently, vibrations caused by the passage of a new subway line have been monitored. Details can be found in Hinzen and Fleischer (2007).

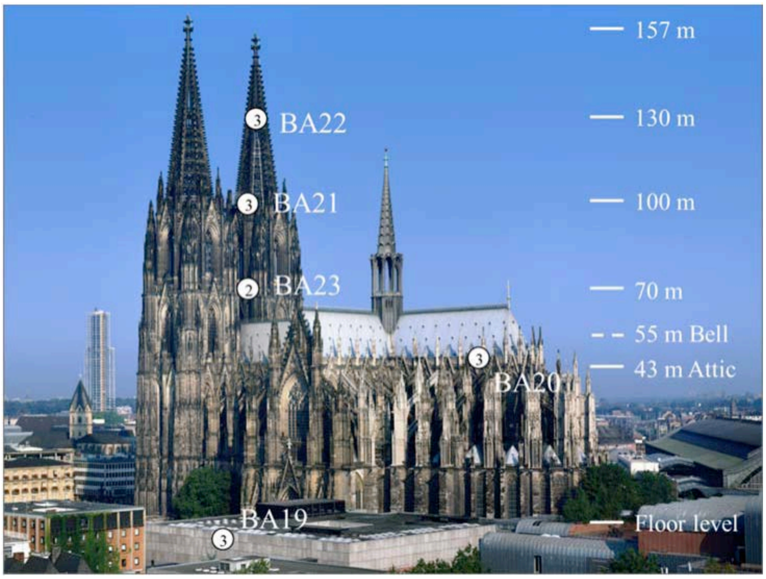


Fig. #. Seismic strong motion stations in Cologne Cathedral

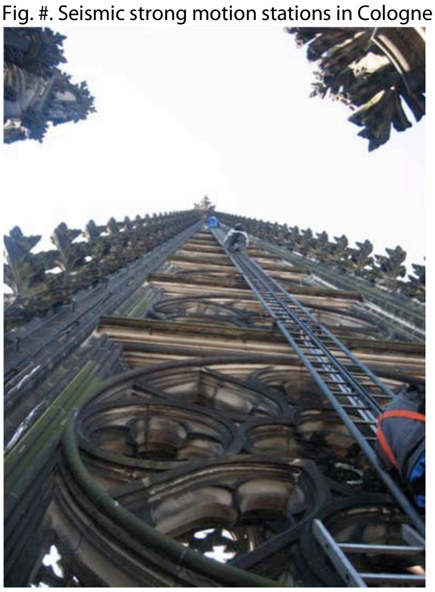


Fig.# Climbing up to station BA22

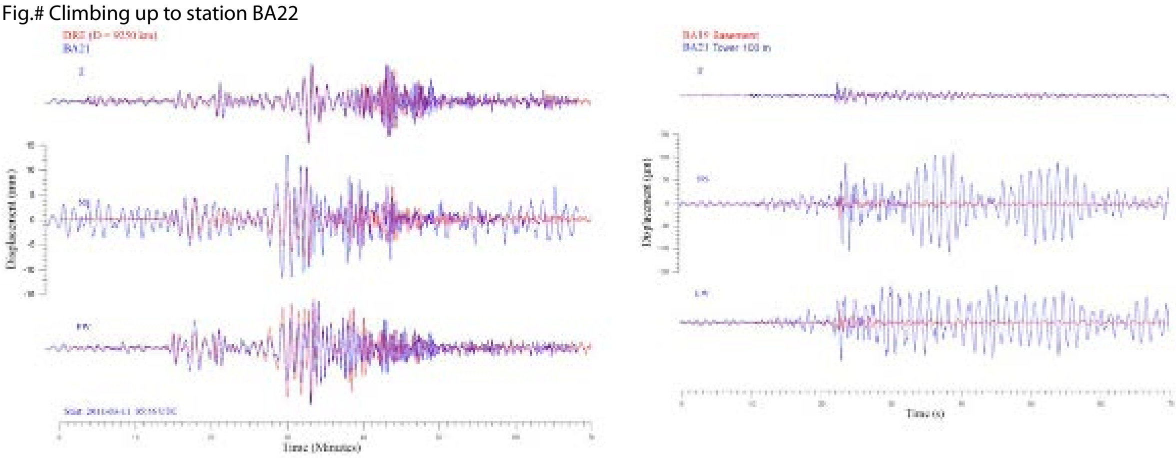


Fig. #. Record of the 2011 Tohoku earthquake. In red, seismogram recorded at hardrock broadband station DRE in the Eifel Mountains, in blue record from station BA21 at the 100 m level in the north tower of Cologne Cathedral. Records correlated well, indicating insignificant eigenmovement of the cathedral. Maximum displacement amplitudes are on the order of 10 mm.

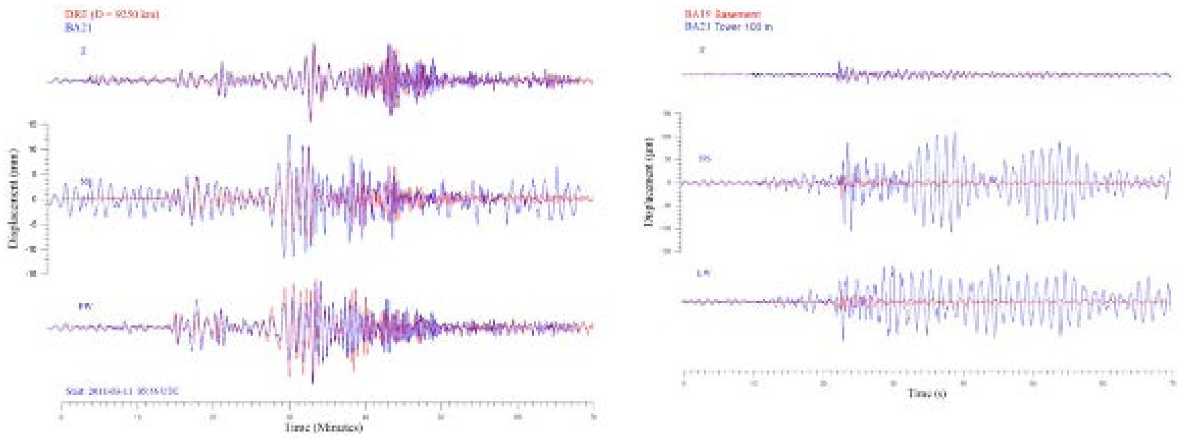


Fig. #. Records of a local ML 4.4 eartquake at 96 km distance from Cologne Cathedral. In red, recording from BA19 at the base in the Domgrabung and in blue station BA21 in the northtower. The high frequency S-wave arrival excites significant eigenmovements of the tower, which lasted for more than two minutes.

References:

Fleischer, C., Hinzen K.-G., Schreiber, S., 2010. Laser scanning eines römischen Brunnens in der Archäologischen Zone Köln. All. Vermessungs-Nachrichten, 5/2010, 176-180.

Precht, G., 1973. Baugeschichtliche Untersuchung zum römischen Praetorium in Köln. Rheinische Ausgrabungen 14:120

Hinzen, K.-G., Schütte, S., 2002. Evidence for earthquake damage on Roman buildings in Cologne, Germany. Seismological Research Letters, 74, 121-137.

Hinzen K.-G., Schütte, S.,2003. Evidence for Earthquake Damage on Roman Buildings in Cologne, Germany. Seismol Res Lett 74:124-140

Hinzen, K.-G., C. Fleischer, C., 2007. A Strong Motion Network in the Lower Rhine Embayment (SeFoNiB), Germany. Seismological Research Letters, 78, 502-511.

Hinzen, K.-G., C. Fleischer, S.K. Reamer, S. Schreiber, S. Schütte, B. Yerli, 2010. Quantitative methods in archaeoseismology. Quaternary International, DOI: 10.1016/j.quaint.2010.11.006.

Hinzen, K.-G., Schreiber, S., Fleischer, C., Reamer, S.K., Wiosna, I., 2012. Archeoseismic study of damage in Roman and Medieval structures in the center of Cologne, Germany. Journal of Seismology, 10.1007/s10950-012-9327-2

Hinzen, K.-G., Fleischer, C., Schock-Werner, B., Schweppe, G., 2012. Seismic surveillance of Cologne Cathedral. Seismological Research Letters, 83, doi: 10.1785/gssrl.83.1.9.

Schütte, S., Gechter, M., 2011. Köln Archäologische Zone / Jüdisches Museum. Von der Ausgrabung zum Museum. Kölner Arächologie zwischen Rathaus und Praetorium, Ergebnisse und Materialien 2006 Stadt Köln, Köln.

Schreiber, S., Hinzen, K.-G., Fleischer, C., Schütte, S. 2012. Excavation-parallel laser scanning of a medieval cesspit in the archaeological zone Cologne, Germany. ACM J. Comput. Cult. Herit. 5, 3, Article 12 (October 2012), 22 pages. DOI = 10.1145/2362402.2362406

Wolff, G., 2000. Das Roemisch-Germanische Köln - Führer zu Museum und Stadt. Bachem Verlag, Köln.

11 October (FRI) Ship cruise and Conference Dinner

Program: riverside-geology of the Rhine valley
(no explanations, only some figures and text provided)
Tour: Andernach – Bonn (river Rhine trip) – Ahrweiler

