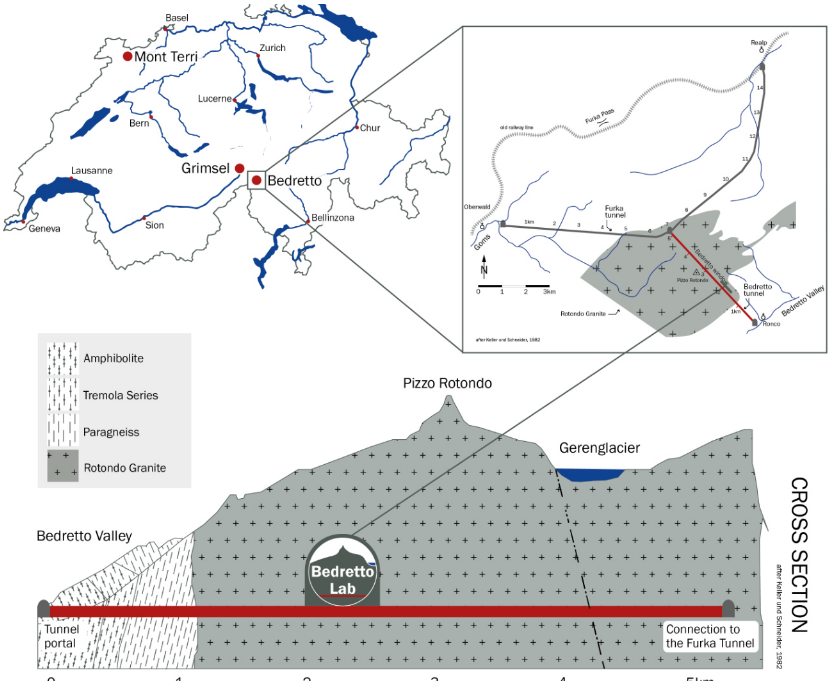
GEOTHERMAL ENERGY FROM SAFE ROCK ZONES

Geothermal energy is already used intensively in Switzerland, mainly by means of geothermal probes that collect heat from the ground to provide heat and hot water for buildings. However, the heat from deeper layers of the earth is hardly used: If one were to drill 1000 m and deeper, one would come across an enormous heat reservoir that can be used for heating purposes, industrial processes and electricity production. At Bedretto rock laboratory of the Swiss Federal Institute of Technology (ETH) Zurich and with its scientific support, Geo-Energie Suisse AG has tested a new approach for the safe use of deep geothermal energy.

The drill rig drives a 22-cm-diameter borehole several hundred meters long into the granite of the Gotthard mountain, into which ETH Zurich scientists then insert their measuring instruments. Photo: Swiss Seismological Service at ETH Zurich, 2019

A technical report about the results of a demonstration project in the field of geothermal energy, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Umweltperspektiven (issue May 2021).



The ETH Zurich rock laboratory is located in the Bedretto Valley, the uppermost part of the Leventina. It is surrounded by granite, a crystalline rock. Photo/graphic: Swiss Seismological Service at ETH Zurich, 2020/Luxwerk.ch

An almost inexhaustible source of energy lies directly beneath our feet: If one drills one kilometer deep in Switzerland, the rock is 40 °C warm. At a depth of five kilometers, the temperature is as high as 160 °C. Geothermal energy provides an enormous supply of heat that can also be used to produce electricity, provided that the temperatures are above 100 °C. Currently, Mr. and Mrs. Swiss draw four billion kilowatt hours (kWh) of geothermal energy every year; it covers 4% of the country's heating needs. Most of the energy comes from the top layer of the earth. Geothermal probes collect the energy before heat pumps with the help of electricity raise it to the temperature level required for heat and hot water.

ROCK LAB OF ETH ZURICH

Access to ETH Zurich's Bedretto rock laboratory is located about 20 minutes from Airolo by bus. The laboratory is located in a tunnel, originally excavated for the construction of the Furka Base Tunnel, which was opened in 1982. The project outlined in the main text builds on investigations carried out in 2017 at the Grimsel rock laboratory of the National Co-operative for the Disposal of Radioactive Waste (Nagra). The reservoir stimulation research project in the Bedretto laboratory, which will run until summer 2021, is being carried out by Geo-Energie Suisse AG (Zurich) with scientific support from ETH Zurich, financially supported by the Swiss Federal Office of Energy. Geo-Energie Suisse is sponsored by seven energy utilities, including the municipal utilities of Basel, Bern and Zurich. The company's main goal is to build a pilot power plant for deep geothermal energy. Such a plant is envisaged at the Haute-Sorne site (Canton of Jura). BV

