

THE HEIDELBERG DRILLING PROJECT (UPPER RHINE GRABEN, GERMANY)



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ABSTRACT

The Heidelberg basin hosts one of the thickest successions of unconsolidated Pliocene and Quaternary deposits in continental middle Europe, and certainly the thickest succession built by the Geosystem Rhine, connecting Alps, Rhine Graben, North Sea and English Channel. Also local Geosystems, first place the Neckar System, contribute to the basin infill. The more or less continuous subsidence of the Upper Rhine Graben (URG) during all periods of Tertiary Graben history, but especially during the last few million years, led to a succession of alternating fluvial and lacustrine environments of various provenances. This archive contains not only various proxies of the mid-European climate evolution during the Plio-Quaternary, but also signals of geodynamic processes controlled by tectonics.

Various pre project activities during the last years prove the feasibility of an extensive research project to begin in late 2005. In its centre will be three drillings envisaged to become 300 m, 350 m and 500 m deep which are all designed to expose the Plio-Quaternary transition. The various techniques of facies analysis, geophysical exploration, geochronology, climate and tectonics modelling, to be combined in a comprehensive 3D evolutionary scenario, will – hopefully – enable us to read and understand the archive of the Heidelberg basin fill. The expected results will not only contribute to the data pools of palaeoclimate and neotectonics, but are also a methodological test in handling complex Geosystems. A considerable fallout with regard to societal use and handling of the geo-environment is also expected: from use of geothermal energy, hydrogeology and pollution handling in a highly industrialized region, right to assessment of climate and seismic risks.

The project will be run by a co-operation of the Leibniz Institute for Applied Geosciences (Hannover) and the Geological Services of the three German federal States sharing the territories of the Heidelberg basin (Baden-Württemberg, Hessen, Rheinland-Pfalz). This paper is designed to outline the project, present some very preliminary results of pre-project research, and stimulate further collaboration into the main project to come.

Key-words: Upper Rhine Graben, Heidelberg basin, stratigraphy, neotectonics.

RÉSUMÉ

LE PROJET DE FORAGE « HEIDELBERG » (FOSSÉ RHÉNAN, ALLEMAGNE)

Le bassin d'Heidelberg présente une des successions de dépôts quaternaires non consolidés les plus épaisses d'Europe continentale moyenne et certainement la succession la plus épaisse du géosystème Rhin, connectant les Alpes, le graben du Rhin, la Mer du Nord et la Manche. Des géosystèmes locaux, avec en premier lieu celui du Neckar, contribuent également au remplissage du bassin. La subsidence plus ou moins continue de cette partie du graben du Rhin durant toute son histoire cénozoïque, mais en particulier durant les derniers millions d'années, a conduit à la mise en place d'une succession d'environnements fluviaux et lacustres de différentes provenances. Cette archive ne contient pas seulement différents proxies de l'évolution climatique durant le Plio-Quaternaire, mais également des signaux des processus géodynamiques contrôlés par le climat et la tectonique.

Différentes activités pré-projet menées durant ces dernières années ont montré la faisabilité d'un programme de recherche important qui a pris corps autour d'un projet de carottage profond prévue pour commencer à la fin 2005. Les différentes techniques d'analyse de faciès, d'exploration géophysique, de géochronologie, de modélisation du climat et de la tectonique, prévues pour être intégrées dans un modèle compréhensif d'évolution 3D, permettront de lire et de comprendre l'archive d'Heidelberg. Les résultats escomptés ne contribueront pas seulement à documenter les aspects paléoclimatiques et néotectoniques, mais fourniront également un apport méthodologique pour l'appréhension des géosystèmes complexes. Des retombées importantes sont également attendues par rapport aux usages sociaux et à la gestion des géo-environnements, en ce qui concerne l'énergie géothermique, l'hydrogéologie et la maîtrise des pollutions dans une région très industrialisée, sensible aux modifications climatiques et au risque sismique.

Le projet sera mis en œuvre grâce à une coopération de l'Institut GGA pour les Géosciences appliquées de Hanovre et les services géologiques des trois Länder recouvrant le bassin d'Heidelberg (Baden-Württemberg, Hesse, Rhénanie-Palatinat). Cet article expose le projet, présente quelques résultats préliminaires ou recherches pré-projets et propose des opportunités de collaboration.

Mots-clés : Fossé Rhénan, bassin de Heidelberg, stratigraphie, neotectonique.

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INTRODUCTION

The Upper Rhine Graben is a north-northeast-trending, crustal scale rift of Tertiary age. It is part of the European Cenozoic rift system, that developed in the northwestern foreland of the Alps. The Upper Rhine Graben extends from Basel (Switzerland) to Frankfurt (Germany) for about 300 km, with a north-northeast trend and has an average width of 35-45 km (Fig. 1).

