



24th -26th February 2020



**Geothermal Application & Research Center
Denizli/Turkey**



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Welcome

Dear participants,

Welcome to the 11th European Geothermal PhD Days, held for the first time in Turkey! This annual event, since its inception, has been connecting the PhD researchers from all over Europe that are working in the field of geothermal energy. This year we have received 31 valuable submissions from various research fields and countries, which makes us very happy and excited. The conference program speaks for itself and includes a broad range of contributions. One day is full of very interesting keynote speakers and diverse poster presentations which will lead to some fruitful discussions and constructive remarks. The event will be wrapped up with a final field trip to UNESCO World Heritage Site 'Hierapolis-Pamukkale' and an engineering excellence-awarded-geothermal power plant at Kızıldere geothermal field.

Do not forget that lunch, dinner and coffee is on us! We hope you will get the best out of the 11th EGPD and enjoy your stay – thank you for joining us!

The EGPD 2020 organizing committee

Honorary President of The Conference



Prof. Dr. Hüseyin BAĞ
Rector of Pamukkale University

Conference Co-Chairs



Prof. Dr. Rafet KILINÇARSLAN
*Vice Rector of Pamukkale
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Assoc. Prof. Ali KAYA
*Manager of Geothermal
Application & Research Center*



Dr. Taylan AKIN
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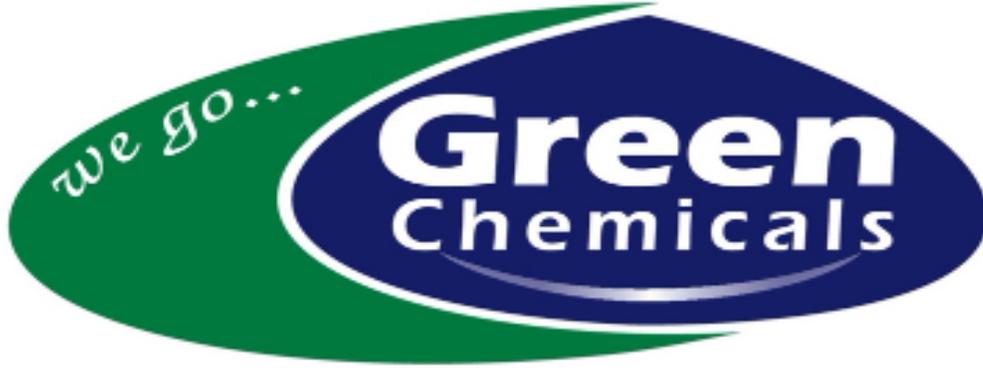
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Schedule

11th EGPD European Geothermal Phd Day 24-26 February 2020 | Denizli, Turkey



Time	Monday, February 24th	Tuesday, February 25th	Wednesday, February 26th
08:00		Registration Opens	Meeting Up at Pamukkale University
08:30			Bus Transfer To Kızıldere Geothermal Field
09:00		Introduction & Keynote Sessions I	Guided Tour at the Kızıldere Geothermal Field
09:30		Coffee Break	
10:00		Presentations Part I	
10:30		Posters Part I	
11:00			
11:30			Lunch Break
12:00			
12:30			Bus Transfer To Hierapolis-Pamukkale Travertines
13:00		Lunch Break	Guided Tour at the Hierapolis-Pamukkale Travertines
13:30			
14:00		Keynote Sessions II	Bus Transfer To Laodikeia
14:30		Coffee Break	Guided Tour at the Laodikeia
15:00		Presentations Part II	
15:30			
16:00		Posters Part II	Bus Transfer To Denizli City Center
16:30			Official Conference Ending
17:00	Ice-Breaker Evening, Registration & Refreshments		
17:30			
18:00			
18:30			
19:00			
19:30		Conference Dinner in Denizli City Center	
20:00			

E-Mail: egpd2020@pau.edu.tr



Web Site

General Information

Geothermal Application and Research Center of Pamukkale University Hierapolis Conference Hall

The venue will take place at the Hierapolis conference hall of Pamukkale University in Denizli. The conference hall is in the building of Tourism Faculty where located next to the Geothermal Application and Research Center.





Geothermal Application & Research Center

Pamukkale University

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Phone: +90 258 296 34 37

Fax: +90 258 296 34 60

Coordinates: 4178888N 685025E (Datum: WGS84/35N)

Journey to Pamukkale University

There are three ways for coming to Denizli city

- **İstanbul to Denizli-Çardak Airport**

There is not any direct international flight to the Denizli-Çardak airport. Therefore, you should connect your flight through İstanbul international airports (İstanbul or Sabiha Gökçen), if you want to reach to Denizli by plane. After landing to Denizli Çardak airport you can directly reach to the campus by taking a taxi or you can choose shuttle bus which takes you to the city center.

Link for shuttle bus: <https://www.bayturbilet.com/ContentLink.aspx?contpg=4>

- **İzmir to Denizli**

İzmir is the third biggest city of Turkey. If you want to include visiting this city in your trip or you need alternative route, you can select this option. Either you can directly fly to Adnan Menderes international airport or you can connect your flight over İstanbul to İzmir. After landing to İzmir, you can take intercity bus or train to Denizli city center.

Link for intercity bus: <https://www.pamukkale.com.tr/>

Link for train: <https://ebilet.tcddtasimacilik.gov.tr/view/eybis/tnmGenel/bolgeselSeferler.jsf>

- **Antalya to Denizli**

Antalya is the most famous touristic city of Turkey. If you plan to visit this city prior to or after the event, you can follow this route. Antalya has an international airport (AYT). You can directly fly to Antalya or you can connect your flight over İstanbul to Antalya. After landing to Antalya, you can take intercity bus to Denizli city center.

Link for intercity bus: <https://www.pamukkale.com.tr/>



The proposed routes to arrive Denizli/Turkey.

After arriving to intercity bus terminal of Denizli, you can take a public bus with a line number of 150. The last station of the line is Pamukkale University. Details of the bus route is given below.



The route of the bus 150.

