Plutonic rock can be used to provide geothermal energy in almost all regions in Germany.

Similarly, sedimentary rocks can be fractured with high water pressure.

New process requires just a single borehole.

In future, an existing office building in Hanover will be supplied with geothermal heat as a demonstration project.

For a long time, it appeared that geothermal energy could only be used on a large scale in three regions in Germany: north-eastern Germany, the Upper Rhine Graben and in the Molasse Basin in southern Germany. The hot water sources there make geothermal heat networks and power stations possible. A European research power station in Soultz-sous-Forêts (Upper Rhine in France), a project with significant German participation, uses the heat contained in the deep rock. A geological requirement for this is crystalline and/or hydraulically permeable rock strata. However, the subsurface in many parts of Germany consists of sedimentary rock. Although also an interesting thermal resource, sedimentary rock was previously considered unusable for geothermal power supply due to its poor hydraulic properties. However, exploitation concepts have now been developed for these rock formations.

The geology of northern Germany has been thoroughly investigated while prospecting for crude oil and natural gas deposits, among other resources. As experts were sceptical regarding the prospects for the success of geothermal use of sedimentary rock, they recommended the construction of a test plant. An exploration company made the former natural gas borehole “Horstberg Z1” in the German Südheide region available for testing. In this deep borehole, high water pressure was used to create fractures in two layers of the Middle Buntsandstein formation, at a depth of approximately 4,000 m. From 2003 to 2009, this system was used for comprehensive geological studies on the thermal and hydraulic long-term properties and chemical analyses of the water. These experimental results were input in a mathematical model. This was used to test a total of three different exploitation concepts. The concepts will be practically tested in a demonstration project started in 2009 to supply the Geozentrum Hannover.

A particularly innovative feature for the exploitation of deep geothermal energy is accessing a geothermal resource via a single borehole. This is mainly an economic advantage. Previous geothermal plants always required at least two separate deep boreholes. The concept development and practical testing at the Geozentrum Hannover were subsidised as part of the German Government’s energy research program.
The North German Basin is bordered by the coasts of the North Sea and Baltic Sea in the north and the central German uplands in the south (e.g. Harz, Weserbergland region). Its current surface was shaped by a series of ice ages and warm periods during the last 2.5 million years. Beneath this, there are 2 to 10 km thick layers of sedimentary rocks. On the one hand, two mountain building events dating back to over 400 million years have contributed to these deposits. The mountains were eroded and the sediment masses gathered in the basin. On the other hand, the area rose and fell repeatedly. As a result of the subsidence, the sea was able to penetrate far into Central Europe. This geohistory provided for the formation of the mineral and energy resources of the North German Basin, such as salt, oil and natural gas.

In the north-eastern part of the area (Mecklenburg-Western Pomerania), saline water of up to 100 °C is used geothermally, e.g. in Neustadt-Glewe and Neubrandenburg. In the north-west (Lower Saxony), no thermal water deposits with temperatures sufficient for geothermal energy supply have been discovered yet. For this reason, only the heat stored in the rock can be used. The target horizon is the Middle Buntsandstein Formation at a depth of 3,000 to 4,000 m. Fig. 2 shows the stratigraphy and temperature profile at the Horstberg site, which is typical for the basin.

**Horstberg – Fundamental geothermal research**

Can water injected into sedimentary rock at high pressure create enduring artificial fractures? Hydraulic fracturing technologies have been used successfully in crystalline rocks, e.g. Soultz-sous-Forêts (BINE-Projektinfo 04/09). However, researchers were surprised to find natural deep waters and rock fractures there.

The geologists from the oil and gas industry were sceptical: Water-bearing strata and fractures are rare at such depths. The clay strata in between are an obstacle to the formation of fractures, and they tend to close again as soon as the water pressure abates. Therefore, the process was tested experimentally on the existing 5,000 m deep and fully cased borehole in Horstberg. The borehole below 4,134 m was backfilled to seal the gas-bearing strata. The temperature at the deepest point is 159 °C, or 30 °C above the regional average. Fig. 3 shows the three sandstone layers selected for the experiments. These are between 6 and 20 m thick and the porosity increases from 3% in the lower sandstone to 11% in the upper. At the level of these layers, the casing was perforated to establish a connection to the stone. Water was then injected through these holes to generate fractures.

A total of 20,000 m³ of water was injected into the Detfurth sandstone and approx. 5,000 m³ into the Solling sandstone. This produced a large-scale system of microfractures, creating new flow paths in the subsurface and connecting the two sandstone layers hydraulically. Introduction of water into the Detfurth layer therefore led to a measurable pressure increase in the Solling. The subterranean fracture area created by the hydraulic fracturing is estimated to be over 100,000 m².

The results support the theory of natural self support of such artificial fracture systems. A certain surface roughness and shearing strain within the rock stratum are the keys for this. The water injections expand the fractures in the rocks minimally. Geophones, a type of seismic instrument, were installed in approx. 100 m deep boresholes around the Horstberg well for observation, which registered only a few seismic events of minor magnitude. They were not discernible on the earth’s surface.