The Rhine Graben is a major accommodation space for sedimentation and preservation of Tertiary and Quaternary deposits. Regarding the Plio-Quaternary within the Graben, sedimentation tends to be discontinuous in the south and more continuous in the north. Within the Northern Graben, the Heidelberg basin contains more than 1000 m of Plio-Quaternary. The transition from Pliocene into the Quaternary, although still a matter of discussion in the geo-scientific community, is expected somewhere around 300 to 400 m in rather fine grained material. There seems to be a good potential that various modern geochronological methods can be successfully applied.

The Plio-Quaternary sedimentary succession of the Heidelberg basin has been a matter of geological discussion since the first deep drilling (called "Radium Sol Therme") was carried out in the early 1920ies. Originally published by Salomon (1927), the succession has been re-interpreted several times (e.g. Bartz 1951, Fezer 1997), but always the Radium Sol Therme remained the main data source. All industrial hydrocarbon exploration in the 1960 – 1980ies took course well outside of the Heidelberg area, with the funny result that in publications of the late 20th century, the area near Heidelberg and the rest of the northern Rhine Graben seem to belong to two different geoworlds.

When in the last few years a new approach was launched, it was widely agreed that not re-interpretation but re-investigation was needed. Without new and reliable data derived from modern core drillings, from sedimentology to geochronology, combined with investigations in geophysics and tectonics, resulting in a comprehensive 3D evolutionary scenario, the unique situation of the northern Rhine Graben and the possibly

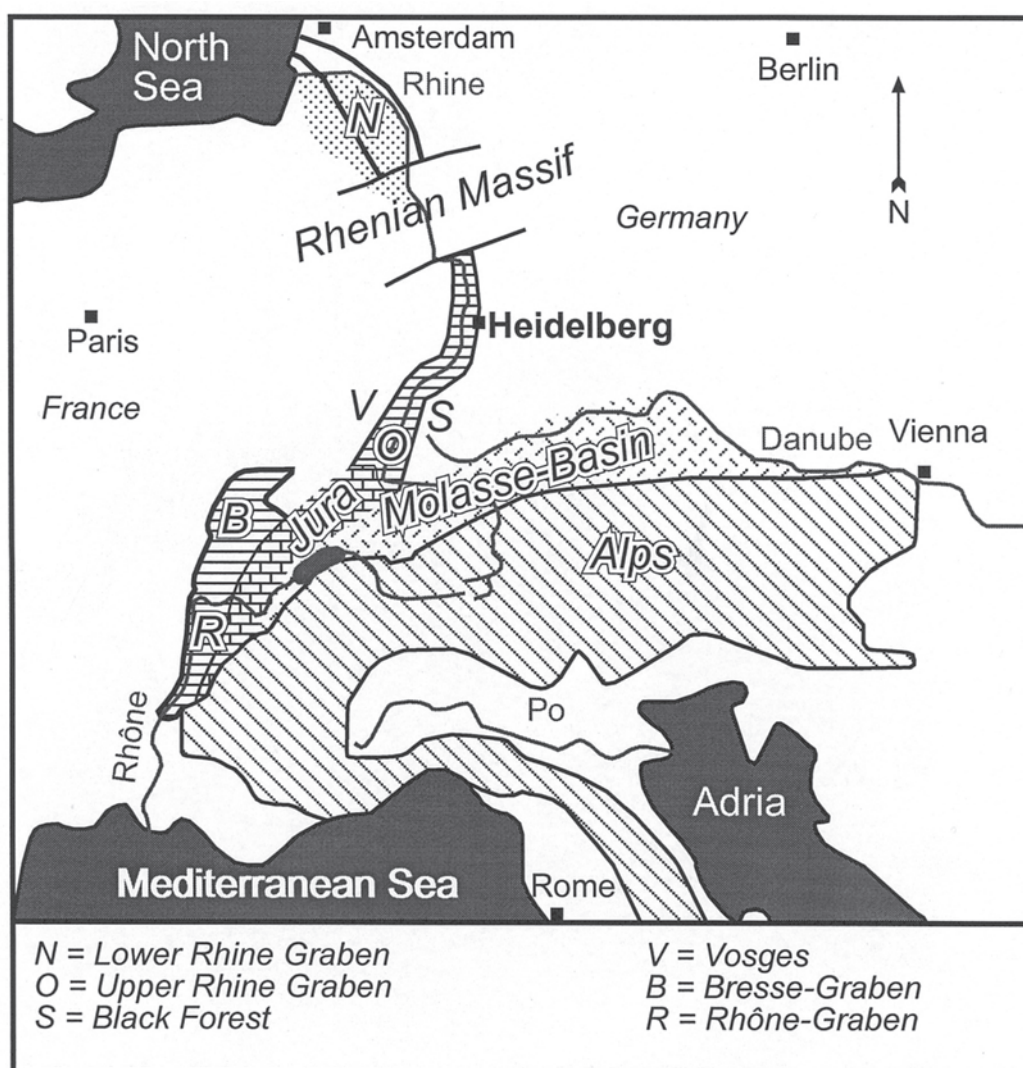


Fig. 1: Situation of the Upper Rhine Graben in Europe.
Fig. 1 : La situation du Fossé Rhénan en Europe.

still more special situation of the area close to Heidelberg cannot be solved.