Water Flows through Jagged Hot Rock

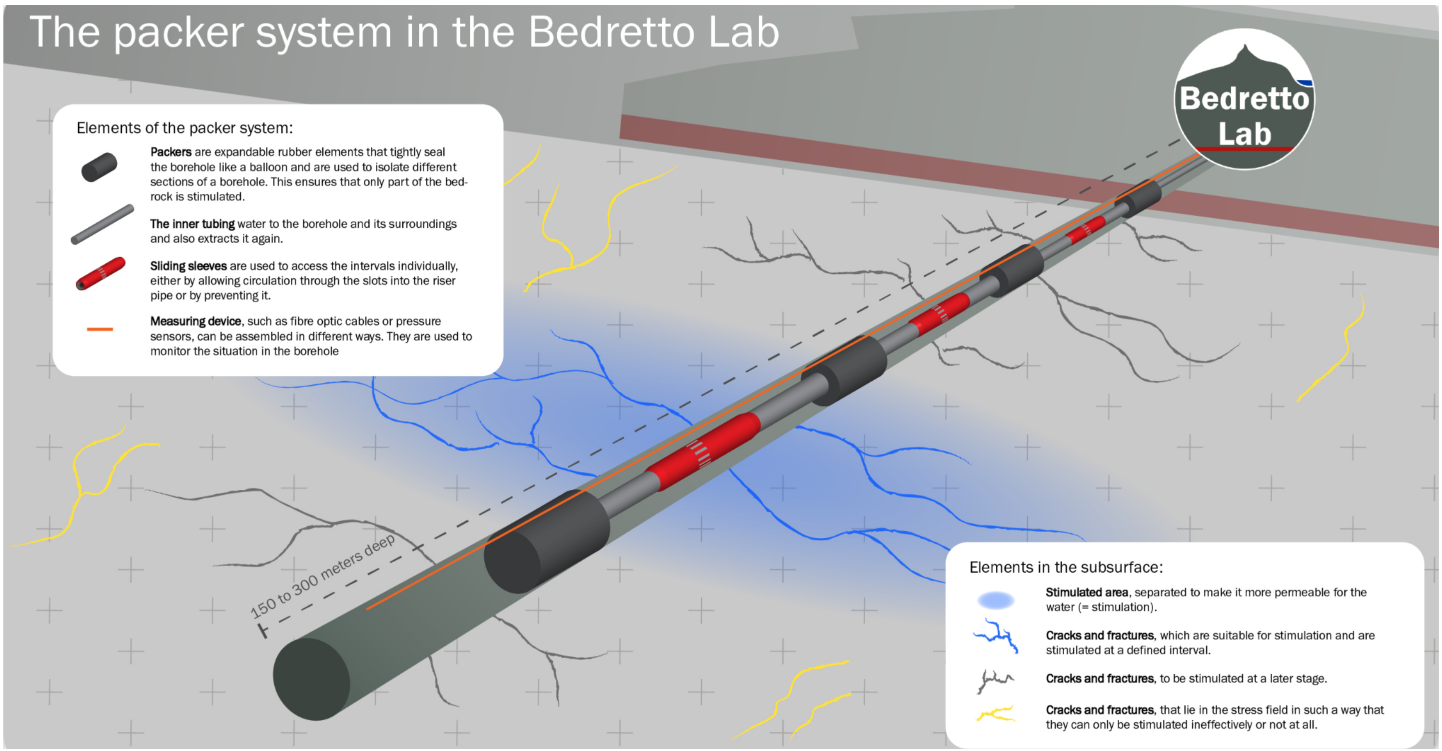
The contribution of geothermal energy to the energy supply can be increased considerably by expanding the use of geothermal probes and also by using geothermal energy at medium depths (500 to 3000 m) and in very deep regions (3000 m and deeper). According to the basic variant of the net zero (ZERO) scenario of the 'Energy Perspectives 2050+' published by the Swiss Federal Office of Energy at the end of 2020, geothermal energy could contribute 5.5 TWh to the energy supply in 2050, of which 2 TWh would be supplied as electricity and 3.5 TWh for district heat production. The umbrella organization 'Geoenergie Schweiz' even places the potential contribution to the heat supply at 17 TWh; that would be about a quarter of the heat demand assumed by the 'Energy Perspectives 2050+' for the year 2050. Depending on the drill depth, different methods are recommended for extracting geothermal energy. At depths of 3,000 m and more, the petrothermal geothermal method is the most evident: In this method, water is injected at high pressure into the crystalline rock via a borehole. The water penetrates existing rock cracks (fractures) and widens them. The hydraulic stimulation creates so-called 'reservoirs' in the rock, i.e. spaces in which the circulating water can absorb heat from the jagged rock. The water, heated to 100 degrees or more, then returns to the earth's surface through a second borehole. The hot steam can be used to produce heat, but above all to produce electricity.

