Third European Geothermal Review

Geothermal Energy for Electrical Power Production

Abstracts & Papers – Tagungsbeiträge

June 24 – 26, 2013

FAVORITE Parkhotel
City of Mainz, Rhineland Palatinate
Germany

BESTEC GmbH
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Dear Friends, Colleagues and Business Partners.

- Geothermal in the spotlight -

In recent years, the number of geothermal power plants for heat and electrical power production has increased steadily in Central Europe. In Germany, this does not only apply to the deep geothermal systems in the Molasse Basin, but also to wells drilled in the Upper Rhine Graben. In this geologically challenging region, two demonstration plants were developed and implemented in Insheim and Landau. After five years of valuabel operational experience, plans are currently made for a second injection well in Landau. In hindsight, this can be seen as a particularly positive development, since, after a series of seismic events in Basel and Landau in the years of 2006 and 2009, operators had found themselves at the center of a controversial public debate. There certainly is a need to promote geothermal energy and to inform about its risks and advantages in order to ease public anxiety. How can public involvement be implemented and facilitated? How have other countries tackled the issue of public involvement? As a consequence of the Fukushima nuclear disaster, the German government implemented a drastic change in energy policy, known as Germany's energy turn-around. Nevertheless, we may have to ask ourselves if Germany's energy turn-around indicates a global trend towards alternative energies and what role geothermal energy will play in this context?

We believe all this to be enough reason to again cordially invite you to join us during the
"Third European Geothermal Review" in Mainz, Germany, June 24 - 26, 2013

We would like to openly debate all aspects, problems, opportunities and challenges of power production from geothermal energy with you. We want to share experiences, listen to your problems and discuss future strategies and technologies. Geothermal resources cannot be carried from one continent to another. We are bound to be linked to the ground beneath our feet. Therefore, we believe that communication links in our geothermal industry should be much less restricted for reasons of competition and professional secrecy than in any other energy industry. Let's make use of this advantage, let's jointly make geothermal stronger, more successful!

Welcome in Mainz!

Dr. Jörg Baumgärtner & The BESTEC team!

Sehr geehrte Freunde, Kollegen und Geschäftspartner.

- Geothermie im Fokus -

In den letzten Jahren hat die Zahl der geothermischen Kraftwerke zur Strom- und Wärmeerzeugung in Mitteleuropa stetig zugenommen. In Deutschland betrifft dies nicht nur den Ausbau der tiefen Geothermie in der Molasse sondern auch die Anlagen im Oberrheingraben. In dieser geologisch anspruchsvollen Region wurde nach Landau nun auch in Insheim ein Demonstrationsprojekt entwickelt. Parallel dazu wird das Geothermiekraftwerk Landau, nach nun mehr als fünf Jahren wertvoller Betriebserfahrung, um eine zweite Injektionsbohrung erweitert. Das ist erfreulich, da sich in Folge der seismischen Ereignisse in Basel und Landau in den Jahren 2006 und 2009 die Geothermiebetreiber und -entwickler plötzlich im Zentrum einer kontroversen öffentlichen Debatte wiederfanden. Der Großteil der öffentlichen Reaktion war und ist sicher der Tatsache geschuldet, dass die Informations- und Öffentlichkeitsarbeit auf Seiten der Geothermiebetreiber aufgenommen und weiter ausgebaut werden muss, um Sorgen und Ängste der Bürger abzubauen. Wie kann dies in die Praxis umgesetzt werden? Wie wird in anderen Ländern mit solchen Herausforderungen umgegangen? Als Konsequenz aus dem Atomunfall in Fukushima in 2011 hat die Deutsche Bundesregierung für Deutschland eine Energiewende eingeleitet, die sich ganz wesentlich auf erneuerbare Energien stützen wird. Findet ein weltweites Umdenken in Sachen Energiemix statt? Welche Rolle spielt die Geothermie dabei?

Vor diesem Hintergrund möchten wir Sie herzlich zu dem
"Third European Geothermal Review" in Mainz, Rheinland-Pfalz vom 24. - 26. Juni 2013 einladen.

Wir möchten gemeinsam mit Ihnen alle Aspekte, Probleme, Chancen, Potentiale und Herausforderungen bei der Nutzung der geothermischen Energie kontrovers diskutieren. Geothermische Ressourcen sind ortsgebunden, Erfahrungen beziehen sich oftmals auf lokale Strukturen, lassen sich nicht einfach übertragen. Dies eröffnet uns im Bereich der Geothermie die Chance, über Länder- und Firmengrenzen hinweg offen diskutieren zu können. Lassen Sie uns diesen Vorteil der Geothermie nutzen!

Willkommen in Mainz!

Dr. Jörg Baumgärtner & Ihr BESTEC team!

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Welcome, Background and Motivation for the Third European Geothermal Review

Dr. Jörg Baumgärtner

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- Geothermal in the spotlight -

In recent years, the number of geothermal power plants for heat and electric power production has increased steadily in Central Europe. In Germany, this does not only apply to the deep geothermal systems in the Molasse Basin, but also to wells drilled in the Upper Rhine Graben. In this geologically challenging region, two demonstration plants were developed and implemented in Insheim and Landau. After five years of valuable **operational experience**, plans are currently made for a second injection well in Landau.

In hindsight, this can be seen as a particularly positive development, since, after a series of seismic events in Basel and Landau in the years of 2006 and 2009, operators had found themselves at the center of a controversial public debate. During that time, geothermal energy was not only in the political spotlight, but also publically contested by local citizens. The lesson to be learned from the strong **public reaction** against geothermal energy is that operators still have a ways to go in terms of public interest in acceptance. There certainly is a need to promote geothermal energy and to inform about its risks and advantages in order to ease public anxiety.

With the purpose of inciting a meaningful dialogue between operators and local citizens, in January of 2011, the federal government of the Rhineland-Palatinate organized a mediation session on deep geothermal systems in the south-eastern Palatinate. The technical discussions of the mediation were completed in March 2012 with a paper of agreement. Throughout the mediation process, representatives of both sides had worked and finally agreed on a set of general regulations for the development of future geothermal projects in that region. A crucial aspect of said agreement was the question of how to **involve locals**. How can public involvement be implemented and facilitated? How have other countries tackled the issue of public involvement, particularly with regard to authorities? Is there adequate previous experience in promoting public acceptance?

- Germany's energy turn-around -

As a consequence of the Fukushima nuclear disaster, the German government implemented a drastic change in energy policy, known as Germany's energy turn-around, a process that will be primarily based on the development and use of alternative energy resources. Nevertheless, we may have to ask ourselves if Germany's energy transition indicates a global trend towards alternative energies and what role geothermal energy will play in this context.

It is the primary goal of the "Third European Geothermal Review" to discuss future strategies and technologies in the field, with a particular focus on recent challenges in the development and operation of geothermal production plants. The conference is intended as an international forum that offers the kind of much needed dialogue long established in neighboring fields of alternative energy technology.

We are looking forward to a lively discussion regarding all aspects, problems, potentials and challenges related to the use of geothermal energy and its image in the public eye.

Welcome to the

Third European Geothermal Review!

The International Energy Agency – Geothermal Implementing Agreement: Activities to Encourage Sustainable, Cost-effective, Global EGS Deployment

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Key Words
international geothermal collaboration, IEA-GIA, sustainable use, EGS

SUMMARY

The International Energy Agency (IEA)-Geothermal Implementing Agreement (GIA) was established in 1997. It provides the opportunity for international cooperation, under the auspices of the IEA, through links between national and industry programmes for geothermal exploration, development and resource utilization. Effectiveness is enhanced through direct cooperation among experts in member countries, industries and organizations. Participants are provided with opportunities for information exchange; participation in R&D projects and in the development of techniques, best practices, databases, models and handbooks; and exposed to global perspectives on geothermal issues and sustainable development strategies. The GIA emphasizes production and dissemination of impartial, authoritative information. As one of 41 Implementing Agreements, the GIA supports the IEA's aims to develop a sustainable energy policy that incorporates energy security, economic development, environmental awareness, and participation with non-member countries.

The IEA has recently extended the GIA's mandate for a 4th 5-year term, continuing its activities to 2018. Our mission is: *to promote the sustainable utilization of geothermal energy worldwide by optimizing international collaboration to improve technologies, thereby rendering exploitable the vast and widespread global geothermal resources, by facilitating knowledge transfer, by providing high quality information and by widely communicating geothermal energy's strategic, economic and environmental benefits, hence contributing to the mitigation of climate change.* To realize this mission, the GIA is working on six wide-ranging topics, termed Annexes: I- Environmental Impacts of Geothermal Energy Development, III- Enhanced Geothermal Systems, VII- Advanced Geothermal Drilling Techniques, VIII- Direct Use of Geothermal Energy, Annex X- Data Collection and Information, and Annex XI- Induced Seismicity.

Three current GIA Annex III activities are specifically aimed at encouraging EGS development and deployment:

1) Review EGS demonstration projects located near hydrothermal systems (Desert Peak and Brady Hot Springs) to identify natural conditions and critical parameters, methodology and technology, to improve reservoir performance, evaluate how stimulation affects performance, and produce a "lessons learned" document to facilitate successful deployment and drive future research;

2) Assemble a handbook of the "current state of the art" in EGS reservoir understanding, stimulation and analysis, which will be available as a guide for future projects and lead to a better understanding of reservoir properties, stimulation methods and reservoir life.

3) Review terminology for global geothermal energy potential and production reporting, which will help develop an internationally adopted classification and terminology framework.

The Annex VII internationally reviewed **Handbook of Best Practices for Geothermal Drilling** and the well cost calculator being developed have direct application to the viability of EGS development and deployment, since well drilling and logging costs in geothermal environments, and especially for the deep (3-5 km) EGS wells, make up a large proportion (up to 50%) of the total project cost of a combined heat and power (CHP) or EGS power plant. As part of its outreach programme, the GIA is also supporting an Annex VII initiative to fund participation of international participants at the Geomechanical Challenges Associated with Geothermal Drilling, Stimulation and Production Session of the 47th US Rock Mechanics/Geomechanics Symposium (23-26 June 2013) and will make available the appropriate material on the GIA public website.

Of considerable importance to EGS deployment is induced seismicity (IS), both for the information it provides about reservoir stimulation and development (management), and because of the need to address any felt IS in a manner that is acceptable to the public, regulators and policy makers. Annex XI is working to determine the steps needed to make EGS fluid injection a safe, useful and economic technology by: 1) developing a set of risk mitigation strategies and best practices; and 2) using IS for optimizing production from geothermal reservoirs. GIA's initial IS activity was in Annex I, when a ***Protocol for IS Associated with***

EGS was produced (2008). Annex XI is working closely with other collaborating organisations (IPGT and GEISER) to ensure the optimal focus of research effort and appropriate dissemination of results.

The GIA was instrumental in the production of the IEA Geothermal Roadmap (June 2011), one of the key energy technology roadmaps prepared by the IEA at the request of the G8 to enable international advancement to 2050. The IEA geothermal roadmap provides a clear growth path that identifies technology, financing, policy and public engagement milestones required to attain geothermal's full potential, with special emphasis on emerging economies and the importance of international collaboration. EGS is clearly identified as a key emerging technology, that can be applied almost anywhere in the world, and provide half of the envisioned 1,400 TWh/yr of geothermal electricity generation (3.5% of global power production) and significant heat for direct use applications (CHP with EGS). Three notable trend-setters are located nearby within the Rhine Graben, at Soultz, Landau and Insheim.

The challenge for the future is to facilitate a scale-up of such projects by several orders of magnitude, worldwide.

The importance of sustainable energy utilization is internationally recognized, and a part of the GIA's mission. Annex I is pursuing its studies of sustainable geothermal utilization strategies on several fronts: including compiling/examining case histories of long-operating geothermal developments to identify successful operational strategies, and comparing various sustainable development scenarios to determine relative environmental and economic benefits. Current international activities are discussed and results widely disseminated through GIA international sustainability modelling workshops (in New Zealand and Mexico), and the production of a Geothermics Special Issue on Sustainable Utilization of Geothermal Energy. Activities include reviewing the relative importance of various monitoring data, tracer and interference tests, on constraining reservoir simulations and thereby improving long-term sustainable management strategies. This effort will become increasingly relevant to long-term EGS performance projections as several EGS projects attain a credible operation history. Predictions can then be matched against performance and strategies adjusted if necessary.

Partizipation – neue Herausforderungen für Unternehmen

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Zusammenfassung

Mit dem Start der Energiewende wurde der Einsatz erneuerbarer Energien fast immer positiv aufgenommen. Mittlerweile wächst die Erkenntnis: Auch die Energiewende hat ihren Preis. Die Erzeugungsanlagen rücken näher an die Bebauung, sind sichtbarer und stellen somit häufiger eine Beeinträchtigung oder Bedrohung für den Bürger dar.
Die Betroffenheit und Ohnmacht des Bürgers gegenüber allem Möglichen ist damit massiv gestiegen. Der Bürger traut den Politikern und den Unternehmen nicht mehr zu, die Probleme unserer Zeit zu lösen. Und er quittiert dies mit Partizipationsdrang. Verstärkung des Netzausbaus, Beeinträchtigung des Landschaftsbildes, Geruchsbelästigung durch Biogasanlagen, Zunahme des LKW-Lieferverkehrs für Holzhackschnitzel oder Lärmbelästigung durch Anlagenbetrieb – der Bürger will mitreden und sich einbringen. Recherchen im Internet bieten dafür in Sekundenschnelle scheinbares Expertenwissen für die Echtzeitgesellschaft des Web 2.0.