Registration

Registration desk is located in **Hierapolis Conference Hall** in front of the **Geothermal Application and Research Center**. Please have a look at the map of the Campus on our webpage:

<http://www.pau.edu.tr/egpd2020/en/sayfa/venue-5>

<http://harita.pau.edu.tr/>

Desk opening hours:

Monday 5.00 pm – 7.00 pm

Tuesday 8.00 am – 9.00 am

Keynote Speakers

Prof. Dr. Serhat AKIN



Presentation Title: Characterizing the declining CO₂ emissions from Turkish geothermal power plants

Biographical information

Serhat AKIN is a professor of Petroleum and Natural Gas Engineering at the Middle East Technical University (METU), Ankara, Turkey, where he has Bsc, Msc and a PhD degree in petroleum and natural gas engineering. He has served on the faculty since 1998. Prior to joining METU, Dr. Akin was a post-doctoral researcher in Petroleum Engineering Department, Stanford University between 1997 and 1998. He was Blaustein Visiting Professor in Petroleum Engineering Department, Stanford University at 2006. Dr. Akin has published more than 150 technical articles, reports, and conference proceeding papers. Dr. Akin is actively involved in Turkish geothermal industry. He has helped to develop more than 700 MWe geothermal power capacity as geothermal investment adviser to leading geothermal power companies and banks. His research interests include reservoir engineering, EOR especially thermal, geothermal, reservoir simulation, tracer, and well test analyses. He received the Society of Petroleum Engineers (SPE) Outstanding Technical Editor award in 2001, 2002, 2004, 2014 and 2019. He also received Prof. Dr. Tarik Somer award in 2004 and the Middle East Technical University Academic Achievement award between 2001 and 2018. He was an associate editor of the SPE Reservoir Evaluation and Engineering between 2007 and 2013. He is currently an editorial board member in Computers & Geosciences. Dr Akin served in several SPE committees including Education and Accreditation, STAR Award and International Faculty Award committees.

E-mail: serhat@metu.edu.tr

Dr. Juliet NEWSON



Presentation Title: Importance of geothermal education

Biographical information

Dr. Newson has been involved in many aspects of the geothermal industry, including geology, geothermal surface feature mapping, monitoring and modelling, reservoir and wellbore simulation, geological modelling and resource evaluation. However, her strong belief that education is the key to progress both in a social and technological sense, has always led her to maintain strong links with academia. She has been involved in tertiary-level energy education in New Zealand, internationally through the International Geothermal Association, and most recently, Iceland. In November 2016 Juliet took up the position of Director of the Iceland School of Energy, Reykjavik University, Iceland. Prior to this, since 2011 Juliet has been a geothermal reservoir modeling engineer for Contact Energy Ltd, working in close co-operation with reservoir modeling researchers at the University of Auckland. From 2007 to 2011 she was the original co-organizer of the Postgraduate Certificate in Geothermal Energy Technology for the University of Auckland, New Zealand. She has managed and delivered many other geothermal courses, including the Short Courses for the International Geothermal Association World Geothermal Congress 2015. Juliet is also a Board member of the International Geothermal Association; she was Chair of the Education Committee from 2010 to 2013 and held the office of President for the 2013 to 2016 Board term.

E-mail: julietn@ru.is

Prof. Dr. Franco TASSI



Presentation Title: Hydrothermal-magmatic gases: an open window on Earth interior

Biographical information

Franco Tassi is a Professor of Earth Science at Università Degli Studi di Firenze in Italy. He is scientifically responsible for the Laboratory of Fluid Geochemistry of the Department of Earth Sciences, University of Florence. He has MSc and Ph.D. in Earth Sciences at the University of Florence. His interest areas are Volcanology, Fluid Geochemistry, Environmental Geochemistry, Organic Chemistry, and Limnology. He is a member of different scientific organizations such as Commission of Volcanic Lakes Steering Committee, Gruppo Nazionale Petrologia, Società Geochimica Italiana and Commission of Volcanic Gases. He served more than 15 international courses. Currently, He is a part of many synergic activities and projects. Dr. Franco edited books and special issues. He is editor of the Journal of Chemistry, Journal of Volcanology and Geothermal Research and Journal of Limnology. He published more than 550 scientific papers, articles, oral and poster contributions for National and International congresses and meetings.

E-mail: franco.tassi@unifi.it

Ass. Prof. Dr. Maren BREHME



Presentation Title: Perspectives for the sustainable use of geothermal resources

Biographical information

Maren Brehme is an Assistant Professor for Geothermal Engineering at TU Delft. She has more than 10 years of research experience in Geothermal Energy. From her background, she is a hydrogeologist aiming to understand subsurface fluid flow using multidisciplinary approaches for sustainable geothermal exploration and exploitation strategies. A main research focus is on finding new well locations and how to operate geothermal systems sustainably. Areas of expertise are geothermal reservoir characterization, hydraulic, thermal and chemical data interpretation, enhancing reservoir performance and its sustainable use. She studied Applied Geosciences at the TU Berlin, worked as consultant engineer before being a research scientist at the German Research Center for Geosciences since 2009. She received her PhD degree from University of Göttingen in 2015 for a study on the role of fault zones in geothermal reservoirs. Her Post-Doc project focused on enhancing reservoir performance by soft stimulation.

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Prof. Dr. Ahmet Tuğrul BAŞOKUR



Presentation Title: The use of electrical resistivity models in geothermal exploration

Biographical information

Ahmet Tuğrul Başokur is a professor at Ankara University where he has worked since 1978. He started there as a researcher and later became an Associate Professor in 1988. He began his current position in 1994. He received a B.Sc. in Applied Geophysics in 1976 from Istanbul University and Ph.D. in the same area from Ankara University in 1982. He has been a member of the Society of Exploration Geophysicists since 1981 and European Association of Geoscientists and Engineers since 1980. In his community, he has been active in The Chamber of Geophysical Engineers of Turkey on the executive committee from 1978 to 1982 and 1985 to 1987, Union of Chambers of Turkish Engineers and Architects as a member of the committee for honours from 1988 to 1996, and the Balkan Geophysical Society as vice-president from 1994 to 1996 and president from 1997 until 2000. He was one of the editors of Journal of the Balkan Geophysical Society between 1999 and 2006. He is currently one of the Editor of Geophysical Prospecting published by the European Association of Geoscientists and Engineers for 'Electrical and Electromagnetic Tomography and Optimization'.

He has published scientific articles in Geophysical Prospecting, Geophysics, Journal of Applied Geophysics, Computer&Geosciences and some other well-known journals. Furthermore, in 1983 he received the Van Weelden award from the European Association of Geoscientist and Engineers. His interests are in modelling and inversion of the electric and electromagnetic data for the real exploration problems including archaeology, engineering, hydrogeology, mining, geothermal and petroleum exploration. He authored seven books about electrical and electromagnetic methods, spectral analysis and filtering theory, parameter estimation methods. He was head of the Department of Geophysical Engineering, Ankara University Faculty of Engineering between 9.19.1997-8.2.2007 and 1.7.2009-2.4.2015. He was the director of Ankara University Earthquake Research Centre between 4.18.2003 -4.18.2015.

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Prof. Dr. Ali KOÇYİĞİT



Presentation Title: The significance and usage of Earth Sciences data in geothermal explorations: A case study in the Nazilli-Buharkent section of the Büyük Menderes Graben, SW Turkey

Biographical information

Prof. Dr. Ali Koçyiğit is expert on Structural Geology. He holds a B.Sc., MSc, and Ph.D. from the Department of Geological Engineering at Ankara University. His studies are specified in the area of structural geology-tectonics, Neotectonics, Active tectonics, Earthquake Geology, Paleoseismology, and Geothermal Exploration. He worked as an instructor at Ankara University from 1975 to 1981. He was a post-doctorate researcher at the University of London in 1981. He became Associate Professor in 1981 at Middle East Technical University (METU) in Ankara. He was visiting Professor in the period 1981-1982. He served as Associate Professor in METU from 1982 to 1988. He had worked as Professor from 1989 to 2012 in METU. He retired in 2012 and since then He has been a part-time instructor in METU. Prof. Dr. Koçyiğit has more than 230 articles, projects, reports, and conference papers. He involved in several first establishments such as the department of earthquake researchers and seismic zonation of Turkey.

