# Final report

## General information

Project details

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|---|---|
| **Project title** | ZoDrEx |
| **File no.** | **64018-0306** |
| **Name of the funding scheme** | Geotermica |
| **Project managing company / institution** | **Welltec A/S** |
| **CVR number** (central business register) | 13478805 |
| **Project partners** | Geo-Energie Suisse, ETH Zurich, RWTH Aachen, *CSIC (*Consejo Superior de Investigaciones Científicas*), Sirius-ES, ES-G (Electricité de Strasbourg Géothermie), Cetim Cermat, Fraunhofer Bochum.* |
| **Submission date** | 08 June 2023 |

# 1. Summary


- English version
  As a part of the ZoDrEx consortium, Welltec has developed a high expansion External Casing Packer (ECP) and improved flow control equipment for enhanced geothermal systems (EGS) application and installed and demonstrated a small-scale multistage completion system's capability in the Bedretto rock laboratory. The result is an entirely new geothermal ECP design with alloy material selection intended for durable zonal isolation for EGS in boreholes dealing with breakout, or ovalization, in crystalline formations with temperatures upwards of 260° degrees Celsius.

  With the assistance of fellow ZoDrEx consortium partners, a two-zone demonstration system was successfully installed and tested in horizontal test borehole in the Bedretto rock laboratory. Once installed the system showed its ability to seal, changing the flow and pressure in its part of the formation and ability to segmentate a well. Additionally, simulations were successfully run to show the feasibility of deploying and installing a full-scale version of the of the completion system. The results obtained will be incorporated into Welltec's geothermal product portfolio and further developed upon to assist in the future develop of EGS projects globally.


- Danish version

Som en del af ZoDrEx konsoriet har Welltec udviklet en høj ekspansions External Casing Packer (ECP) med tilhørende flow control udstyr till brug i Enhanced Geothermal Systems (EGS) og demonstreret et completion systems kunnen i Bedretto sten laboratoriet. Resultatet er et helt nyt geotermisk ECP design i holdbar legering til zone isolering af EGS brønde med breakout eller ovalisering i krystalline bjergarter med temperatur op til 260° grader Celsius.

Med assistance fra ZoDrEx konsortium partnere, blev et to-zones demonstrations system installeret og testet i en horisontal test brønd Bedretto sten laboratoriet. Ved installation viste systemet dets evne til at forsegle, da det ændrede tryk og strømning i sin del af formationen og viste sign evne til at segmentere brønde. Yderlige simuleringer blev succesfuld udført for at vise gennemførligheden i at deployere systemet i fuld størrelse. Resultater fra projektet vil blive inkluderet i Welltec's geotermiske produkt portefølje og vil blive videreudviklet for at sikre videreudvikling af EGS projekter på verdensplan.

# 2. Project objectives

The combined objective of ZoDrEx has been to develop and demonstrate various drilling, exploration and completion technologies to facilitate the continued development of enhanced geothermal systems (EGS) in Europe and around the world.

EGS holds the ability to provide non-metrological dependent renewable energy at over 90 percent capacity factor. However, development of EGS is expensive in part to the long development periods and geological uncertainties associated with geothermal energy in general. The full potential of EGS can only be achieved if wells can be divided into multiple zones that allows for access to larger heat exchange surfaces, thus making the wells more effective. To achieve this zonal isolation is required to support both zonal isolation during stimulation to allow for effective propagation and help reduce the effects of shadow stress. But also, to isolate different sections of the well, while eliminating the effects of undesirable sections of the wells from the desirable sections.

Due to formation pressures, weaknesses around the borehole and sometimes drilling mishaps, many geothermal wells struggle with breakout and ovalization of the borehole, which can compromise the potential of well and lead to vast additional costs. To mitigate this Welltec's contribution is the development and testing of a high expansion External Casing Packer (ECP) and flow control to provide zonal isolation and control for EGS capable of managing geothermal conditions for use in crystalline formations, based on its metal expandable packer technology.

To demonstrate viable zonal isolation and the potential of using all metal multistage lower completion in EGS, Welltec will demonstrate it's potential in the Bedretto rock laboratory in collaboration with international consortium partners to support the development of a multistage geothermal systems in granite in order to facilitate the future development of EGS projects.

To further demonstrate the viability of the small scale multistage EGS completion demonstration system installed in the Bedretto rock laboratory, full scale feasibility simulations has been be carried out to show the feasibility of deploying a full-sized zonal isolation system, using the same components.

The ultimate end goal has thus been to develop and demonstrate a zonal isolation solution capable of managing the challenges faced by EGS.

# 3. Project implementation

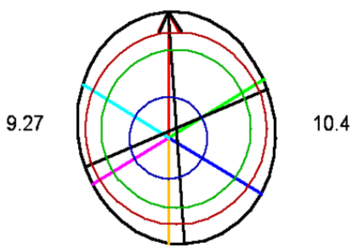
As described above, Welltec's objective was to simply supply zonal isolation and develop an ECP with a higher expansion ratio. As we learn about the challenges previously encountered by our consortium partners and other industry players, we adjusted our setup, tests and simulations. Although, this did not change the scoop, two key aspects did change under way:

1. Originally a rather ambitiously targeted was set for the high expansion ECP to be able to expand upwards of 80 percent expansion to manage wellbore ovalization and breakout. This we found early had to be adjusted to ensure a robust high temperature design with minimal leakage to make sure it was in line with Weltec's use of ISO 14310 ratings for this particular development.

2. For the demonstration in the Bedretto rock laboratory, the original plan of deploying a small scale went unchanged. However, one significant aspect changed. The consortium partners operate on the basis that the wells should be drilled at an angle into the maximum stress to facilitate shearing in a piece of the formation that is already naturally fractured. The other wells were thusly drilled into such sections at a decline of 35 to 45° degrees. Welltec on the other hand theorized based on completion experience in from oil & gas that the well and completion system would be able to better facilitate stimulation more efficiently and with a greater degree of control if the well was drilled perpendicularly, and closer to horizontal, into the maximum stress direction in a highly competent tight section of the formation with less or no pre-existing fractures. While being more comparable to the condition of deep basement formation that will be used in areas where deeper wells (4-7 kilometres) are required when developing EGS systems when it comes to propagation and initiation related to stimulation of the formation. As a resulted it was decided that Welltec installed its multistage systems in its own separate horizontal well drilled with a 6°degree decline.