Neben dem Begriff der *Energiewende* hat sich auch die Formulierung *German Angst* international etabliert. Ängste sind hierzulande häufig der Grund für die Ablehnung neuer Technologien. Und selbst eine so saubere Art der Energiegewinnung wie die Geothermie löst Ängste und Proteste aus, weil mit seismischen Ereignissen Existenzängste um Hab und Gut geweckt werden. Mittlerweile werden die psychologischen Phänomene rund um die Energiewende auch von der Hirnforschung untersucht.

Die Unternehmen müssen heutzutage transparent und dauerhaft informieren. Aber das reicht bei Weitem nicht aus. Alles was zählt sind die *Momente der Wahrheit.* Jeder Mitarbeiter ist hier gefordert, denn die Summe der Einzelerlebnisse mit dem Unternehmen addiert der Bürger zu seiner Wahrheit. Schafft das Erlebte Akzeptanz, dient das Erlebnis dem Vertrauensaufbau und könnte es gar zum Loyalitätsaufbau beitragen? Oder weckt das Verhalt Misstrauen und bestätigt die Bürger in ihren Vorurteilen über das Unternehmen? Werden die Sorgen und Nöte wirklich ernst genommen, wie werden die Bürger eingebunden oder gar Schäden reguliert, begegnet das Unternehmen den Bürgern juristisch oder nachbarschaftlich? Partizipation hat viele Facetten und bedeutet ein Anpassen der Erlebnisfelder nach innen und nach außen.

Mediationsverfahren „Tiefe Geothermie Vorderpfalz“ – Ergebnisse und Chancen

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Zusammenfassung

Seit den ersten seismischen Reaktionen auf Grund des Betriebes des Geothermiekraftwerkes in Landau im August und September 2009 ist die Nutzung der Tiefen Geothermie im Bereich des Oberrheingrabens in der Öffentlichkeit umstritten. Weiteren Vorhaben in Rheinland-Pfalz begegnete die Bevölkerung mindestens kritisch, bisweilen ablehnend. Nicht immer glückliche Öffentlichkeitsarbeit von Unternehmen und Behörden trugen nicht unerheblich zu dem entstandenen Misstrauen bei.

Die Landesregierung Rheinland-Pfalz hat vor diesem Hintergrund das Mediationsverfahren „Tiefe Geothermie Vorderpfalz“ mit dem Ziel initiiert, in einem ergebnisoffenen und konstruktiven Dialog Lösungen für die zu Tage getretenen Probleme zu finden. In neun Sitzungen und vielen Arbeitsgruppentreffen wurden unter professioneller Leitung eines Mediators und Hinzuziehung unabhängiger Experten für die Problemschwerpunkte Lösungswege und Lösungen vereinbart. Thematisiert wurden die ökonomische und ökologische Bewertung der Energiegewinnung aus Tiefer Geothermie, die Beteiligung der Bürgerinnen und Bürger an der Entscheidung über solche Vorhaben, die Möglichkeiten der Standortsteuerung für Kommunen, die Minderung von Emissionen durch Schadstofffreisetzungen, Lärm und Erdbeben sowie der Umgang mit möglichen Gebäudeschäden und die Versicherbarkeit.

Mit der Unterzeichnung der Dokumentation der Verhandlungsphase konnten die bisher erreichten Ergebnisse festgehalten werden. Die Überleitung in das Geothermie-Forum Vorderpfalz eröffnet nun die Möglichkeit, offen gebliebene Punkte einer Lösung zuzuführen und bestehende Projekte zu begleiten.

Das Mediationsverfahren hat einen wichtigen Beitrag zur Versachlichung der Diskussion um die Tiefe Geothermie geleistet. Für die unterzeichnenden Unternehmen steht mit den Ergebnissen ein Instrumentarium zur Verfügung, sich frühzeitig Planungssicherheit zu verschaffen. Für Unternehmen und Projektentwickler ist das Umfeld nun besser einschätzbar geworden. Mit dem Geothermielotsen beim Ministerium für Wirtschaft. Klimaschutz, Energie und Landesplanung des Landes Rheinland-Pfalz wurde darüber hinaus ein Ansprechpartner für Unternehmen installiert, der auf der Grundlage der Mediationsergebnisse eine zielgerichtete Beratung für Unternehmen, Mandatsträger und Bürgerinitiativen zur Verfügung stellen kann.

EGS-Projekte in der Schweiz: Kommunikation und Bewilligungsverfahren

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ABSTRACT

Die Geo-Energie Suisse AG entwickelt in der Schweiz ein Portfolio von drei bis fünf Standorten für EGS-Projekte. Aufgrund der Erfahrungen mit dem Projekt in Basel kommt dabei der Kommunikation und den Bewilligungsverfahren mit Umweltverträglichkeitsprüfung inklusive Risikostudien eine sehr grosse Bedeutung zu. Die Projekte sowie die bisherigen Erfahrungen bezüglich der Akzeptanz durch die Bevölkerung werden im Vortrag vorgestellt sowie einen Überblick zu den nächsten Schritten.

First acceptability study of an EGS plant in northern Alsace: the Soultz-sous-Forêts case study

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ABSTRACT

An opinion survey about social acceptability of the Soultz geothermal power plant located in northern Alsace has been carried out. About 203 individual interviews were conducted during summer 2012 with a representative sampling of the local population of Kutzenhausen and Soultz-sous-Forêts. A detailed questionnaire was presented in order to test the sensibility of the local population about this rather new and unacquainted technology. More than 200 adults fulfilled the questionnaire and detailed answers were collected, analysed and interpreted in order to get a better understanding about deep geothermal energy in general and risk acceptability in particular.

The main results of this investigation show that both, the lack of information and the low level of knowledge about geothermal energy of the local population are clearly proved. Moreover, it appears that the local population is not aware about the potential risks. The main cause of nuisance which is felt is related to the noise generated by the technical equipment of the power plant. Other risks, such as induced seismicity, pollution or natural radioactivity do not seem to worry the population.

This study also clearly demonstrated that communication has to be enhanced by using different media such as press, local newspaper, as well regular and updated public information meetings. In conclusion, the risks and nuisances related to the geothermal exploitation are rather accepted as a whole by the local population however some improvements must be done in terms of communication.

Geothermie-Anlage Sauerlach: Planung, Bau und Inbetriebnahme des Heizkraftwerks

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ABSTRACT

Im Rahmen ihrer Ausbau Offensive „Erneuerbare Energien" realisieren die Stadtwerke München in der Gemeinde Sauerlach, ca. 25 km südlich von München ihr erstes Geothermie-Heizkraftwerks-Projekt. Die Umsetzungsphase dieses Projekts begann mit dem Bau des Bohrplatzes im Juni 2007. Die Bohrarbeiten dauerten von Oktober 2007 bis August 2009. Es wurden drei Bohrungen mit Teufen von 4.757 bis 5.567 m MD abgeteuft. Im Juni 2010 wurde der Auftrag zur Errichtung des Geothermie-Heizkraftwerks an die Fa. Karl Lausser GmbH als Generalunternehmer vergeben. Im Februar 2011 begann mit dem Rückbau des Bohrplatzes die Errichtung des Geothermie-Heizkraftwerks. Die Inbetriebnahmephase begann mit der Inbetriebnahme der Tauchkreiselpumpe und wird derzeit mit der Inbetriebnahme des ORC-Kreislaufs fortgesetzt. Bis zum Kongress soll die Anlage planmäßig im Dauerbetrieb sein, so dass geplant ist über erste Betriebserfahrungen zu berichten.

Der Vortrag gibt einen Überblick über die Geschichte des Projekts von der Motivation bis zum Bau des Heizkraftwerks. Den Schwerpunkt bilden die Darstellung des Anlagenkonzepts sowie der eingesetzten Technik. Es wird über die Erfahrungen aus der Inbetriebnahme der Tauchkreiselpumpe und des Kraftwerks berichtet. So weit möglich werden erste Betriebserfahrungen berichtet.

Geothermal 2.0: The Insheim Geothermal Power Plant The second generation of geothermal power plants in the Upper Rhine Graben

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ABSTRACT

Southeast of the community Insheim, in South-Palatinate (Germany), the second geothermal power plant in the megawatt range in the Upper Rhine Graben was established in the period between 2008 to 2012. At the end of the year 2008 PFALZWERKE AKTIENGESELLSCHAFT acquired 100 percent of the shares of the „HotRock geothermal power plant Insheim GmbH & Co KG“. Planning for a deep geothermal power plant at this location had already started in spring 2007. Since late 2008, the project is operated by Pfalzwerke geofuture GmbH, a 100 % subsidiary of PFALZWERKE, the largest energy provider in Palatinate and the Saar-Palatinate district. The project was executed by BESTEC GmbH from Landau who acted as general contractor for the whole project. Conditions for geothermal energy use are particularly advantageous in the area near Insheim: In approximately 3,800 meters depth, temperatures of more than 165 °C were measured.

The power plant in Insheim is able to supply around 8,000 households with electricity. The residual heat from electricity generation can also be used for district heating to about 1000 households. Alternatively local businesses can be supplied with heat. Both options are currently being evaluated. Power power plant operation and maintenance at Insheim is presently performed by BESTEC Services GmbH, who also operates the Landau geothermal plant.

Until May 2009, 2 deep wells were successfully drilled for the geothermal power plant to depths over 3,800 m. Several months of circulation experiments in the summer and fall of 2009 demonstrated that the injection well was not sufficiently permeable. Therefore, in April 2010 several hydraulic stimulation tests were performed in this borehole with stepwise increasing injection rates. A sensitive seismic monitoring network as well as a special „immission data network” for the recording of ground vibration velocities secured the controlled and safe execution of these investigations. Unfortunately, a thorough evaluation of the results of these tests showed that the hole still was not sufficiently permeable.

With the aim to distribute the water in the underground at larger scale, while reducing the micro-seismic risk further and also to improve the permeability of the hole, a second side arm („side-track“) near the bottom of the injection well was drilled from a depth of about 2,500 meters in the fall of 2010. Drilling was successfully completed by the end of

October 2010 despite numerous technical difficulties. Injection at Insheim occurs now through two borehole legs at the same time. During the hydraulic tests which were conducted immediately following the drilling operations in November 2010, no seismic activity was registered. The borehole showed during these experiments significantly improved hydraulic properties and fulfilled the required boundary conditions.

In spring 2011, an ORC power plant was ordered for Insheim at ORMAT SYSTEMS LTD in Israel with a rated electrical output of about 4.8 MW (at 10 °C ambient temperature). Because of the good experiences from Landau, again isopentane was chosen as medium for the binary cycle. Construction of the plant started in November 2011. First trial runs of the plant occurred only one year later, in early October 2012. The formal inauguration of the power plant was performed in the presence of government and industry in mid November 2012.

Geothermal Project Brühl – specific challenges for geothermal projects in Baden-Württemberg

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Key Words
Brühl, Regulatory Environment, Monitoring Systems

ABSTRACT

As a result of the induced seismic events in several geothermal projects, the lift up of the land surface in Staufen i.Br. and the subsequent substantial concerns of the population, but also the authorities and politicians, with respect to the potential damage of property, high obstacles have been raised in the federal state of Baden-Württemberg for the developers of geothermal projects in the form of regulations or the requirements for investigations/ expertises and monitoring systems.

On top of this in many regions of the Upper Rhine Graben area of Baden-Württemberg there is a strong competitive situation for the geothermal heat by “waste heat” from existing power plants or refineries. This leads to the situation that in many cities and towns there is no interest for geothermal heat and, as a result of this, little to no public political support from the communities for the development of geothermal projects - especially those initiated by private companies.

Due to the numerous requirements and regulations raised in the past years the initial development of the geothermal project Brühl has already consumed a time period of approx. 7 years until the completion of the first well. This imposes of course substantial “friction” to the financing of this project and also for subsequent geothermal projects. As a result of the specific requirements in Baden-Württemberg there is today with the Bruchsal project, drilled already in the 1990ies, only one project in operation and - with the Brühl project – just one more in the exploration phase. Despite the many regulatory obstacles encountered during the development process it has been possible for GeoEnergy to drill a first well in the Brühl project, which has confirmed now the expected very high geothermal potential of this project site.

The presentation will describe the “regulatory environment”, the measures taken to fulfill all regulations and finally also report the results achieved to date in the Brühl geothermal project.

