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The geology of Basle in view of Deep Heat Mining

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ABSTRACT

There is a strong possibility that the frst Enhanced Geothermal System (EGS) pilot-plant in Switzerland will be situated in Basle. This may be the case on account of a number of practical, economic, political and geothermal reasons. This paper concentrates on the geological aspects which led to the conclusion, that Basle may be one ***of*** the most suited regions for a EGS pilot-plant in Switzerland.

The City of Basle lies in the southeastern corner of the Rhinegraben, a failed rift system of Oligocene age. The discussed area lies close to the triple point of the trough, the tabular Jura mountains to the east and the folded Jura mountains to the south. The Cenozoic graben fill sequence is well documented as well as the underlying Mesozoic sedimentary sequence. **A** major unknown however is the thickness of Permocarboniferous sediments, which are known to occur in narrow troughs in Northern Switzerland. The top of the cristalline basement is expected at a depth ***of*** 2 to ***2.5* km. A** temperature gradient of up to 40°C/km in the sedimentary sequence is believed to be the expression of the insulation effect of the sediments. However a thinned crust as result of the rifting may contribute to an increased temperature gradient in the basement as well. Tectonic activity is monitored by a dense network ***of*** modem digital seismic stations. They document one of the highest seismically active areas of the Rhinegraben system. These data offer good indications of the state of stress of the deeper subsurface in the area.

KEYWORDS

Deep Heat Mining (DHM), Hot-Dry-Rock (HDR), Enhanced Geothermal System (EGS), exploration drilling, Rhine Graben, failed rift, Permocarboniferous, crystalline basement

1. Regional geology

The city of Basle is located at the southeastern end of the Rhine Graben (figure 1). To the east lies the Dinkelberg block, a fault block of the Plateau Jura adjacent to the southern Black Forest. To the south the Rhine Graben is limited by the Landskron-Blauen chain, the northemmost anticline of the folded Jura mountains. The southeastern margin is characterised by a flexure zone, an narrow segment at which the Mesozoic sequence steeply dips under the Oligocene graben sequence.

The relatively young graben structure – the main subsidence phase occured during Oligocene times – can be best described as a failed rift. The trough shows characteristics of a distensive plate boundary, like e.g. a marked thinning of the lithospheric crust. Resulting from these tectonic activities and its position as a buffer against the alpine compression, the Basle region is one of the seismically most active regions in Switzerland. In the southern Rhine Graben the area around the eastern borderfault shows the highest level of seismic activity. Focal depth of 12 – 13 km are characterisitic within the graben, and 18 – 20 km beneath the western foothills of the southern Black Forest (BONJER 1997). In such an area the understanding of the state of stress is of particular interest, not only for a prognosis of a Hot-Dry-Rock reservoir development, but also for a better comprehension of the seismic activity. MAYER et al. (1997) suggest that the seismic activity is the result of an activated intra-crustal detachment horizon responding to the built-up intra-plate compressional stresses realted to collisional coupling of the Alpine orogen with its foreland.

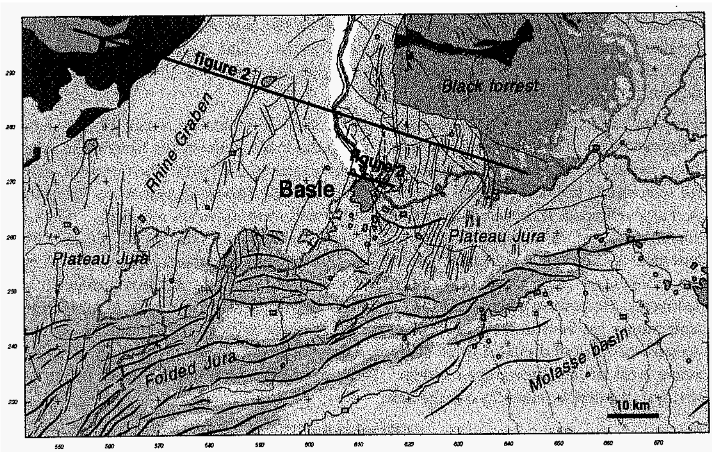


Figure 1: Regional structural elements

In a study for the Deep Heat Mining project EVANS & ROTH (1998) assessed the state of stress in the crystalline basement of northern Switzerland. Two types of data have been examined : fault plane solutions from earthquakes in the basement, and in-situ stress measurements in the basement and overlying sedimentary section. The majority of the in-situ data in the area were obtained from near-surface measurements, with the measurements in the basement being restricted to breakouts in deep NAGRA boreholes of Zürich supplemented by data from Germany.

Evans and Roth obtained reasonable agreement between the stress state indicated by the inversion of focal mechanism data and the in-situ stress data. The focal mechanism data indicate that the minimum principal stress is oriented N55°E±15° and is subhorizontal. Breakouts in the crystalline sections of the Nagra boreholes consistently indicate a minimum stress oriented N41°E±4°. The results are in accord with the large-scale pattern of stress in Europe which appears to be dominated by NW-oriented compression.