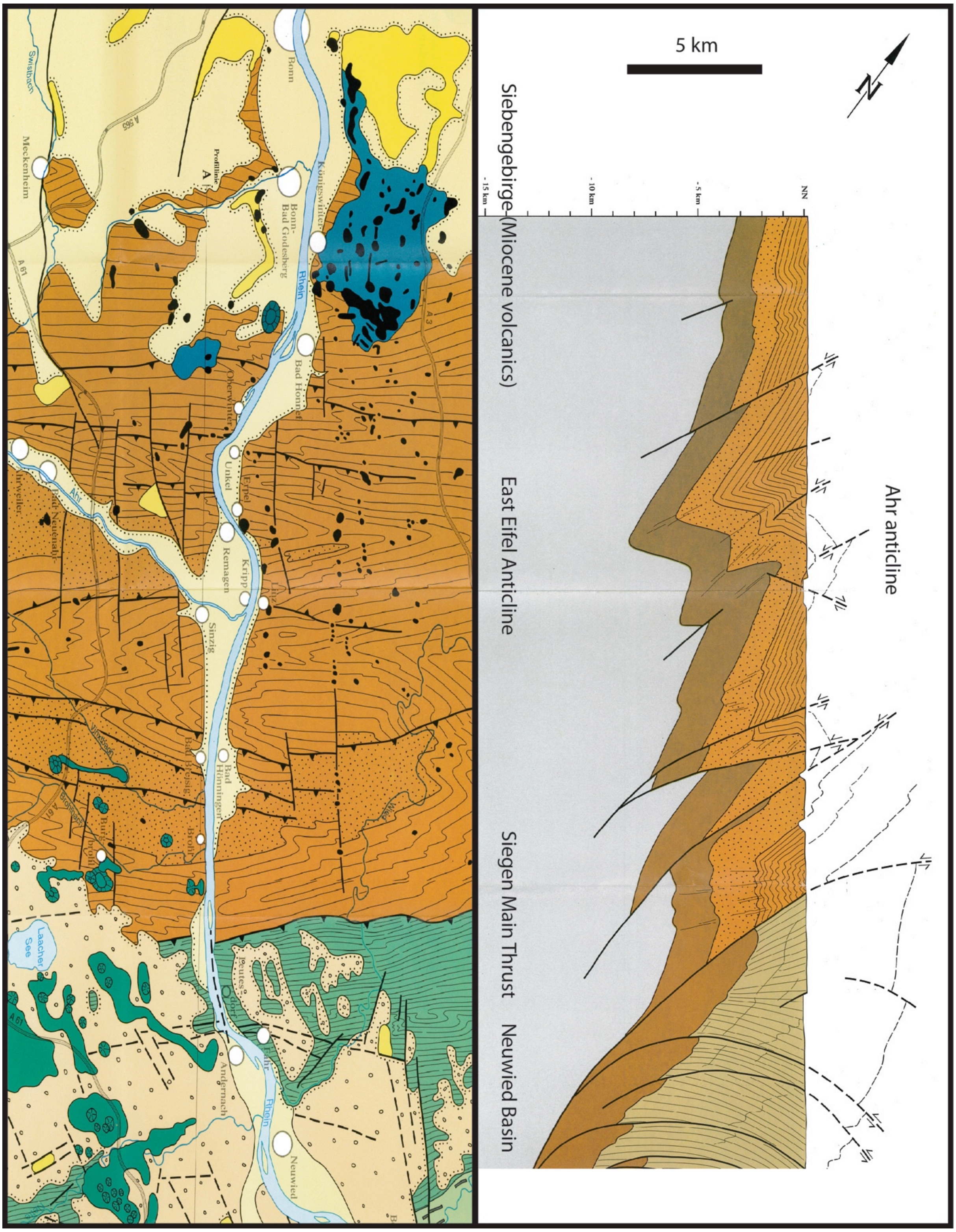


Fig. #. Geological and structural map of the middle Rhine valley. Section shows the main structural features of the area (modified from: Meyer and Stets, 2000: Geologische Übersichtskarte und Profil des Mittelrheintals, Geol. Landesamt Rheinland-Pfalz)

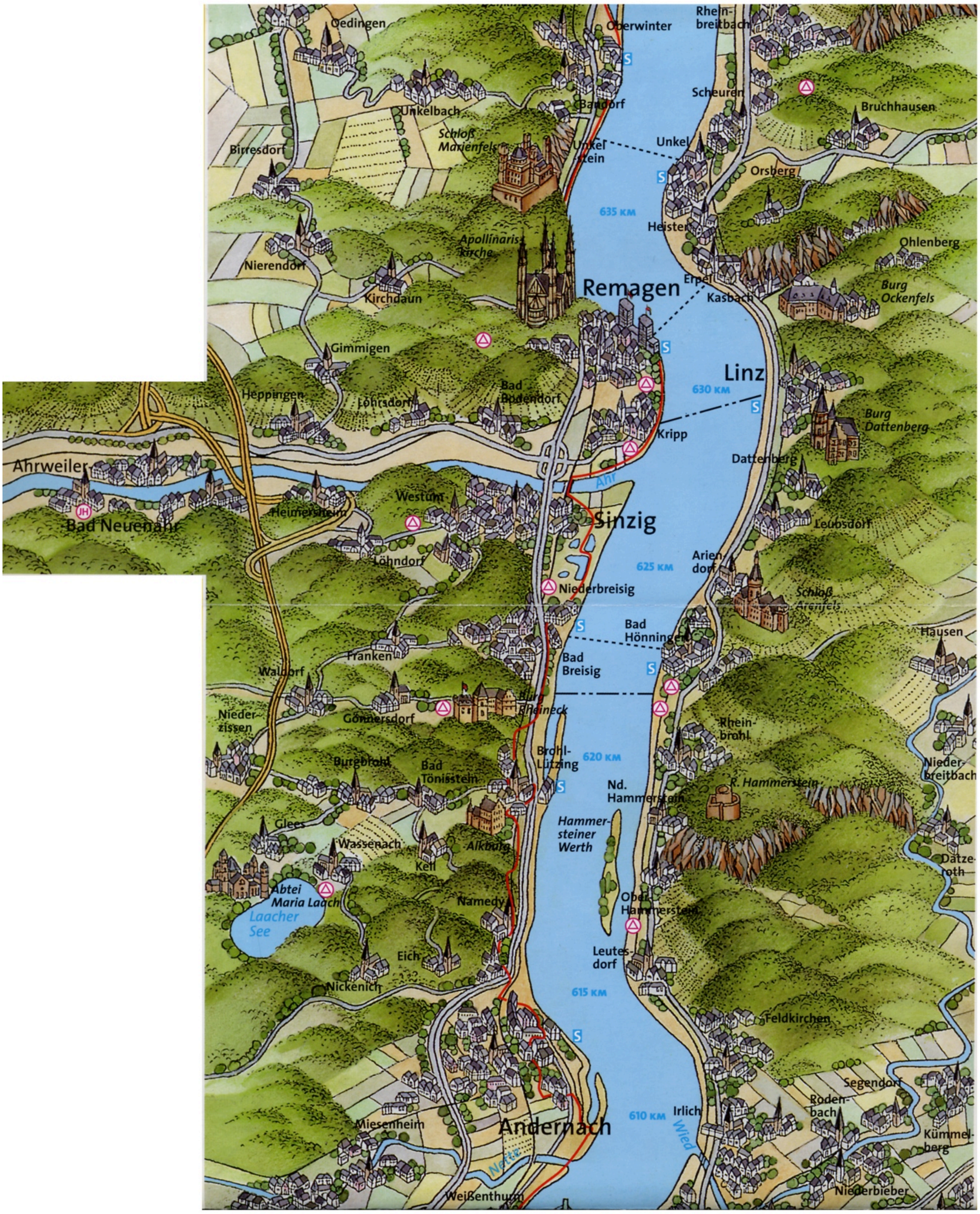


Fig. #. Topographical and touristical map of the middle Rhine valley (Part 1, south).

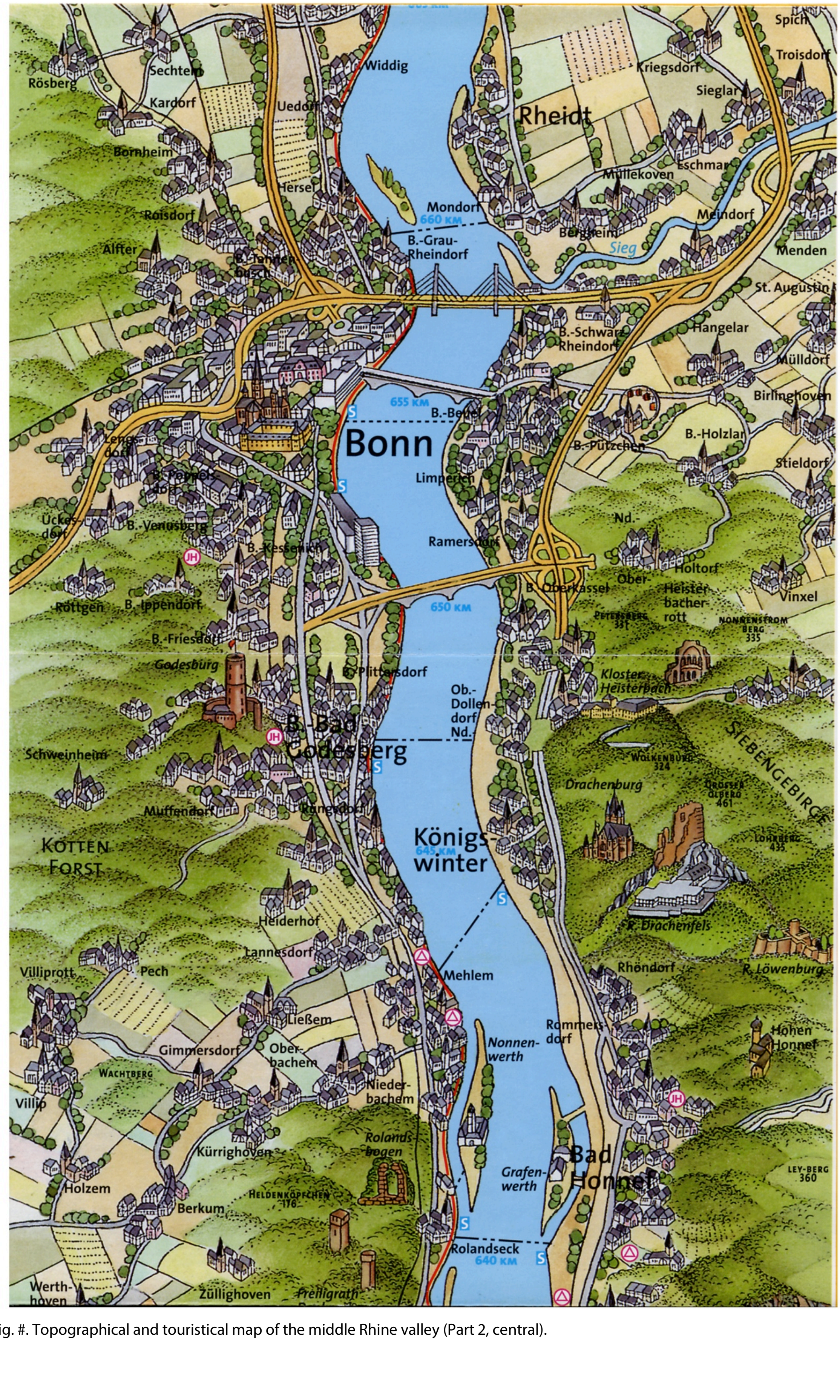


Fig. #. Topographical and touristical map of the middle Rhine valley (Part 2, central).