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ABSTRACTS



Predictive Modeling of CO₂ – Brine Co-Injection Conditions in Re-Injection Wells

Taylan Akın*, Serhat Akın, Serhat Küçük, Önder Saraçoğlu, Ali Başer, Selçuk Erol

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Emissions of greenhouse gases such as CO₂ emitted at Turkish geothermal power plants are an obstacle to call geothermal energy as green power. However, recent advances in carbon capture and storage technologies have enabled low emissions by re-injecting produced CO₂. The phase of injected CO₂ is crucial for the success and safety of the operation. Injecting CO₂ directly into a reservoir as pure gas or at supercritical state may cause the leakage of CO₂ via fractures or abandoned wells. This problem can be prevented by the dissolution of CO₂ into brine prior to, or during its injection into the reservoir. Various projects have been being conducted around the world to reduce geothermal emissions. Among these projects, GECO (Geothermal Emission Control) is an EU funded project through the Horizon 2020 and aims to develop near-zero emission geothermal power plants. Through the GECO project, Zorlu Energy and METU (Turkey) aim to reduce the CO₂ emissions for more green geothermal power production while maintaining the sustainability of Kızıldere (Turkey) geothermal field (KGF).

The objective of this study is to calculate possible ranges of CO₂ molar ratios to ensure all injected CO₂ will dissolve in brine and preclude the gas formation in re-injection wells at KGF. In order to compute partial pressures of dissolved CO₂ at elevated temperatures for a given CO₂ molar ratio, chemical analysis of injection water was defined as a solution in PHREEQC and various amounts of CO₂ were irreversibly added into the solution. Temperature range in geochemical modeling was selected from injection temperature at the well head and static temperature at reservoir level of the boreholes. Pressure profiles of the wells were calculated by assuming hydrostatic condition. The model results showed that the dissolved CO₂ in the wellbore should not exceed 1.5 %wt during injection at 105°C. It was concluded that injection flow rates of both water and gas phases should be arranged with this constraint.



Well Integrity: Sustainable Material Selection of Tubulars for Highly Saline Sweet Geothermal Environments

Oghenerukevwe Eru*, Anton Trautmann, Prof. Gregor Mori, Prof. Ravi Krishna

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Corrosion must be understood for effective material selection and for the design, fabrication, and utilization of metal-based structures for the optimum economic life of facilities and safety in operation because metals are utilized in wide areas because of their high strength and ductility, but they are thermodynamically unstable and corrode/oxidize to a more stable state. Corrosion science is the study of the chemical and metallurgical processes that occur during corrosion. Corrosion engineering is the design and application of methods to prevent or control corrosion in a safe and economical manner. It is dedicated to slowing, reversing, preventing, and avoiding the impact of corrosion. A combination of both specialties helps to invent new methods of mitigation, and aids in correct application of methods. Material selection with respect to Corrosion rate, is important because it determine the life span of equipment, which is directly reliant on the choice of metals for different purposes and for deployment in different environments. In this work, mounted coupons of L80, P110, Super 13Cr, Duplex 2205 and Böhler A975 was tested under a sweet and highly saline environment with CO₂ in an autoclave, and checked periodically over a period of time. The coupons were removed, cleaned and subjected to various analysis. It was discovered that there was varying reaction, leading to pitting corrosion, depending on the microstructure and chemical composition of the various coupon.



Handling of CO₂ in Binary Geothermal Systems

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Non-condensable gases (NCG) are present in geothermal power plant systems worldwide. When producing the hot fluid, the gases flow as part of the fluid into the surface installations (pipelines, heat exchanger etc.). The solubility of the gases decreases with lower pressure and higher salinity of the brine and may result in two phase flow. This can cause problems like corrosion as well as decreasing heat exchange efficiency. Depending on local governmental regulations, the emission of those gases to the atmosphere is not rare. Geothermal energy as a renewable energy has to deal with this subject in order to receive a zero-emission status. Different techniques exist already to deal with this subject, but comparatively high operational cost is inherent. Thus, the motivation of this work is the reduction of NCG emissions accompanied by optimized facility design and minimized operational cost. To reach this target, a general approach is the concept to reinject the NCG as it is also done with the cooled fluid after heat exchange. There exist different technical process solutions to handle NCG within the surface installations and approaches to reinject the gases back into the reservoir. However, as different NCG contents occur and inter alia variations in operation pressures, temperature and salinity exist, the handling is always fraught with several difficulties. In a first approach, different CO₂ solubility models have been compared, evaluated and validated with different CO₂ solubility data. After choosing the appropriate solubility model, the thermal water circuit of a binary plant in Germany has been modelled. The system shows two-phase flow in the surface installations and this shall be pictured accurately by a process simulation software. Furthermore, several tests at wellhead and surface Installation have been carried out to detect the CO₂ content in different ways to deduce the gas breakout pressure. With those tests, the process simulation could be validated and will be improved further.



Analysis of A Comprehensive Tracer Test in Alaşehir Geothermal Field

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Tracer test has been used as a sophisticated characterization method for reservoir engineering applications. Specifically, it is widely used in geothermal reservoir engineering. A tracer test is not only used to understand the existence of hydraulic connection between injection and production wells but also used to gather crucial information about reservoir properties by using analytical models. There are different analytical models that could be used in matching tracer return curves: Double porosity Model, Homogenous Model, Multi-Fractures Model, Single Fracture Model, Pseudo Steady State Model. In this study, a comprehensive tracer test that is carried out using naphthalene sulfonates in Alaşehir geothermal field is analyzed with analytical models. The study showed that the multi-fractures model has the best match with actual test data. As a result of the matches, the following reservoir properties have been obtained: recovery factor, average fluid velocity in the reservoir, swept pore volume, thermal velocity, peclet number, and dispersity which are highly important properties for better reservoir management.