The authors suggest that the stress orientations in the sedimentary section may differ from that in the basement. What could not be taken into account by this study are local effects which are likely to overprint these regional effects. In order to find an answer to this question a first exploratory well is scheduled for this year in the designated Deep Heat Mining (DHM) pilot plant area in Basle.

2. Temperature gradient

The geothermal map of Switzerland (MEDICI & RYBACH 1995) highlights the region of Basle with a calculated heat flow density of 110 mW/m^2 as one of the geothermically outstanding areas in Switzerland. The data for this calculation are derived from well data in particular from the wells Reinach 1 and Riehen 2, which both penetrated sediments to a depth of 1793 m and 1247 m respectively. Both wells bottomed in the Upper Muschelkalk. In the vicinity of the borderfault zone vertical convective transport of fluids is likely, resulting in a temperature gradient for these wells in the order **of** 40°/km. This information is however insufficient **for** an extrapolation of the temperature gradient into the crystalline basement in particular to a depth of 5 km, the target depth of an EGS reservoir. In an exclusive study for the DHM project RYBACH (1998) extracted temperature values of various depth in crystalline rock from NAGRA wells in order to calculate a characteristic temperature profile, considering temperature- and pressure dependence of the heat conducitvity as well as a range of values for the specific heat production. It can be assumed that the Vosges-Rhine Graben – Black Forest region forms a contiguous crystalline province. The values extrapolated from the NAGRA wells can therefore be regarded as representative. RYBACH (1998) concludes that the temperature gradient of 40°/km may well be extrapolated into the crystalline basement, resulting in a 200" isotherme at a depth of about 4.8 km.

3. Exploration concept

The exploration concept for a pilot plant of a enhanced geothermal system depends on a number of constraints : The project is based on a combined cycle installation, therefore the vicinity of a heat consumer – in this case a large district heating system – is a prerequisite. Three possible plant sites could be identified in the city of Basle. In order to evaluate the suitability of the subsurface prior to any large investments on a uncertain future site it was decided to drill an exploration well to a depth of approximately *2* km depth, primarily to test the first couple of hundred meters of crystalline basement in the Rhine Graben. **A** suite **of** wireline logs, hydraulic and analytical tests are planned (VUATAZ & HAERING in prep.) before the borehole will be completed as a seismic monitoring well.

The well results as well as the evaluation **of** the potential plant sites will give sufficient information for an optimal site selection **for** a first deep well. The reservoir development concept of the enhanced geothermal system includes the drilling of two additional monitoring wells prior to drill a second deep well for first circulation tests.

4. Surface constraints

With the constraint to provide a monitoring well which may serve all three potential plant sites the choice of drilling locations becomes very limited. The «ideal » horizontal distance to an Enhanced Geothermal System (EGS) reservoir is considered to be three kilometers. The criteria was set that a horizontal distance of less than one kilometer would be insufficient and four kilometres would be the upper limit. In an ideal monitoring setup a minimum of three wells would be situated in an equilateral triangle around the reservoir. This setup would guarantee an optimal spacial localisation of acoustic events created by hydraulic fracturing. Too closely spaced monitoring station may be subject to aliasing effects and result in a blurred signal.

It is obvious that in a built up agglomeration this ideal setup is illusionary. It was however possible to focus in on three exploration sites which fulfilled the criteria to be in a distance of at least one kilometer and at most four kilometres from all three potential plant sites. In the last evaluation round two sites were dropped for groundwater protection reasons. Exploration drilling from the selected site in the north-east of the city of Basle should be conducted in 1999.

5. Local geology

The exploration as well as the potential plant sites are situated on the structural element called « Basler Ruecken », a horst like feature, separated from the eastern trough margin by the « St. Jakob - Tuellinger Mulde » a synclinal depression related to the sag along the margin (figures *2* and **3).** This sag is well documented by outcrops of the flexure zone at the Roettler Schloss north of Loerrach or at the protected geological monument St. Jakob, along the road to Muttenz near the Birs river. The complex faulting **of** the near vertical and even overturned Mesozoic sediments in the flexure zone is documented in the geothermal well Riehen *2*. To the west the « Basler Ruecken » is separated from the Wollschwiller trough by the fault zone of Allschwil.