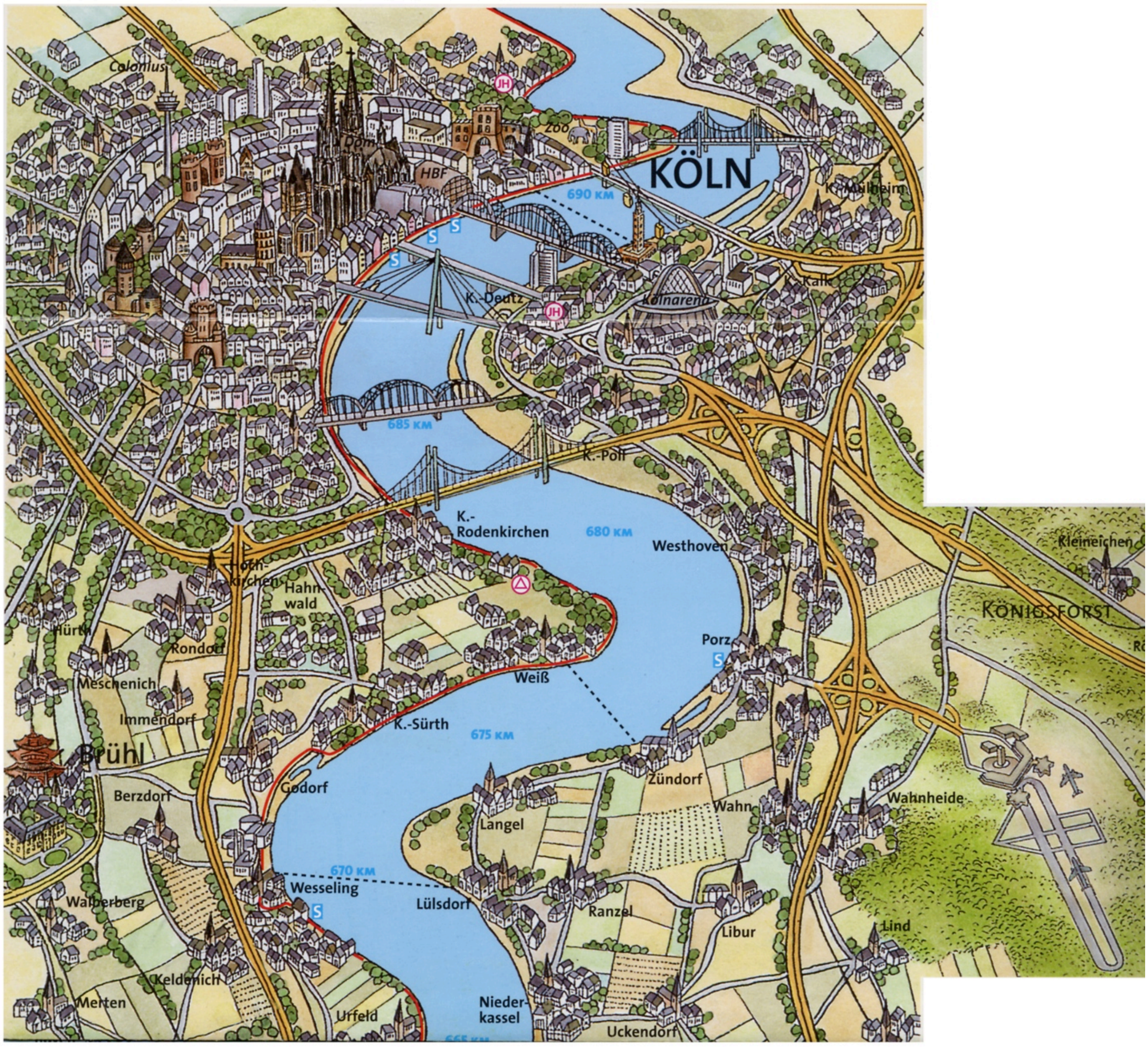


Fig. #. Topographical and touristical map of the middle Rhine valley (Part 3, north).

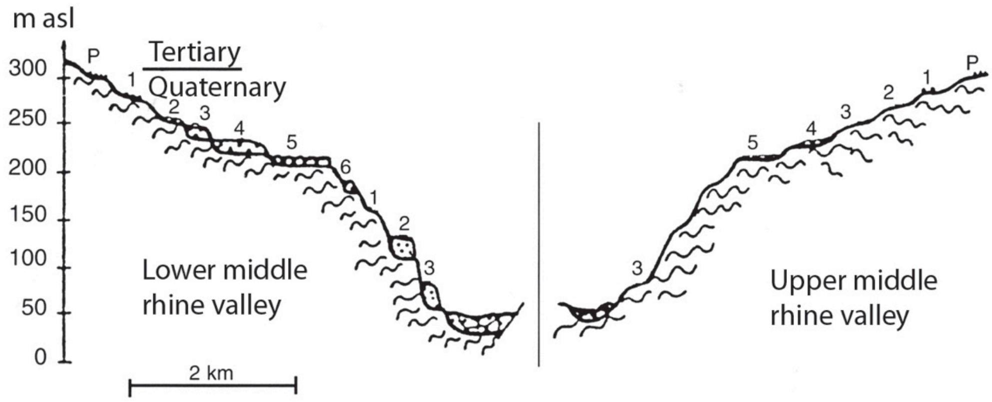


Fig. #. Fluvial, partly glacial, terraces in the middle Rhine valley, note differences between the upper and lower middle Rhine valley areas (after Andres, 1989).

12 October (SAT) Wine tasting

Program: soil and geology of the Ahr valley
(no explanations, only some figures and text provided)
Tour: Ahrweiler downtown
The little town of Ahrweiler along river Ahr (Ahr valley, Ahrtal) is famous for its red wine and with a well-preserved medieval city walls. Half-timbered buildings are found in the city, which has a long history as witnessed by a Roman villa (today a museum), one of the best preserved north of the Alps. The sister city Bad Neuenahr (Bad = spa) has in contrast a lot of buildings associated to the mineral and thermal springs and bathing culture that flowered in the last two centuries. The oldest remaining church in Ahrweiler (1269 AD) is St. Laurentius, it is the oldest hall church in the Rhineland. It features three naves and two galleries. The chair lofts are attached in sloping position. Inside the church frescos are of the 14 and 15th cent., the organ and kneeling bench are of baroque style of the 18th century. Currently, the Ahr valley is Germany´s northernmost wine area (for industrial production), however, even in Aachen we find remnants of the Roman and later medieval climate optima as evidenced by geographical names, e.g., Wingertbergstrasse (vineyard road). So, the Romans brought the grapevines (*Vitis vinifera*) far to the North.

Wine and soil and rocks (extra guide available, but only in German)

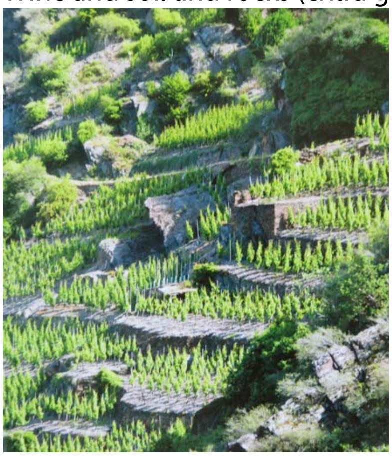


Fig. #. Typical vineyards and terraces along the river Ahr

13 October (SUN) Laacher See Volcanic Area

Program: Laacher See (Laacher Lake) Volcanic Area, excursion natural hazards and critical facilities
Tour: Ahrweiler – Maria Laach – Rursee/Simmerath

Das zentrale Laacher Vulkangebiet. *B* Brohl, *K* Kell, *M* Mendig, *N* Nickenich, *Ni* Niederzissen, *W* Wassenach; *1* Bausenberg, *2* Herchenberg, *3* Steinbergskopf (tertiärer Basalt), *4* Kahlenberg (tertiärer Basalt, quartärer Bimsvulkan), *5* Leilenkopf, *6* Fornicher Kopf (Hohe Buche), *7* Lummerfeld und Kunkskopf, *8* Dachsbusch, *9* Wehrer Kessel, *10* Veitskopf, *11* Laacher Kopf, *12* Rother Berg, *13* Thelenberg, *14* Wingertsberg, *15* Krufter Ofen, *16* Alte Burg, *17* Nickenicher Weinberg, *18* Nickenicher Hummerich, *19* Nastberg, *20* Laacher See.

Fig. #. Block map of the Laacher See volcanic area (by Meyer, 1978). 20 = Laacher See (lake), in red: volcanic ashes and pumice, in green: Tertiary basaltic volcanoes and lava flows.

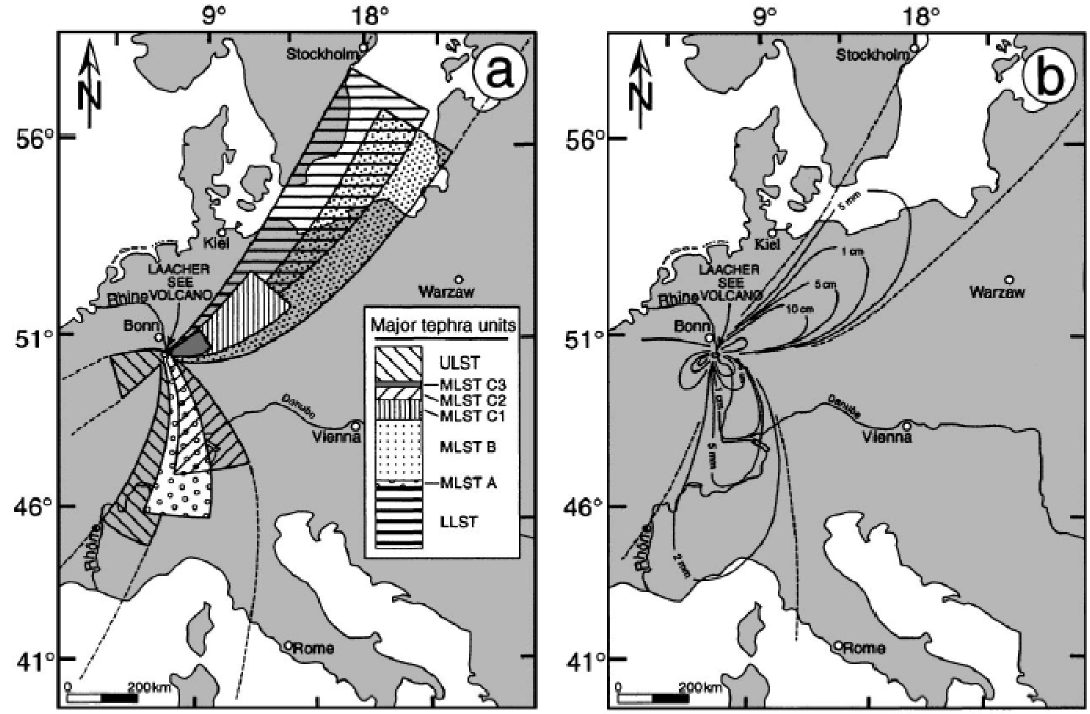


Fig. 5. (a) Areal distribution and (b) isopach map of major Laacher See Tephra fans in Central Europe. Dashed line: outer detection limits of distal tephra layers. After Bogaard and Schmincke (1985).