This was exactly the idea behind a 5000 m deep geothermal well created in 2005 in Basel. However, the 'Deep Heat Mining Basel' project had to be abandoned after several perceptible earthquakes occurred and raised fears of a major earthquake. In 2011, municipal utilities and regional energy providers from all over Switzerland founded Geo-Energie Suisse AG. The company drew lessons from the Basel experience and decided to take a new approach. To safely extract geothermal energy, those responsible turned to the multistage stimulation concept familiar from the petroleum industry. "In 2012, we patented this process for Switzerland; in the late fall of 2020, we were able to demonstrate in the Bedretto Laboratory at ETH Zurich that we can use the process to reduce the earthquake risk in deep geothermal drilling to a minimum," says Dr. Peter Meier, CEO of Geo-Energie Suisse.

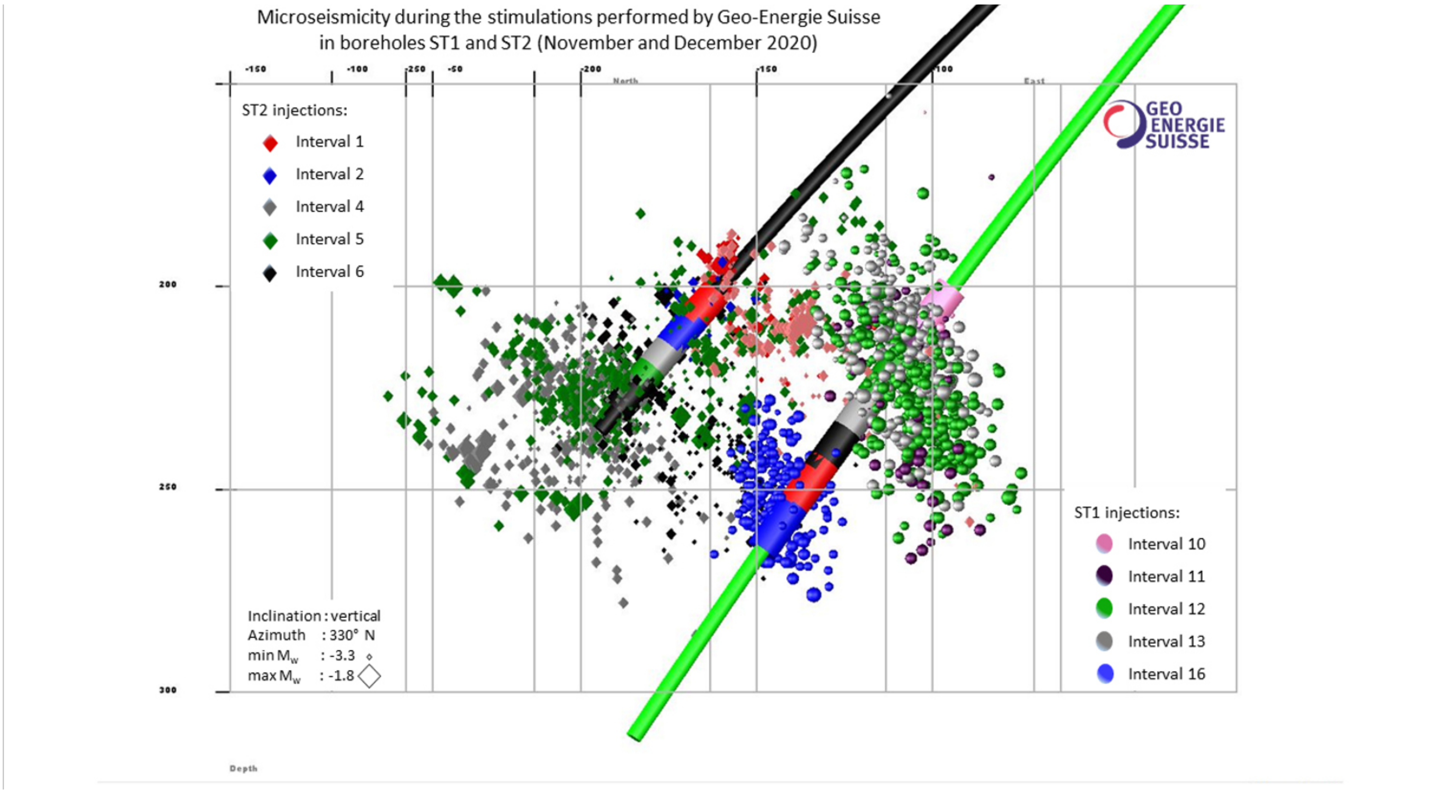
A packer is inserted into the borehole. A packer is an inflatable rubber sleeve (visible in the photo between the two blue pipe sections). This divides the borehole into individual zones. Packers are subjected to pressures up to 200 bar during the tests. Graphic: Geo-Energie Suisse