**In-house**

Initially three new and very different high expansion packer designs were modelled and simulated to find the design best for managing ovalization and breakout. The target was to develop an 8 ½ ECP for EGS capable of managing high breakout boreholes capable of managing minimum temperatures of 200°degree Celsius with a 30-year lifespan, allowing it to be used in wells for both heating and power generation application. Making it ideal for EGS deployment in European crystalline formations, but also with the ability to function in the mid-temperature range hydrothermal systems elsewhere in the world.




Above: An example of a borehole diameter profile from a calipher log of an 8.5" borehole where the effects of ovalization has caused the borehole to deform to 9.27¨ by 10.4¨ inches. The new ECP will make it possible to fully seal deformed bore holes of this size.

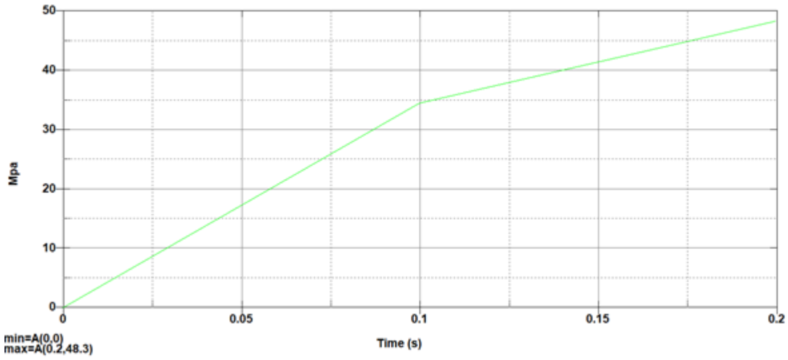
The ECP is based on Welltec's Metal Expandable Packer (MEP) technology. This type of packer is a permanent, non-retrievable packer which is mounted onto the liner and hydraulicly expanded through the casing, causing the packer elements to plasticly deform into either the open bore hole or casing, sealing of the annulus. Because of the robustness, it also supplies anchoring power, allowing it to function in a variety of ways when it comes to providing zonal isolation.

Based on the MEP technology, a new sleeve design developed to improve setting in a crystalline setting and making breakout. To ensure it could also manage long term high temperature geothermal fluids, it was combined with an ultralow carbon, nickel alloy cable of managing both high temperatures and hydrogen sulfide(H2S), as often seen in hydrothermal systems. As importantly it was selected to withstand repeat thermal stress, as associated with geothermal workovers over life span, where wells are cooled to allow for maintenance work.

To ensure the best possible standard the packer had to be qualified to ISO 14310 V6 (V3 leak criteria), to ensure optimal sealing conditions for life of well. To ensure this standard, the design, and as a result the expansion ratio was limited to the maximum stress that the material around the minimal properties of its construction.

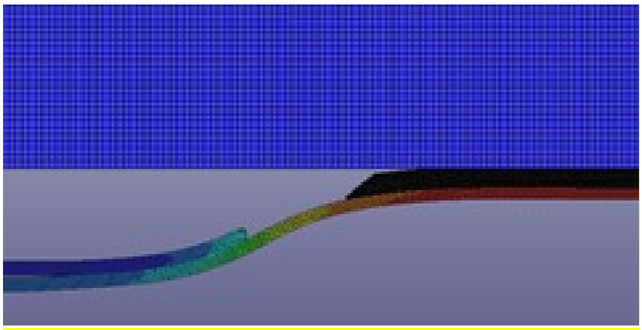
Based on its history of working with it, Welltec has high confidence in expansion using FEA modelling with years of fine tuning the mechanical material models with experimentation and testing. The design expansion limit was evaluated as the maximum stresses that the materials can support based on the minimum material properties of the packer's design.

LS-Dyna was used to simulate expansion in two steps, first at expansion pressure increase from 0 to 5KPSI at .1 seconds, then expansion from 5 to 7Kpsi at .2 seconds.




Above: FEA model showing the pressure history of the new packer design.

Ultimately limiting the expansion ratio of the packer design materials maximum acceptable stress. This was based on extensive laboratory testing performed with the material with UTM values above 800 Mpa.

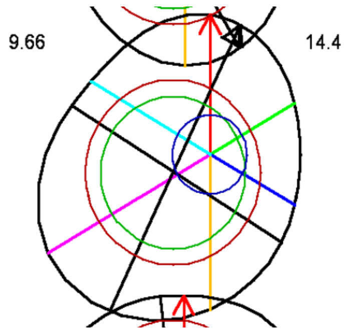


Above: FEA screenshot of contouring of effective plastic strain of the new packer design.

The model assembled for test was a full scale 8 1/2¨ model with an expansion ratio up to 27 percent. A smaller version that would have allowed for a greater expansion rate was also modelled but not manufactured, as smaller diameters are not commonly used in geothermal systems.

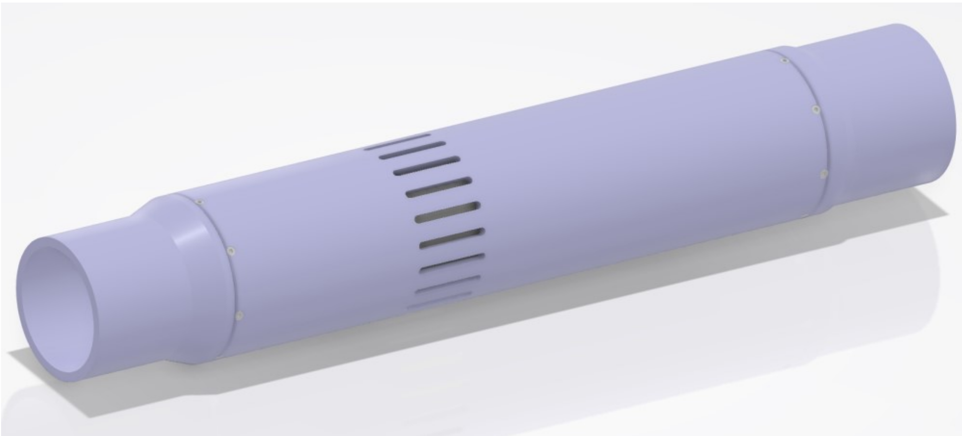
Above: The assembled new high expansion packer design being assembled and prepared for testing.