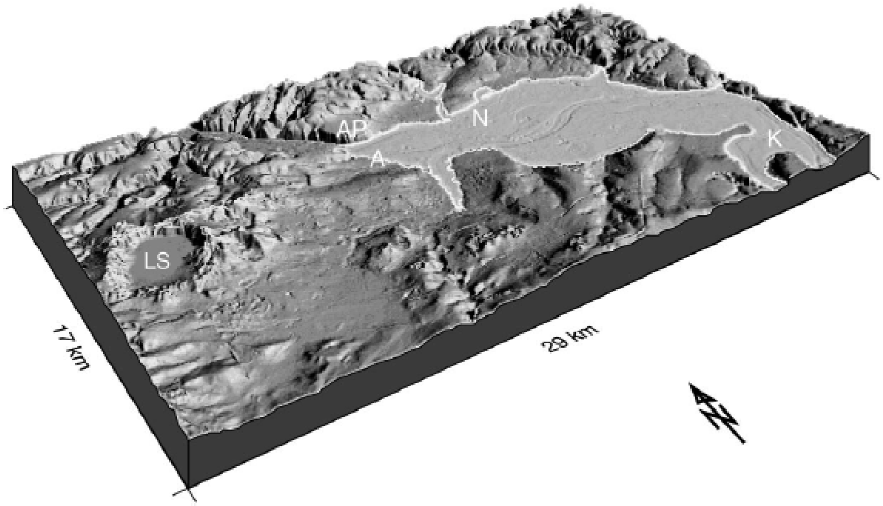


Fig. 6. Three-dimensional view of the temporary lake dammed up within Neuwied Basin during LSE, resulting from the extensive congestion of the Rhine River with tephra and the formation of a major dam at the narrow, bottleneck outlet of Neuwied Basin (AP = Andernacher Pforte). The lake (ca. 0.9 km^3 of water) probably extended over 140 km^2 and reached more than 15 m above the pre-eruptive land surface. Sudden collapse of major parts of the tephra dam probably caused one or several major floodwaves downstream. Larger present-day towns within Neuwied Basin: K = Koblenz, A = Andernach, N = Neuwied. LS = Laacher See. Vertical exaggeration 3 × . View from the SW. From Park and Schmincke (1997).

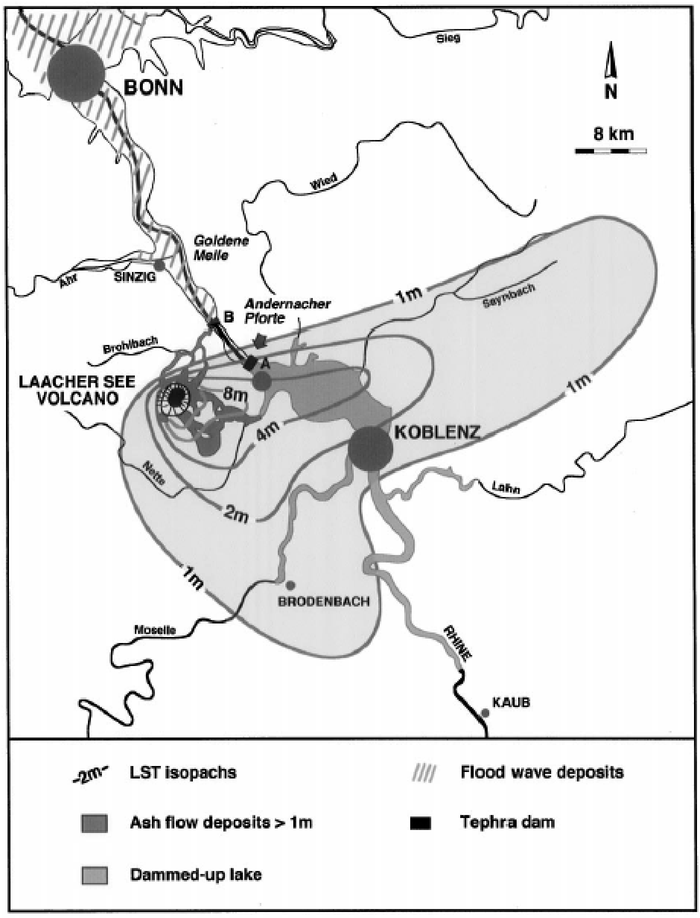


Fig. 1. Map of area severely devastated by Laacher See eruption 12,900 a BP showing area of major fallout deposition (light gray area; after Bogaard and Schmincke, 1984), areal distribution of major ash flow deposits (dark gray area; after Freundt and Schmincke, 1986), approximate extent of the lake dammed up within Neuwied Basin during LSE (intermediate gray area; after Park and Schmincke, 1997) and possible extent of the flood waves resulting from the sudden collapse of the tephra dam (hatched area). A = major tephra dam at bottleneck outlet of Neuwied Basin near Andernach; B = dam caused by ash flows entering the Rhine River at the mouth of Brohl valley.

14 October (MON) - excursion to Aachen

Program: Aachen and surroundings
10:00 Excursion: Geology and archeoseismology in Aachen (guided cathedral tour)
12:00 Time for individual sightseeing, lunch etc.
14:00 Feldbiss-Fault in Aachen surroundings (bus trip, guide: Roland Walter)
18:00 Arrival in Rursee/Simmerath

Introduction in to the geology of Aachen
(from Fernández-Steeger et al., 2011 and Reicherter et al., 2011; both papers are on stick)

The neotectonic and landscape evolution of the Lower Rhine Graben (LRG) in western Germany are directly linked to the Alpine Orogeny and the Upper Rhine Graben, and, mainly characterized by subsidence (Michon et al., 2003). However, secondary processes like earthquakes, extensional tectonics, the Pleistocene volcanism in the Eifel area, the influence of glaciation/deglaciation of northern Central Europe, and overall the anthropogenic modifications, i.e. open cast lignite mining, strongly influence landscape. The geomorphology of the area is typical for a "seismogenic landscape" with pronounced scarps and active faulting, however, in humid climates. Dominant structural features are mainly normal faults. Palaeoseismic and historical earthquake data suggest several major events during prehistoric times (Camelbeeck and Meghraoui, 1998; Vanneste et al., 2001), instrumental data, however, show minor to moderate seismicity with dominantly normal focal plane mechanisms (Camelbeeck et al., 2007). The last event was the moderate Roermond earthquake in the Netherlands, April 13, 1992, with ML 5.9 (MW 5.4; e.g., Camelbeeck and van Eck, 1994; Hinzen and Reamer, 2007), leading locally to liquefaction (Davenport et al., 1994).

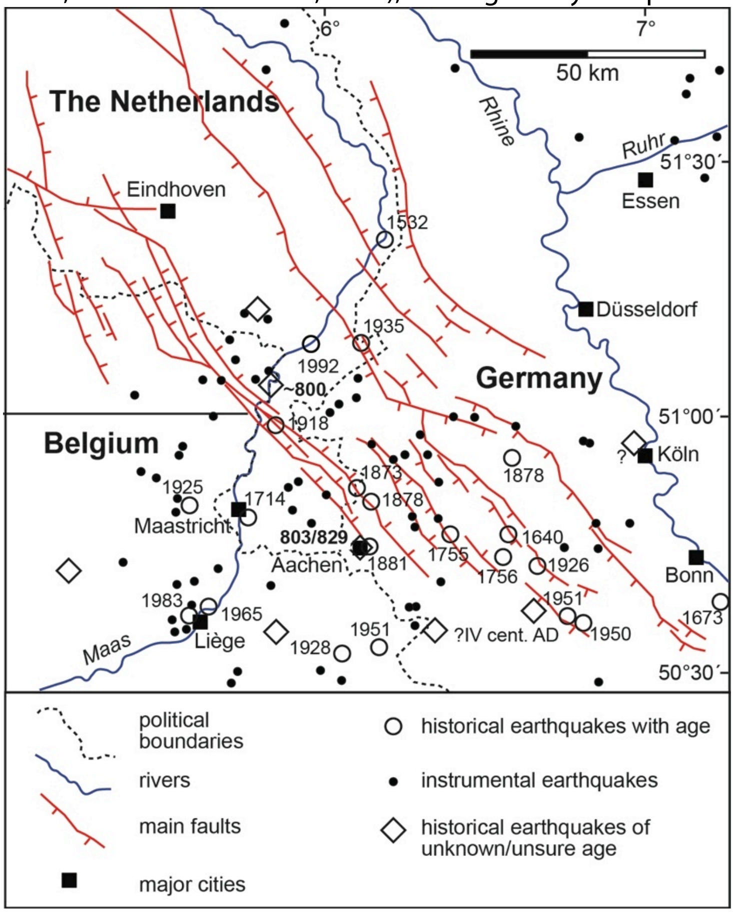


Fig.#. Location and tectonic features (red) of the Aachen and Lower Rhine Graben area, historical and instrumental earthquake epicenters are compiled from Hinzen and Reamer (2007), Vanneste et al. (2001) and data from the Erdbebenstation Bensberg (http://www.seismo.uni-koeln.de/) and the data from the Geologischer Dienst NRW (http://www.gd.nrw.de/).

Palaeoseismic investigations along young NW-SE trending normal faults provided evidence for

much stronger earthquake in the LRG in pre-Roman times (Camelbeeck and Meghraoui, 1996; 1998; Meghraoui et al., 2000; Vandenberghe et al., 2009, c. 2500 ± 300 years BP) with an estimated palaeomagnitude of around M 7. Vanneste et al. (1999; 2001) described the youngest event along the Bree fault, a subordinate fault of the Feldbiss fault system (Houtgast and van Balen, 2000; Houtgast et al., 2003) with a surface rupture c. 1000-1350 years ago. However, the same authors considered the 14C-dating as too young, after comparing with IRSL dating (Camelbeeck et al., 2007). The Feldbiss fault system reaches the Aachen region in the very SE, where in 1873, 1878 and 1881 the last smaller earthquakes occurred. Manifold trenching studies have been carried out in the German, Dutch and Belgian parts of the LRG (summaries in: Houtgast et al., 2003; Skupin et al., 2008; Vanneste et al. 2009), however, the results were often ambiguous. Largest vertical movement attributed to one event did not exceed 0.8 m and were observed by the Geological Service NRW (Skupin et al., 2008). Estimates of palaeomagnitudes from trenching in Bree (Belgium) result with M 6.3 (Vanneste et al., 2001). These values are slightly higher than the 1756 Düren event (Meidow, 1995), which was considered to be the strongest historically documented earthquake with MS 5,7 (Camelbeeck et al., 2007). Return periods of such earthquakes were calculated to be on the order of 35 – 165 ka (Skupin et al., 2008), whereas Camelbeeck et al. (2007) have found recurrence periods of c. 14 – 23 ka along the Bree fault.
Archaeoseismic studies in the LRG area are rare. The Roman Pretorium in Cologne was probably damaged during an earthquake between 800 and 840 AD and abandoned afterwards (see above 10.Oct. by K.-G. Hinzen). Archaeological excavations carried out at the Tolbiacum village (the present-day Zülpich, Germany) revealed heavily damaged and destroyed late Roman fortifications (Hinzen, 2005), which have been attributed by 14C-dating to an earthquake in the late 3rd century AD.

Geological and structural framework of the Aachen area

Aachen is situated along the northernmost edge of the Rhenish Massif at the transition to the Cretaceous Limburg platform and directly on the frontal Variscan thrust fault trending NE-SW. Marl- and claystones of the Frasnian unit (Devonian) are thrust over the Carboniferous limestone complex and folded with NE-SW fold axes (Ribbert, 1992). Mesozoic units are missing except the chert-rich sandstones of the Late Cretaceous, which are covered by Pleistocene loess loam and alluvial deposits. Like other Roman and medieval cities with a long settlement history, the inner city area is covered by anthropogenic debris and locally thick fillings modify the original landscape. The construction ground of the Aachen Cathedral is covered by 2-3 m thick anthropogenic debris, partly also a Carboniferous limestone ridge is incorporated in the foundation. The contribution of the thermal springs of Aachen (Ahha = water in the Germanic Parent Language) on the weathering of the Frasnian shales and claystones is still under debate. A companion paper highlights the engineering geology of the Aachen cathedral. Most of the foundation compartments are today accessible due to a recent archaeological excavation.