EGS geothermal challenges within the Upper Rhine Valley based on the Soultz experience

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SUMMARY

The EGS site at Soultz-sous-Forêts is under continuous development since 1987 and represents a reference for most of the projects in operation or under development in the Upper Rhine Graben (URG) and elsewhere in the crystalline basement. In the first 20 years, the development of a productive reservoir at temperatures of 200 °C at 5 km depth was the focus of the scientific work. During a first exploration phase, three hydraulic stimulation experiments were accomplished in the reservoir at the top of the crystalline (1400 to 2200 m) in the well GPK1 (Jung, 1992). Stratigraphically, this situation is comparable to the industrial projects of Rittershofen, Landau and Insheim, where the top crystalline is exploited. These experiments were executed at relatively moderate condition of a maximum flow rate of about 15 l s^{-1}, a maximum down-hole pressure of about 28.5 MPa (at 1968 m) and a total injected volume of 2700 m^3 at maximum flow rate (Jung, 1992). They led, however, to a considerable enhancement of the injectivity index from about $6{\cdot}10^{10}$ to $7.7{\cdot}10^9$ m^3 s^{-1} Pa^{-1} (factor of 10). It should be mentioned here that the injectivity index has been determined from short-term single borehole tests.

An intermediate reservoir was developed between 1991 and 1998 at a depth between 3000 and 3900 m. The success of four hydraulic stimulations has been demonstrated in a long-term circulation experiment in 1997, which proved highest enhancement of the productivity by a factor of > 100 and resulted in the highest productivity ever reached at Soultz EGS site of about $1{\cdot}10^7$ m^3 s^{-1} Pa^{-1} (Baumgärtner et al., 1998; Hettkamp et al., 1999). This exceeds the values from the short-term tests of Landau, where reservoir depth is comparable to Soultz, and that reveals an improvement from $2{\cdot}10^9$ to $1{\cdot}10^8$ m^3 s^{-1} Pa^{-1} (factor of 5, Schindler et al., 2010). A circulation test in Landau in April and May 2007 demonstrates the improvement of injectivity with time by a wellhead pressure decrease by at least 1 MPa over the duration of the test (Schindler et al., 2010). This effect was observed also during the long-term test in Soultz in 1997. In terms of reservoir geometry the stimulation has shown that, in contrast to GPK2, where the seismicity reveals a vertical extension of 3000 to 3900 m, in GPK1 the intermediate reservoir is connected to the upper one.

Deepening of GPK2 and drilling of GPK3 and GPK4 to a bottom-hole temperature of about 200 °C were followed by four hydraulic and seven chemical operations. Between 2000 and 2005 four hydraulic stimulations were accomplished. In GPK2 a volume of 23.400 m^3 was injected with a maximum flow rate of 50 l $s^{-1}$and maximum pressure of 15 MPa over six days (Nami et al., 2007). In a joint stimulation of GPK2 and GPK3 additional 3400 m^3 were injected over two days at maximum pressure and flow rate of 16 MPa and 25 l s^{-1}, respectively. These two stimulations are responsible for 76% of the final injectivity/productivity of GPK2 determined from single well testing. Two HCl stimulations have contributed to an increase to $5{\cdot}10^{-9}$ m^3 s^{-1} Pa^{-1} (factor 5) by injection at maximum concentration of 0.18% and maximum flow rate at 30 l s^{-1} (Portier et al., 2009). GPK3 has been stimulated hydraulically in combination with GPK2 in 2003. A volume of 34000 m^3 has been injected at maximum flow rate of 80 l s^{-1} and maximum pressure of 16 MPa (Nami et al., 2007). Hydraulic stimulation has increased the injectivity of the initially most injective well to $3.2{\cdot}10^{-9}$ m^3 s^{-1} Pa^{-1} (factor < 2). Similar to this rather low enhancement, chemical stimulation using HCl (0.45%) and OCA at maximum flow rates of 20 l s^{-1} did not improve considerably the injectivity of GPK3. Two hydraulic stimulations in 2004 and 2005 with injected volumes of 9300 and 12300 m^3, respectively, with a flow rate of 45 l s^{-1} led to a productivity of about $2.2{\cdot}10^{-9}$ m^3 s^{-1} Pa^{-1} in GPK4 (factor 20). The majority of productivity has been obtained by chemical stimulation using HCl, RMA and OCA. All three acids have contributed nearly equally and resulted in a final productivity obtained from single well testing of $5{\cdot}10^{-9}$ m^3 s^{-1} Pa^{-1} in GPK4. The increasing of productivity was also partly interpreted by the occurrence of leaks in the casing (Schindler, 2007; Schindler and Nami, 2008). Those leaks could be interpreted by corrosion effect (4385 m) and shear movement on pre-existing fractures (4710 m) (Daghmach, 2012).

Finally, an increase of productivity to $8{\cdot}10^{-9}$ m^3 s^{-1} Pa^{-1} has been observed for GPK2 during circulation test caused by an increased reservoir pressure (Nami et al., 2007). In 2005 a long-term hydraulic circulation test between GPK3 (injection) and GPK2/GPK4 (production) has shown that GPK4 was poorly connected based on tracer test study (Sanjuan et al., 2006). Following the installation of the power plant between 2007 and 2009, a three-year research program (2010-2012), the so-called "Phase III",

associated with the geothermal exploitation of the Soultz-sous-Forêts EGS power plant was conducted with a scientific and technical monitoring. The research program was focused on three main topics such as reservoir study, surface technology and environmental studies.

In 2009, a rough estimate of the productivity of GPK4 yields a productivity that is significantly smaller than the anticipated $5 \cdot 10^{-9}\ m^3\ s^{-1}\ Pa^{-1}$ from former short-term production and injection tests (Schindler, 2009). GPK4 could not be well connected to GPK3, so production rates stay low although the stimulation was efficient (Schindler et al., 2010). Mixing of water of 156 °C from GPK2 and of 147 °C from GPK4 with variable flow rates have led to strong variation in input temperature to the ORC cycle.

For reservoir study, several hydraulic circulation tests in were executed Phase III by producing mainly from GPK2 and re-injecting in one or two re-injection wells (GPK1, GPK3) simultaneously: a long-term circulation (11 months) in 2010 was followed by short-term circulation tests in 2011 and 2012. Due to its limited hydraulic performance, GPK4 was not used anymore during Phase III. Most of those hydraulic tests were sharply stopped due to down-hole pump failure under operational conditions. In terms of reservoir production, flow rate was increased from 18 to 25 $l\ s^{-1}$.

During 2010 exploitation, fluid discharge from GPK2 reached about 500´000 m^3 at 18 $l\ s^{-1}$ and a temperature of 164 °C. A tracer test showed good connection between GPK3 and GPK2. A number of > 400 induced micro-seismic events at low magnitude occurred with an average well-head pressure of 4.5M Pa at reinjection (Cuenot et al., 2011). Geochemical monitoring indicates that with on-going production, the chemical composition of this fluid approaches the composition of the native geothermal brine (salinity of 100 $g\ l^{-1}$).

In 2011, fluid discharge reached about 300´000 m^3 at 24 $l\ s^{-1}$ and a temperature of 159 °C. An enhancement of productivity is observed for GPK2 reaching peak values from $1.2 \cdot 10^{-8}$ to $1.9 \cdot 10^{-8}\ m^3\ s^{-1}\ Pa^{-1}$. This enhancement is partly attributed to the self-cleaning of fractures from cuttings during circulation (Genter et al., 2011). However, casing restriction located at about 3900 m could contribute to this enhancement by between 15 and 30 % (Jung et al., 2010). The strategy was to increase the re-injection flow rate in GPK1 and simultaneously minimize it in GPK3 in order to decrease reinjection pressure. Consequently, induced seismic activity was very low with a total number of 5 micro-seismic events in the entire year of 2011. Down-hole pump technology was tested in various geothermal conditions during exploitation. In 2011, occurrences of cuttings (granite particles) at high flow rate, generated abrasion of the production pump reinforcing its damaging.

In 2012, one long-term hydraulic circulation test was planned but stopped due to major down-hole pump failures. After pump failure analysis resulting in the determination of corrosion and abrasion as major issues, re-designing of the hydraulic part of the pump was initiated. Surface technical investigations with a major focus on corrosion and scaling were conducted. On-site corrosion study on several kinds of materials indicates a corrosion rate of about 0.2 $mm\ yr^{-1}$ at re-injection conditions. A high temperature corrosion tool was designed and installed on site on the production line. In parallel, research has been carried out on the characterization of scaling (sulfate, sulfide) and the concentration of natural radioactivity derived from natural brines circulating within the deep fractured granite reservoir. Such scaling is preferentially located in the cold part of the geothermal installations (re-injection side).

Environmental nuisances such as noise, seismic activity, and natural radioactivity have been investigated in order to evaluate their impact on the local population. An opinion survey has been conducted in order to evaluate the impact of deep geothermal energy on local public acceptance. The main result was that the Soultz project is relatively well accepted even though induced seismicity and noise generated by the plant represent the two main issues mentioned by the local population.

The overall aim for the next phase IV at the Soultz EGS site is to reach full production at low environmental impact and high net power. This implies the application of optimised stimulation methods in order to improve the hydraulic connection of single wells with the existing reservoir with specific focus on connecting wells that are initially poorly-coupled to a larger reservoir. In the case of the Soultz EGS project, the aim is to improve the connection of GPK4 with the final aim to operate a four-well-system with a total mass flow twice times higher than today. This will positively influences not only the total production, but also the decrease the cost of energy production.

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The Korean EGS pilot project: its progress and prospect

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Key Words
EGS, Korea, binary cycle, geophysical data, micro-seismicity, drilling, hydraulic stimulation, seismic-while-drilling

ABSTRACT

Geothermal utilization in Korea has been direct use because there is no high temperature resource associated with active volcano or tectonic activity. But, Pohang area covered with Tertiary sediments in south-eastern part of Korea shows relatively high heat flow (> 80 mW/m^2) and geothermal gradient (> 33 °C/km), where intensive exploration activities for low-temperature development have been made since 2003 including drilling of four wells. Korean government launched the geothermal power generation project in this Pohang area adopting Enhanced Geothermal System (EGS) technology at the end of 2010.

The EGS pilot plant project is the first attempt to realize geothermal power generation in Korea. It is a five-year term, government funded and industry matching project. The project consists of two phases: I) site preparation, drilling down to a 3 km deep well and to confirm the temperature anomaly in two years, and II) extending the 3 km deep well down to 4.5 – 5 km, hydraulic stimulation and reservoir creation, drilling another well and completing doublet system, and finally installing a MW class binary power plant in another three years.

During the first phase, geophysical data were reassessed and stress measurement along a survey hole down to 1 km was made to figure out stress distribution around the site. A micro-seismicity monitoring system with nine borehole three-component accelerometers has been installed and is currently under operation. The first well spudded in September, 2012 and reached 2.25 km in December which is to be extended and completed in 2013. During the drilling, a seismic-while-drilling (SWD) survey was tried by deploying four radial surface geophone arrays to determine velocity structure which is critical in micro-seismic interpretation. Covered depth interval by the SWD survey was between 300 m and 1,700 m in depth.

There have been numerous difficulties; insufficient budget support, procurement problems of equipment and materials, and most of all, lack of experience in deep drilling and engineering, and thus the progress was slower than anticipated. These may cause some delay of overall project and a careful management scheme should keep working to minimize possible adverse factors. Considering recent assessment of EGS potential and deployment roadmap in Korea we can expect 200 MW installations by 2030. Realization of this prospect would definitely depend on the successful accomplishment of the first EGS project in terms of not only technological advance but also industry participation.

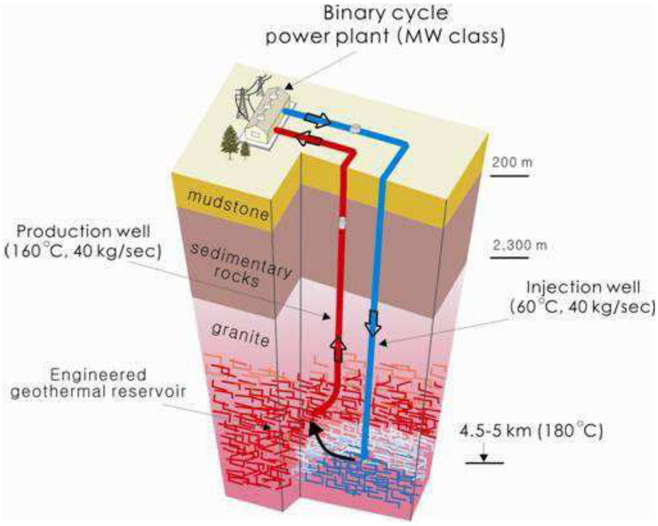

Figure 1: A conceptual model of the Korea EGS pilot project.