Hydrothermal Fluid Circulation and Alteration Processes in An Analogue of a Fractured Granitic Reservoir (Noble Hills Range, CA, USA)

Johanne Klee*, Ghislain Trullenque, Béatrice Ledésert, Sébastien Potel, Ronan Hébert

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This work presented here is part of the H2020 European MEET Project (Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potentials). The overall goal of this project is to enhance demonstration of geothermal energy production throughout Europe. Part of this project is the study of the interaction between the hydrothermal fluid and the rock in granitic fractured reservoirs as the one present of Soultz-sous-Forêts (SsF) located in the Upper Rhine Graben (Alsace, France). Indeed, alteration of the encountered rock changes the petrophysical properties of the reservoir and minerals can precipitate and clog the fractures. Depending on host rock alteration and fracture infills, the reservoir productivity can drastically evolve through time and space. Additionally, stimulations strategies can become challenging and great care has to be taken to select them. It is observed that fractures in the SsF reservoir are filled by calcite and quartz and more sporadically by barite. The host rock alteration only affected plagioclases and biotite. Plagioclases (oligoclases) are transformed into tosoxite and biotite into illite. The problem in the SsF plant consists in a limited borehole dataset. It is for instance under question if the alteration and the fracture infills are comparable in the whole reservoir through space and time. In order to circumvent this data limitation, it has been chosen to work on an analogue showing virtually 100% outcrop exposure on a geographical extent comparable to the inferred reservoir at SsF. This analogue is located in the Noble Hills range (NH, Southern Death Valley, CA, USA). Preliminary observations and results are presented here and based on petrological analyzes of encountered rocks. We concentrate on 1) the nature of fracture infills and 2) on the host rock properties depending on alteration processes. The NH granite is highly fractured, with fractures spanning over several orders of magnitudes in length and width. These can be either opened or filled by precipitation of secondary minerals due to fluid circulations and the complex interplay with tectonic. We have been investigating those infills at both outcrop and sample scale. At the outcrop scale different infills are observed: - At the middle and frontal



part of the range fractures are diffusely filled by carbonates across the fracture network. - At the rear part carbonates and oxides diffusely filled fractures in a localized corridor. Moreover, late generation of oblique fractures showing limited amounts of shearing and possibly linked to the strain incompatibility with the surrounding Garlock system are present. These are filled with geodic barite. - In the middle of the range a major fault gouge (up to 10 meters width) completely filled with clay minerals runs the entire length of the range. - Quartz veins are rare. At the thin section scale, the same association of oxides, carbonates and sometimes quartz veinlets are found. Microscopic analyzes reveal that the carbonates veins are composed by calcite and/or dolomite and that carbonate veins are composed by different generation of filling. It has also been observed that the granite present traces of alteration due to the interaction between granite and fluids, which have circulated through the fracture network. Plagioclases, which are oligoclases, and sometimes biotite are the only minerals affected by the alteration processes. Quartz and K-feldspars remain intact. The alteration of plagioclase causes its transformation into calcite, illite and mostly into kaolinite, which is considered as a geochemical analogue of tosudite. Biotite alteration is less developed but according to SEM-EDS the product of its alteration corresponds to illite. During this process, Mg and Fe are released from biotite and formed oxides which are nearby present. Based on those preliminary data, it is obvious that the NH allows a clear analogy with alteration and circulation processes observed in SsF. However, these investigations show that the infills are geographically different across the reservoir and also different in term of evolution through time. It is emphasized that geothermal reservoirs are complex and dynamic systems evolving through time. Fractures evolve with strain but this evolution can be modified depending on the nature of the infill and play the role of barriers or drains. Care has to be taken during reservoir exploration and exploitation strategies as a fault network petrophysical properties might drastically change depending on the fault tectonic history and fluid/rock interaction processes.



Analysis of The Estimations of Heat Flow and Geothermal Gradient Using The Curie Point Depth, Relationship With Bottom Hole Temperature Data And Their Tectonic Interpretations In Coahuila Mexico

Juan Luis Carrillo-De La Cruz*, Rosa Maria Prol-Ledesma

**Universidad Nacional Autónoma de México*

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Thermal state of the crust is often analyzed using the Curie point depth (CPD) estimations, calculated from airborne or satellite magnetic data, due to the lack of borehole temperature data, nevertheless, this method needs to be used carefully because the calculations are an average value. Using the Curie temperature of the magnetite (580 °C), the average thermal conductivity and the average heat generation rate, under a steady-state conductive heat transfer mechanism, it is possible to estimate the heat flow and geothermal gradient from the estimated CPD. The CPD calculations were carried out using the Fast Fourier Transform over windows with 180 x 180 km size (at least 8 times the expected Curie point depth), 100 % of data coverage, window overlapping of 50% and applying fractal corrections of the magnetization derived from the use of de-fractal method. In this work, we analyzed the heat flow and geothermal gradient values calculated with the available borehole dataset to compare the results obtained with the CPD, by averaging the heat flow and geothermal gradient for the boreholes contained in every window. The results from the estimations are highly correlated with the borehole data, showing a conductive heat transfer mechanism in the study area, also, major tectonic features control the CPD, obtaining shallower values between two main faults, in volcanic areas and zones with hot-springs.



Geothermal Exploration with An Electrical Resistivity Induction Log: Application to A New Well Drilled in Granite (Strasbourg, France)

Carole Glaas*, Jean-François Girard, Patricia Patrier, Albert Genter

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In the Upper Rhine Graben (URG), geothermal resource is located in the first kilometer of the fractured granitic Palaeozoic basement, under a pluri-kilometric thick sedimentary cover. The targets of geothermal wells in the granite are the local normal faults and their associated fracture networks, in which highly salted brine circulates. Geothermal water-rock interaction led to precipitation, as well as dissolution of minerals. Generally, precipitation of minerals is expressed by secondary clay minerals (illite) deposition which tend to plug the zone, while dissolution of minerals is mainly primary silicates (biotite, plagioclase) dissolution and favours fluid circulation. It is crucial in a drilled geothermal well to locate the permeable fracture zones (FZ). That for, several geophysical logs are generally acquired and used to determine the response of permeable and non-permeable FZ. In this case, we are investigating the electrical resistivity induction log acquired in the open-hole section of the well. The main key-questions which arise during this study are: What is the electrical response of a permeable zone versus a non-permeable zone? What is the impact of clay minerals versus highly salted brine on the electrical resistivity response? Through simple case studies, the potential of electrical resistivity logs for geothermal exploration is demonstrated, using the modelling software RtEvrest by simulating with 1D and 2D methods (respectively integral equation and finite elements methods).



Prediction of Soil Thermal Conductivity: Preliminary Results

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Many mayor cities have developed on sedimentary basins where unconsolidated sediments are present. Because of increasing awareness on climate change issues, shallow geothermal energy, as a part of renewable energy, is in their rise. Therefore, reliable information is important when sizing geothermal systems. One of the most important thermal properties is the thermal conductivity of sediments, which is induced because of heat transfer processes and controls configuration of isotherms within the basins (Brigaud et al., 1990, Incropera et al., 2007, Banks, 2012). Their calculation is based on the ratio between sediment matrix thermal conductivity, porosity and thermal conductivity of the pore fluid (Albert et al., 2017). Furthermore, the factors that influence the change in this property are degree of saturation, dry density, mineral content of soil, particle size, etc (Popov et al., 2006). Laboratory measurements of thermal conductivity need to be made on dry and saturated samples; thus, this can be a time-consuming process. Alternative is estimation of these properties using various mixing and empirical models, such as a geometric mean model, arithmetic mean model, Kersten model, Johansen model and Cote and Conrad model. They are used to enable us to obtain the necessary parameters faster and to theoretically estimate the impact of different properties on the thermal conductivity of unconsolidated sediments (Woodside and Messemer, 1961; Fuchs and Föster, 2010; Dong at al., 2015; Kämmlin and Stollhofen, 2019). The main aim of the research is to determine the best mixing or empirical models of thermal conductivity for dry and saturated soil sediments. So far, preliminary results show which models might have the best fit to the actual data, depending on different soil formations. In the future, suitable models will need to be precisely defined by validation with larger amount of laboratory measured thermal conductivity.