In this paper, the very first steps on this way are reported. Several pre-projects set up to test the applicability of various methods have just been successfully completed (Hagedorn 2004, Knipping 2004, Litt & Ellwanger 2005, Neeb *et al.* 2004, Rolf 2004a 2004b, Rolf *et al.* 2005, Weidenfeller & Kärcher 2004, 2005). In the text to follow, overviews of

- the geology of the Heidelberg area,
- a proposed project architecture,
- summaries of pre-project investigations

are outlined. Looking towards the main project to be started in late 2005, which will certainly take several years, further national and international collaboration is cordially welcome.

PLIO-QUATERNARY GEOLOGY OF THE HEIDELBERG BASIN

Frequent discontinuities in sedimentary successions and in geomorphological patterns are probably the major difficulty of Quaternary geology of any continental and especially of the alpine and pre-alpine environment. This is due to rapid and strong changes of geodynamics controlled by climate and tectonics, which become even more rapid and stronger if glacial events are involved.

The classical approaches towards Quaternary stratigraphy handle these difficulties using markers from sediments deposited in periods of low or no sedimentary dynamics, e.g. palynostratigraphy in interglacial lake deposits, or pedostratigraphy. While the investigation

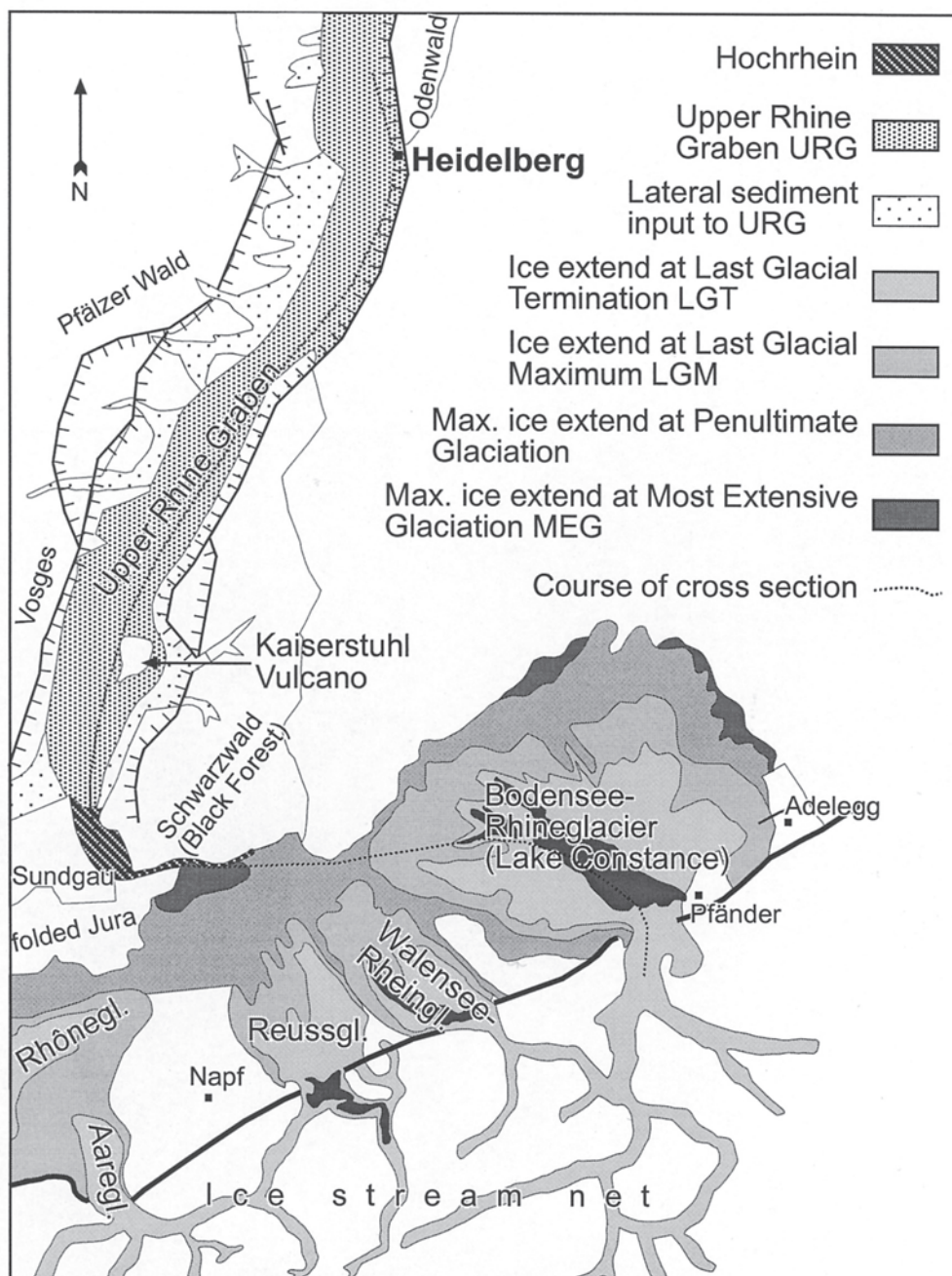


Fig. 2: The URG with its alpine sediment delivery area.