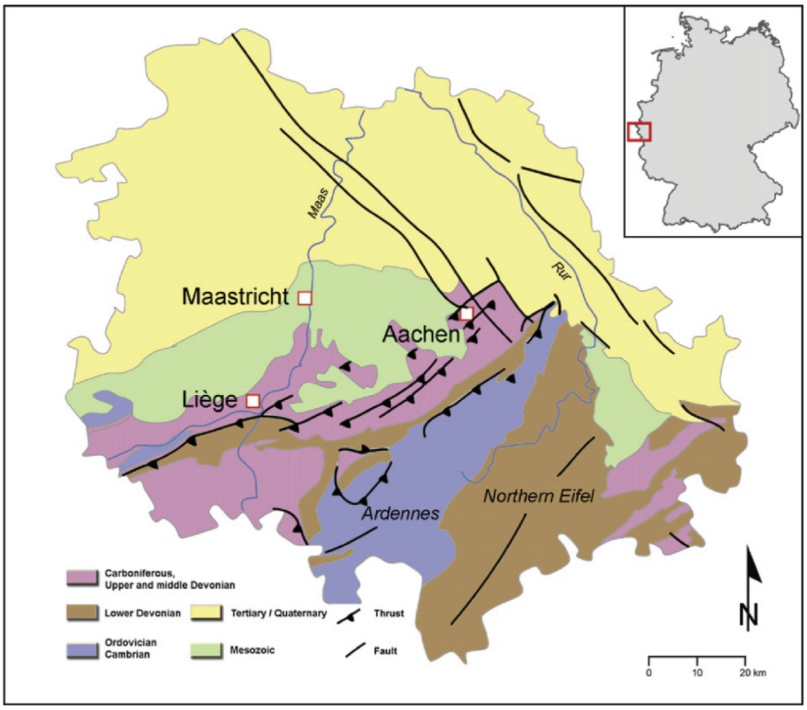


Fig.#. Geological setting and tectonic features of the Lower Rhine Graben and the city of Aachen (modified after Walter, 2010).

One of the Variscan major thrust faults, the Aachen fault, crosses the plaza between the ancient palatine (today: city hall) and the Carolingian chapel of Maria. The tectonic evolution of the Aachen area is connected with the Miocene to recent subsidence of the LRG and the uplift of the Rhenish Massif at the end of the Tertiary (e.g. van den Berg, 1994). SW-NE extension led to a NW-SE striking system of normal faults and a complex tectonic graben. Aachen is situated on the western graben shoulder, and younger, NW-SE trending normal faults of the Feldbiss fault system cut and displace the old Variscan thrusts. The present-day stress field is characterized by S_{Hmax} directed SE-NW due to compression of the Alps (Baumann and Illies, 1983; Reicherter et al., 2008).

Engineering geology of the city and Aachen cathedral area

The construction site of the Aachen cathedral is covered by a 2-3 m thick anthropogenic fill from Roman and post-Roman age. Up to a depth of 3 m, Roman buildings of the ancient baths penetrate the site and are covered by loamy debris. Generally, the density and bearing capacity of these units change over short distances and therefore, they are not suitable as construction substrate. The anthropogenic filling is followed by meter-thick yellow-brown loess loam. In the upper part the loess loam is very stiff, changing to a more soft plastic consistency in the lower parts, as the water content increases. As the investigation sites are located below the building in the foundation compartments, water must have migrated upwards due to capillary forces. The colour of the sediments changes to grey or grey-green with depth, probably due to reduced oxidation in the lower parts. In surrounding construction pits, this loess loam was often described as mottled (Dieler, 1960). At the base of this unit the grain size increases and thin sandy or fine gravel layers are intercalating. The base of the Pleistocene loess loam units is characterised by thin flint-rich sand and gravel layers (up to 0.3m thickness). While under the NW basement the loam and loess loam units are up to 4.5 m thick, the thickness reduces to the south due to an ENE-WSW striking limestone ridge below the cathedral (Dieler, 1960; Breddin and Vogt, 1969). Below those units or directly below the loam, the hard rock basement is made up of SW-NE striking Frasnian marls and shales. The surface of the units shows a palaeorelief as the resistant limestone layers form a 2.5 m high ridge, while the much thicker marls and shales are deeply weathered and eroded (Breddin and Vogt, 1969).

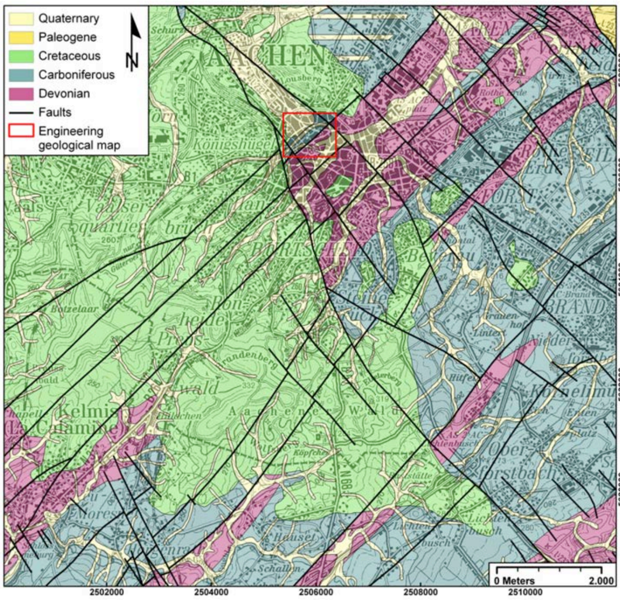


Fig.#. Geological map of the Aachen area. The repetition of the Devonian and Carboniferous formation due to NW oriented folding and thrusting. NW-SE striking faults are cutting and crossing the Variscan thrusts (from Fernández-Steeger et al., 2011).

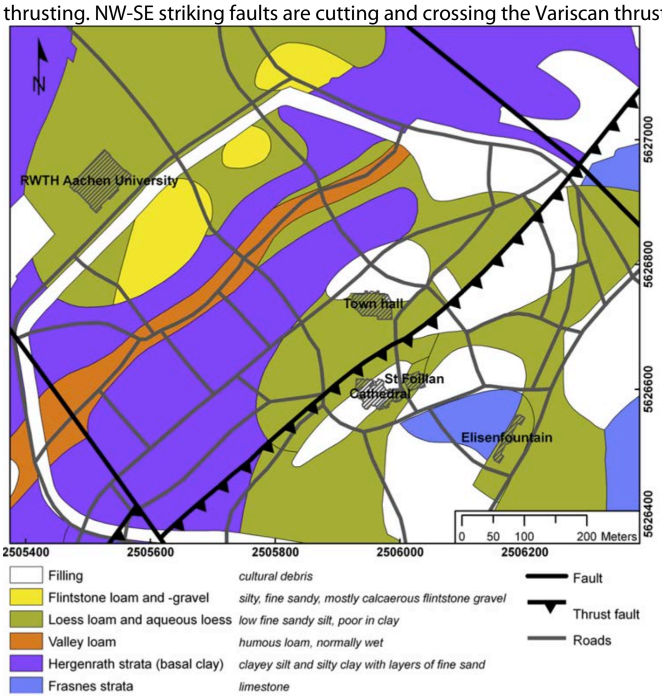


Fig.#. Engineering geological map of the inner city of Aachen with the Aachen cathedral in the center. While SE of the cathedral Frasnian strata from the basement reach the surface, to the NW they are covered by younger sediments. Below the cathedral anthropogenic fillings and Quaternary loess loam covers the Devonian basement (from Fernández-Steeger et al., 2011).

Springs and spa Aachen

(modified and shortened from wikipedia)

During the Iron Age, the area was settled by Celtic people, who were perhaps drawn by the marshy Aachen basin's hot sulphur springs where they worshiped Grannus, god of light and healing. Later, the 25-hectare Roman spa resort town of Aquae Granni was, according to legend, founded by Grenus, under Hadrian, in ca. 124 AD. Instead, the fictitious founder refers to the Celtic god, and it seems it was the Roman 6th Legion at the start of the 1st century that first channelled the hot springs into a spa at Büchel, adding at the end of the same century the Münstertherme spa, two water pipelines, and a likely sanctuary dedicated to Grannus. A kind of forum, surrounded by colonnades, connected the two spa complexes. There was also an extensive residential area. The Romans built bathhouses near Burtscheid (today a part of Aachen in the south). A temple precinct called Vernenum was built near the modern Kornelimünster. Today, all that remains are two fountains in the Elisenbrunnen and the Burtscheid bathhouse.

Aachen became attractive as a spa by the middle of the 17th century, not so much because of the effects of the hot springs on the health of its visitors but because Aachen was then — and remained well into the 19th century — a place of high-level prostitution in Europe. Traces of this hidden agenda of the city's history is found in the 18th-century guidebooks to Aachen as well as to the other spas; the main indication for visiting patients, ironically, was syphilis; only by the end of the 19th century had rheuma become the most important object of cures at Aachen and Burtscheid.

History of Aachen and monumental geology

(taken from Dr. Kurt Heinrichs excursion guide 2008)

Aachen´s history is long and been summarized in tables # and #. The cathedral, Town Hall, remains of the two medieval city walls, town gates, towers, churches, chapels, residential buildings, public buildings, older buildings of the RWTH Aachen University, memorials, cenotaphs, fountains, viaducts, bridges, statues, sculptures, reliefs, sepulchres, road pavement, foundations of historical buildings, stone cladding of façades of modern residential and commercial buildings are constructed using natural stones, which are outcropping in the vicinity of Aachen. A stratigraphical chart and associated rocks for construction are found in table #. Most famous is the Blaustein, a collective name for the dense (porosity < 1%), hard, very weathering resistant limestones (massive limestones) of the Devonian (Middle-Upper Devonian) and the Carboniferous (Lower Carboniferous) in the Aachen area. The name "Blaustein" (Bluestone) probably originates from Flemish stonemasons, who came to Aachen in the 17th century after the big city fire and who introduced the name "Blaw Stejn" (Blue stone) for the limestones, as these are of blue-greyish colour in unweathered or polished condition. As high quality Aachen Bluestone today is rarely available from the local quarries, "Belgian Granite" (trade name for a Belgian limestone of the Lower Carboniferous with similar stone properties) is increasingly used as alternative.

First city wall: „Barbarossa wall", built in the late 12th century, length: 2400 m, height: 8 – 10 m, thickness: 1.70 m on average, 10 gate buildings, 10 towers after the big city fire (1656) partly used as "quarry"

Second city wall: Built in the period between mid of the 13th century and mid of the 14th century, Length: 5500 m, 11 gate buildings ("Ponttor" and "Marschiertor" preserved), 22 towers city wall largely razed at the instigation of Napoleon (1794-1815).