Sustainability Factors of Los Humeros Geothermal System

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Sustainable development means to meet the needs of the present generation without compromising the ability of future generations to meet their needs (UN, 1987). Geothermal projects are usually planned to not only meet energy-generation needs, which means to maintain the production rate of the field, but also some other factors involved with physics characteristics of the field. As the production rate is involved with the sustainability use, this study aims to detect all the possible factors that define the sustainability in the field with the production data we had. One of the main features is the proximity of the wells and their rate of production. The intention is to find if they have a negative impact on the performance of the electric generation from Los Humeros, Mexico. We analyzed the productivity data from three wells on the southern part of the reservoir area (H-6, H-12, and H-39) to calculate the productivity index for each well. The resulting PI trends changed 3 times in the entire production period. The first notable change appeared after 10 years of production, when the PI of the wells H-6 and H-12 fell simultaneously. Furthermore, we calculated the equivalent area corresponding to the mass and heat extracted considering the effective thickness of the reservoir (Limberger et al. 2018) and applying the "Heat in Place" linear model (Muffler and Cataldi, 1978; Garg and Combs, 2015). These results could be an appealing baseline for profitability calculations and therefore for an assumption of sustainability.



The Role of Geothermal Resources in Local Development

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Introduction Among the renewable energy resources geothermal is specific to a local production and consumption. Next to the heat and energy production, geothermal energy presents with opportunities for rural and suburban areas linking sustainable development goals with expansion of new local economy sectors (i.a. tourism, agriculture). Therefore, we assume that local exploitation of geothermal resources delivers a local added value other than energy generation. Moreover, a change of a municipality socioeconomic structure is presumed while geothermal establishments are introduced. The aim of this research is to fill in the gap in the literature and establish an empirical link between the use of the geothermal renewable and measures of local development. The assumed added value of the geothermal can be analysed as direct, indirect and induced effects on a municipality of exploitation. This research attempts to provide a methodology that measures the induced impact related to the socioeconomic development. The theoretical conceptualization underpinning this studies is reflected in endogenous growth theories as well as in regional economics approach. Methodology This study attempts to establish a methodology that is able to measure geothermal resources impact on local development. Our approach is to implement the added value analysis of the locations where the renewable is used in multiple forms. Municipalities in Poland are chosen as the main object of the research because of particularly high geothermal potential and private sector experience in bringing up geothermal enterprises. The developed model is to demonstrate the statistical relation between exploited geothermal energy and parameters of local development. The versatility of this study lies in the fact that exercised on the Polish municipality cases our model is applicable for analysis to any geothermal municipality in the world. Results throughout the selected statistical methods we obtain significant results to justify our research assumptions. The comparative analysis of the geothermal resources competitive advantage in the local economies is econometrically illustrated. We as well observe faster development of the geothermal municipalities compering to the referred municipalities or regions. Geothermal energy development is found locally inducing new forms of employment. Moreover, we built a local development model with geothermal parameters that we reckon is replicable in further studies about the local geothermal energy impact. Discussion and Conclusion The research aims to deliver statistical argument for the expansion of geothermal resources extraction in Poland and worldwide.



Geothermal Education – Challenges and Solutions

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Geothermal energy is multidisciplinary and multi-objective field which requires interdisciplinary approach with combination of geology, chemistry in science to mechanical and civil engineering or marketing and management. This nature of multi-disciplinary makes it difficult to offer all-inclusive program in undergraduate or graduate levels for universities. Simplest shortcut to overcome this shortage is short courses or intensive training courses offered by several countries such as Iceland, New Zealand and Japan. Meanwhile there are several graduate programs offered by several universities worldwide. The main issue for this type of programs, is financial issues and it becomes crucial parameter when the geothermal development industry slows down. It has been common practice by governments to introduce incentives for geothermal development. Geothermal education requires incentives and supports from financial organizations and governments to continue its effort to train and educate professionals in geothermal industry. This paper will investigate the availability of geothermal education in the world to discover challenges and difficulties in order to propose practical solutions.



Impact of Hot-Water Injection on Geochemical Reactions in Potential Aquifer Thermal Energy Storage Formation Rocks: A Methodological Approach

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Aquifer thermal energy storages (ATES) can be a possibility to overcome the acyclic heat demand and supply by storing the surplus heat in an aquifer and discharging it during periods of heat deficit. The injection of hot water may have a negative impact of the aquifer caused by geochemical reactions. Clogging of aquifer pores thus reducing the porosity and permeability or the release of contaminants are possible consequences. Formation-specific knowledge about physico-chemical processes and release mechanism could prevent undesired effects on the ATES systems. Sandstone and carbonate aquifers are considered as potential ATES formation rocks in the study area Berlin. For a better understanding of the impact of hot-water injections on the chemical reactions, batch experiments with rock samples and synthetic as well as natural groundwater are planned. The following field experiments (e.g. push pull tests with hot water injection) are intended to compare the results. Finally, hydrogeochemical modeling using the software PHREEQC should help to understand the mechanism of water-rock interaction and evaluate the results of the lab and field work. A further simulation based on the lab and field tests will be set to model an ATES operation with several storage cycles.



Usage of The Lower Muschelkalk As Aquifer Thermal Energy Storage in Berlin – Preliminary Results of The Hydro-Thermal Rock Characterization

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On its way to become climate neutral the capital of Germany aims to reduce its CO₂ emissions by 85 % compared with 1990 levels. To reach this target a comprehensive development of sustainable and renewable energy supply systems across the city is required. One promising solution are aquifer thermal energy storage (ATES) systems where surplus heat from the summer time is stored in water bearing formations and recovered in winter time. In a collaborative project between the German Research Centre for Geoscience, Potsdam (GFZ) and the University of Potsdam a regional model of the Rüdersdorfer Schaumkalk (upper part of the Lower Muschelkalk) below Berlin, Germany is developed. The Rüdersdorfer Schaumkalk formation is generally characterised by well sorted and cross-bedded oolitic grainstones formed in a shallow marine high-energy environment. For the parametrisation of planned numerical ATES simulations we determined the thermal conductivity, specific heat capacity, density, effective porosity and permeability of corresponding core samples from the gas store in Spandau (West-Berlin) and outcrop samples from an opencast limestone mine in Rüdersdorf (East-Berlin). For the high energy facies a mean thermal conductivity, specific heat capacity and density of 3.36 W m⁻¹K⁻¹, 822 J kg⁻¹K⁻¹ and 2.7 kg m⁻³, respectively, was determined for the rock matrix. The measured mean effective porosity of 20 % would be sufficient for an ATES system, the average permeability of the rock matrix is, however, with 0.345 mD too low.