Fig. 2 : Le Fossé Rhénan avec la région d'origine des sédiments alpin.

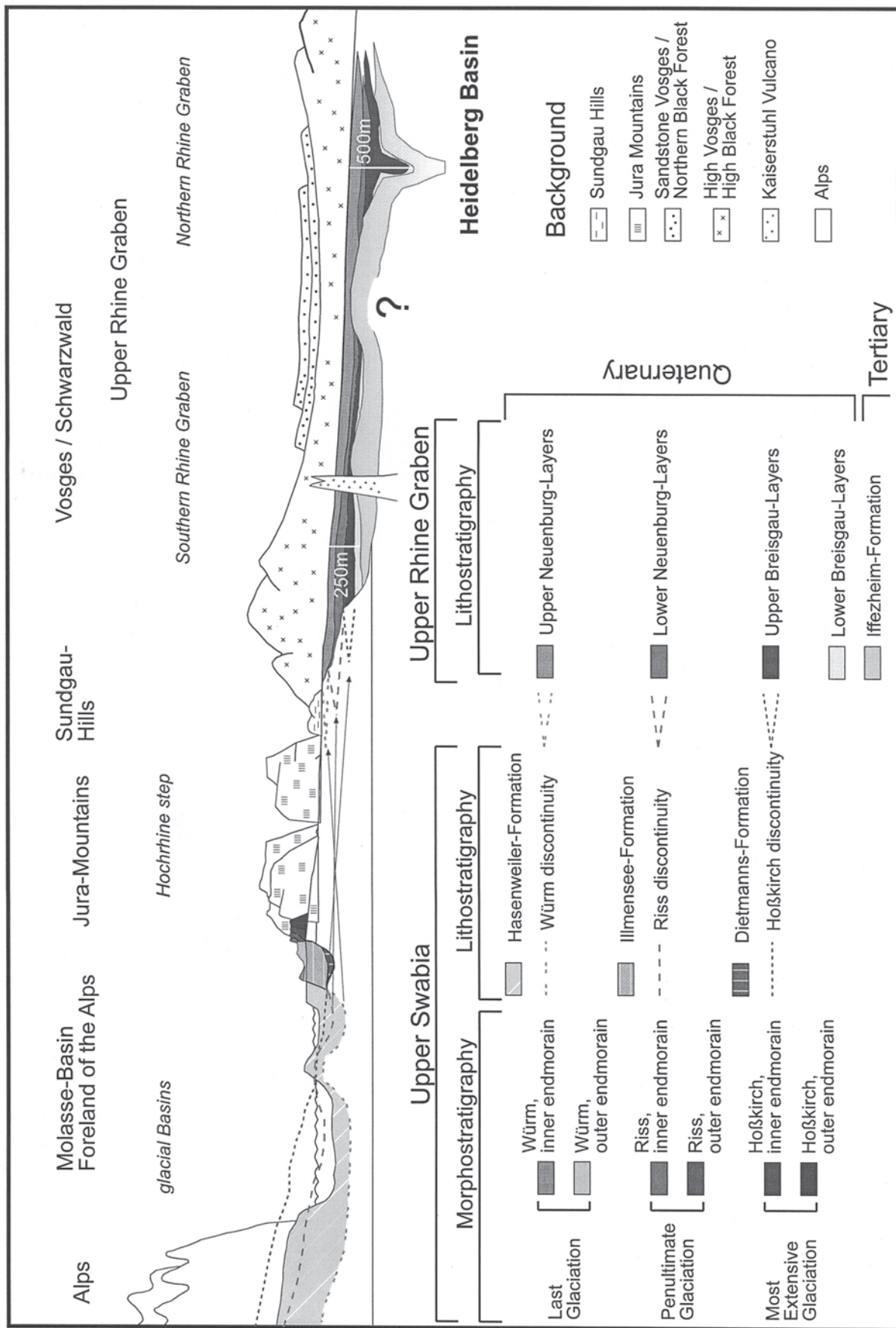


Fig. 3: Cross section from the Alpine valley to the URG as indicated in Fig. 2. For the peri-alpine area, geomorphological markers are correlated to sedimentary units. For the whole geosystem, the peri-alpine morpho- and lithostratigraphy is correlated to the URG lithostratigraphy. Until now, this correlation is valid only for the southern part of the URG and still has to be proven for the north.