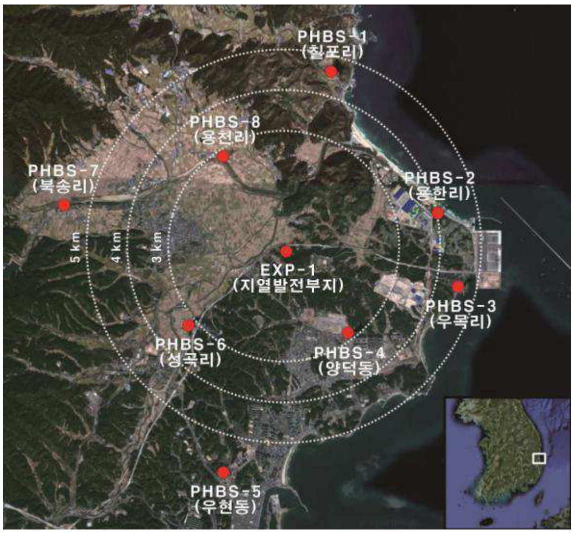

Figure 2: Location map of the micro-seismic monitoring boreholes. EXP-1 is at the drilling site.

Update on Geothermal Activities in Australia

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Key Words
Australia, geothermal energy, carbon price, renewable energy target, diversification, EGS, power, ARENA

ABSTRACT

This paper outlines the current state of the Australian geothermal industry together with changes in federal government policies and formation of new government agencies to support the development of geothermal energy in Australia.

Despite Australia recently having one of the world's strongest economies, a strong currency and rising retail power prices, the geothermal sector in Australia has struggled in recent years to attract sufficient investment funds to progress commercial geothermal activities in Australia and abroad. Together with a lack of any demonstration of large scale commercial geothermal success this has resulted in a substantial slow down of geothermal industry activity in Australia. The only significant sub-surface project activity has centred on EGS projects in South Australia while planning for other power and direct heat projects within sediments in the Perth Basin continues. This decline has been accompanied by a trend of Australian geothermal companies heading outside Australia to pursue geothermal activities in more conventional volcanic settings or diversifying their investments into other renewable and non-renewable energy sources.

Against this difficult financial background for the geothermal sector, in 2012 the Australian Government implemented substantial changes to federal policy on climate change and renewable energy. Two of the key objectives of this policy shift were intended to reduce carbon emissions in Australia and increase the use of renewable energy technologies. In 2012 the Australian Government addressed the first objective of reducing carbon emissions by legislating to increase energy efficiency and imposing a carbon tax on emissions starting at A$23/tonne in 2012/13 and rising with inflation until it is replaced from July 2015 with a flexible cap and trade scheme with a market determined carbon price. In May this year, less than a year after it came into effect and as a result of the substantial collapse in the price on carbon emissions in Europe, the Australian Government has more than halved the carbon tax to a projected $12 per tonne in 2015 when the "cap and trade" scheme is due to commence.

The Government announced last year that its carbon tax scheme will be linked with Europe's greenhouse framework from July 1, 2015. However the opposition party has promised to repeal the carbon tax altogether if elected in September. The Government's second objective of encouraging the uptake of renewable energy is to be met by expansion of the national Renewable Energy Target (RET) with the addition of an additional target of 41,000 GWh of renewable energy generation by the year 2020. To assist with achieving this objective the Australian Government has installed two new federal government funding bodies for renewable energy; the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation.

Lack of Risk Capital for Geothermal Energy

Geothermal activities by companies in Australia have withered substantially as funds for geothermal investment have dried up. Investment in upstream exploration activities such as geophysical surveys and drilling for energy and minerals resources in Australia is normally funded by equity investment from private sources or public funds raised by companies listed on recogised stock exchanges such as the Australian Securities Exchange. In recent years this source of finance for risk capital for geothermal drilling has substantially dried up as investors have seen their investment value eroded due to lack of success and declining share prices. Reasons for this decline are the general market weakness contributed to by economic weakness in the European and US economies and related financial volatility. Bad economic news out of Europe and the USA has had a strong negative effect on investments at the middle and smaller end of the share markets in Australia.

Share prices of all listed geothermal energy companies in Australia have declined substantially in recent years. This malais has not been restricted to geothermal companies. Some renewable energy companies in Australia, focussed on other renewable energy sources such as wind, wave energy and solar energy, have also suffered from a similar decline in share prices and investor interest.

According to DMITRE, South Australia's geothermal regulator, in January this year 56 companies held 361 exploration licences or permits across Australia covering 440,000 km^2. Some Australian companies are looking to withdraw from the geothermal sector altogether, while other companies have renegotiated with State government regulatory authorities a reduction or revision of their tenement work commitments required to retain their geothermal title. This has occured in the States of South Australia, Western Australia and Tasmania. This revision in obligations allows the companies to hold onto their tenements and plan for future activities and capital raisings. Over A$750 million was spent in Australia from 2002 to 2011 on geophysical surveys, studies, drilling, reservoir simulation and flow tests comprising the geothermal work programs associated with the geothermal tenements.

This difficulty in accessing risk capital from industry required by Government to match Government grant funds has resulted in nearly $300 million in government grant funds, allocated to geothermal companies such as Geodynamics, Green Rock Energy, Green Earth Energy and Petratherm, lying dormant. These funds will remain unused until matching funds can be raised from non-government sources by those companies. In the current tight investment climate this is proving very difficult to achieve.

Challenge to Achieve Commercial Success

Failure to demonstrate any commercial success by the geothermal sector in Australia has not helped. There have been no commercially successful deep geothermal wells drilled in Australia. Adequate resource reservoir temperatures have been obtained in both sedimentary and EGS terrains but permeability and geofliud flow have been a long way short of commercial requirements.

In December 2011 Australia's Bureau of Resources and Energy Economics (BREE) noted that much of Australia's large geothermal energy potential is considered subeconomic due to this failure to demonstrate commercial viability and acceptable investment risk. This risk is exacerbated in Australia by the high and increased cost of drilling and associated materials and services.

Withdrawal of Power Companies

The larger resource and power companies have typically avoided investing in geothermal energy in Australia. The few major power utilities that did have an interest in the development of geothermal power have substantially withdrawn from geothermal pursuits in Australia, namely Origin Energy, AGL and TruEnergy. Origin has withdrawn from the EGS venture with Geodynamics in the Cooper Basin. Origin remains a substantial investor in New Zealand through its ownership of Contact Energy and is expanding its geothermal investment into Indonesia. TruEnergy, the major Hong Kong owned power utility has withdrawn from its geothermal joint venture in South Australia with Petratherm to focus on wind power. AGL withdrew from its EGS exploration venture with Torrens Energy in South Australia. Only Green Rock Energy's power generation partner Pacific Hydro remains as a significant participant in the geothermal sector in Australia, but it seems to be unwilling to take on exploration and sub-surface risk by contributing to the cost of exploration and drilling wells. Pacific Hydro is Australia's largest generator of power from renewable energy, mainly wind power.

Shift to Alternative Investments

Some of Australia's geothermal companies have diverted their main geothermal activities to more conventional volcanogenic geothermal terrains outside Australia. In the current difficult financing climate this diversification is also proving to be a challenge. Difficulties with financiers, slowness, relative indifference, ignorance or impediments from governments or their agencies and bureaucracies in some foreign countries and lack of basic data have proven to be major hurdles outside Australia.

Companies investing in volcanic terrains such as; Panax (now name Raya) and Green Earth in Indonesia, Hot Rock Limited in Chile and more recently in Peru, Kuth in Papua New Guinea and Vanuatu, New World Energy in Philippines and Petratherm in Tenerife, Canary Islands; have struggled to get sufficient traction from financiers in Australia or abroad and made limited progress or given up geothermal projects altogether. In May this year Panax changed its name to Raya Group Ltd to reflect its new focus on projects in Indonesia. Hot Rock Limited has applied for geothermal exploration rights to a number of areas in Peru, the latest being at Achumani in southern Peru, and have been granted one at Quellaapacheta subsequently joint ventured with Energy Development Corporation. In January Kuth Energy received a production licence from Vanuatu's government for geothermal power generation on Efate Island. Kuth now aims to proceed with exploration and to secure a Power Purchase Agreement with UNELCO, the local electricity utility before commencing construction of a power plant.

Despite some potential challenges in developing nations, in 2012 Geodynamics decided to branch out from its flagship EGS project in the Cooper Basin and diversify its geothermal activities by venturing outside Australia to the volcanic environment in the Solomon Islands. In November 2012 Geodynamics announced it had entered an agreement with a gold mining company to earn up to a 70% interest in a conventional geothermal power supply project in Savo Island in the Solomon Islands.

In Hungary, Green Rock and its co-venturer MOL, Hungary's largest company have been frustrated by a seemingly indifferent Government and bureaucracy there as the venturers have waited for around 3 years for secure title so they can proceed to implement a combined heat and power project in this non-volcanic sedimentary environment. At the time of writing they are still waiting. In Spain, Petratherm's progress has similarly been slowed by bureaucracy and lack of sufficient subsurface data.

In Australia Petratherm chose to divert some of their focus to other renewable energy sources like wind and solar energy. Green Rock Energy chose to diversify into exploring for conventional and unconventional hydrocarbons such as shale gas and liquids, where they consider there are significant similarities in technologies used to identify and drill prospective areas and extract the contained energy.

EGS Geothermal Activities in Australia

In light of the financing difficulties for geothermal projects in Australia the only substantial geothermal project activity in Australia in 2012 and to date in 2013 was carried out by Geodynamics at its three EGS high pressure, high temperature fields (Habanero, Jolokia, Savina) near Innamincka in remote north eastern South Australia.

Geodynamics has drilled six deep EGS wells in these fields and is aiming to produce geothermal fluid at a sufficient flow rate to power its 1 MWe capacity power plant. In April this year Geodynamics announced commissioning of its 1 Mwe Habanero power plant had commenced. Commissioning is expected to take about 100 days. Previously Geodynamics had demonstrated flow connection via tracer and pressure testing through fractures linking two of the four stimulated wells in the Habanero field. The two other EGS wells drilled by Geodynamics were Jolokia-1 (4911 m depth) in the Jolokia field and Savina-1 (3700 m) in the Savina field.

Geodynamics in joint venture with Origin Energy also drilled Celsius-1 well into the Jurassic Hutton Sandstone formation to test the geothermal potential of hot sedimentary acquifers overlying the hot EGS granites of the Cooper Basin. Although Celsius-1 intersected a bottom hole temperature of 140°C the matrix permeability was too low. As a result of this disappointment the joint venture with Origin Energy has not drilled the two followup wells they had budgeted.

Habanero-4 was drilled 489 m into the Carboniferous granite to a total depth of 4204 m to replace Habanero-3 which had suffered casing failure. For Habanero-4 Geodynamics elected to use reverse circulation cementing of the 9 7/8“ section in this high temperature (241°C at 4130 m) and high pressure well (34.47 MPa or 5000 psi above hydrostatic pressure) as a means to avoid the causes of the Habanero-3 casing failure. Geodynamics stated that investigations of this casing failure had attributed the cause to caustic cracking from high pH annular fluids remaining from normal cementing operations at the top of the well. Results of the reverse circulation cementing were claimed to be successful by Geodynamics. The high overpressures encountered in this and all the other Cooper Basin EGS wells has contributed to the complexity and cost of drilling and cementing operations, and measures to prevent drilling formation damage by loss of drilling mud into the natural fractures.

In November 2012 Geodynamics announced that its second open flow testing at Habanero-4 achieved an average of 38 kg/s for 104 minutes at over 29 MPa (4,200 psi) flowing pressure after local stimulation. This compared to the first injection test which achieved a maximum flow rate of 35 kg/s at 27.7 MPa (4020 psi) through a variable choke and a temperature of 191°C prior to shut in. The stimulation pumped 2.5 ML of water at a maximum rate of 52.5 l/s and 44.2 MPa maximum surface pressure. Geodynamics suggested the stimulation enhanced the well's productivity by improving the connection between the well and the fracture zone as evidenced by higher flows and flowing pressures. Geodynamics has not yet announced if this fracture zone is considered to be the same one where hydraulic connectivity has been demonstrated between Habanero wells 1, 2 and 3. In contrast it is understood that stimulation at the Jolokia field about 10 km from Habanero and in the same Carboniferous Big Lake Suite granite may not have duplicated this result with injection flow testing of Jolokia indicating tight fracturing.

Subsequently, in late 2012 Geodynamics carried out a major stimulation of Habanero-4 by injecting 34 ML of water over 14 days with micro-seismic events extending over 1500 metres from the well. The maximum event recorded was 3.0 magnitude. Geodynamics plans to carry out and evaluate further testing in 2013 to demonstrate flow in fractures connecting wells Habanero 1 and Habanero 4 with a view to commissioning the existing 1 MWe pilot power plant to demonstrate technical viability.

Hydraulic fracture stimulation was also carried out in South Australia by Petratherm in its joint venture with Beach Petroleum. Up to the end of 2011 Petratherm had drilled two wells at Paralana in an area with no history of deep wells to target fracture permeability in Mesoproterozoic sediments and underlying basement sediment interface but with evidence of hot rocks at depth. Paralana-2, drilled to 4030 m, intersected highly fractured metasediments and overpressured brines (22.4 MPa or 3,300 psi of overpressure) between 3670 m and 3864 m. The well had a bottom hole temperature of 190°C but well bore stability problems limited wire line logging to a depth of 3725 m. In 2011 fracture stimulation and flow testing were carried out with 1.28 ML of fluid produced at flow rates ranging from 1 l/s to 6 l/s with well fluid temperatures of 171°C from the bottom 200 metres. Petratherm hopes to drill a production well in late 2013 and carry out large scale hydraulic stimulation and flow circulation testing of Paralana-2 and Paralana-3 in 2014.