Well Integrity Monitoring Using Distributed Fiber Optic Strain Sensing

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Borehole integrity is essential for the successful and sustainable utilization geothermal energy and sites for geological storage. The success of the primary well completion is a crucial step to ensure the integrity of a well over its lifetime. The cementation of casings represents a great risk because many factors have an influence on the composition and distribution of the cement suspension due to the natural conditions in the borehole. This PhD study investigates the monitoring potential of fiber-optic distributed strain sensing (DSS) using a measurement cable which is installed in the annulus of a well. Like distributed temperature sensing (DTS), which is used for temperature monitoring in industry applications for many decades, fibers also transport information about their mechanical stress state. Laboratory and theoretical work was performed to assess the effect of load changes on a standard telecommunication fiber. Afterwards, the influence of multilayered downhole cable on the strain response is examined. This study shows field data from two stages of a well completion – the filter gravel packing and the cementation of the production casing. Due to difference in density of gravel and drilling fluid, a deformation is measured on the cable. The depth at which the stretching occurs correlates with wire-line gamma-gamma density data measured comtemporously. The subsequent solidification of the gravel head, which was not revealed by the logging measurement, was detected by the installed cable in the form of an increasing mechanical load on the cable. During cement pumping, fluid shear stresses create a measurable load on the cable, especially in the mixing zone of liquids with different rheological properties. DSS measurements extend the understanding of fluid displacements in wellbores and allow an assessment of well completion process in real-time.



Geothermal Resources in Nigeria

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The geothermal resources in Nigeria is one that has received little attention in the last decade with respect to research and development. These resources are widely spread across the country, giving room for new frontiers in research especially in the development of new alternatives for power generation to augment the current low power output in the country. Research studies have shown that there are high potentials for geothermal energy in the country coupled with the good underground storage potential, environmental impact advantage and a very good geothermal enthalpy resource characteristic, it is important to draw attention to these vast resources waiting to be explored.



Travertine and Tufa Deposits in An Arid Environment, Controlled By Palaeo-Thermal Springs Related To Regional Faults, Case Study Of Jebal El Mzar (Southeastern Tunisia)

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Located in North Africa, Tunisia has an important geothermal potential. It is known with more than 90 thermal manifestations including 50 thermal springs (Temperature ranging from 20° C to 75° C). The Southern part of Tunisia represents an important hydrothermal basin with a lower and medium energy used in bathing (Hammams and pools) and Greenhouses and oasis irrigation. Their most important aquifers are: the 'continental intercalaire' aquifer, the complex terminal aquifer, the sand and sandstone Triassic aquifer and the Plio-Quaternary aquifer. The project of my PhD thesis is addressed to analyze for the first time: the tufa, travertine, banded calcite veins and springs mounds deposits located in the paleo-geothermal area of Southern Tunisia in order to make sure their origin and their formation scenario by highlighting the occurrence of buried or unexposed regional faults and its role played in controlling and channeling hydrothermal fluid flow (active and fossil). A field work investigation and geochemical, sedimentological, petrographic, diagenetic and petrophysical studies were carried out for the first time from Jebal El Mzar (Tataouine city, Southern Tunisia) highlighted the presence of tufa mounds and fissure ridge-type travertine deposits, Miocene in age (Aquitainian), related to palaeo-hot springs (the Triassic sand and sandstone) , aligned along the major active Gafsa-Jeffara fault trending NW-SE. Moreover, we have identified seven tufa lithofacies : Stromatolites ,Phytoherm Limestone of stems (palisades and bushes),Phytoherm Limestone of stems (curtains) ,Phytoherm Limestone of bryophytes , Phytoclastic Limestone ,Massive or laminated marls and Speleothem Limestone and two travertine lithofacies : Crystalline crusts and Banded travertines , firstly described in this locality.



Collective Versus Individual ATES System Performance with Optimal Utilization of Subsurface Space in High Density Areas

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Heating and cooling of buildings contributes to about 40% of the total worldwide energy end-use and is therefore an important source of Green House Gas (GHG) emissions. In many buildings a discrepancy exists between the availability and need for thermal energy for space heating and cooling during the year. Sustainable heating and cooling of such buildings can be done by seasonal or diurnal heat storage and recovery in aquifers. As a result, Aquifer Thermal Energy Storage (ATES) systems are increasingly used to reduce primary energy consumption and provide sustainable heating and cooling. In the Netherlands, ATES is widely used and ATES systems tend to cluster in urban areas. Management of subsurface space use for ATES is therefore important to prevent negative interaction between wells of nearby located ATES systems. Therefore, the goal of this study is to assess the effect of dense ATES well placement policies on the primary energy use of individual ATES systems. To obtain this insight, a simulation study is carried out. Spacious and dense ATES well placement policies are applied while these ATES wells are connected to a newly developed and benchmarked highly detailed model of the ATES system climate installation for each building in the simulation. The subsurface interactions between the wells of different buildings is simulated in a groundwater model including all ATES well. Comparing the primary energy use of the ATES systems under the various ATES well placement policies will then provide the insight in how subsurface interactions between ATES wells at dense and spacious setting affect their primary energy use and individual GHG savings as well as the overall GHG savings from ATES systems in the specific aquifer. The results of this study confirm insights from previous studies that there is a strong correlation between increased use of subsurface space and the negative effect on the recovery efficiency of ATES systems. However, this study shows that decreased recovery efficiency does not have a significant effect on the primary energy use of these individual buildings. On the other hand, extensive subsurface space use provides the possibility for to the accommodation of more ATES systems which leads up to a 40% decrease in GHG emissions in the next decade compared to spacious well placement policies. The results of this study therefore suggest that denser well placement policies can be used to accommodate more ATES systems while having no significant effect on the performance of individual buildings with ATES.



Well Placement for CO₂ Plume Geothermal Electricity Generation

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The primary goal of the present work is evaluation and comparison of vertical and horizontal well placements and their impact on the power output of a CPG (CO₂ Plume Geothermal) system. Performances of vertical and horizontal wells arranged in a repeated five-spot pattern are evaluated for single- and multi-phase flow cases. Numerical models were developed in MOOSE (Multiphysics Object Oriented Simulation Environment), tested and compared against each other and previous studies. The study discusses the accuracy of present models, the effects of buoyancy, phase mobilities and different well placements on the power output of CPG systems.