Fig. 3 : Coupe géologique de l'Alpenrhéin au Fossé Rhénan, comme indiqué en Fig. 2. Pour la région péri-alpine, les phénomènes géomorphologiques sont en corrélation avec les unités sédimentaires. Pour le système Alpes-Fossé Rhénan, la stratigraphie morpho- et lithologique péri-alpine est en corrélation avec la stratigraphie lithologique du Fossé Rhénan. Jusque présent, cette corrélation est valable seulement pour le Fossé Rhénan du sud. La continuation plus au nord sera l'objet du projet «Heidelberg».

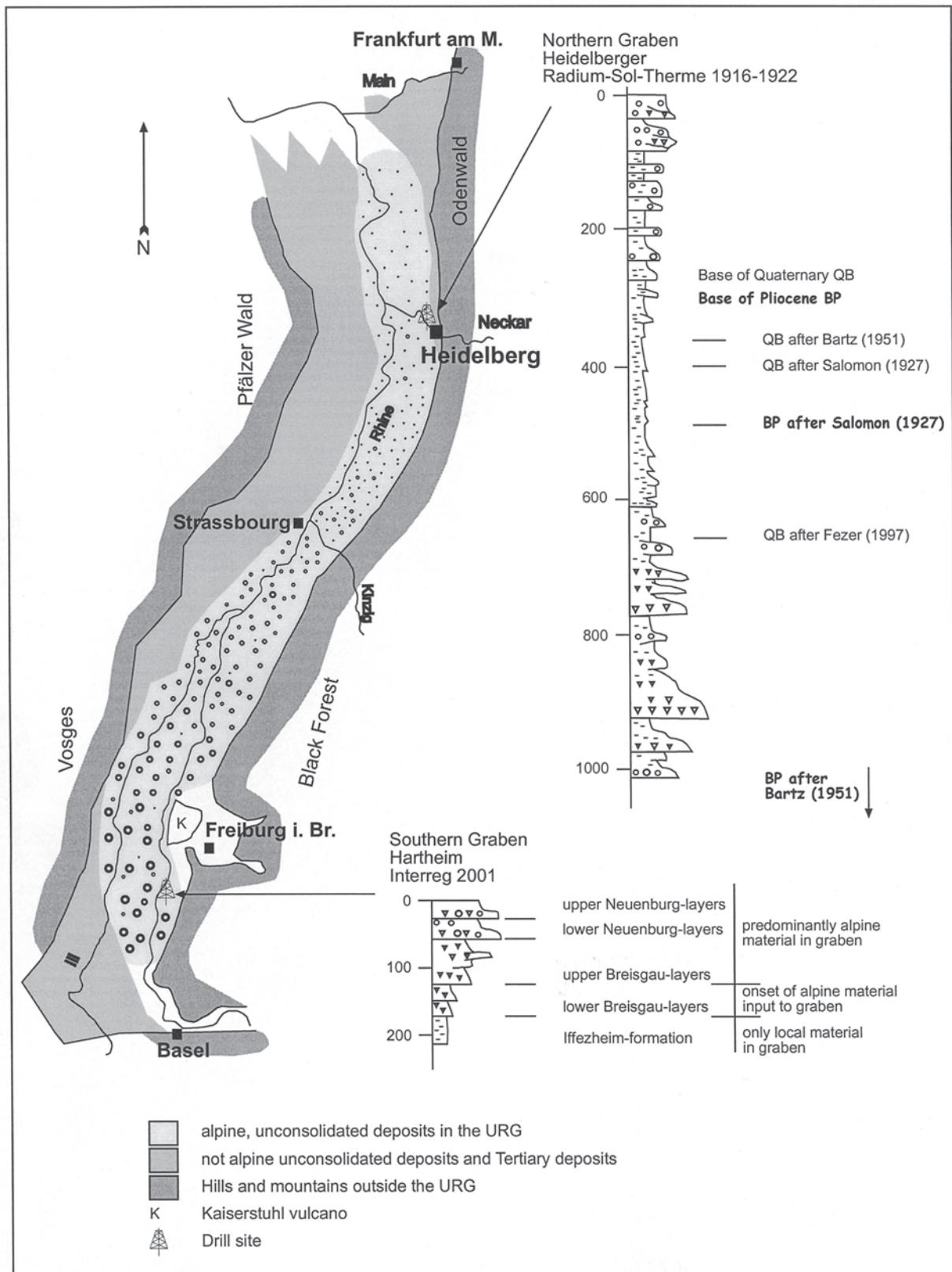


Fig. 4: The Plio-Quaternary of the Rhinegraben.