Stimulation in Isolated Zones of the Borehole

The basic idea of the new approach: In Basel the entire lower part of the borehole was pressurized during the injection of water. In the new method the borehole is divided into several stages ('zones') using rubber collars ('packers'). A reservoir



Packers - four black cylinders in the illustration - divide the borehole into individual zones. The rock surrounding the individual zones is then stimulated with injections of water so that fissures form. This creates so-called reservoirs in which water can circulate and absorb heat. Graphic: Swiss Seismological Service at ETH Zurich



During the experiments in late fall 2020, stimulations were performed in two boreholes (black and green) in different zones of the borehole (the zones, here called 'intervals,' are marked with colors). For this purpose, two packers were moved to the desired location in the two boreholes. The diamonds and spheres show the locations in the rock where microseismicity (very weak shaking) was generated by each stimulation to induce the desired microcracks in the granitic rock. The graph illustrates a key result of the rock laboratory tests to date: the microseismicity induced by hydraulic stimulation of the different zones is quite clearly separated spatially. In other words, by choosing what zone to stimulate the rock and to what extent, one can selectively influence in which rock region microquakes are induced to form reservoirs. Graphic: Geo-Energie Suisse

can now be stimulated independently in each zone, with water injections staggered spatially and temporally. The method allows to stimulate micro-earthquakes in each rock section with exactly the strength necessary to form a reservoir. Potentially critical zones can thus be detected at an early stage. Uncontrolled strong earthquakes should thus be avoided.

In the Bedretto laboratory (cf. text box p. 2), the 'isolated zones' method was tested by placing two packers 6.5 m apart in the borehole and stimulating the rock in between them. By moving the two packers in the borehole, stimulations could be performed at different locations within the borehole. A total of ten borehole sections were thus stimulated during the tests in late fall 2020. The multi-stage stimulation concept proved successful: According to initial evaluations, water permeability in the compact Rotondogranite was increased by a factor of 10 to 100. "Although we injected significantly smaller amounts of water than in Basel, the reservoirs we created have the permeability required for economic heat utilization," says hydrogeologist Meier. The microearthquakes (microseismicity) required for the cracking had a maximum magnitude of -1.8 M_w on the Richter scale. The earth thus shook about a hundred thousand times weaker than during the largest quake at the geothermal project in Basel (magnitude of 3.4). Peter Meier's conclusion: "With these results, the use of petrothermal deep geothermal energy is within reach."

ETH Zurich's Comprehensive Measurement Program

In spring 2021, another test series is planned in the Bedretto laboratory. In a 400 m long borehole, packers will be used to create a total of ten zones, each 10 to 20 m long, which will be stimulated individually or in various combinations. The test series will increase the volume of water injected to expand the reservoirs. As with the first test series in the fall of 2020,

Dr. Marian Hertrich, head of the SFOE project, in conversation with a research assistant. Photo: Werner Siemens Foundation, 2019/Felix Wey