Despite, the improved expansion ratio, it was concluded that to ensure a robust high temperature design with minimal leakage to ensure zonal isolation at the required qualification standard, packers should be set in less affected areas, above or below, to ensure an efficient seal to isolate that section of the borehole from the rest of the borehole. As some examples of breakout studied (see example below) were so extreme that that the material could be expected to handle the elongation let alone sealing the borehole’s annulus.



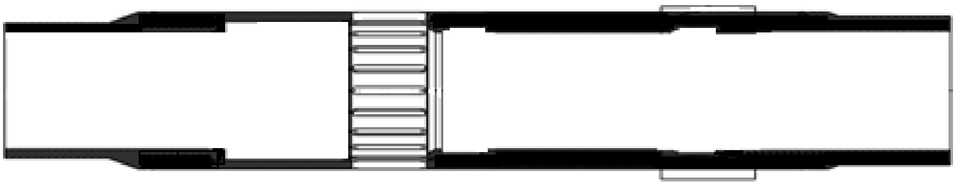

Above: An example of a borehole diameter profile from a calipher log of an 8.5” borehole where the effects of ovalization has caused the borehole to deform to 9.66¨ by 14.4¨ inches.

The work included the development of a 7” flow valve to function as both inflow and as stimulation gate. Historically valves have not been used in geothermal wells, as the instalment of valves was though to reduce and restrict the flow of fluids to the well. However, valves provide a means for taking control of the formation, while providing a fixed access point to the formation that can be stimulated directly and closed off if the zone should prove to have a negative effect on the rest of the well, be it a lose zone or if there is any sign of stress clusters that is threating to short-circuit the heat exchange surface system.



Above: A 3D model rendering of the 1250mm long flow valve with a diameter of 208 mm (8.19¨) with closed ports

For the demonstration and test a valve with a 110 percent capacity flow was used, although this could be increased, either by number of number or size or ports. Adjustments to the designs were made to the open/close mechanism to suit geothermal, primarily it was a question of adjusting the alloy managing hydrogen sulfide (H2S) conditions rather than temperature. A successful test of the mechanism was carried out to ensure it could be manipulated prior to deployment.



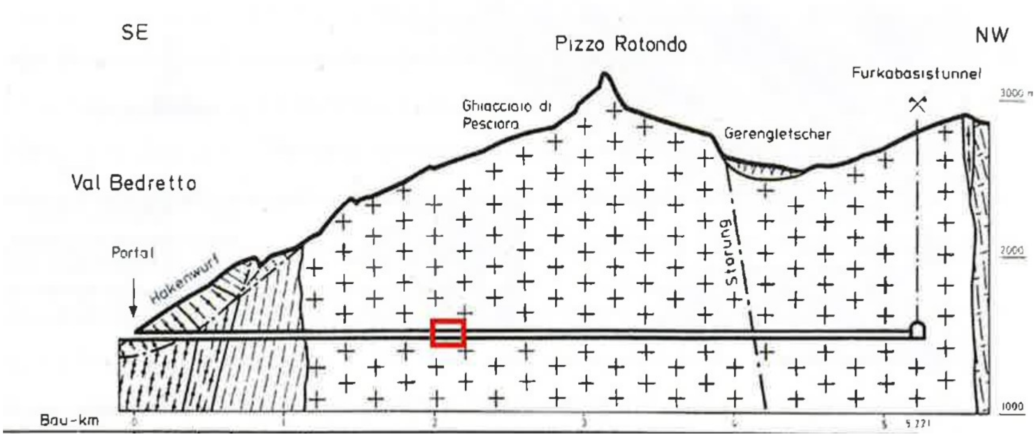
Above: Schematic of the 8.19¨ flow valve with ports open to be mounted on a 7¨ liner for full bore access for both injection and production.

With the flow valve designed to withstand upwards of 300° Celsius and the high expansion packer being able to manage 260° Celsius, the two should easily be able to be implemented in multistage EGS systems, with the packer also being able to function as a standalone to assist line hangers or function as cement assurance/replacement.

Material selection was done on a generic geothermal basis, as ultimately each formations and fluids will have unique properties, that will threaten the life span of any equipment installed in it. However, the selected material should outlive the liners that have commonly be used in geothermal systems.

**Bedretto Demonstration**

The Bedretto rock laboratory or Bedretto Underground Laboratory for Geoenergies (BULG) is an abandoned train service tunnel, drilled in 1982, that has been repurposed into a rock laboratory by Eidgenössische Technische Hochschule Zürich (ETH Zurich), to study various aspects of rock mechanics, hydrology, and drilling technologies. The estimated stress components of the rock laboratory is he vertical stress of Sv = 26.5 MPa, the maximum horizontal stress of SH max = 0.8 − 1 × Sv oriented approximately along N100E, the minimum horizontal stress of Shmi n = 13 − 16 MPa[1]




Above: A cross-section of the Bedretto RockLab or gallery where the testing took place is a little over 2000 meters inside the mountain and has approximately 1100 to 1200 metres of mountain above it (overburden9. .

An 8½" (220mm) borehole horizontal borehole with a 6° degree decline was drilled to a total depth of 120 meters in the spring of 2021, but a video log run in June showed that the borehole was blocked at 99 meters. According to ETH Rock laboratory team this was likely because the borehole had prematurely intercepted a section of the formation affected by another wise well documented fault line in the formation informally known as the "bad boy". Already when drilled a water flow of 2.5 l/m was detected coming from the borehole, which kept flowing throughout installation and testing.