Fig. #. Plan of the medieval Aachen city with the two city walls (Henrick van Steenwijck, 16th century).

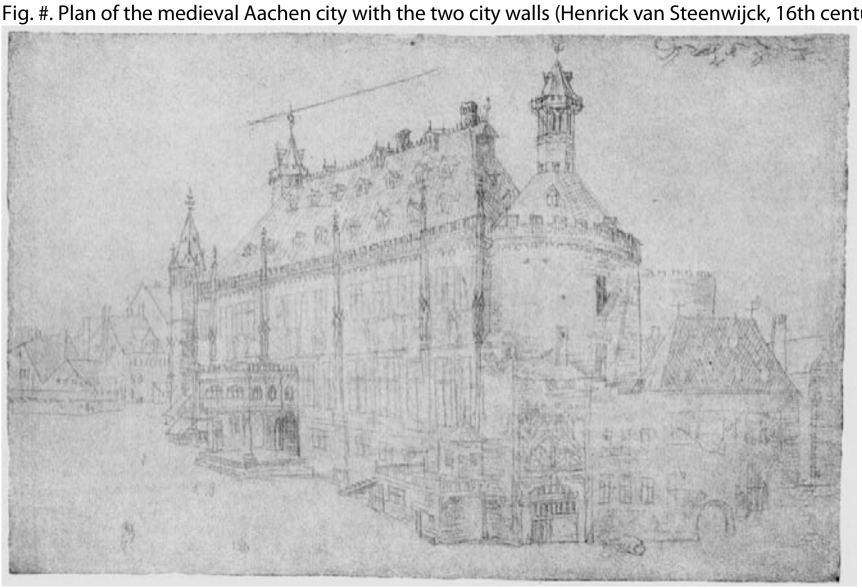


Fig. #. Drawing of the Aachen town hall in 1520.

Fig. #. Drawing of the Aachen town hall in 1840.

Fig. #. Photo of the Aachen town hall in 1900.

Fig. #. Photo of the Aachen town hall in 1925.

Stratigraphic sequence of rocks in the Aachen area and utilisation of the rocks

Translated from KASIG, W.: Die Nutzung der geologischen Gegebenheiten durch den Menschen im Bereich der Stadt Aachen; Zeitschrift des Aachener Geschichtsvereins, Band 102, 1999 / 2000

System		Stage		Rocks	Utilisation
Quaternary 2		Holocene		River gravel, loess, sands, clays	Gravel, sand, clay, meadow ore
		Pleistocene			
Tertiary 65		Pliocene to Paleocene		Gravels, sands (partly silicified), clays	Base material for ceramic, building stones („Tertiary quartzite"), clays for brick production
Cretaceous 100	Upper Cret.	Maastrichtian to Turonian		Limestones, marlstones (with or without flint), sands (partly glauconitic, partly silicified), clay	Building stones, burnt lime, utensils, tools, weapons, clays for brick production, Ceramic
135	>>>>>>>>>>>>>>>>>>>>>>>>> stratigraphic gap <<<<<<<<<<<<<<<<<<<<<<<<<				
Jurassic		no deposits			
Triassic					
Permian					
290	>>>>>>>>>>>>> stratigraphic gap = Variscan orogenesis <<<<<<<<<<<<<<<<<<<				
300 Carboni-ferous	Upper Carb. (Silesium)	Westphalian		Sandstones and mudstones with coal seams	Bituminous coal (anthracite), building stones, clays for brick production
		Namurian			
	Lower Carb. (Dinantium)	Visean		Limestones	Burnt lime, building stones (eg. "Aachen Bluestone"), ores (Fe, Pb, Zn), water catchment
360		Tournaisian		Dolomites	
Devonian	Upper Dev.	Famennian		Limestones, „Condroz" sandstone, „Cheiloceras" limestone, nodular limestones	Building stones Clays for brick production
		Frasnian		Limestones, marlstones, dolomites	Mineral and thermal water, building stones (eg. "Aachen Bluestone"), ores (Fe, Pb, Zn), water catchment
	Middle Dev.	Givetian			
		Eifelian		Red and green sandstones, siltstones and mudstones with plant remains (psilophytes)	
	Lower Dev.	Emsian		Red and green sandstones, siltstones and mudstones with plant remains (psilophytes)	Clays for brick production Building stones
		Siegenian		Grey sandstones and shales	
410		Gedinnian		Red sandstones and shales with vertebrates and plant remains (psilophytes)	
(Silurian)	>>>>>>>>>>>> stratigraphic gap = Caledonian orogenesis <<<<<<<<<<<<<<<<<<				
490 Ordovician 500		Tremadoc (Salmian)		Red and green, grey shales, quartzitic sandstones with graptolites (Dictyonema)	Building stones, roofing slates
Cambrian		Revinian	Rv5	Shales and quartzitic sandstones, tonalite of Lammersdorf (magmatic rock)	Building stones
			Rv4		
590 Ma			Rv3		

Table.#. Construction rocks for monumentals and house in Aachen and their stratigraphy

Prehistory	*A Stone Age flint stone quarry on the Lousberg, other Stone Age findings and burial cairns from the Bronze Age bear witness to settlements in the Aachen region long time ago. From about 600 BC until the 1st century AD the Celts settled in the Aachen area and still today their heritage can be found in the many names of places and from locations of Celtic origin.*
1st – 4th century AD	*The Romans turned Aachen into a military spa town (hot springs in Aachen!). They built temples and bath buildings for the ritual and recreational use of the Roman legionaries.*
4th – 7th century	*Christianisation of the Aachen region. Frank tombs from the middle of the 7th century AD show that today´s Aachen city centre was inhabited by the Franks at that time.*
765	*Aachen was named in writing for the first time by King Pippin as „Aquis Villa".*
Late 8th – early 9th century	*768: King Charlemagne (Charles the Great, Carolus Magnus) resided in Aachen. Approx. 20 years later the Palace and the Palace Chapel (today´s Cathedral) were built. The town became Charlemagne´s favourite residence and the centre of his empire.*
936	*Otto I was crowned as king in Aachen (first coronation ceremony in Aachen). From that time onwards Aachen remained the coronation place of the German kings for six centuries.*
1165	*Charlemagne was canonised. Friedrich I (Barbarossa) confirmed the rights of liberty for Aachen. The town was given the market rights and the prerogative of coinage.*
1171	*The first city wall was built ("Barbarossa Wall").*
1257 – 1357	*The outer city wall was built.*
14th century	*The citizens of Aachen constructed a Gothic Town Hall on the very same foundations of the Carolingian King´s Hall.*
1349	*The first Aachen pilgrimage took place (since then every seven years).*
1355 – 1414	*Construction of the Gothic choir hall of the Aachen Cathedral.*
15th century	*Construction of the Gothic chapels of the Aachen Cathedral.*
1531	*Last coronation in Aachen of a German king (Ferdinand I).*
1656	*Big Aachen fire. Most of the Aachen houses destroyed.*
1755 / 1756	*Earthquakes rock the Aachen region.*
1794 – 1814	*Aachen under French occupation. Numerous artefacts were deported to Paris.*
1815	*Aachen was given to Prussia.*

Table.#A. History of Aachen (part 1)

1865	*The foundation stone of the Polytechnical School (today´s RWTH Aachen University) was laid by Wilhelm I.*
1914 – 1918	*World War I.*
1918 – 1929	*As a result of World War I the western outskirts of Aachen and the adjacent countryside were given to Belgium.*
1930	*The diocese of Aachen was created.*
1939 – 1945	*Due to its situation at the most western tip of Germany, Aachen was heavily involved in the events of World War II. About 65 % of all houses were destroyed. The most important facilities were reinstalled in 1945.*
1950	*The "International Charlemagne Award" was awarded for the first time in the Coronation Hall of the Aachen Town Hall.*
1969	*Rebuilding of the Aachen city finished (remedy of war damage).*
1985	*A new hospital complex ("Klinikum") was officially handed over to the RWTH Aachen.*
1991	*Opening of the Ludwig Forum for International Art.*
1995	*Inauguration of Aachen´s new synagogue.*
2001	*Opening of the Carolus Baths of the Aachen Spa.*

Table.#B. History of Aachen (part 2)

History of the Aachen cathedral

(modified and shortened from wikipedia)

Aachen Cathedral, frequently referred to as the "Imperial Cathedral", is a Roman Catholic church in Aachen, Germany. The church is the oldest cathedral in northern Europe and was known as the "Royal Church of St. Mary at Aachen" during the Middle Ages. For 595 years, from 936 to 1531, the Aachen chapel was the church of coronation for 30 German kings and 12 queens. The church is the episcopal seat of the Diocese of Aachen. **Charles the Great** (Charlemagne) began the construction of the Palatine Chapel around 796, along with the building of the rest of the palace structures. The construction is credited to Odo of Metz. It suffered a large amount of damage around 881, by the Northmen and was restored in 983. In the 14th and 15th centuries, Gothic additions were added, including the choir in 1355. It was restored again in 1881. The core of the cathedral is the Carolingian Palatine Chapel, which is notably small in comparison to the later additions.In order to sustain the enormous flow of pilgrims in the Gothic period a choir hall was built: a two-part Capella vitrea (glass chapel) which was consecrated on the 600th anniversary of Charlemagne's death. A cupola, several other chapels and a steeple were also constructed at later dates. In 1978, it was one of the first 12 items to make the entry into the UNESCO list of world heritage sites, as the first German and one of the first three European historical ensembles.

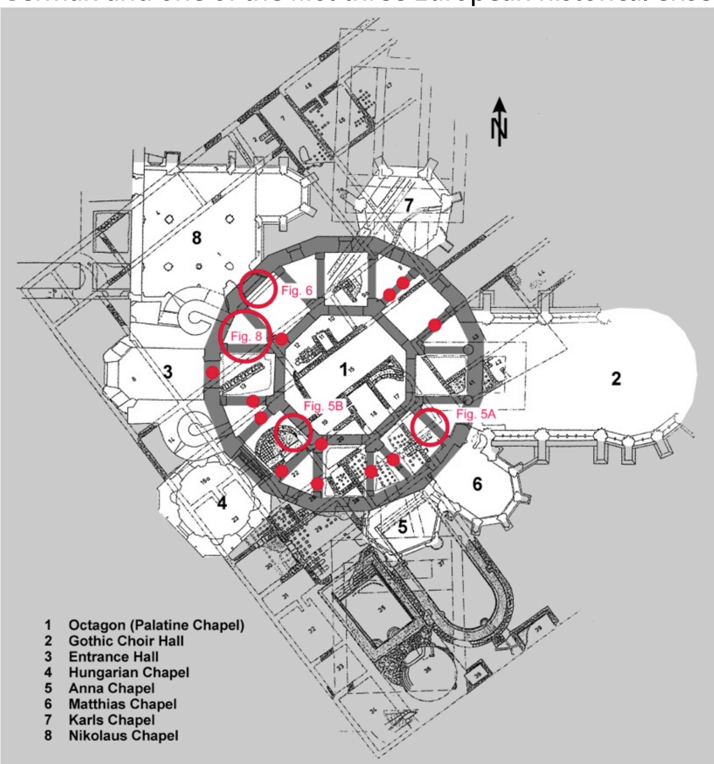


Fig.#: Plan of the Aachen Cathedral with its annex chapels. The dark grey shaded part mark the Carolingian Octagon, which spans up to a hexadecagon. Red dots show locations of fractures, red circles mark figures in the following. Note that below the Cathedral roman thermas of the Münster thermal spring have been found and mapped during excavation in 1910/11 (plan modified after Siebigs, 2004).