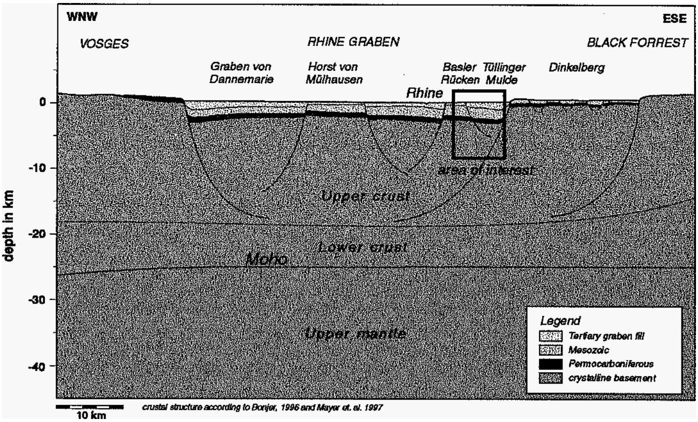
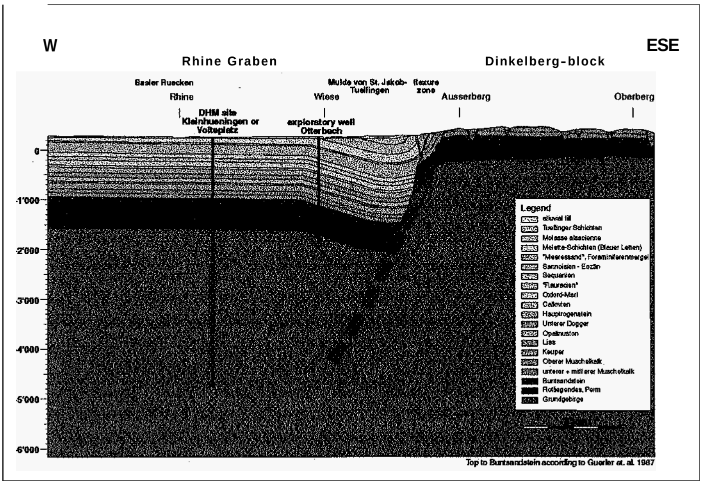


Figure 2: Cross section across the Southern Rhine Graben



'igure 3: Cross section across Rhine Graben margin at Basle

The sedimentary sequence starts with alluvial gravels of the Rhine, a major groundwater reservoir. The Oligocene graben fill sequence consists of a mainly clastic sequence with thin intercalation of shallow marine and freshwater carbonates. The Mesozoic sequence dominated by shallow marine carbonates and evaporitic sediments is well known as far down as the Muschelkalk. To this depth the two geothermal wells of Riehen and the geothermal exploration well of Reinach have penetrated the sequence in the closer region. The underlying Buntsandstein is know from outcrops towards the Black Forest block to the east.

5.1. Permocarboniferous

Uncertain **is** the thickness of the Permocarboniferous clashc sequence It is known from NAGRA wells and seismic as well as petroleum exploration seismic that a narrow Permocarboniferous trough, locally exceeding three lalometres **in** depth, strikes across Northern Switzerland **in** a east-north-east direction Seismic data in northern and north-eastern Switzerland suggest the possiblity of offset branches to the main trough There is however no seismic data **in** the Basle area The nearest well penetrating the Permocarboniferous lies 15 kilometers to the west near the French town of Knoeringue The well Knoeringue-1 penetrated about 600 m of Permocarboniferous clastics overlying crystalline basement rock Another well at Wintersingen 19 lalometres east-south-east of Basle drilled **in** 1932 for coal prospection penetrated 400 meters of Rotliegendes Based on **this** very rudimentary informahon a thickness of 500 meters is proposed in the area of interest

5.2. Crystalline basement

In the Basle area the basement has not been penetrated before The Variscian crystalline basement of the nearby Black Forest consists of granites and gneisses penetrated by quartz and granoporphyritic dykes (THURY et al) It is planned to penetrate the basement **in** the order of 200 metres Parts of this interval will be cored Measurements of the fracture orientation as well as measurement of the stress field are central to the investigations It is however clear that the basement characterishcs in these uppermost portions cannot be extrapolated directly to the planned reservoir depth of **5** kilometres

6. Why not seismic first ?

With the uncertainty about the structuration of the pre-Mesozoic sequence and the lack of informahon on the surface structure **of** the basement it would be desirable to acquire reflection seismic data prior to drilling This procedure was indeed planned as a first exploration step A cost / benefit analysis indicated however that for DHM purposes an exploration well will produce superior information. One reason **is** that there is only rudimentary velocity information on the sedimentary sequence available Also known is the poor acoushc contrast between Permocarboniferous clastics and basement rock which makes a seismic interpretahon rather ambiguous And last but not least the shape of the crystalline surface is not of such great importance to an enhanced geothermal system which has to be developed a long way below this interface. The planned well will provide the lacking velocity information and subsequent seismic survey will provide much more information.

7. Synergies

As the example shows the exploration activity for the DHM pilot plant will provide a wealth of information for ongoing projects, in particular the micro-zonation project in Basle, which endeavours to map areas of varying earthquake risk in relation to petrophysical characteristica of the shallow subsurface. A full wave sonic wireline survey in the borehole may provide the shear wave velocity data. At the end of the test programme an acoustic monitoring array will be installed at the bottom of the well. This will not serve only its purpose as a monitoring tool for the reservoir development, but will additionally provide an excellent recording station for seismic events, unfiltered by a sedimentary cover.

Acknowledgments

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