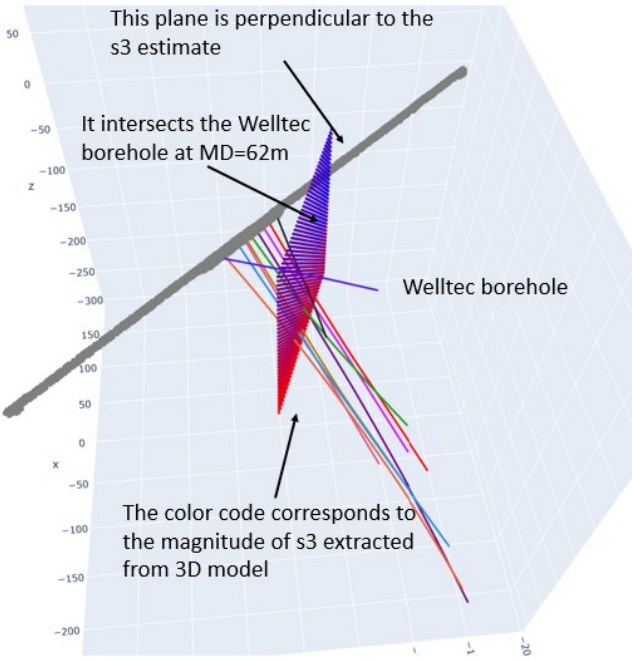

*Above: A screenshot from a camera of the originally 120-meter-long test borehole blocked at 99 meters.*

[1] David, Christian; Nejati, Morteza; Geremia, Davide (2020) On petrophysical and geomechanical properties of Bedretto Granite - Research Collection (ethz.ch) Retrieved: 15/11/2021

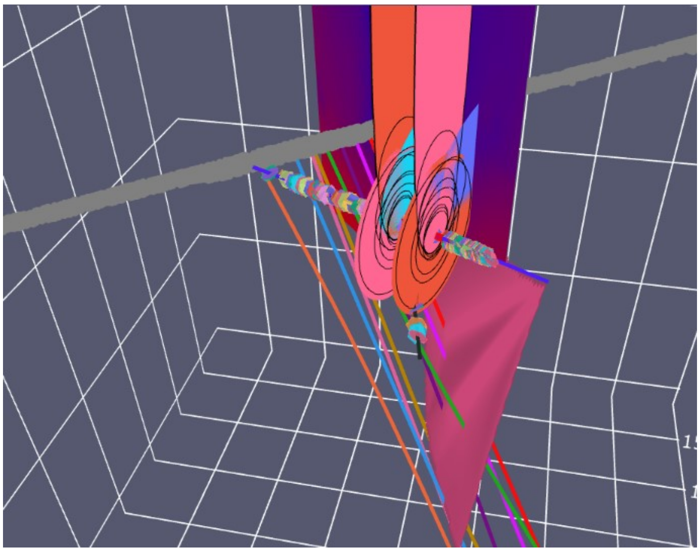
Nevertheless, it was decided to proceed with what remained and a caliper log was later run in the well and based on the readings the two sections in the wells with the most competent borehole characteristics were selected, centralizing the zones at 62 and 76 meters.


*Above: Part of the 8 ½" hammer-drilled borehole where the most upper packer was set at 60 meters.*

With the assistance of Geo Energie Suisse and ETH Zurich, an injection protocol was developed based on the known properties of the formation stress values to test the completion system. These properties include vertical and horizontal stress overburden in the formation to determine suitable pressure, flow rates and shut-in periods to test the completion system.

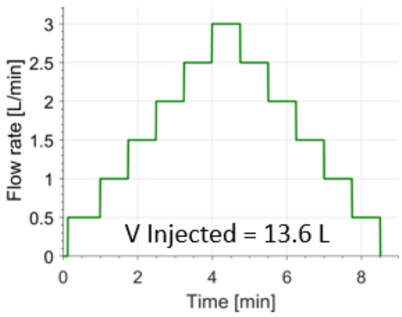



Above: A 3D oblique stress gradient model prepared by Geo Energie Suisse, showing the Welltec borehole (the short blue one) with neighbouring wells below. The colour code that intersects Welltec borehole shows the stress plane at 62 meters which is where the upper zone would later be installed.



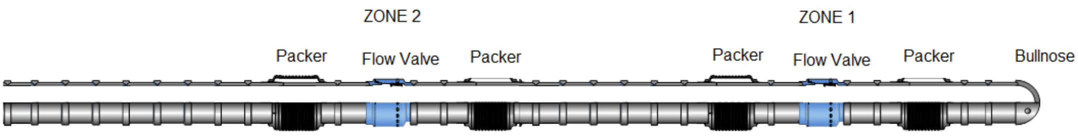
Above: This 3D model as prepared by Geo Energie Suisse shows the same as the previous model, but it also shows part of the fault line known as the “bad boy”, in the form of the pink plane, which all the neighbouring wells intersects below. Additionally, it shows the expected vertical hydro migration stress patterns by the planned zones at both the 62and 76 meters zones. The stress plane from the tunnel which would later effect the tests can be seen in the background.

The stimulation protocol developed by ETH dictated a constant 1-1.5 l/m injection flow rate, after which a clear pressure peak should be visible and a allow for fracturs to propagate until a constant pressure was observed. After which shut-in periods should abided by. From here repetition of cycles with increasing injection flow rate would be carried out. Lage stimulation cycles of maximum 35 MPa were also planned with shut-in periods between cycles.



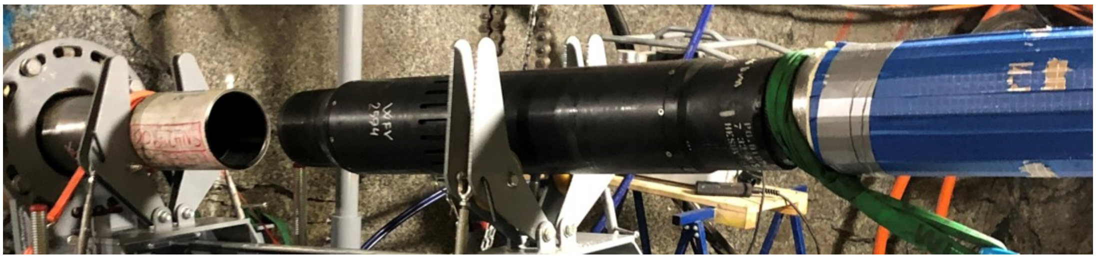

Above: The step-rate protocol with step up and stepdown protocol as prepared by ETH Zurich

Prior to drilling the borehole, it was decided that given the low temperatures and pressures of the Bedretto laboratory, a different packer and different material should be used for the flow valve in the same 8 1/2¨ size as the new designs would use to save on high temperature material costs. Before shipping the equipment to Bedretto, the 125 cm long flow valve and 250 cm long packer were mounted on 7¨ 32ppf VAM TOP 2- and 3-meter pup-joints and a detailed tally was prepared detailing the exact setting depths of the packers and flow valves.