Geothermal Activities in Sediments

Since Panax's Salamander-1 well, and Geodynamics' & and Origin's Celsius-1 wells drilled in 2010 to intersect hot sedimentary aquifers failed to intersect sufficient matrix permeabiliy in the target Otway Basin and Eromanga Basin sediments respectively there have not been any geothermal wells drilled specifically for deep hot sedimentary aquifers in Australia.

This situation is set to change with the plan by CSIRO, Australia's largest national science research organisation, to develop a geothermal demonstration project to aircondition the Pawsey Supercomputer Centre associated with the Square Kilometer Array, the world's largest radio-telescope, being built in Western Australia. The first stage of this process is underway. It involves extracting cool ground water from a shallow aquifer under the CSIRO's site at the Australian Resources Research Centre (ARRC) in Perth, using this to cool the supercomputer then reinjecting the heated water back into the same aquifer at a sufficient distance.

The second stage involves drilling a well over 3,000 metres deep into hot sedimentary aquifers below the ARRC in the Perth Basin to evaluate the deep geothermal resource potential beneath the city of Perth, Australia's fastest growing city. The Perth Basin, a half graben, contains thick aqifers with high permeabilities, at least at shallower depths. Drilling, expected to commence in late 2013, is planned to prove the temperature, permeabilities and reservoir capacity are sufficient for commercial scale applications to power absorption or adsorption chillers. This activity is fully funded by the Australian Government which has allocated A$20 million to CSIRO for the task.

Another bright note in Australia has been the recent agreement between AWE, a successful petroleum explorer and producer and Green Rock Energy to participate together to demonstrate the development potential of geothermal power generation in hot naturally fractured sedimentary aquifers in the north Perth Basin adjacent to major expanding energy markets in the region. AWE produces oil and gas from the area and is also targetting unconventional hydrocarbons from the area. There are substantial synergies between Green Rock and AWE from this cooperation and data sharing. For example in addition to its use of data from past 3D seismic surveys, Green Rock may obtain access to new 3D seismic surveys conducted in the area for unconventional hydrocarbon purposes. In the past year Green Rock has been improving its understanding of the potential geothermal resource at depth in its north Perth Basin geothermal exploration permit areas. This has been achieved through the analysis of existing open file 3D seismic data combined with the use of automated fracture detection techniques to target natural fracture zones and relating them to natural fractures recorded in image logs from wells to maximise the probability of the flow rates needed for commercial production.

Green Rock already has a grant of A$5.4 million from the Western Australian State government for the geothermal project and is seeking further funding from the Australian Government to drill two deep geothermal wells in the north Perth Basin.

Australian Government Policy Changes

Against this difficult financial background for the geothermal sector, in 2012 the Australian Government implemented substantial changes to federal policy on climate change and renewable energy. The aim of the Government was to move Australia away from its traditional heavy reliance on fossil fuels for power generation. Currently coal accounts for around 75% of electricity generated in Australia and a substantial proportion of that is thermally poor quality coal resulting in substantial CO_2 emissions. Two of the key objectives of this policy shift were intended to reduce carbon emissions in Australia and increase the use of renewable energy technologies. The Australian Government addressed the first objective of reducing carbon emissions with measures to increase energy efficiency and by imposing a carbon price on emissions.

Imposition of Carbon Price

The Government imposed a price on carbon emissions to discourage the burning of fossil fuels and to provide an incentive for non-government investment in low-emissions technologies. In 2012 coal accounted for about 75% of electricity generated in Australia. As a means of achieving this reduction in carbon emissions the carbon tax was started at A$23/tonne in 2012/13 and rising with inflation to A$24.15 in 2013/14 and $25.40 in 2014/15 until it is replaced from July 1, 2015 with a market determined price. As a result of the collapse in April this year of the carbon trading price in Europe the Australian Government has stated that there may be pressure to decrease the carbon tax rate in Australia.

The Government's second objective of encouraging the uptake of clean, renewable energy is to be met by expansion of the national Renewable Energy Target (RET) with the addition of an additional 41,000 GWh of renewable energy generation by the year 2020. Another measure the Australian Government has used is to replace previous diverse government funding bodies for renewable energy with the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation (CEFC).

Australian Renewable Energy Agency

ARENA commenced on July 1, 2012 as an independent body with the objectives of; providing funding assistance until 2020 for R&D, deployment and early stage commercialisation of renewable energy technologies, and to increase the supply and competitiveness of renewable energy technologies. ARENA will administer all geothermal funding from this new funding and also existing funds including A$14 million allocated previously to Geodynamics and Petratherm under the Geothermal Drilling Fund and A$153 million allocated to same two companies under the Renewable Energy Demonstration Program.

ARENA will take over the administration of A$3.2 billion in existing funds previously administered by other government agencies for renewable energy. In January this year A$1.7 billion remains uncommitted. ARENA will continue to administer the Emerging Renewables Program which commenced in August 2011. Under this Program at least $40 million will be allocated to large scale base load power generation including wave, solar and geothermal and another $26.6 million has been allocated specifically to assist the geothermal sector. So far only two small geothermal energy research projects have been awarded grants under the Emerging Renewables Program. One is a A$1.9 million grant to a research body to collate existing geothermal data from a variety of sources with the stated aim of improving the exploration, discovery and characterisation of potential geothermal resources using data fusion and machine learning technologies. The second is a $1.25 million grant to Adelaide University for the South Australian Centre for Geothermal Energy Research to investigate reservoir characterisation and quality of Hot Sedimentary Aquifer resources.

Clean Energy Finance Corporation

The Clean Energy Finance Corporation (CEFC) was set up to invest from July 1, 2013 directly in businesses seeking funding to overcome investment barriers or hurdles for innovative to clean energy technologies and projects. Primary funding must be obtained from private or other public sources with the CEFC providing supplementary funding support by way of loans or equity investments to assist the deployment of the technologies by overcoming the barriers or hurdles.

Geothermal Energy Reserves and Resources Reporting Code

In 2010 Australia introduced the Second Edition of the The Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves. The Code has been developed as a joint initiative geothermal research institutions and industry in Australia. This is the world's first uniform code to guide the reporting of geothermal data to the market and is designed to underpin the quality of the Industry's relationship with the public company share market. The development of a Geothermal Reporting Code, and its adoption by operating companies to shape the way they report their geothermal exploration results, resources and reserves, is an important step in the development of Australia's geothermal energy industry. Further improvements to the Code are being considered by the committee appointed to oversee the development and use of the Code by industry.

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A Geological Overview of the Proposed Target Zone for the Eden Deep Geothermal Plant

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ABSTRACT

EGS Energy Ltd is in the process of developing a 4 MW_e deep geothermal energy plant at the Eden Project in Cornwall, UK. This site lies on the southeast flank of the exposed St Austell Granite. The geology of Cornwall is well documented to a depth of less than 1 km as a result of information that has been compiled from the county's extensive metal mining history, together with data gained to a depth of 2,500 m from the Hot Dry Rock Project at Rosemanowes during the 1980s. Cornwall is underlain by a large granite batholith, covering an estimated area of over 3,000 km^2 and varying in depth between 10 and 20 km. The granite was generated by the anatexis of lower crustal rocks, with possible mantle contribution, in a series of magma batches over a period 295 – 275 Ma. Variscan tectonic convergence, pre-dating the granite emplacement, led to the formation of NNW – SSE fault structures, locally known as 'crosscourses'. There are two main types of crosscourse: (i) fissure fill crosscourses – extensional fissures filled with clay and quartz, having a 'vughy' nature (ii) shear/wrench crosscourses – zones of intense microshearing in which feldspars and micas have undergone advanced argillic alteration into a clay gouge infill. Cornwall is one of the most highly mineralised regions in Northwest Europe. This mineralisation occurred in three main episodes, largely influenced by the fracture-controlled migration and mixing of hydrothermal fluids variably sourced from the granites: (1) Permian granite-related lode mineralisation; (2) Triassic crosscourse mineralisation; (3) post-Triassic stage mineralisation and kaolinisation. The fracture systems that resulted from interactions between regional stresses and magmatic fluid pressures facilitated the migration and mixing of magmatic, meteoric and basinal fluids and were fundamental to the mineralisation process. Reactivation of fracture systems was primarily controlled by the evolving post-Variscan tectonic regime where repeated episodes of fluid flow have commonly resulted in structures hosting more than one paragenetic type.

Evidence suggests that the major NNW – SSE faults acted as transfer faults and were an important component of structural control during mineralisation. Isotopic data from inclusion fluids have been used to infer that kaolinisation involved high salinity fluids that were either highly evolved meteoric fluids circulating the granite host rocks or brines derived from nearby marine basins. The kaolin veins in the western part of the St Austell Granite trend predominantly NW – SE and are steeply dipping, occasionally occurring as conjugate sets, consistent with tectonic deformation. It is thought that these structures were the pathways along which basinal brines would have been conducted. This demonstrates the significance of the major fault structures in hydrothermal and subsequent episodes of fluid flow. Additional observations in local mines have shown that crosscourses can act as pathways for significant ground water ingress into underground workings.

3D conductive heat flow modelling shows the subsurface temperature within the Cornish granites are dependent on the distribution of elevated levels of radiogenic minerals and on the granite thickness, giving rise to a linear temperature gradient of 35 – 38°Ckm^{-1}. Observations of the stress regime in Cornwall below a depth of 500 m show a uniform diverging linear relationship between σ_H, in a NW – SE direction, and σ_h , in a NE – SW direction, where $\sigma_h < \sigma_v < \sigma_H$. Evidence indicates that the growth of an EGS reservoir in a strike-slip regime is structurally controlled by the fractures that will preferentially shear – the critically aligned joints – which are those that lie at 21-22° from the direction of maximum horizontal stress. In Cornwall this corresponds to the crosscourse alignment.

Having undertaken a detailed resource assessment, EGS Energy identified the Eden Project as being a preferred location for the development of the first deep geothermal heat and power plant in the UK. A detailed target zone assessment in the vicinity of the Eden Project has identified a major wrench fault, known as The Great Crosscourse, in close proximity to the site. Exposure in nearby mine workings at depths up to 300 m has characterised this structure striking N 22° W; dipping 75° ENE; the width of the central structure is 45m and it exhibits dextral heave of 230 m, including heave of the granite/metasediment contact. Observations of similar structures elsewhere in Cornwall indicate that the central structure is likely to be surrounded by a relatively wide zone of disturbed, fractured ground together with additional sub-parallel faults. Therefore, the Great Crosscourse is considered to comprise preferentially aligned structures of enhanced permeability within the granite which make it

an optimum target for the development of an EGS reservoir.

The vision of EGS Energy (in conjunction with BESTEC GmbH) is not only to successfully drill the wells and produce electrical power at the Eden Project and heat but also to establish a road map whereby future EGS developers can see the potential industrial application of the use of heat. The plan is to develop a cascade of industrial heat users at the local, community level - greenhouses, fish-farming, crop-drying, swimming pools, etc. initially. This will be followed by the regeneration of Cornwall by enhancing its recreation industry through building water-based parks such as “Water World”, marinas, spas, etc., so that Cornwall can have visitors throughout the year and not just in the summer only.

Experiences from 5 years operation in Landau

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ABSTRACT

In November 2007 the geothermal power plant in Landau was put into operation. This plant was the first of its kind in Germany operating within the Megawatt range, a prototype with a nominal gross power of 3.6 MWe. The geothermal power plant in Landau has been operating for nearly 5.5 years and good as well as some bad experience has been made by the operators so far.

In 2008 and 2009 the power plant was not operating for approximately two months, because the new developed bio-oil in the line shaft pump turned into a kind of tar and destroyed the lube string. Additionally in autumn 2009 the power plant was not operating for another three months, because two seismic events of magnitude 2.4 and 2.7 were located close to the geothermal wells. A correlation of the seismic events and the operation of the power plant seemed to be very likely.

After the seismic events in 2009 further requirements and conditions were developed and imposed together with the mining authorities for maintaining the operation in a safe manner. The insurance sum for the mining damage insurance was raised to 50 M€, a velocity model of the underground in Landau was developed to optimize the location of the seismic events, the injection pressure was kept always below 45 bar, an additional seismic network was installed to measure ground velocities, a seismic risk analysis for common damage was performed, the installed filter technology for the brine was optimized, an inhibitor was injected to avoid scaling and a gentle operation mode was arranged to avoid sudden starts and stops of the power plant.