- Left: Proximal - distal fining of the younger Quaternary infill of URG.
- Right: Lithologs of two drillings (same scale).
 - Southern Log: complete Plio-Quaternary sediment succession
 - Northern Log: Plio-Quaternary sediment succession, base of Pliocene not reached. Radium Sol Therme after Salomon (1927) and with several re-interpretations.

Fig. 4 : Le Plio-Quaternaire du Fossé Rhénan

- Gauche : affinage proximo-distal des sédiments quaternaires du Fossé Rhénan
- Droite : Lithologies des forages (même échelle)
 - Forage sud : succession sédimentaire complète du Plio-Quaternaire
 - Forage nord : succession sédimentaire du Plio-Quaternaire, la base du Pliocène n'étant pas atteinte. Radium Sol Therme après Salomon (1927) et autres interprétations.

potentials are focussed on the markers, the main sediment bodies, which are of primary societal and economic interests, are just infill between the markers. They are generally regarded by using standards of geotechnics and not of geology.

Another way of solving the problem is to focus research on environments where dynamics remain permanently low in all phases of climate cycles, e.g. around closed or very distal sediment traps. They give the best possible, highly resolved stratigraphical record, but are again unrelated to the major sediment bodies.

The new approach, which will be applied to the Heidelberg project, tries to handle the difficulty by using proximal-distal geosystems of various scales (Ellwanger *et al.* 2004, Neeb *et al.* 2004). Proximal event discontinuities and their correlative event sediment bodies are used to relate the high dynamics and discontinuous erosion/deposition patterns of proximal environments with the stratigraphically well resolved and more continuous deposits of distal environments. Three examples are:

1. Regional geosystems, usually highland-lowland systems. Most important is the geosystem Alps – alpine foreland which is set up across the alpine margin, relating inner-alpine erosion and proximal deposition with distal infill of the glacial basins, following patterns of climate control. – Other regional to local geosystems are correlative from Black Forest or Vosges to the URG, following tectonical control.

2. The geosystem Alps – URG is an example for a large regional geosystem. It relates the erosion dynamics of the alpine margin with the alpine infill of the URG, with proximal facies in the southern URG and distal facies in the northern URG / Heidelberg basin. In between there is a transfer area (terrace landsystem). Both climate and tectonics control the sedimentation-accumulation pattern.

3. Finally, on an almost continental scale, the geosystem Rhine relates Alps and North Sea / English Channel. This is a “fine sediment geosystem”. North of the URG only fine sediments of alpine origin can be found. In terms of coarser sediment geosystems (sand, gravel) the geosystem Rhine is better considered as a puzzle sequence of regional and large regional geosystems (Alps-URG, Neckar-URG, Mosel-Middle Rhine, Rhine delta etc.). Again climate and tectonics are the controlling factors.

During the Quaternary, the subsiding part of the northern URG acts as distal and final accommodation space for the coarser alpine material (Fig. 2, Fig. 3). As a subsidence structure it is part of the Oligocene and Neogene rifting and oblique rifting of the URG which represents 40 Ma yrs of active graben tectonics (Behrmann *et al.*, 2003). During the Plio-Quaternary, the major subsidence shifted towards the eastern part of the Graben (Heidelberg basin), with an area of maximum subsidence located at the central eastern part of the basin, just around the city of Heidelberg. The Plio-

Quaternary deposits add up to probably more than one kilometer, and the Quaternary alone, depending on which boundary is applied, around 300 to 400 m. This “basin in basin” structure, located where the River Neckar enters the URG, has been referred to as “Heidelberger Loch”. It is a relatively small area, the outer limits being within the western city boundaries of Heidelberg.

The Plio-Quaternary infill of the Heidelberg basin has been mainly deposited by the Rhine (Fig. 4). Here, the most distal signals of alpine climate dynamics i.e. of the major events of alpine glaciations can still be identified as sediment bodies within the Pleistocene succession. They are embedded in relatively fine alpine material and coarser local material. The material is suitable to derive markers for chronostratigraphy and geochronology. There are also coarser event layers present, which are related to the Neckar input.

One of the questions regarding the Heidelberg sub-basin is the relation of proximal Neckar input and distal Rhine input. Obviously it depends on the relation of accommodation space to sediment supply (a/s) with regard to the two sediment sources. The a/s ratio will decrease during Neckar events and increase in phases of slow but continuous Rhine input. In this scenario, an interfingering succession of deposits of the two provenances is to be expected, similar to what is expected in the whole Heidelberg basin, but better resolved. Only if a and s (Neckar) increase and decrease contemporaneously, with the a/s relation remaining unchanged, a scenario of Neckar-only input seems possible. E.g. the increased subsidence relates to a contemporary uplift in nearby sediment source highlands. Any result this way would be of major importance with regard to (neo-) tectonics (Lämmermann-Barthel *et al.* in review).