Above: Bedretto test well completion schematic with zone 2 (upper) at 61.25m to 63.98m and zone 1 (lower) at 75.03m to 77.76m. The upper was set at 59 meters.

In August 2021, the completion system consisting of the four ECP's and two flow valves were deployed. Prior to deployment the packers were mounted on 7¨ pup-joints. In the Bedretto the toe pup-joint, fitted with a bullnose was slowly pushed into the nearly horizontal borehole, after which the next piece of pup-joint was torqued up, one at a time till the whole system with packers and valves were pushed into place.



Above: A picture from Bedretto, where a flow valve, already connected to a packer, temporally wrapped in blue packaging is about to be connected to a 7¨ pup-joint with a packer already partially in the well.

Above: Flow valve (black, left) and packer (right) installation in Bedretto (August 2021)

Once fully in place in place, the casing was hydraulicly pressurized in steps. The system was slowly pressurized in steps of 500 psi with 3-5 minutes between steps, allowing all four packers to slowly plastically deform into the borehole, thereby sealing off the annulus. Once fully expanded the expansion pressure was perfectly held for 10 minutes before pressure was bleed off. Throughout the installation and expansion, the well kept producing water at 2.5 l/m, indicating the inflow came from above the upper packer installed 59 meters.

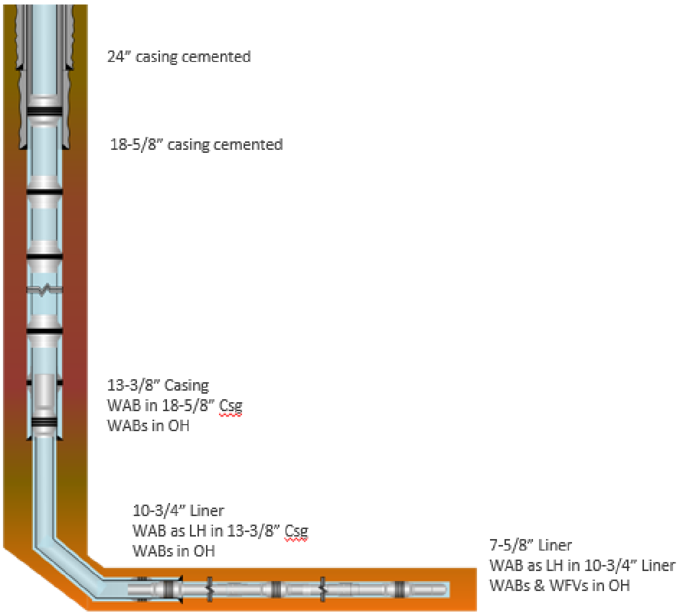
**Full scale simulations**
To demonstrate the feasibility of installing a full large-scale version of the completion system installed in Bedretto can be deployed, WellPlan simulations were carried out to confirm the plausibility of running and installing a full cementless lower well EGS multistage completion system.

The simulation was based on running the system with packers and flow valves from the production liner into a side-track and into a horizontal well from where were run in sizes down to the 7" liners in the horizontal lower well section. Which included the setting of packers in both open and cased-hole sections. The lower well remains cementless while the upper well upper uses cement to support the upper casing strings, with ECP's providing anchoring force. Anchoring points were tested down from 6 meters and up to a hundred meters apart.

This was carried out with generic test scenarios combined with two case examples, where horizontal sections were everything from a few hundred meters to a few thousand.

Testing boundaries were set to run the completion system in an up to 300° Celsius environment, taking into account the thermal expansion and contraction, along with tensile and buckling loads. The length of the horizontal section of the well varied in size from 300 to 3000 meters. ,

Additionally, a heat exchange model was incorporated to support the completion systems stimulation and reinjection requirements for use in long horizontal wells. To ensure a large multi-stage system can manage the required flow rates and heat exchange required the WellPlan simulation were supplemented with information corresponding to a heat exchange model using TOUGH2 (Transport of Unsaturated Groundwater and Heat), a multi-dimensional numerical software system developed specifically for geothermal application.




Above: A schematic showing a simplified horizontal well using metal expandable packers, like the ECP to keep the well in place, incorporating tensile load, buckling load and helical buckling calculation. To manage thermal contraction and expansion the well design incorporates the use of telescopic joints, also known as slip joints.

Although it was only the plan that this was done to check the viability of deploying a full scale multistage EGS completion system. An off-scoop realization in the heat exchanging modelling did confirm previously seen effects from other studies, that once a well is laid out horizontally, with multi-stage access, the heat exchange potential increases greatly as a result.

To ensure the viability of deploying a full scale all metal completion system in the lower well, generic torque and drag simulations were based on two cases, where existing wells would be fitted with horizontal 8 ½” side-tracks, fitted with 7” liners, on which the packers and flow valves would be run and installed in open hole. Although not commonly used in geothermal wells, smaller liner sizes were also considered.