Another interruption of the operation of the power plant in Landau in 2011 was caused by a damage of a bearing of the turbine shaft, which is very rare after such a short time of operation. Because no spare parts were stored in Landau the interruption was app. 2 months long. Nevertheless, the average operating hours of the first five operating years from 2008 to 2012 of the Landau plant is close to 7200 hours per year, which yields to an average operating time of 82%. In years like in 2010 or 2012 where no big interruption happened the operating time of the power plant is higher than 92%. In table 1 the operating dates of the power plant in Landau between 2008 and 2012 are summarized.

Table 1: Operating dates of the Landau power plant

	2008	2009	2010	2011	2012	Average
Average Power	2,0 MWe	2,4 MWe	1,9 MWe	1,3 MWe	1,5 MWe	1,82 MWe
Operating Hours	6.725 h	6.023 h	8.276 h	6.846 h	8.036 h	7.181 h/a (82%)
Brutto Production	17.454 MWh	14.496 MWh	16.712 MWh	11.230 MWh	13.235 MWh	14.625 MWh/a
Consumption	5.247 MWh	4.498 MWh	4.622 MWh	3.439 MWh	4.293 MWh	4.420 MWh/a (30%)

Geo x GmbH based in Landau, a 50 percent subsidiary of the PFALZWERKE AKTIENGESELL-SCHAFT in Ludwigshafen and a 50 percent subsidiary of the Energie Südwest AG in Landau, is the operator of the geothermal power plant. BESTEC GmbH also based in Landau acted as general contractor for the subsurface part and the construction of the brine circle. The ORC-plant was bought from Ormat Systems LTD. in Israel and built up by IGATEC GmbH from Speyer. The well construction in Landau was done by Oil & Gas Exploration Co. Jaslo Ltd, from Poland, together with daily supervision by BESTEC Drilling GmbH, a subsidiary of the BESTEC GmbH. BESTEC Services GmbH, also a subsidiary of the BESTEC GmbH, is carrying out the technical operational management of the power plant in cooperation with Energie Südwest AG.

Without the experience with bio-oil, without the occurrence of the seismic events in 2009 and without the failure of the turbine bearing the story of the power plant in Landau would be a full success story. The reliability of the ORC unit and the reliability of the line shaft pump are showing, that a permanent, long life and stable geothermal power production in Landau is possible.

The power plant in Landau was designed for a brine flow rate of 70 kg/s and a production temperature of 155 °C. Because of the restrictions introduced after the felt seismic events, now the power plant is operating at 55 l/s and 158 °C production temperature. The improvement of the production parameters by adding a second injection well for full circulation flow is still being debated.

Scaling with Upper Rhine valley fluid: main issues at Soultz in the geothermal installation and in the wells

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Key Words
scale formation, barite, galena, geothermal loop, precipitation front, scaling inhibitor

ABSTRACT

Scale formation in the surface and subsurface installations of the geothermal power plant of Soultz-sous-Forêts affect negatively the performance of power plant operations. At Soultz, geothermal brine with a salt load of 97 g/l is produced from a granitic reservoir at 160˚C and 20 bars (2 MPa). For power production an Organic Rankine Cycle (ORC) is operated where the heat is transferred from the geothermal brine to an organic fluid (isobutane) in a heat exchanger system. After heat extraction the geothermal brine is injected with 60-70˚C and 18 bars (1.8 MPa).

Circulation of Upper Rhine Valley geothermal fluids in a geothermal loop (production–heat extraction–injection) involves several physical and chemical processes which can cause scale formation in the geothermal installations. Theoretically, four different types of scales can occur: carbonates, sulfates, sulfides and silicates.

Carbonate scaling can be avoided just by physical and mechanical measures which include appropriate pressure maintenance at the surface installations and, if necessary, two phase flow consideration. Formation of silicate scales at the cold side of the geothermal loop is possible based on thermodynamic calculations. However, until today it was not observed. Scales in Upper Rhine valley geothermal power plants are dominated by strontium rich barium sulfate (barite, $Ba_{1-x}Sr_xSO_4$) and contain minor amounts of lead sulfide (galena, PbS) and trace amounts of mixed sulfides of Sb, As, Fe and Cu.

Barite and galena form a thin scaling layer that covers all surfaces which come in contact with geothermal brine. Main amounts of the scales are formed at the cold part of the geothermal loop, starting at the heat exchanger system due to cooling of the brine and the formation of barite. Inside of the heat exchanger act those scales like an insulation material and decrease thereby the heat transfer from the geothermal to the organic fluid. In consequence measures for scale avoidance like continuous injection of scaling inhibitors or intensive mechanical cleaning proceedures have to be applied. Inside of the injection wells the thickness of the scaling layer increases as a function of injected brine volume and temperature. Moreover, recently conducted well loggings showed that a precipitation front of barite scales exists in the main injection well of Soulz, GPK-3. This scale front already reached a depth of 4000 m and is slowly progressing towards the open-hole section.

To maintain geothermal power plant performance for circulation operations from several years to decades, appropriate measures for scale treatment needs to be applied.

On-site experience with anti-scaling inhibitors during geothermal exploitation within the Upper Rhine valley projects

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Key Words
scaling, barite, phosphonic acid, inhibitor selection, inhibitor test on-site

ABSTRACT

At geothermal power plants of the Upper Rhine valley the formation of scalings is observed in the surface installations. Scale formation is related to the production of very saline brine (100 – 120 g/L) and equilibrium changes of the fluid by cooling at the surface.

The deposits consist of strontium rich barite ($Ba_{1-x}Sr_xSO_4$) and minor amounts of sulfide minerals like galena (PbS). Within the heat exchanger system those scales form an insulation layer inside of the tubes and decrease the efficiency of the heat transfer between geothermal and organic fluid. In consequence, cleaning operations for scale removal are required in regular time intervals to keep up efficiency of the energy production. During cleaning and disposal operations, strict regulations for safety at work have to be followed due to radioprotection regulations, related to the presence of ^{226}Ra and ^{210}Pb in the scalings. In the injection wells, the inner diameter of the casing decreases slowly but continuously by deposition of scales. Moreover, a progressing precipitation front exists in the injection wells versus depth which can reach the open-hole section as a function of the injected brine volume.

For reasons of safety at work and long term power plant operation, the formation of barite needs to be inhibited continuously. Therefore, different inhibitors, based on phosphonic acid, were tested in laboratory experiments. These study included tests for calcium tolerance, effectiveness, dose rate adjustment, thermal stability and the interaction with reservoir rocks. Out of these products the DTPMP based one showed the best results for barite inhibition. On-site efficiency tests showed very good results during short time tests (Soultz) and long term injection (Landau).

One important fact was observed after the long term inhibitor injection: sulfide scale become the dominating deposit in the surface installations after efficient retardation or blocking of barite formation. Appropriate measures for sulfide inhibition have to be identified in the near future in order to avoid the accumulation of lead-rich deposits in surface installations.

Radioprotection investigations during geothermal exploitation with Upper Rhine Valley fluids: power plant mapping and recommendations for future geothermal sites

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ABSTRACT

The Soultz-sous-Forêts geothermal power plant exploits geothermal fluid circulating within granite, which naturally contains radionuclides. Thus some radionuclides can be leached by circulating fluid and come to surface, which may generate radioactivity in the installation. Following the first radioactivity measurements performed in 2005 during a long-term circulation test at the Soultz-sous-Forêts site, which were evaluated by ASN (French National Agency for Nuclear Safety), ASN asked for a regular monitoring of the evolution of radioactivity in and around the geothermal installation. The main purpose of this monitoring is to ensure the protection of workers against potential dangerous radiation, and thus to set up radioprotection procedures if needed. In any case of emitted radiation, even at low level, French regulation requires, at least, to do some measurements and to guarantee that the employees do not receive a cumulative dose higher than 1 mSv over a period of 12 consecutive months.

In order to respect the French regulations, the following measures were taken:

- A regular and precise monitoring is performed if possible before, during and after each circulation period to observe the evolution of natural radioactivity and to locate the places which show the highest dose rate values;
- Scientific research to determine the origin of radioactivity and the ways to avoid it;
- In regard of the results of the measurements surveys, set up of proper radioprotection procedures;
- Personal dosimetry and medical follow up for employees;
- Radioactive waste management, storage and removal

Concerning the monitoring, 9 surveys have been performed since 2009 during the recent circulation tests both on GPK2 and GPK1 installations. The measured data is the dose rate, which is the relevant data for radioprotection. Two kinds of measurements are performed: "contact" (~1 cm from the installation) and "ambient" (~1 m away from the installation) measurements. Thus around 350 contact values and 50 ambient values are sampled during each survey, allowing a precise dose rate mapping of the installation. Two main results were observed. Firstly, the dose rate values tend to increase with increasing circulated volume and time. Secondly, most of the highest dose rate values are located on the reinjection pipe line, where cooled geothermal fluid circulates.

This observation led us to launch scientific research to understand the mechanisms that are responsible for radioactivity. First results show that it is highly correlated with scaling forming inside the pipes. Mineralogical analyses show that scalings are mainly sulfates (solid solutions between Barite, $BaSO_4$ and Celestine, $SrSO_4$) and sulfides (Galena, PbS). The pressure and temperature conditions inside the reinjection line favorize the precipitation of those minerals. During their formation, they are able to trap some radionuclides, mainly Ra^{226} in the case of Barite and Celestine and Pb^{210} for Galena. Thus two technical solutions for removing radioactivity are either mechanical cleaning of the pipes or use of scaling inhibitor (see Julia Scheiber's presentation for more details on that part).

Because of presence of radioactivity, radioprotection procedures have been set up, especially for people who work close to the installation. First step was to train and nominate two PCR (in French: Personne Compétente en Radioprotection, Person skilled in radioprotection), who are in charge of analyzing the surveys results, setting up proper radioprotection procedure and exchanging with authorities. First action was to establish a restricted zone around the installation, marked by a blue line and "radioactive" signs. Then, a specific analysis of every work station has to be made so as to evaluate the dose that can be received. This has to be further confirmed by real measurements. Once it has been done, specific radioprotection procedures can be set up. In view of the low dose rate values and the emitted radiation (mostly α and β, few γ), the risk of external contamination is very low. So adapted equipment must be worn by workers (one-use suits, gloves, glasses). Masks are important to wear, because there is a risk of

internal contamination in case of ingesting or inhaling particles that can emit α and β radiations, which are very dangerous for health if present inside bodies.

Linked to this, GEIE workers must wear personal dosimeter when working on the installation. Personal dosimeters records the received cumulative dose and are sent every three months to IRSN (Institut de Radioprotection et de Sûreté Nucléaire) for checking if the legal maximum dose of 1mSv has been reached. Results are sent directly to the works doctor, who has to proceed to a specific follow up of the workers.

Rocks particles or scaling residues (called NORM – Naturally Occurring Radioactive Material) are collected from filters or from cleaning installation parts. As they may be radioactive, they have first to be stored in a specific, isolated place. Then their removal has to be done following French regulation. After a full radiological characterization, the residues are removed by ANDRA (French National Agency in charge of radioactive waste management), either to be eliminated or to be stored.

The presence of radioactivity in the installation requires then many efforts, especially because French regulation about nuclear safety is well-established and strict. However the existing regulation about NORM mainly concerns mining industry and underground water exploitation, but is not very adapted to geothermal energy. It means that the laws have to be interpreted to fit to the regulation. But with the development of geothermal energy in France and in Europe, it is very likely that a specific regulation will quickly emerge.

Generating Renewable Energy from Small-Scale Geothermal / Co-Produced Fluids

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ABSTRACT

Low temperature geothermal heat and co-produced fluids at oil and gas wells offer significant power generation potential, with tens of thousands of oil and gas wells currently untapped. At present, low temperature geothermal brine is considered a nuisance in oil & gas operations today and un-economical for geothermal power generation. However, technology is available to tap into those existing resources to produce fuel-free, emission-free power and increase power output and efficiency at these sites.

Maarten van Cleef will discuss its project with the Department of Energy (DOE) to customize its waste heat to power generator for geothermal applications. ElectraTherm, a leader in small-scale, distributed power generation from waste heat, was recently awarded a DOE grant to demonstrate its technology at a geothermal demonstration site in Nevada. Maarten van Cleef will discuss the challenges and lessons learned, and provide a sneak peak at the product development resulting from the findings.

Operate a line shaft pump in a slim-hole with highly aggressive geothermal conditions: new results from the LSP at Soultz

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Key Words
Soultz-sous-Forêts, down-hole water lubricated lineshaft pump, corrosion, abrasion

ABSTRACT

The Soultz geothermal power plant is the first EGS (Enhanced Geothermal System) technology, involving one production well and several reinjection wells drilled into a deep fractured granite (5 km). The geothermal fluid, a very saline brine with a high gas-liquid-ratio, produced at 160°C is pumped by Line Shaft Pump (LSP). This LSP is installed in the production well GPK-2, designed with a 9 5/8" pump chamber. Since 2008, several LSP technologies have been tested and improved in order to face all the technical challenges to be solved.