Age (AD)	Source/evidence	construction/event
1656		great city fire in Aachen
1414		completion of Gothic choir
829 (pre-Easter)	Annales Regni Francorum[1]	earthquake? windstorm?
823	catalogues[5]	earthquake
814		Charlemagne died
812	visit of Byzantine legates	finish chapel construction
805 (?)	Annales Tiliani[2]	inauguration of chapel
803 ±10	wooden anchor at roof[3]	repair work
803 (winter)	Annales Regni Francorum[1]	destructive earthquake
798 (July)	Alkuin Letter[4]	marble columns erected
post-794	Carolingian Denar (Charles)	foundation accomplished
798±5	wooden plank at pillar[3]	construction started

Fig.#: Time frame of the different construction periods of the Aachen Cathedral, the dating and three possible medieval earthquakes in Aachen area between 800 and 840 AD.

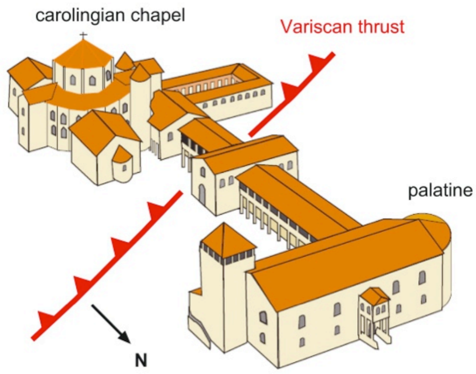


Fig. #.Model of the Carolingian chapel of Maria (Marienkapelle) and Palatine in Aachen (today: city hall) and the Aachen Thrust of Variscan age, crossing the place between both historic buildings (modified from Nathan, 1997)

Archeoseismology of Aachen

Several typical indicators of earthquake deformation (structural and geological) have been found in the Carolingian Chapel of Aachen (Fig. #), which indicate a high-energy event, possibly accustomed by differential ground settling. Historical documents reveal evidence for three earthquakes in the considered time interval. Taking all the available constructional information and dating of the individual steps of the construction and repair work, we place the damaging earthquake at 803 AD. If we take into account that structural damage in the Aachen Cathedral occurred during the construction as evidenced by the warped ground floor, we favor strongly the 803 AD event as the candidate earthquake for the damage in the medieval Aachen city area. The observed damage, including the liquefied "injection structures" suggest a minimum magnitude for this event around 5.5. However, the causative fault has not been detected so far, an issue for further investigations.

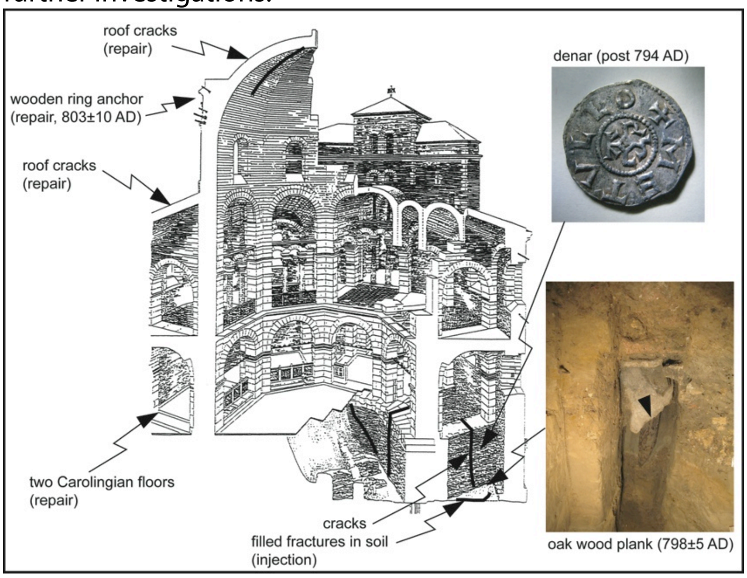


Fig.#. Evidences of repair work, fractures and time frame (dating) in the Carolingian part of the Aachen Cathedral (from Reicherter et al., 2011; drawing modified from Siebigs, 2004).

Feldbiss Fault system

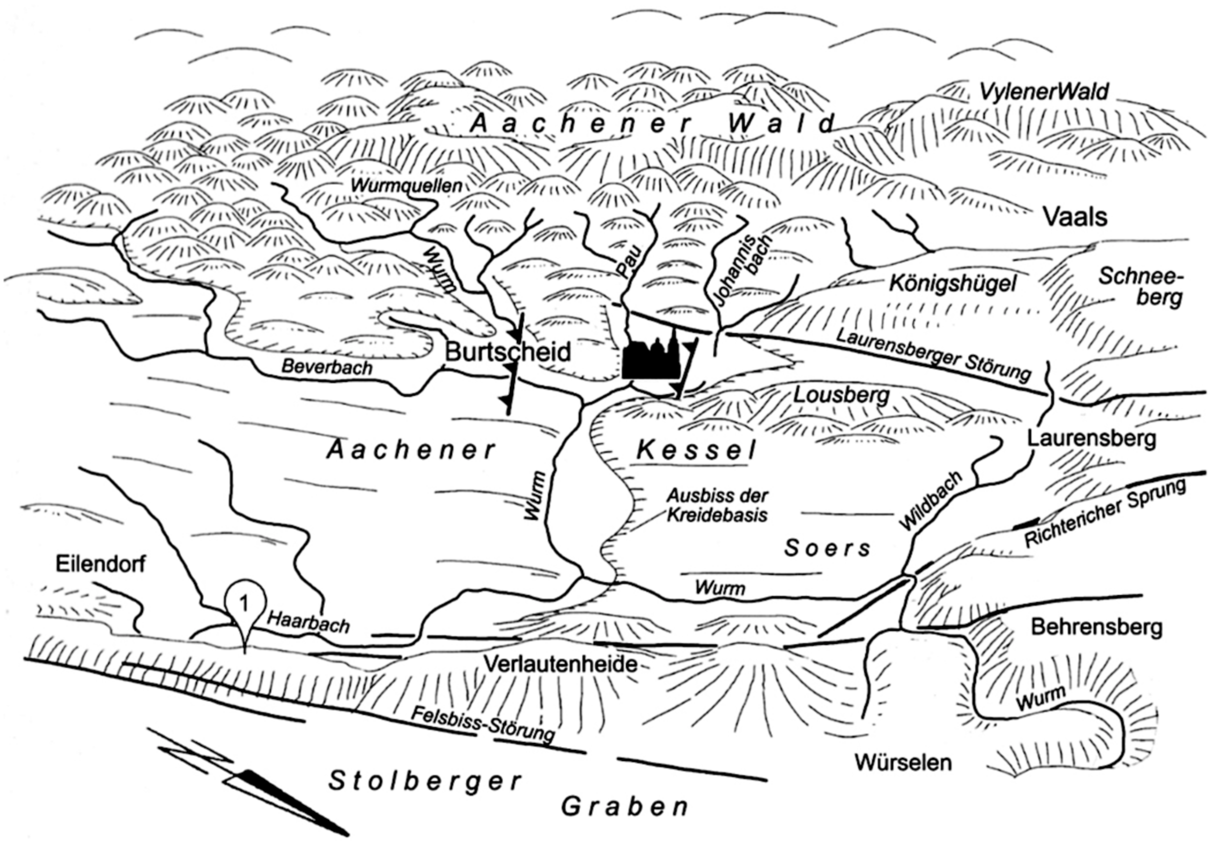


Fig. #. Topographical and structural map of the Aachen area (modified from Walter, R., 2012, Aachener Georouten). View point for this stop is 1. Note that: Störung and Sprung mean fault.

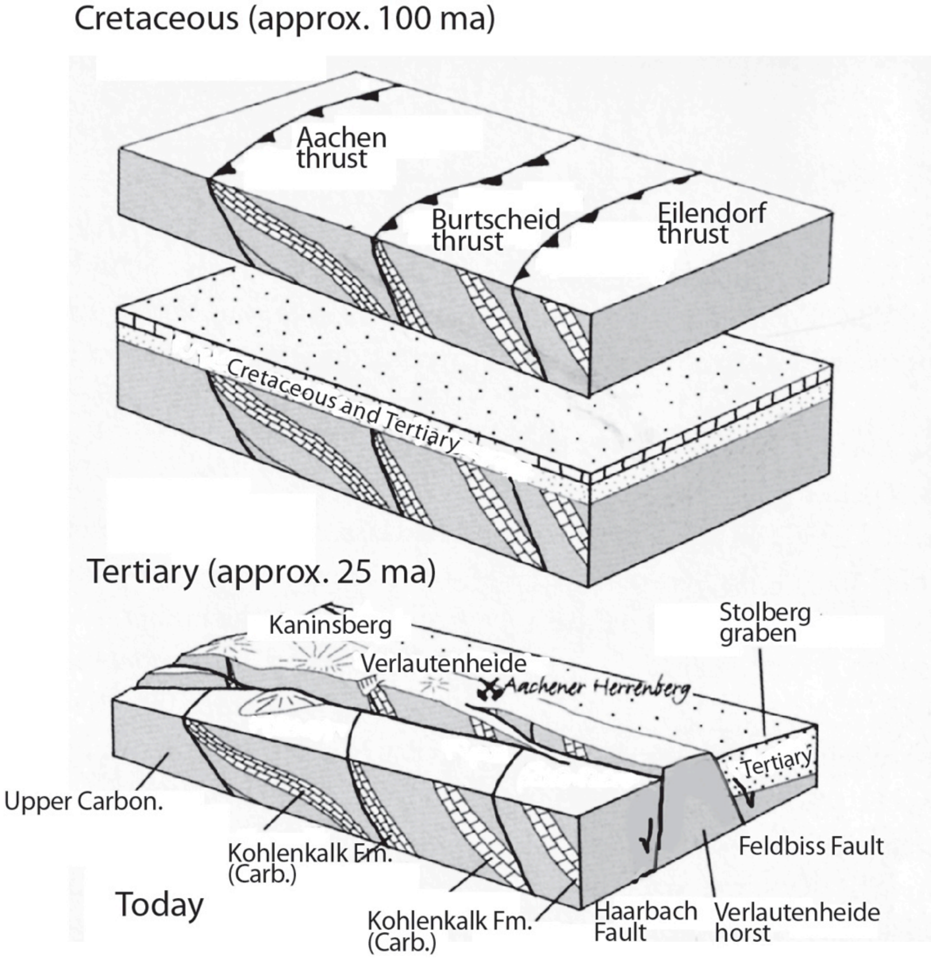


Fig. #. Structural block sketch of the Feldbiss fault area (modified from Walter, R., 2012, Aachener Georouten). View point for this stop is close to the Aachener Herrenberg (closed lead-zinc mine, Smithsonite, $ZnCO_3$).