| MD (m) | CL (m) | Inc (°) | Azi (°) | TVD (m) | NS (m) | EW (m) | V.Sec (m) | Dogleg (°/100ft) | T.Face (°) | Build (°/100ft) | Turn (°/100ft) | Section Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1199.00 | | 1.04 | 235.33 | 1198.88 | -9.32 | -5.66 | 3.57 | 0.00 | 0.00 | 0.00 | 0.00 | Tie Line |
| 2200.00 | 1001.00 | 1.04 | 235.33 | 2199.72 | -19.62 | -20.55 | 15.96 | 0.00 | 0.00 | 0.00 | 0.00 | Straight MD |
| 3491.24 | 1291.24 | 90.00 | 298.88 | 3016.28 | 58.70 | -818.58 | 812.58 | 2.36 | 27.00 | 2.10 | 1.50 | BT3 Inc. |
| 3891.24 | 400.00 | 90.00 | 298.88 | 3016.28 | 251.89 | -1168.84 | 1195.67 | 0.00 | 0.00 | 0.00 | 0.00 | Straight MD |
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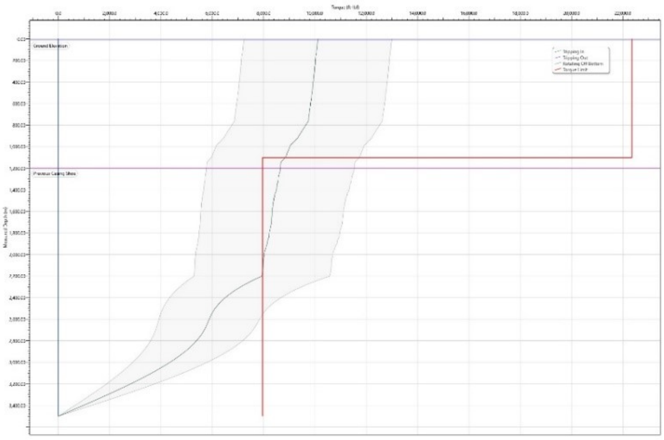
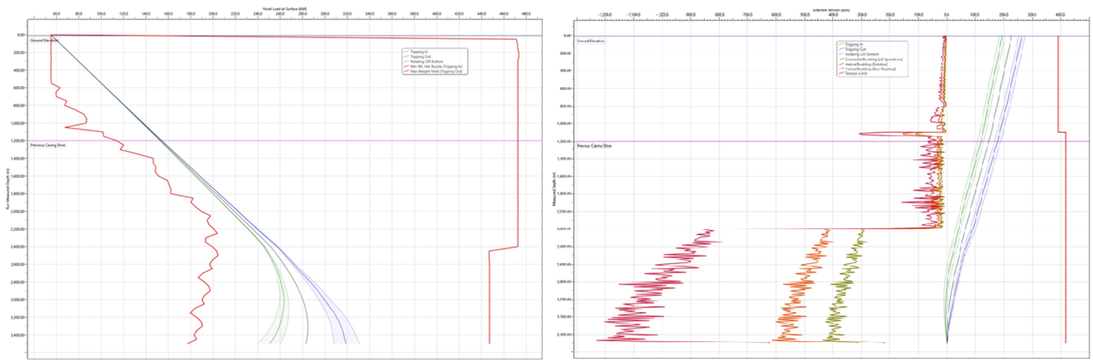
Above: One of the side-track trajectories used as case in the Compass and WellPlan simulations. Here with a 400-meter horizontal section.



Above: Torque requirements of 7” liner, did show that a VAM Top HT liner or equivalent should be considered for deployment.



Above: Liner drag (left) using a soft string model and effective tension (right) of the 7” liner model did not highlight any warning signs in WellPlan

Although not incorporated into the simulation the side-track should have been drilled perpendicularly into the maximum stress direction. The completion system was envisioned and simulated run-in hole with a 5” drill pipe with the top of the liner run 50 meters above the 9 5/8” casing shoe. The WellPlan’s drag and effective tension model did not see any red lights when friction factors were set at 0.2 for cased and 0.25 to 0.50 for open hole to secure installation of the system.

Risk relating to the project came primarily in the unfamiliarity of installing the demonstration system in an unfamiliar environment, with space restrictions and ultimately a rock laboratory that has different rock mechanical properties from a deeper well. To eliminate any probability of any equipment being pushed back towards, tunnel, a custom made well test cp was manufactured to fit onto the flange. Drilling into a lesser known part of the formation to establish a network in a less known section of the formation proved challenging.

The new ECP and flow valve adjustments were relatively low risk, but also difficult as the high expansion ECP required a different assembly process than other packers, especially the new seal.

The milestones were pushed on multiple occasions, to facilitate and coordinate with our partners efforts. We also encountered a few production bottlenecks, which meant we had to shelve several partially completed items and delay finalization of in-house testing. This meant that the the Bedretto tests and final in-house testing of equipment both got pushed into 2021.

The overall international ZoDrEx consortium was naturally affected by the Covid-19 restrictions, the project was challenged slightly by prolonged operation time in Bedretto, additional so-called “Bedretto Factors”, as called by ETH were encountered that prolonged the installation and testing.

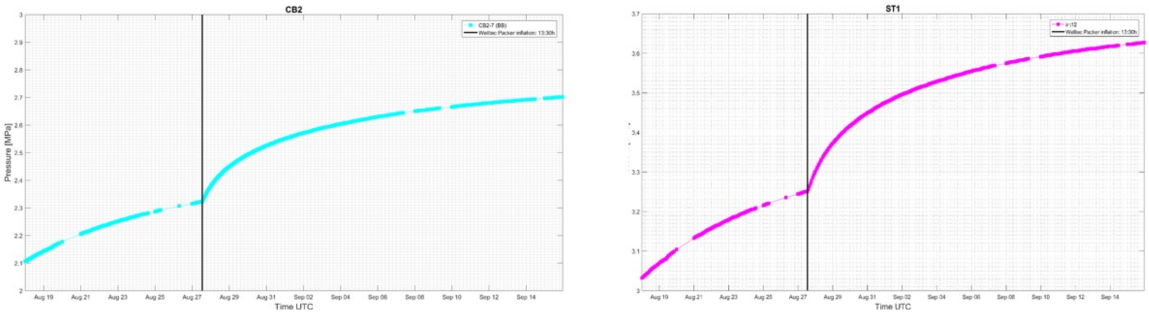
# 4. Project results

As explained above the new high expansion ECP design, had to go on compromise with the expansion rate to ensure that it could live up to qualification standards. Although based on the same MEP technology as other Welltec packers the result was a much different looking packer, as the seals were changed, but with the same robustness made in a ultralow carbon, nickel alloy and with a 260° Celsius temperature capability and a 5.000psi Delta P, designed for ISO 14310 V6 (3V leak criteria) qualification. With an expansion rate of 27 percent, the new ECP will be able to seal off breakout section or ovalized borehole, with deformities as large as the example shown on page 3. However, installation of permanent packers should rather be installed above and below such sections with serve cases of breakout of opalization to thoroughly isolate them.