The first LSP was installed in Soultz in May 2008 and was supplied by an Icelandic company. This LSP was based its column assembly and an 8JKH/2900 rpm cast iron bowl unit with extra impeller lateral clearance. Since its start-up in June 2008, the LSP assembly has been removed and reinstalled six times due to different operational and technical failures. Most of the failures were related to damages of the bowl unit due to abrasion and corrosion because of the very aggressive geothermal conditions in Soultz. Unfortunately, the supplier of the first generation of bowl unit could not offer proper technical solution for the Soultz well conditions.

Thus, it was decided with a German supplier to design a new slim-hole bowl unit based on existing electrical submersible pump (ESP) technology. The new bowl unit was first tested in laboratory conditions in a test hole in December 2012 and then installed in the GPK-2 well in Soultz at the beginning of January 2013. Since January the 17th, the pump has been running at 30 Hz.

BRIEF HISTORY OF THE SOULTZ LSP EXPERIENCE

The Soultz geothermal power plant is located within the Upper Rhine Valley in Northern Alsace about 50 km NNE of Strasbourg. This is the first EGS demonstration site producing electricity in France (Genter [1]). Soultz geothermal fluid is Na-Cl-Ca dominated brine with a salinity of 100 g/L and a gas-liquid-ratio of 1:1 (mainly CO_2, 85%, N_2, 10%, and CH_4, 2.5%) (Sanjuan [2]). Production well GPK-2 is designed with a 9 5/8" pump chamber of a length of 510 m (Baumgaertner [3]). This production well is slightly deviated from the surface to 150 m deep, but then start to be significantly deviated: at 300 m deep, deviation is about 3 m. Figure 1 presents GPK-2 trajectories from the surface to 350 m deep and the setting depth of the LSP in operation since January 2013.

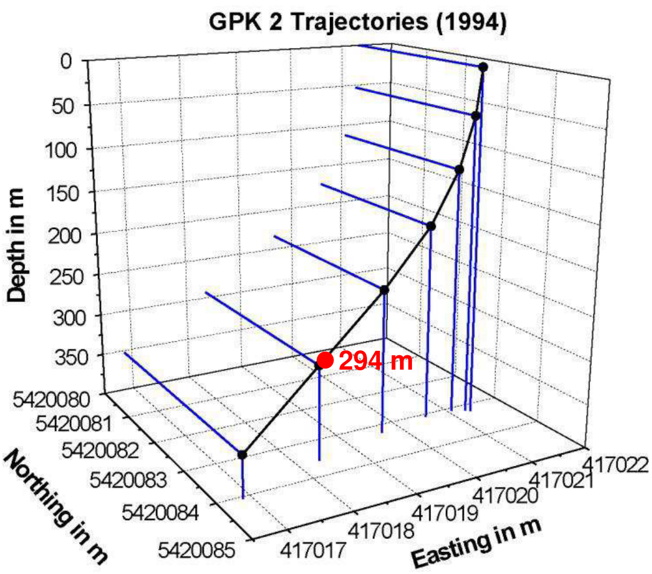

Figure 1: GPK-2 trajectories from the surface to 350 m deep and the setting depth of the LSP in operation since January 2013 (red point)

The first LSP tested in Soultz was supplied in 2008 by an Icelandic company, which offered the possibility of running LSP with Teflon line shaft bearings lubricated with water. This company supplied more than 100 pumps operating in Iceland and 15 in other countries.

Moreover, Soultz production casing is 9 5/8” and this company was also the only one offering LSP adapted to this slim-hole diameter. They proposed its standard column assembly with 8JKH/2900 rpm cast iron bowl unit with 17 stages and extra impeller lateral clearance of 18 mm. Standard line shaft is constructed with 3040 mm long carbon steel shaft with two 316 stainless steel sleeves and two 1520 mm long carbon steel enclosing tubes coupled together with Teflon bearings.

The first LSP was installed in Soultz in May 2008 and operating from June 2008. Unfortunately, Soultz operation conditions are more aggressive than Icelandic conditions: high content of chlorine in the brine, high gas-liquid-ratio, high dissolved carbon dioxide in the brine, carry-over of cuttings from the reservoir and deviated well. That is why since May 2008, the LSP pump has been installed seven times in the production well. Table 1 presents a brief history of the installation and removal dates, cause of failure and running time.

First failure in August 2008 was caused by carbonate scaling inside the enclosing tube due to the use of potable water for lubrication. Carbonate scaling was solved replacing potable lubrication water by osmosis purified water. Since that change, no more scaling has been observed. Following failures are all mostly related to damages of bowl components due to abrasion and corrosion. Each time the pump assembly was removed from GPK-2 well, considerable wears and damages could be observed on rotary and stationary parts. Impellers and bowls were highly corroded.

Table 1: Brief historyof the installation and removal dates, cause of failure, running time and suppliersof the LSP components installed in GPK-2

N°	Date of Installation	Installation depth	Running time	Cause of pump withdrawal from well	Date of removal
1	May 2008	350 m	2 months	Carbonate scaling in enclosing tubes leading to a breakdown of the line shaft	August 2008
2	September 2008	250 m	4 months	Line shaft blocking after electrical grid failure	June 2009
3	October 2009	260 m	11 months	No failure: Maintenance	October 2010
4	November 2010	260 m	4 months	Decrease of production flow and pressure, corrosion-erosion of bowls and impellers	April 2011
5	August 2011	265 m	2,5 months	Stress corrosion leading to leakage in one enclosing tube	November 2011
6	March 2012	250 m	5 days	Line shaft blocking probably due to high corrosion-erosion of bowls and impellers	May 2012
7	January 2013	296 m	Up to 4 months	-	-

GTV BOWL UNIT: A NEW BOWL UNIT DESIGNED BY A GERMAN COMPANY

Unfortunately, the supplier of the first generation of bowl unit could not offer a technical solution for Soultz well condition. Thus, it was decided to develop a new 8” slim-hole bowl unit, GTV, based on the technology of a German company derived from one of their existing submersible pump.

The GTV bowl unit has been developed on the basis of the UPA range of submersible borehole pumps which have proved their worth over the long term. For more than 50 years, this pump type has been successfully employed in a wide range of applications from the water, to the oil and gas industries, and has provided reliable service under demanding pumping conditions, e.g. in mining.

After clarifying the hydraulic parameters, such as flow rate, head, inlet pressure and the required system pressure, it was necessary to look at the bowl unit's geometry, i. e. to define the maximal possible casing diameter. At the same time, optimization options were explored to reduce the drive speed, in order to reduce erosion forces. The bowl unit design was adapted to the existing line shaft and column assembly. Having cleared up these issues, the UPA 200 type series was selected for use as the basis for design adaptation. An evaluation of the various properties of the fluid to be handled was undertaken at the same time, with customer consultation, materials laboratory and UPA design engineers' experience combining to achieve a definition of the materials for the geothermal pump, detailed in Table 2.

Table 2: Material list of the different parts of the bowl unit

Pump parts:	Materials:
Stage casing	1.4517
Suction drainer	1.4462
Pump shaft	1.4057.09
Impeller	1.4517
Bearing bush	Bronze
Bearing sleeve	1.4462
Casing wear ring	1.4138
Stage sleeve	1.4462

Operational Soultz conditions requested a larger impeller axial clearance in bowl houses, so 40 mm were defined jointly with design engineers. Figure 2 present a drawing of one pump stages developed .To obtain this large axial clearance, it was necessary to extend the impeller necks and adapt the stage casings' length accordingly. In order to cater for all operating parameters, the pump has been designed with a total of 21 stages.

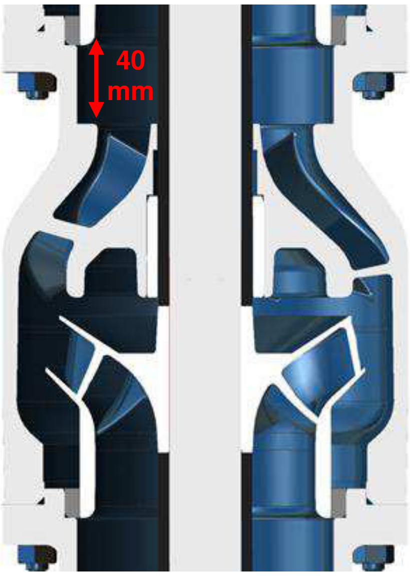

Figure 2: Cross section of one GTV bowl stage

As the production of very long, thin shafts complying with the required run-out tolerance would have been very expensive, the bowl unit has been designed with a split shaft. The split is provided between stages 10 and 11. A coupling required to connect both shafts is radially supported in its own intermediate stage and designed as a shaft bearing. Figure 3 presents a view of the complete bowl unit designed with 21 stages, one coupling stage and a strainer.

The GTV bowl unit was designed and produced in only 3 months. It was installed on the 3rd of December 2012 into an 18 m deep test well. Three column units were installed with the GTV bowl unit, the bottom of the strainer being at 16.3 m depth. Initial line shaft lubrication system was not needed for such a short installation because the line shaft bearings could be directly lubricated with pumped water.

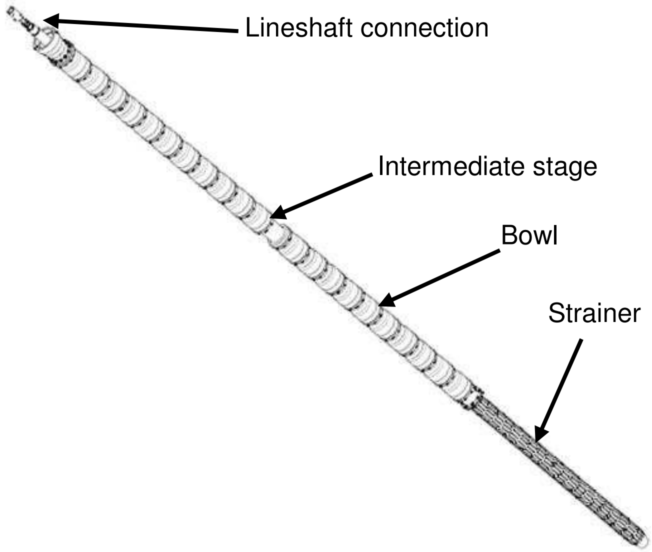

Figure 3: Drawing of the GTV bowl unit with 21stages

The bowl was tested on the 6th of December at full speed without usage of frequency controller, its flow varied instead by control valve connected to its discharge head. Impellers were adjusted in their highest position, at +39.5 mm. Motor currents, voltage, power factor, power consumption, vibration, discharge pressure and flow were all monitored for the following test points: 47.0, 38.6, 33.4, 25.5, 17.8, 10.0 and 0.0 l/s. Figure 4 presents the measured performance curves of the GTV bowl unit at 50 Hz (~2 992 rpm).

Maximal efficiency of the GTV bowl unit is around 72%, at 33.4 l/s and Total Dynamic Head (TDH) around 325 m. Bowl unit efficiency is lower than the ESP UPA 200 used for the design of this bowl being around 80% at best point of efficiency. The difference is due to the increase in axial clearance, UPA 200 has only 10 mm of lateral clearance compared to 42.3 mm for this special geothermal GTV bowl unit. Larger impeller lateral clearance induces increased fluid recirculation in the diffuser. However, efficiency is still good and comparable to the initial bowl unit used for the first LSP installations in Soultz, having twice as much lateral clearance.

The pump was also previously tested at three other impellers positions: +29.0 mm, +37.0 mm and +39.0 mm. No significant performance difference between these three positions has been measured by the manufacturer. Indeed, for these different positions, the length of the sealing between the impeller skirt and diffuser is the same, facilitated by the wear ring. Concerning vibration measured on the motor, they decreased with increased power consumption, i.e. increased flow. For the bowl unit vibration increased with flow being between 1.8 mm/s (top) and 5.8 mm/s (bottom) at nominal flow.

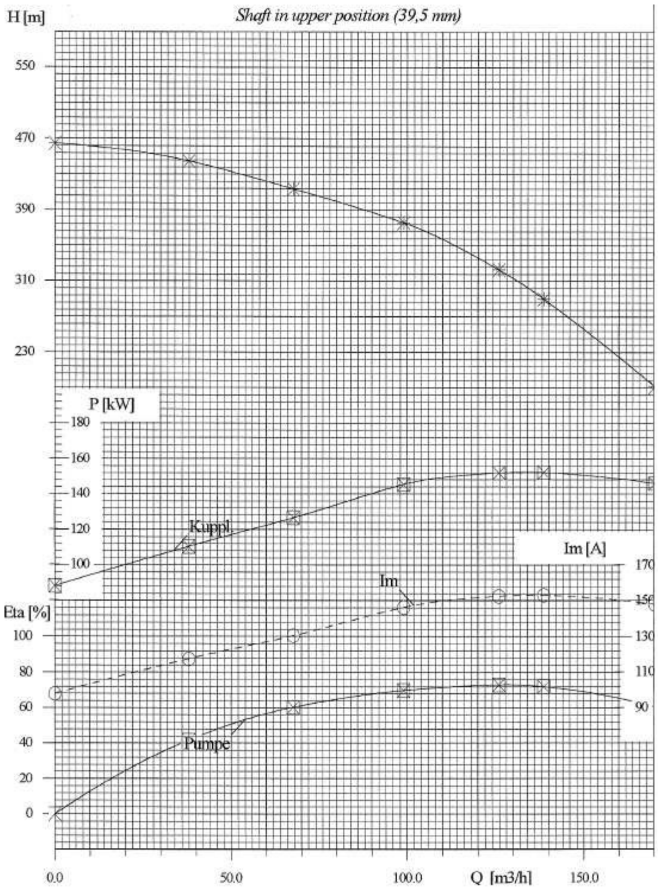

Figure 4: Performance curves of GTV bowl unit at 50 Hz

After the performance test finished the bowl unit was removed from the test well, it was cleaned and taken to the assembly facility for inspection and throttle bearing installation. Top impeller and top bearing were inspected: Impeller adjusted positions used for the different tests are slightly visible on the impeller skirts as miscolours without any erosion, demonstrating proper alignment of the bowl's internal components. The bronze bearing inside the enclosing tube prolongator also appeared to be in good condition despite an operation without operational lubrication system. Figure 5 presents pictures of the top impeller.