PROJECT OUTLINE

The Heidelberg basin infill is related to (1) the sedimentary Geosystems (Alps – URG, Black Forest and Vosges – URG, Neckar – URG), controlling sediment input, and to (2) the synsedimentary basin subsidence, controlling actual sedimentation and preservation. The Heidelberg drilling project is also related to other projects concerned with research of deeper parts of the subsurface. Industrial research on hydrocarbon in the URG during the 20th century focused on the Miocene and Oligocene. Near future industrial research on geothermal energy will focus on the Permo-Mesozoic. Today, there is little known about the Plio-Quaternary and the basement. Schematic overview:

- Plio-Quaternary
 - Presently few data. New data expected from this project.
- Miocene
 - Industrial data from hydrocarbon exploration outside of the city boundaries of Heidelberg, only partly available on request

- Oligocene
 - Industrial data from hydrocarbon exploration outside of the city boundaries of Heidelberg, only partly available on request
- Permo-Mesozoic
 - New industrial data expected from near future geothermal projects
- Basement
 - Few data.

Investigations of the Plio-Quaternary basin infill will close the knowledge gap between surface and the potentially usable industrial data on Miocene and Oligocene (rifting) sediments and structures (which are yet to be worked out in a modern sense). The expected industrial data on Permo-Mesozoic (pre-rifting) sediments and (rifting) structures are hoped to close the gap down to the basement. Once modern data are available for the whole sedimentary cover, a closer view on the basement, using geophysical methods, may follow.

According to the available data, potentially available data and the data expected to come in near future, as outlined above, the Heidelberg drilling project has to be embedded into a larger investigation architecture involving many other research projects. They incorporate mainly geophysics but also geomorphology and others. The whole topic will be approached in a multi-step strategy, related to the “increasing depth” slices as follows:

1. A continuous sediment core of the Quaternary and well beyond the T/Q transition is planned for late 2005. This will illuminate the onset of climate controlled signals or even climate control within a sedimentary environment more or less controlled by tectonics.

2. The remaining Pliocene will be cored beyond the Mio-Pliocene transition, revealing signals of interaction between hinterland and accommodation area. This will illustrate two aspects: (1) a succession merely controlled by tectonics but as part of the unconsolidated succession of the Plio-Quaternary, and (2) close the gap to the middle and lower Tertiary strata, which were formerly looked at in good detail during hydrocarbon exploration.

3. The data from hydrocarbon exploration, i.e. Oligocene and Miocene, normal rift and the lower part oblique rift, will be reconsidered using scenarios of modern tectonics. There are sedimentological data from hydrocarbon deep drillings which include only a few cored segments, but also (and mainly) seismic data. Being privately owned, most of these data are yet and will also remain unpublished.

4. The pre-rift succession will be provisionally addressed, using several deep geothermal drillings planned around 2008 in the Heidelberg basin. This will exhibit Mesozoic and late Palaeozoic strata (Rotliegend), definitely only cuttings, but various other parameters. These geothermal drillings will also deliver cuttings from the Tertiary and Quaternary, which may be used for spatial correlation, once the above mentioned core investigations produced results.

5. Finally, some focus will be given to the basement, too. This will not be exhibited by drilling yet, but as multiple parameters of the sedimentary cover are expected from (1) to (4), which also includes new insights on the tectonic setting, some basic data on basement geology may be revealed by 3D gravimetrical modelling.

Step (1) should produce comprehensive and more or less continuous sediment succession down to and beyond the Plio-Pleistocene transition. The drillings will be about 300 to 500 m deep, depending on which drilling site is chosen. The sediment succession will give insight into climate and tectonical signals of the various sediment source areas of the Geosystem Rhine. This comprises climate signals of alpine provenance, especially for the Pleistocene, and tectonical signals of regional to local provenance. A variety of dating techniques will be applied, reaching from classical biostratigraphy and ecostratigraphy (Palynology) to the actual burial age estimates like diverse OSL methods, U/Th and new approaches on the decay of cosmogenic nuclides in buried sediments. The drilling related activities will comprise various geophysical investigations and reinterpretations to work out a comprehensive 3D model of the Heidelberg basin.

RESEARCH TOPICS, PRE-PROJECT INVESTIGATIONS

The feasibility of the project has been proven in various pre-project activities. This comprises geophysical and geomorphological investigations as well as pilot drillings where the applicability of various sedimentological, stratigraphical and chronological methods were successfully tested.

Seismics: Four high resolution reflection seismic lines have been done in preparation of the first drilling, with main focus on strata and structures of the upper 2000 m. These investigations were concentrated in the area of the “Heidelberger Loch” where (within the city boundaries of Heidelberg) no hydrocarbon exploration has been done. Preliminary results suggest that the “Heidelberger Loch” is indeed a sub-basin within the Heidelberg basin. The additional overdeepening, compared with the depths of the basin, adds up to 500 m (Buness, Leibniz Institute for Applied Geosciences, Hannover, oral comm.). Outside Heidelberg, there are plenty of industrial seismic lines of various quality. If authorized it is intended to reprocess and reinterpret as many of these existing industrial seismic data as possible.