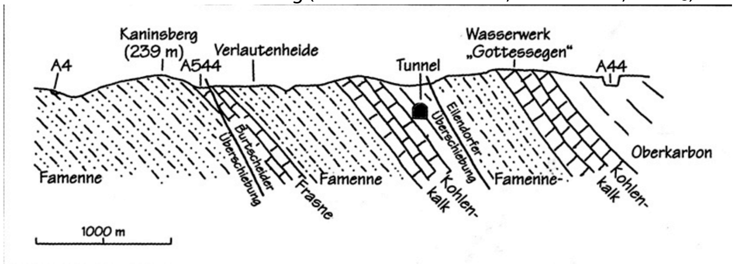


Fig. #. Cross section of the Aachen area (modified from Walter, R., 2012, Aachener Georouten).

Inden open lignite pit mine

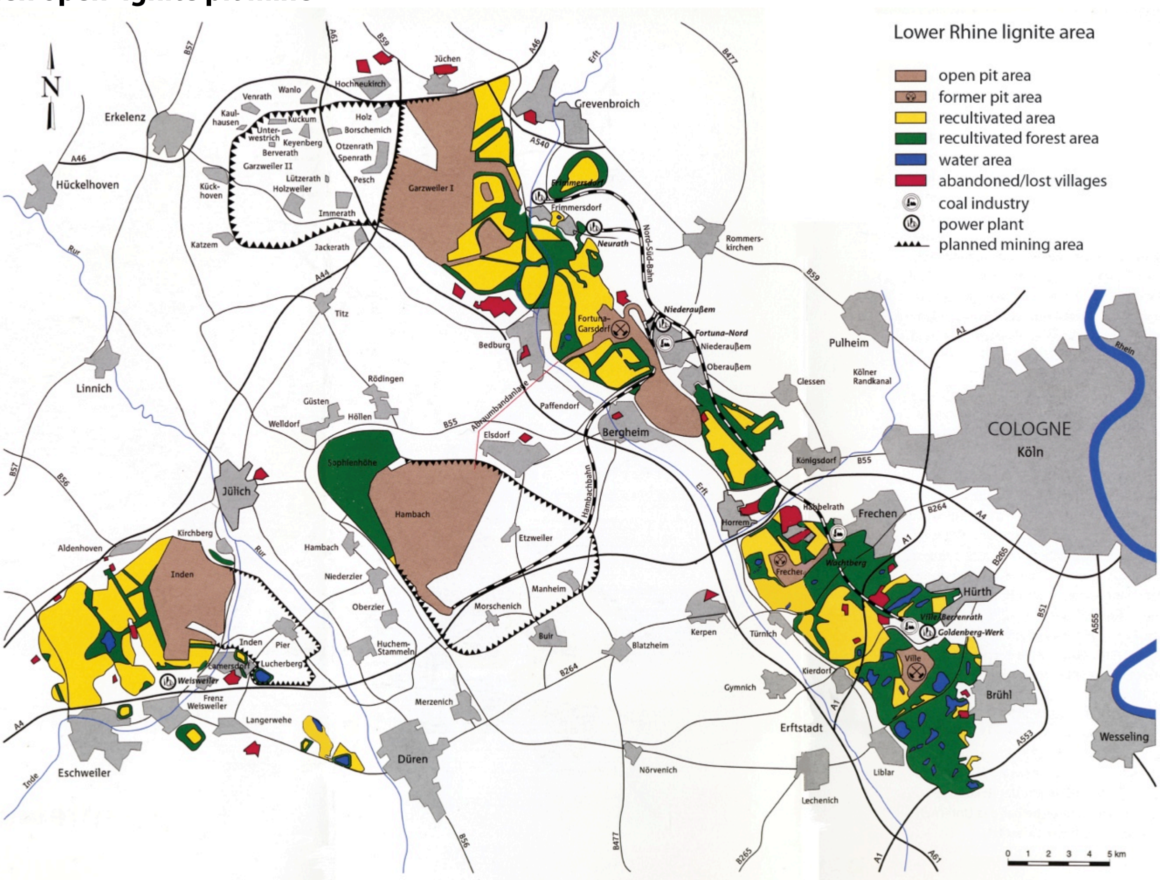


Fig. #. Overview of the Lower Rhine coal mine area (taken from RWE Power)

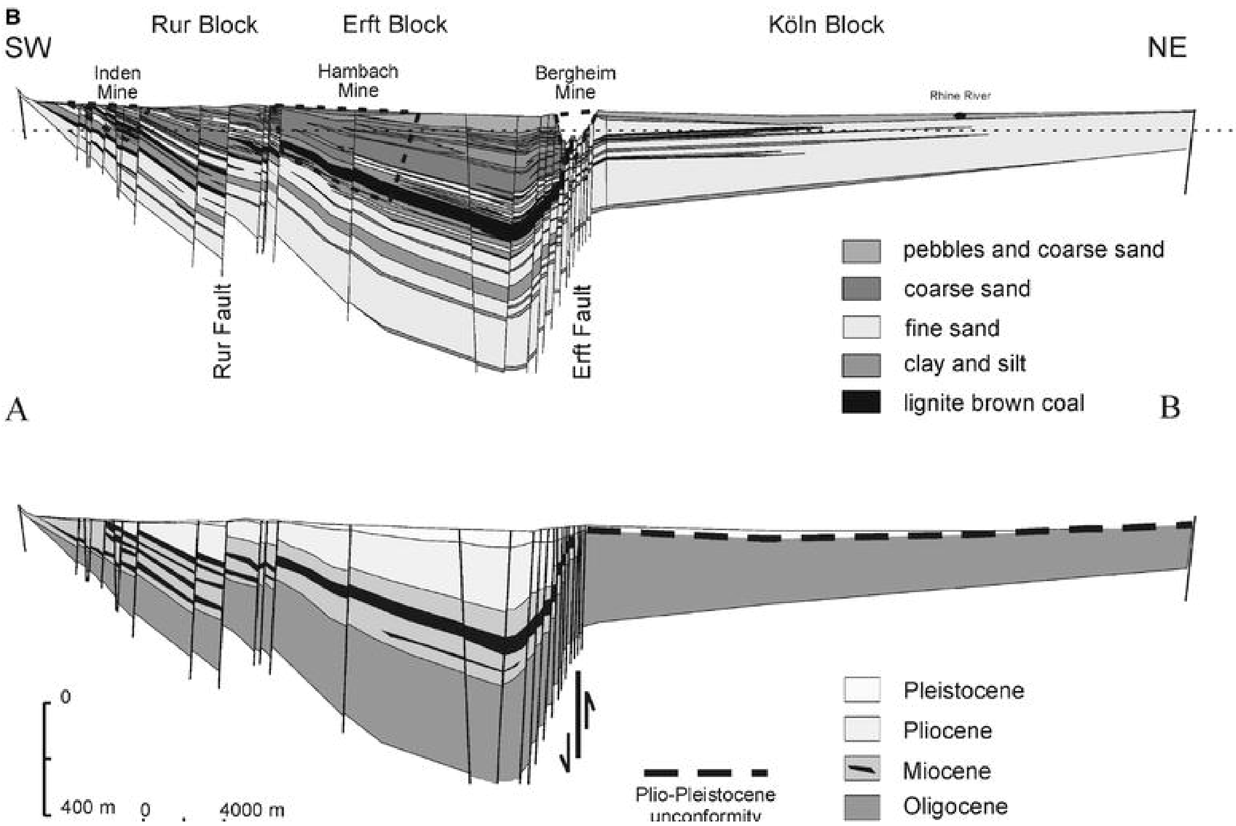


Fig. #. Cross section of the Lower Rhine Basin, note major faults and open pit mines (lignite)

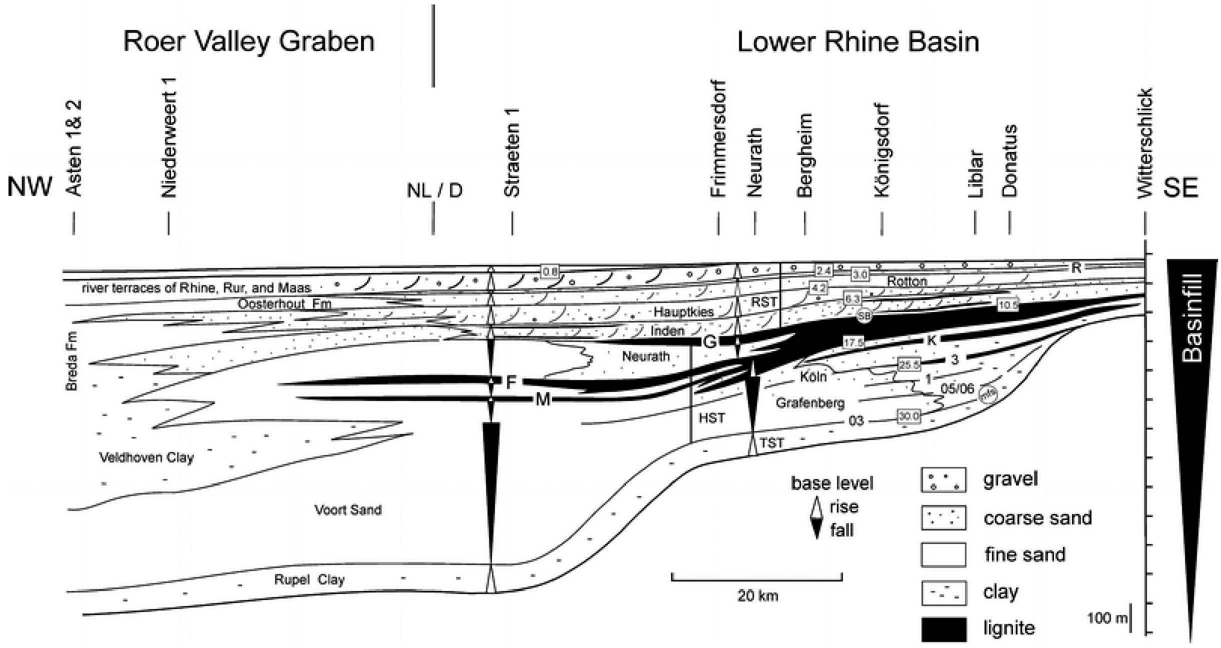


Fig. #. Restored stratigraphy of the Lower Rhine Basin.


Fig. #. Photo of the Hambach open pit mine (lignite). Begun in 1978, the mine currently has a size of 33.89 km^2 and is planned to eventually have a size of 85 km^2. It is the deepest open pit mine with respect to sea level, where the ground of the pit is 293 meters below sea level.


Fig. #. Bucket-wheel excavator in the Hambach mine