Behavior of Selected Organic Compounds in Brines of Different Composition at High Temperature & Pressure Conditions

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The efficiency of geothermal utilization depends heavily upon the behavior of the fluids that transfer heat from the subsurface to the power plant, which is determined by their chemical and physical properties. In terms of the chemical properties, there are few data on the composition and stability of organic components in geothermal fluids. This presentation focuses on this area, and the work forms part of the REFLECT project (Redefining geothermal fluid properties at extreme conditions to optimize future geothermal energy extraction). Organic components play an important role and are frequently found in sedimentary basin fluids. They serve as nutrients for microorganisms and can affect fluid chemical properties by complexation, and fluid physical properties through decomposition with increasing temperatures. While both, inorganic and organic compounds affect fluid properties, the following laboratory experiments intend to focus on the composition of organic compounds in natural geothermal fluids, and also their stability in very high salinity ($X > 35$ g/L) synthetic geothermal fluids. A range of organic compounds in aqueous solution will be analyzed using Fourier-Transform Infrared Spectroscopy (FTIR) to determine their molecular composition under elevated temperature & pressure up to 200°C and 200 bar. These preliminary experiments should give a first insight into the stability of organic compounds in high salinity geothermal fluids, and contribute to future studies aimed at optimizing geothermal energy production.



Water-Rock Interactions in Geothermal Systems in the Framework of CO₂ Storage

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The alarming increase of CO₂ concentrations in the atmosphere and its effects on global warming, have led the scientists to seek for a solution for the mitigation of anthropogenic CO₂ emissions. Carbon Capture and Storage (CCS), being one of the major strategies, involves the injection of CO₂ into subsurface geologic formations (e.g. deep saline formations). The assessment of CO₂-water-rock interactions is an essential part of CCS, as both the movement and entrapment of CO₂ depend on the geochemical characteristics of the reservoir. In this study, selected geothermal fields from Turkey are considered as potential CO₂ storage sites and the dominant hydrogeochemical processes as well as the possible trapping mechanisms in these systems are evaluated. The assessment of CO₂-water-rock interactions are performed with the utilization of various geochemical approaches including the geochemical characterization of the system, speciation-solubility calculations and modelling studies (equilibrium modelling, kinetic modelling, inverse modelling, and dedolomitization modelling). Prior studies are performed using the published data of the selected fields whereas current work includes geochemical-mineralogical investigations on drill cuttings from two fields (Akköy-Denizli and Edremit-Balıkesir). Since the mineralogy of the reservoir rocks are the input parameters that highly affect the results of the geochemical models, the determination of the mineralogy and the abundances of these minerals are quite important in CCS studies. The litho-geochemical characterization which is to be used as inputs for prospective geochemical modelling, constitutes the current focus of my studies.



Optimization of Production and Injection of Geothermal Fields: A Machine Learning Approach

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Optimizing field injection and production requires a calibrated numerical model, typically consisting of thousands of grid blocks. Optimization carried out using such a model usually takes a very long time. If the numerical model is replaced by an accurate proxy model, run-time can be significantly reduced. A numerical model has been developed using TOUGH2 to optimize the production of Kızıldere geothermal field. A proxy model developed in Python is used to optimize the production and injection of the field. The results are compared with the TOUGH2 model. The proxy model results are consistent with the field model. This approach significantly reduces time and effort.



REE Systematics of Reservoir Rocks in Kızıldere Geothermal Field, Turkey

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Kızıldere Geothermal Field is located on the easternmost of the Büyük Menderes Graben, Western Turkey. This graben and several other grabens, which have been developed almost parallel to each other, are located at the easternmost of Aegean Extensional System. Among the several liquid dominated reservoirs hosted in fractured sedimentary and metamorphic rocks, this study focused on the reservoir in mica-schist units with secondary permeability. The REE mobility has been investigated considering mineralogy and geochemical composition of reservoir rock, in this high-enthalpy geothermal field. Drill cutting samples are collected as depth-dependently throughout a geothermal well. XRD analysis of the samples has been conducted to determine the mineralogical composition. REE compositions of the same samples have been determined using ICP-OES technique. This data evaluated along with the well-log data to assess the relations between mineralogy and REE composition within the scope of this study. Our data suggest that the samples can be divided into two groups as altered rocks caused by hydrothermal effects from fault zones, and unaltered rocks from outside of the fault zones. These grouping has been based on alteration mineralogy, and well-log data such as mud loss and temperature changes detected during drilling. According to XRD analysis, the major constituents of the samples are quartz, albite, muscovites, and chlorite. Illite, kaolinite, dickite, calcite, dolomite, and ankerite accompany to this primary mineralogy at the fault zones. REE compositions have been tested statistically to reveal the differences between these two groups are whether meaningful. PAAS-normalized REE results indicate that samples represent fault zones have not shown completely different patterns from out of the fault zone samples. The altered samples that secondary minerals identified in it, however, show meaningful negative Ce anomalies and lower normalization values. In the first sight, these can be indicated REE addition to the system with hydrothermal fluids. REE is retained mainly by secondary minerals in rocks and sorption on mineral surfaces. Although differences between two groups cannot be followed on $(La/Lu)_n$, $(La/Sm)_n$, and $(Gd/Lu)_n$ ratios, according to the result of the Mann-Whitney U test results, $\sum REE$ differs between two groups statistically. It can be said that the difference of $\sum LREE$ between two groups caused the regarding difference rather than the difference of $\sum HREE$.



Flowing Bottomhole Pressure Prediction in Geothermal Production Wells by Using Artificial Neural Networks

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Reliable bottomhole pressure measurements are key to effective reservoir monitoring and reservoir management. In geothermal fields, the main application for monitoring reservoir pressure is recording static bottomhole pressure using observation wells. Although observation pressure data could be used as an indicator for local reservoir pressure behaviour, it may not be a representative measure for overall reservoir behaviour due to placement of the observation well. In order to quantify reservoir pressure response to production, it is favorable to use flowing bottomhole pressure data of production wells as it is directly related production rate, reservoir properties and wellbore conditions. Since the sensor technology for pressure recorders is limited by ambient temperature, it is harder to record flowing bottomhole pressures constantly due to high flowing temperatures in geothermal wells. It is more applicable to conduct dynamic PT (pressure, temperature) surveys on production wells for monitoring of flowing bottomhole pressures. In this study, an alternative workflow for monitoring bottomhole flowing pressure is proposed in which flowing bottomhole pressure will be predicted from surface measurements by using artificial neural networks.