Only minor adjustments were made to the flow valve adjustment. Although the valve used has a flow capacity of 110 percent, some may prefer to see an even greater inflow sections, as the conventional geothermal industry has grown accustomed to using perforated liners with large inflow area, in which case future work could incorporate more or even larger flow gates.

The Bedretto tests were not as extensive as hoped, but it was demonstrated that the system could help change the flow and pressure in its section of the formation. The completion systems consisting of valves and packers were installed in the 8 ½” diameter and 99 meter long bore hole in August 2021. The borehole had intercepted the nearby fault line earlier than expected. The pre-existing flow of 2.5 l/m that had becoming from the well since it was drilled and continued continued during installation continued to flow throughout testing and after. The system was successfully run and set hydraulicly, plastically deforming all 4 packers into the borehole simultaneously to ensure a seal annulus. As this did not change the flow, it was evident that the inflow came from somewhere above the upper packer set at 59 meters.

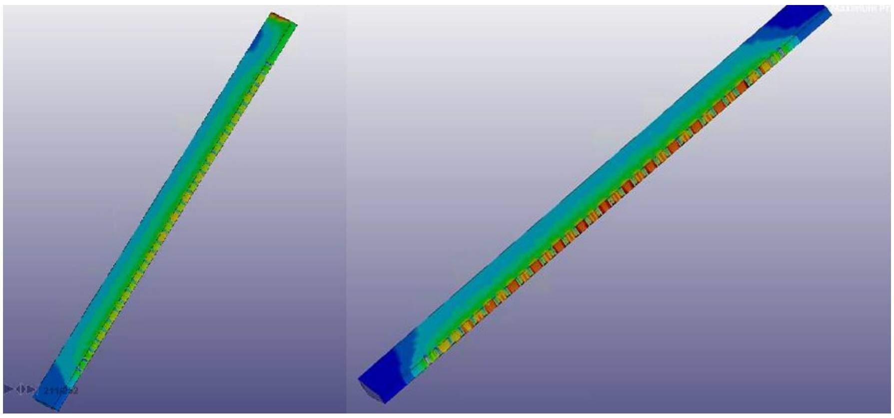
The setting and effect of the packers were confirmed over the next 20 days, as sensors (pressure and flowmeters) in the neighbouring wells, ST1 and CB2 registered a 50psi increased indicating a change in fluid flow in the formation following setting, indicating the system successfully created a new seal inside the borehole causing the pressure in a part of the formation to formation. This was reconfirmed during shut-in, as the system held pressure over an 11-day period.




Above: GeoMonitor data from sensors in CB2 (left and ST1 (right) captured a change consistent change in pressure in the formation following the installation of the system.

Despite attempts running multiple stimulation cycles in the upper zone results were inconclusive. Upon opening lower zone, water was immediately detected coming through the casing/valve in rates of 2.83 to 2.95 l/m, which stopped immediately once the zone was closed again, indicating the system's ability to isolate separate zones with different flows.

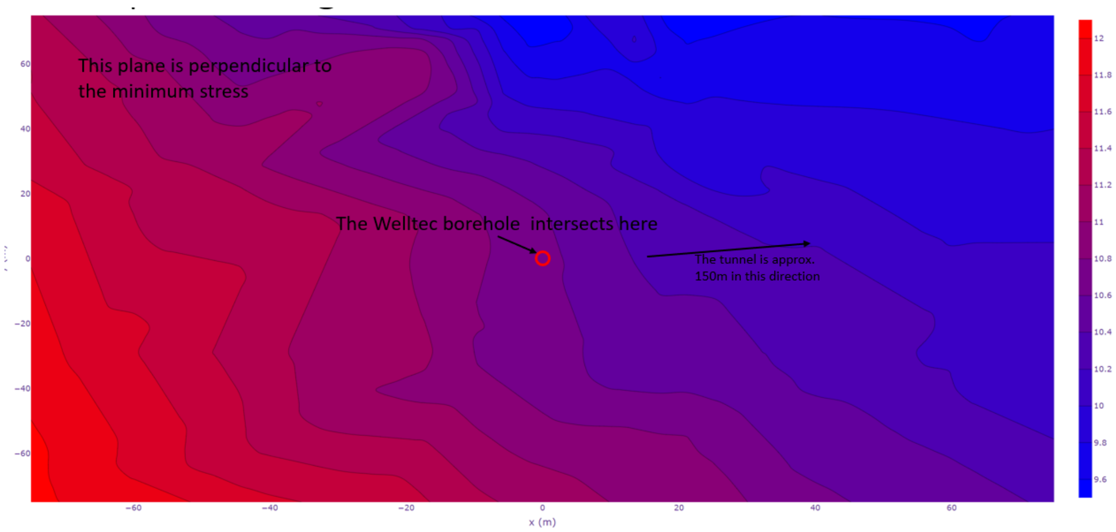
A five-step step-rate-test was carried out with initial rate of 0.5 and finally 7.5 l/m showed that the zone was in communication with an existing network, very likely dominated by the large nearby fault. This made further testing of the completion system difficult, as there was an indication of a cross-over flow in the formation, which pressed water across the formation around the bore hole. Nevertheless, the effects of the step rate test in the lower zone were detected by ETH's micro-seismic sensors on a single channel in MB7.



Above: FEA model showing the packer to rock contact stress without (left) and with (right) overburden stress. The pressure applied to the formation changes as the rock mechanical pressure changes. Interestingly, the squared darker elements along the seals, are not where the micro-localized contact stress is applied, but the areas in between them.

To obviate effects of potentially causing mini fractures along the system the expansion was carried out in steps with time intervals between pressure increases. Likewise, prior to, and after testing, FEA modelling incorporating the formation's vertical and horizontal overburden stress only indicated minimal contact stress on the borehole, rendering the probability of borehole bypass low. However, to further eliminate doubt micro-localized stresses and expansion procedure could be further investigated when it comes to setting the packers in highly competent rock formations. Additionally, further tests could in the future be caried out in the upper zone.