The chemical composition of the produced water was also studied intensively, with particular attention on possible precipitation processes. The produced water must be kept free of oxygen to prevent precipitation of iron minerals. Precipitation of sulphates is difficult to prevent and can lead to problems in the subsequent operation due to the possible sealing of rock pores.
Can a geothermal system be operated with just a single borehole for production and reinjection? This would significantly improve the economy of geothermal energy, as the borehole costs generally account for over 50% of investment costs.

The objective of developing a geothermal system with a single borehole was to reach a production rate of 25 m³/h (approx. 7 l/s) and a surface temperature of the produced water of over 100 °C. In a single-borehole system, it is important to prevent the injected colder water from withdrawing heat from the produced water. In an initial step, geological data (e.g. stratigraphy) and geophysical data (e.g. porosities, permeabilities) were collected in Horstberg, and hydraulic experiments were performed. The resulting data were then entered in a mathematical model.

Three different exploitation concepts were developed in Horstberg. The single-borehole, two-layer concept did not prove viable due to the local geological conditions.

**Cyclical process**

In the cyclical process (Fig. 4), water is introduced into the target horizon, left there to warm up for a certain time, and then produced back from the same horizon. This concept can also be applied in low permeability rock formations. Daily and weekly cycles were examined. The results were also transferred to an annual cycle in a mathematical model. Calculations showed that the annual cycle model promised the best success prospects in energy and economic terms. The available geothermal potential would suffice for over 25 years and more than 60% of the original heat resources would still be available after that time.

During winter, geothermal energy is enough to supply all heat required in the building, but during the re-injection period in the summer, an additional water heating system is required. In tests, the production rate was 7 to 11 l/s and the water temperature on entering the pumping system was 110 °C.

**Deep circulation process**

For the deep circulation process (Fig. 5), the Detfurth and Solling sandstone layers were accessed via a single bore. The fracture system was used to create hydraulic circulation. Although the feasibility of the system was proven, the maximum production rate was only 4 l/s. The success of this concept is heavily dependent on the hydraulic permeability achieved. From a technical point of view, an additional, vacuum isolated tubing must be installed in the borehole to separate the injected from the produced water.

**GeneSys – Heat for the Geozentrum**

In November 2009, the borehole reached the target horizon of the Middle Buntsandstein at a depth of 3,700 to 4,000 metres. The temperature of 150 °C at the deepest point of the borehole greatly exceeded the expectations. The drilling had been performed in the immediate vicinity of a residential area. A sound-proofing wall, low-noise drilling system powered by electricity from the public grid, and a special pipe handler device, which lowered the drill pipes extremely silently, allowed the noise thresholds to be observed. Public acceptance for the project was high among the local residents, and over 6,500 visitors came to the information centre.

The borehole is 3,901 m deep, is at an angle of 30° in the lower section and was diverted in the direction of minimum horizontal principal stress. The Wealden sandstone, which is 1,150 to 1,350 m deep, is being tested for its suitability as an absorption horizon. The analysis of the borehole cores shows that the Wealden sandstone is largely permeable and the Buntsandstein horizon is largely impermeable.

The test and exploitation work started in spring 2010. In the current test phase, only minor hydraulic fracture operations are being implemented. The results of these tests will determine how the major operations will be performed. Two alternative exploitation concepts are being pursued: the deep circulation concept, which would require a good hydraulic connection of the two rock layers and acceptable pressure losses, and the (annual) cyclical process.
Outlook

Hydraulic fractures can also be created in sedimentary rocks. In tests at Horstberg, the fractures extended over 500 m horizontally and over 120 m vertically from the injection point, and even penetrated clay strata. Key factors in the formation of these tension fractures are the shearing strain and the roughness of the rock. In Horstberg, the fractures have remained open for over 5 years, confirming the self-supporting theory for sedimentary rocks.

The use of a low-noise drilling system (Fig. 7) facilitated compliance with the thresholds of the Technical Instructions on Noise Abatement (TA Lärm) during drilling work in the immediate vicinity of residential buildings. This is also a success of the project.

The geothermal systems described can produce sufficient heat to supply large building complexes and similar consumers. This closes the gap between shallow borehole heat exchangers (< 1 MW) and the deep geothermal systems with multiple boreholes common to date (> 10 – 20 MW). Hydraulic fracture operations via perforated casing could become more important, in particular for geothermal projects with difficult geological conditions.

The results from Horstberg allowed the development of geothermal exploitation concepts for sedimentary rocks despite the initial concerns of geologists from the oil and gas industry. The findings can be transferred to many regions, expanding the geothermal map of Germany and increasing the number of possible geothermal methods. Horstberg will remain available as a versatile test site for geothermal research on sedimentary rock.

Fig. 7: Innova Rig low-noise drilling system