Gravimetry: The Heidelberg basin (Heidelberger Loch) is characterised by the strongest negative gravity anomaly observed in the URG.

Due to their sedimentary input, Graben structures generally cause negative gravity anomalies. The most recent gravity map of the Rhine Graben compiled by Rotstein *et al.* (2005) comprises about 33,000 gravity

values, about two thirds from the Bureau de Recherches Géologiques et Minières (BRGM) and the Leibniz Institute for Applied Geosciences, and one third from the Mines Domaniales de Potasse d'Alsace (MDPA).

The gravity map of the URG shows the typical features known from other continental rift valleys like internal basins, ridges and faults. But the mean density of the sediments is known to be smaller than that of other graben structures (e.g. Plaumann 1967; Edel and Weber 1995). Furthermore, lithology of the graben shoulders is quite variable and therefore density contrasts in the basement of the URG must also be expected.

Quantitative interpretations of the Bouguer anomalies in the sense of forward modelling confirm this qualitative conclusion. Rotstein *et al.* (2005) calculated four gravity profiles across the southern Rhine Graben and found, that the density contrasts of the sediments alone do not explain the observed anomalies within the graben. Significant lateral density contrasts within the basement have to be assumed, either to compensate the anomalies caused by the sediments alone, or to reinforce them.

In the area of Heidelberg, the strongest negative gravity anomalies of the URG occur. These anomalies of nearly -50 mGal ($1\text{mGal}=10^{-5} \text{ m/s}^2$) demand for low density rocks. Especially large amounts of sediments can be assumed. For a quantitative interpretation along a profile across the URG, again increasing densities have to be assumed towards the graben shoulders, here the Pfälzer Wald and the Odenwald. Otherwise, the gravity gradients at the rim of the Rhine Graben cannot be explained.

In contrast to the four southern profiles, here only small variations of basement density are needed, to explain the anomalies.

Varying gravity anomalies in this part of the URG can mainly be explained by changes of the sediment thicknesses. Only in the area of the Frankenthaler Terrasse, west of the Heidelberg basin, a slight increase in density of the basement rocks is necessary in order to explain a local gravity high.

Pilot drillings: A wide variety of methods was applied in several pilot drillings around the "Heidelberger Loch". Pollen, molluscs and micro mammals analysis for biostratigraphy; lithofacies analysis, sediment petrography and heavy minerals as sedimentological techniques; palaeomagnetism and magneto-mineralogy as a climate stratigraphical method, were all successfully applied. Various geochronological dating techniques are presently under investigation.

- In the core drilling Ludwigshafen Parkinsel (Rheinland-Pfalz) at the western margin of the Heidelberg basin, the T/Q transition was identified by lithofacies analysis, palaeomagnetism, palynology and heavy minerals. Geochronology samples are still under investigation (Hagedorn 2004, Knipping 2004, Neeb *et al.*

2004, Rolf 2004a, 2004b, Rolf *et al.* 2005, Weidenfeller & Kärcher 2004, 2005). Micromorphological studies on possible palaeoseismic sediment structures are in progress (Menzies, Brock University Canada, oral communication).

- In various core drillings in Kronau (Baden), at the Southern margin of the Heidelberg basin, investigations on sedimentary cycles, heavy minerals, palynology and molluscs were carried out. A palynological "Holsteinian" was identified for the first time in the Rhine Graben, and Waalian was identified, too (Litt & Ellwanger 2005, Hahne 2004). Heavy mineral investigations were done and various allo-pedostratigraphical marker were identified.

- From the numerous drillings in the Heidelberg area during the last decade, only few are of sufficient quality and interest to deserve scientific attention. A series of research drillings near Groß-Rohrheim (Hessen) exposed a typical succession of the northern margin of the basin. Heavy minerals, bio- and magnetostratigraphy are presently under investigation. A core drilling near Viernheim (Hessen) produced the thickest and maybe best resolved succession of the "Oberer Ton" which is a widespread low-dynamic sediment body to be investigated with regard to palynology. Finally, a 1000 m deep geothermal drilling near Weinheim (Baden) provided cutting samples. They led to a good heavy mineral log by Hagedorn (2005).

FINAL OUTLOOK

Motivation, aims and scientific background of the Heidelberg drilling project have been outlined. The topics addressed include considerations on the Geosystem Rhine as the major link between alpine and north European glaciation, the climate versus tectonics issue of the control of deposition, fluvial sedimentation dynamics and petrographical control of sedimentation rates. Geochronology and Chronostratigraphy will be addressed by various techniques. The (palaeo-) seismic issue will be studied. As results come forward, they will be summarized in an evolutionary 3D scenario which will have to be improved as the project proceeds. – The project remains open to welcome any further collaboration.

ACKNOWLEDGEMENT

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