Although the rock laboratory offered a unique opportunity to test the equipment in a granite formation, the test was likely affected by the proximity to the tunnel, after the section of the borehole that was left for testing after the well was cut short to 99 meters, which meant the stress plane gradient overburden was overshadowed by the stress perturbation caused around the tunnel, thus those making the results difficult to transfer.




Above: The oblique stress gradient plane at 76 meters, the red circle indicates where the borehole intersects the plane with the wellhead located behind the plane. The gradients from the increase of overburden are heavily overshadowed by the stress perturbating from the tunnel 150 meters away. The plane intersecting at the 62-meter zone showed a similar overburden effect on the area around the borehole.

The WellPlan simulation results confirmed the feasibility of deploying and installing a full-scale version of the lower completion system in different lengths. Although feasible, higher quality liners should be used to ensure that the system can be rotated into place. Given the torque required to push it into place larger rigs will be required.

Although the developed hardware has yet to see deployment in a real well, the test in the Bedretto laboratory has offered a unique opportunity to test the equipment in the actual dimensions. Over the cause of the material selection process, we have also learned that some of the geothermal material selection choices can to a degree also be implemented in carbon capture storage (CCS) well solutions, especially when it comes to ensure long-term durability.

The developed result will aid in ensuring better control of both EGS and hydrothermal resources by allowing for better control of the well borehole through improved zonal isolation, thereby allowing wells to function optimally to its individual geological circumstances.

Because EGS is still new and there is currently only roughly 20 ongoing EGS projects in development, as of the time of writing, the largest market potential lies in hydrothermal application, where it can be used in both in the low and midrange temperature market. According to Rystad, this currently includes more than 6000 active wells world-wide with an additional expected 350-520 new wells to be added annually in the next 4 year. However, beyond 2025 Rystad (2021) estimates that the annual number of wells drilled for geothermal power production will rise to 600-700 wells and that the number of EGS projects will increase.

The equipment will be targeted towards projects geothermal developers, drilling companies, and steam-field developers, as well as engineering consultants involved in geothermal well design.

The results from the Bedretto Rock laboratory will, in part, be published along with our consortium partners, with results pertaining to our part of the project will later be incorporated in technical papers for upcoming events, such as the European Geothermal Energy Council (EGEC)'s Congress, Geothermal Rising and various geothermal workshops amongst others in the Americas, Africa, Asia and Europe.

References to our efforts and collaboration in ZoDrEx, with Geothermica and EUDP, are already incorporated into our client specific geothermal presentation material.

# 5. Utilisation of project results

The equipment designs will be incorporated into Welltec's geothermal application portfolio. The design supports application in over 260° Celsius which is excellent for EGS, but it will likely later date be modified to manage more specific field properties. Likewise, lessons learned from the packers to rock contact stress can be further developed upon and adapted to unique field properties.

- The obtained commercial results will, as already mentioned likely first be implemented in more conventional geothermal well designs, such as for cement assurance, rehuvination and relining in ovalized wellbores. As the geothermal market currently has more active conventional rather than EGS projects. As of the time of writing, we are in dialogue with multiple developers and operators, who are considering using our applications. Patience should be considered in relation to the commercialization of flow valves in geothermal, as the industry has yet to embrace the use of them, thinking them either too expensive or that they will restrict mass flow.

The obtained results will be used to further development of EGS completion solutions and help with the develop of new EGS projects to help provide more baseload energy for both power generation and heating.

As for competition in the market. Within the last year some competitors have started showing signs of pursuing the same market, but as of this time Welltec's technology, qualification standards and pre-existing technology track record puts it ahead of the curve when it comes to supplying robust completion solutions for EGS and conventional geothermal wells alike.

- However, as conventional geothermal well designs intrusts cement to provide cheap annular integrity, there is further need for additional communication of value advantages of using more production packers to make wells more efficient, which can only come with developing a solid deployment track record, and of course developers willingness to allow deployment of new equipment.

The results have helped to showcase the plausibility of using metal expandable packers and flow valve technology to secure zonal isolation in bedrock formations, enabling the wells to have controlled multistage access, thus allowing for greater heat exchange surfaces to be used and thereby making the well more efficient, ultimately helping to secure more reliable renewable geothermal energy and making it more accessible to people in more regions.

The equipment can also play a role in helping to manage cost in conventional geothermal wells, according to Finger & Blankenship 2010[2], cementing costs can increase from 5 to 15 percent of a drilling budget if there are high circulation loses. As breakout and ovalization is common near fractured zones, the high expansion packer can here function as cement assurance, allowing it to reduce the amount of cement required in hydrothermal systems. Ultimately the equipment can help to provide the best possible well given their geological circumstances, allowing them to produce more and in the long term, help make EGS projects more economical.

# 6. Project conclusion and perspective

The project has produced a new high expansion metal expandable packer design for EGS application and modified flow valve for use in up to 260 Celsius EGS environments. The Bedretto demonstration and tests have shown that the completion system as a whole can provide a tight seal and zonally with different formation properties even within short distances in a brittle crystalline formation, thus making it possible to zonally engineer a robust controllable completion system in tight basement rock. However, due to formation uncertainties tests had to be cut short.

Additionally, work can potentially be carried out to adapt both ECP and flow valve to client or field property specifications. Otherwise, the next logical step is deployment in a full-sized operational wells.

Findings from ZoDrEx will be incorporated into other on goings and upcoming geothermal projects. Early this year Welltec were fortunately enough to be accepted into the FORGE project in Utah. Here we will be able to continue the development and lessons learned from the rock laboratory multistage system and potentially install it a crystalline formation at a temperature in the range of 230° Celsius.

The demonstration has helped to show that MEP technology can provide robust zonal isolation strong enough to alter formation pressure and flow in a crystalline formation, which should ultimately help install trust from investors to developers to attracted investment into EGS new projects.

[2] *Finger J & Blankenship D(2010), Handbook of Best Practice for Geothermal Drilling, National Laboratories*

# 7. Appendices

- No publications have as of time of writing been prepared with Welltec's tests, although some of the consortium partners have already made various publications pertaining to the characteristics of the rock laboratory available.