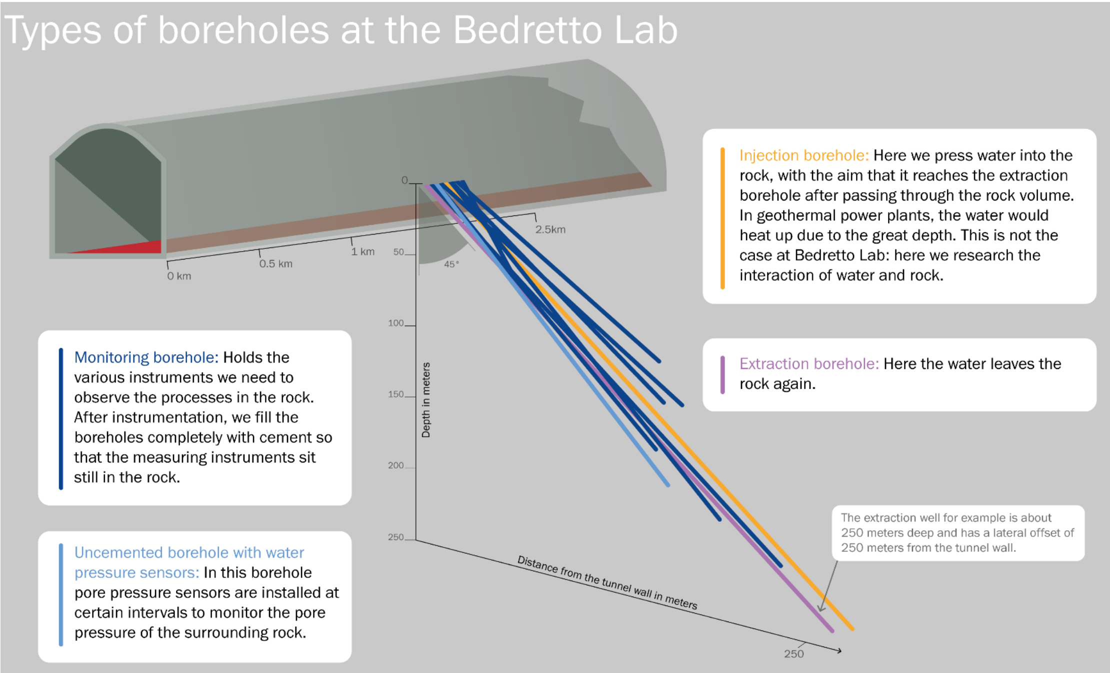
scientists from ETH Zurich will accompany the tests with an extensive measurement program. After all, many detailed questions are still open: Do the packers seal the zones well, and do they do so over the long term? How much heat can be extracted from the artificially created reservoirs? How can the flow rates be controlled? What chemical processes take place in the rock? Can the reservoirs be used as seasonal heat stores from summer to winter?

ETH Zurich has expertise in very sensitive sound measurements. Its measuring instruments register vibrations that are ten million times smaller than a perceptible earthquake. Based on such measurements, the scientists have developed a method for predicting seismicity that was successfully used in the current series of experiments. To do this, the researchers measure the slightest tremors in the rock, which are considered harbingers of larger tremors. "Our method allows us to identify rock zones, in the case of stimulation, where there is a threat of a severe earthquake and therefore should not be stimulated," says Dr. Marian Hertrich, who heads the research team at ETH Zurich.

Pilot Project in Haute-Sorne

Following the positive results in the Bedretto rock laboratory, Geo-Energie Suisse intends to test the multi-stage stimulation concept at a test site in the US state of Utah before the end of the year. There - unlike in the Bedretto rock laboratory - the temperatures required for petrothermal geothermal energy are above 100 °C. The next stage for Geo-Energie Suisse in Switzerland is an exploratory well at the Haute-Sor-

The drill cores provide researchers with important clues about the mineralogical composition and properties of the rock in the area of the reservoir, the heat of which is to be used for energy. Photo: Swiss Seismological Service at ETH Zurich, 2019



Schematic representation of the different boreholes in the Bedretto rock laboratory. Graphic: Swiss Earthquake Service at ETH Zurich

ne pilot site in the canton of Jura. A pilot plant is planned there that would supply electricity to 6,000 households with a capacity of five MW. The plant has so far met with resistance in the canton. The new results from the Bedretto rock laboratory could help to promote public acceptance of the use of heat from deep earth regions.

- Further information on ETH Zurich's **rock laboratory**: www.bedrettolab.ethz.ch

- The **final report** on the demonstration project 'Validation of reservoir development technologies' is expected to be available by summer 2021 at: https://www.aramis.admin.ch/Texte/?ProjectID=38726

- For **information** on the project, contact Céline Weber (cweber[at]focus-e.ch), head of the SFOE Geothermal energy Research Program, and Dr. Men Wirz (men.wirz[at]bfe.admin.ch), responsible for the SFOE Pilot and Demonstration Program.

- For more **technical papers** on research, pilot, demonstration and flagship projects in the field of geothermal energy, visit www.bfe.admin.ch/ec-geothermie.

P+D PROJECTS OF SFOE

The project to research reservoir stimulation in the Bedretto rock laboratory was supported by the Pilot and Demonstration Program of the Swiss Federal Office of Energy (SFOE). With this program, the SFOE promotes the development and testing of innovative technologies, solutions and approaches that make a significant contribution to energy efficiency or the use of renewable energies. Applications for financial assistance can be submitted at any time.

- www.bfe.admin.ch/pilotdemonstration

Author: Dr. Benedikt Vogel, on behalf of the Swiss Federal Office of Energy (SFOE)
Version: May 2021