Reactive Transport Modeling of CO₂ Injection into Kızıldere Geothermal Field

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Geothermal energy is commonly recognized as an environmentally friendly source of energy. However, the co-produced non-condensable CO₂ gases are considerably high in the geothermal fields of Turkey which adversely affect the general opinion about geothermal energy. An efficient method to mitigate the CO₂ emission of geothermal power plants is to re-inject the captured CO₂ into the deep geological formations. One of the major concerns in such applications is to predict the geochemical interaction between the injected brine- CO₂ and rock, and the corresponding changes in the reservoir parameters. In this study, reactive transport modeling (coupling between subsurface fluid flow and chemical reactions) was conducted with TOUGHREACT program for a potential operation of brine-CO₂ injection into deep metamorphic formation rocks of Kızıldere geothermal field. The reactive transport model was constructed based on the existing heat transfer and flow model of the field. Permeability distribution was determined by analyzing mud-loss data of the re-injection well and the nearby production wells. Batch reactions between chemical species of geothermal fluid and CO₂ gas was carried out using PHREEQC program. The results demonstrate that injecting CO₂ into geothermal reservoirs is not only an efficient method to reduce the CO₂ emission of geothermal power plants but also contributes to the reservoir pressure and thus increases the power plant performance.



Comparison of Büyük Menderes and Gediz Grabens Hydrogeochemical Parameters in Turkey

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The Büyük Menderes Graben (BMG) and the Gediz Graben (GG) are two major graben systems which have important medium-high temperature geothermal systems for electricity production. High temperature geothermal systems are located in highly fractured zone because of the Aegean Extensional. Although the main reservoir rocks have more or less similar compositions in each graben system, the geothermal fluids chemistry could present variable results along the BMG and GG such as a paleosea effect, the concentration of non-condensable gases (NCG), as well as mineral effects.

Although water chemistry parameters are dependent on reservoir rock, heat source and temperature values in general, due to the fluid chemistry, isotopic compositions and pH values, thermal waters in Alaşehir and Germencik is different from Kızıldereli located at the intersection of BMG and GG. Results for $\delta^{13}\text{C}$ isotopes indicate that the origin of the large amounts of CO_2 is the marble in metamorphic rocks in the reservoirs in both graben systems. $\delta^{34}\text{S}$, $\delta^{34}\text{S}-\text{SO}_4$ and $\delta^{18}\text{O}-\text{SO}_4$ values indicate that the origin of SO_4 indicates that the origin of sulphur looks gypsum in the east edge of the BMG while mantle sulfur contribution is possible for Alaşehir geothermal system in the GG. Although both these graben systems have different type hydrocarbon evidences, oil wells exist close to Alaşehir geothermal system in the Gediz Graben.



Combined ERT and EM for Laboratory Modelling Experiment

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This study aims to elaborate an experimental modeling process for buried plastic and metal pipes in a 2 x 0.68 x 0.68-meter Metal Free Model Tank (MF-MT) which was constructed by using 5 tempered glass sheets glued together with silicone and reinforced with a wooden frame. Models were prepared by burying pipes in shallow depth to be then the subject of Electrical Resistivity Tomography (ERT) and Electromagnetic (EM) measurements. The ERT measurements were accomplished by using 50 electrodes with an interspacing of 4 cm. Resistivity data was collected for the Wenner array for both metal and plastic buried pipes. The collection of electromagnetic data was assured using two emitter and receiver coils winded in the laboratory and equipped with a power amplifier, a function generator and an oscilloscope. Results showed high accuracy proving the efficacy of the applied methods in locating buried pipes.



A Coupled THC Modelling Approach Based on Outcrop Analogue Samples and Borehole Data from the Variscan Crystalline Basement in Cornwall (UK): A Case Study for EGS

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The EU H2020 funded ‘MEET’ project (‘Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potentials’, grant agreement no:792037) assesses the four different geological settings of Variscan basement as reservoir rocks for potential EGSs. The study presented here, as a part of MEET project, specifically focuses on the Cornubian batholith in SW England chosen as representative of the crystalline Variscan basement not overprinted by younger tectonic regime.

With the ambition to increase the clean energy share in United Kingdom’s energy portfolio, Cornwall has been the focus of deep geothermal resource studies starting from 1980s with the Rosemanowes Hot Dry Rock project conducted in the region and continuing today with the United Downs Deep Geothermal Power Project (UDDGP), the first deep geothermal power project of UK. The main reason of this interest is the high heat flow arising from the radioactive decay of U, Th, K elements within the Cornubian batholith.

The present work aims to investigate the untapped geothermal potential of fractured Cornish granite in more detail. To do that representative samples from the Cornubian Batholith were taken from the outcropping Land’s End, St. Austell and Carnmenellis pluton. 47 granitic samples with a total weight of 1 ton, were collected from fractured and/or hydrothermally altered areas of 19 outcrops representative of the fracture and fault zones within the United Downs wells. 254 cores with different diameters were drilled in the HydroThermikum Research and Teaching Laboratory of Technical University Darmstadt to do a comprehensive petrophysical and rock mechanical characterization. 50 samples were selected to prepare thin sections, required for a detailed petrographic analysis including degree of weathering or alteration and fluid inclusions.



The UDDGP was selected as the demonstration site for the MEET project and data was provided by its two recently drilled wells (UD-1: 5,275 m MD, UD-2: 2,393 m MD) targeting the Porthtowan Fault zone (PTF), which is a 40 km long NW-SE trending strike-slip fault. Drill cuttings from 44 sections representing 10 m intervals each, were taken from the potential target zones between 3,980 and 5,275 m MD in UD1 with intense fracturization, fluid losses, gas intrusions and/or anomalies in the geothermal gradient. Additional data was available from the Rosemanowes hot dry rock project site, which within MEET was selected as reservoir analogue site; this included fracture network characterization from well logs as well as hydraulic parameters of the deeper sections drilled into the Carnmenellis granite.

We defined a conceptional workflow for a coupled thermo-hydraulic-chemical model, which is planned to be set up using FRACMAN and COMSOL to evaluate and analyze whether a sustainable operation of the reservoir is possible and what flow rates can be achieved with realistic pressure differences between producer and injector. Additionally, time till thermal break through assuming different values for fault zone permeability shall be assessed.

If the natural productivity is insufficient part of our task within MEET is to develop a chemical stimulation strategy. Therefore, lab investigations on how to enhance the fluid flow in fractured granite, based on the state-of-the-art techniques for chemical stimulation developed in ongoing EGS projects in the Upper Rhine Graben, e.g. Soultz-sous-Forêts and Rittershoffen have been applied. These lab experiments aim to quantify the possible permeability increase by chemical treatment of the fractured samples and are designed to select the best chemical blend for increasing permeability at reservoir scale.

Measurement of the petrophysical (grain density, permeability, bulk density and porosity, compressive and shear velocity, thermal conductivity, thermal diffusivity, heat capacity and radiogenic heat production) and rock mechanical properties (uniaxial compressive strength, Poisson's ratio, Young's modulus, bulk modulus and compressibility as well as tensile strength, shear strength, cohesion, coefficient of friction and shear modulus and finally Biot and Skempton coefficients) on outcrop analogue samples are still ongoing.

Planned future work includes, but is not limited to, petrographic analyses of thin sections made out of drill cuttings of the production well UD-1 and outcrop analogue samples. Additionally, petrophysical and petrographic analyses of sidewall cores, planned to be taken in March 2020, will be performed. This input data will be used for a statistical parametrization of the numerical model of the system.