Figure 5: View of the top impeller removed after the performance test

LSP installation in GPK-2 started on the 7th of January 2013 for bowl and strainer installation. The installation of the LSP assembly lasted for 5 days. A total of 95 pieces of column units were installed, i.e. the setting depth of the line shaft is around 289 m, bowl unit inlet being at 294 m depth in the well.GPK-2 was reactivated on the 12th of January and artesian production started on the 15th of January. Geothermal well water temperature increased in one day from 10°C to 135°C.

The Icelandic engineering company supervised the start-up of the LSP after thermal equilibrium was established to tension the enclosing tube, connect the motor shaft to the top line shaft and in co-operation with the German supplier of the bowl unit to decide and implement proper adjustment of the bowl impellers prior to start-up. The adjusted position of the impellers was based on calculations of impeller relative movement inside bowl houses, the bowl's hydraulic trust and bowl's lateral clearance being 40 mm. Adjustment of pump impellers was finalized the 16th of January and the LSP was started on the 17th.

The first step was done at a motor frequency of 20 Hz. As vibration, torque and currents were all normal the frequency was increased to 37 Hz, geothermal production was around 82 m^3/h and well head pressure around 20.5 bar. At this operating point, head developed by the pump was around 217.5 m, which is well in accordance with the manufacturer hydraulic test, giving for this point 220 m, the difference being due to pressure losses in the column assembly. Motor vibrations were measured between 0.3 and 0.4 mm/s and the motor torque around 40% of its nominal value. The commissioning of the LSP was considered successful and motor frequency was reduced to 30 Hz, the minimal operating frequency recommended by the manufacturer.

Table 3: Operation parameters measured on the 24th of January and on the 24th of May

Date:	**24/01/2013**	**24/05/2013**
Flow:	49.8 m3/h	53.4 m3/h
Discharge wellhead pressure:	21.3 bar	21.3 bar
Annulus pressure:	13.7 bar	16.7 bar
Bubbler tube (N_2) pressure:	30.5 bar	
Temperature:	151.2 °C	157.1 °C
Torque (% nominal):	22,5 %	22,4 %
Current:	132,1 A	133,7 A
Voltage:	240,2 V	240,2 V
Vibration:	0.3 mm/s	0.2 mm/s
Lubrication pressure:	33.9 bar	30.0 bar
Lubrication flow:	2.3 l/min	3.3 l/min

Since start-up on the 17th of January the LSP has been operating continuously at 30 Hz, it stopped once only for a short time on the 19th of April because of an electrical grid failure. The Soultz technical team is following the LSP operation parameters and water level drawdown in the GPK2 closely. Table 3 presents the main operation parameters taken on the 24th of January and on the 24th of May.

Unfortunately, after two months of operation, bubbler tubes used to determine the water drawdown in the production well were damaged by corrosion. Since then, it has not been easy to monitor all pump operating parameters. However, after almost four months of operation, the LSP pump assembly doesn't show measureable performance losses.

Vibration values monitored on top of the motor are generally very low, between 0.3 and 0.4 mm/s. Some short peaks (max 1 mm/s) were observed when water lubrication pressure was not enough to lubricate properly the Teflon line shaft bearings. Some lubrication pressure variations were observed in the past with Teflon bearings possibly because of their wearing due to the excessive deviation of the well.

Close attention is paid to the lubrication water treatment because it was the source of the first pump failure. The lubrication water treatment seems to work properly since the start-up. However, some internal water sampling revealed dissolved oxygen in the water. Sulphite reaction used to eliminate the oxygen seems to be quite low at the temperature of the lubrication water (~15°C). Soultz technical team is looking for a new solution to protect better the lubrication water against oxygen and reduce corrosion inside the enclosing tube.

Figure 6: Picures of duplex 1.4517 and bronze samples before testing and after 18 days of exposure to the geothermal brine

Soultz scientist team is leading some corrosion investigation on the new designed pump materials. Two samples of the duplex 1.4517 and bronze were prepared according to the ASTM standard (ASTM [4] and [5]) and installed in the high temperature skid (Scheiber [6]) installed on the power plant. Figure 6 presents pictures of the materials before testing and after 18 days of exposure to the geothermal brine.

Duplex 1.4517 samples don't show any sign of general or pitting corrosion. Concerning the bronze material used in bowl bearings, after 18 days of exposure, this material is covered by some general layer of corrosion. This layer was quite easy to remove in some parts of the samples.

These samples were reinstalled into the high temperature skid during 4 more weeks. Operation conditions were nearly the same, the only difference was the start of anti-scaling injection before the high temperature skid (Scheiber [7]). Figure 7 presents pictures of the materials after 4 more weeks of exposure to the geothermal brine.

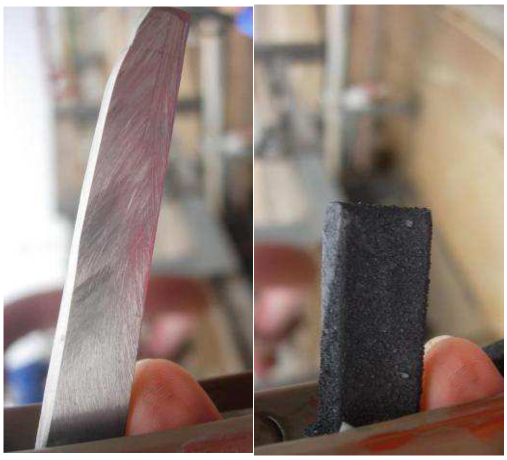

Figure 7: Picures of duplex 1.4517 and bronze samples after 4 more weeks of exposure to the geothermal brine

Duplex 1.4517 samples still don't show any sign of general or pitting corrosion. This material seems to be able to resist to the highly aggressive Soultz geothermal brine. However, when the LSP is removed from the well, inspection of the bowl's components will be required to confirm this point and also to check the resistance to abrasion of sand particles.

Bronze samples were covered by a new corrosion or scaling layer harder than the layer of the previous exposure. This may be related to the start of anti-scaling injection. Further corrosion investigations will be conducted to determine the chemical composition of the layer on the bronze samples.

Investigations after removal of the LSP from the well are also planned to check and analyze whether this bronze material is suitable for usage in the Soultz geothermal brine. The bowl's bearings are very important for its performance and to reduce vibration. Selection of bearing material has to be chosen very carefully. However, since the start-up, vibrations monitored on the surface are very low and stable, no sign of either bowl bearings or line shaft bearings degeneration has been observed, nor in LSP performance.

CONCLUSION AND FURTHER WORK

The new bowl unit for the Soultz LSP meets the requirements according to the invitation to tender. Corrosion investigation has confirmed that impellers and stage housing made of Duplex 1.4517 material are resistant to the highly aggressive geothermal brine in Soultz. Its abrasion resistance will be known after several months of operation when the withdrawal of the LSP is planned from the well for inspection. However, German manufacturer has a good result with this material even in more abrasive conditions. For the moment, the LSP doesn't show a sign of performance loss, which hopefully confirms sound selection of materials and design. However, corrosion samples tested on the Soultz conditions revealed that bronze material used for the bowl bearings is subject to some general corrosion with formation of a corrosion layer. Research is required to validate this bronze bearing material and find a new material more resistant to corrosion.

The Soultz technical team will also improve the treatment of the line shaft bearing lubrication water because oxygen is not completely eliminated by the injection of sulfite. Sulfite is commonly used in the industry but for Soultz potable water it doesn't seem to work properly. It is planning to use another anti-oxygen agent or to use a thermic degassing process for removal of the oxygen.

Two other aspects of the LSP require further developments. First is improving the monitoring of pressures (annular and discharge) and down hole vibrations. Electrical devices for this purpose are commonly used for ESP in the oil industry for temperatures up to 220°C. These electrical devices can possibly be adapted to LSP installations to improve their operation. Second is to find a solution for high pressure artesian wells like Soultz to keep the top shaft sealing arrangement in the discharge head for maintenance operations without having to kill them. Indeed, if the well in Soultz is killed, it costs two weeks of stop.

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Case History of the Lineshaft Downhole Geothermal Pump in Landau

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Key Words
Downhole Geothermal Pump, LSP, Lineshaft Pump, ESP, Binary, Frost, Production Well, Goulds Pumps

ABSTRACT

The Bestec GmbH contracted and geo x GmbH owned power plant in Landau in der Pfalz, Germany has been operating since November, 2007. It is the intent of this article to detail the timeline and experiences of the Lineshaft Downhole Geothermal Pump in Landau and the lessons learned.

Fundamental Prerequisites

If one is not familar with the general configuration and mechanics of a Lineshaft Pump (LSP), it is highly recommended that one first refers to that of previously submitted paper entitled ***Introduction to Downhole Geothermal Pumps*** (Second European Geothermal Review; Mainz, Germany 2010). See Page 30 of http://www.bestec-for-nature.com/j_bestec/tegr/SEGR_ABSTRACT_PAPER_BOOK.pdf and attached Figure 1. The information contained therein is relatively basic but also describes the history of LSPs in general, the adaptations for geothermal appications as well as Electric Submersible Pump (ESP) versus LSP for geothermal applications. The information contained therein is relatively basic but also describes the history of LSPs in general, the adaptations for geothermal appications as well as Electric Submersible Pump (ESP) versus LSP for geothermal applications.

It is important to emphasize, however, that the Frost Consulting designed/Goulds Pumps manufactured Downhole Geothermal Pumps are highly specialized and share only passing similarities those of water well pumps (common for over 100 years in the western hemisphere) or those of employed in geothermal applications in Iceland or the Soultz, France Rearch Facility.

Further, it is important for the European geothermal community to realize that these LSPs (exclusively designed by Frost Consulting Group) have been the mainstay of geothermal production in the United States for well over 30 years with hundreds of installations. Lifetimes vary but 5-8 years operation is common with over 10-15 years operation not untypical. Generally, where operating life has exceeded 2 years, the issues of the well and/or resource (abrasives) has little impact. After 2 years operation, lifetimes of less than 8-10 years are generally cut short due to (a) operator error ... improper impeller adjustment, poor monitoring, flashing, etc. (b) or, damage done within the first 2 years ... over producing and consequences of erosion and abrasive wear beyond that of normal routine wear. Lastly, there is a widespread European misconception regarding the oil lubrication of these pumps: That the lube oil (for lineshaft/bearing lubrication down to the pump bowls and impellers) is dispensed into the well bore and drawn into the pump suction and upon injection may contaiminate the water table. This is not true:

a) First, consider that the normal lube oil rate is only 11.5 – 19 liters/day versus that of, say, a low production rate of 50 liters/second. The oil, if it were to contaminate, would be near microscopic at less than 0.027%.
b) Second, consider that "oil floats". The oil dispensed into the annulus is done at the top of the pump bowls, "floats" to the stagnant water level and is not drawn into the pump suction.
c) Thirdly, as has been practiced at Landau and Insheim, the oil that does accumulate at the top of the water level in the annulus may be easily and periodically evacuated. Shut the pump down and open the annulus until clean.
d) Lastly, another option may be provided in that of oil return to surface via capillary tube.

Brief of Lessons Learned at Landau

As the Timeline and supporting Archives substantiate, three very distinct conclusions can be made:

1) Repeatedly products such as lubricating oil and pipe dope (thread lubricant/sealant) in particular that are designed or modified to be "environmentally friendly" have without redeem been bad for machinery and, at least in the case of geothermal applications, proven to fail completely. This has not been an exclusive European issue. The same problems (pipe dope) in the USA began occurring in the last 3 years.
2) One must be very careful in selecting the proper petroleum or synthetic lube oils in Europe. ISO standards notwithstanding, oils common in the USA are not of same quality in Europe. Complicating matters are brand names used in USA may be used in Europe for oils that are not of the same specifications.

3) Given the minimal amount of mechanical wear under extreme conditions, the original 2007 installation of the pump in Landau would likely still be in operation had it not been for the attempt at biodegradable lube oil. The subsequent pulling of the pump in December 2012 was due to "environmentally friendly" pipe dope failure on subsequent installation.

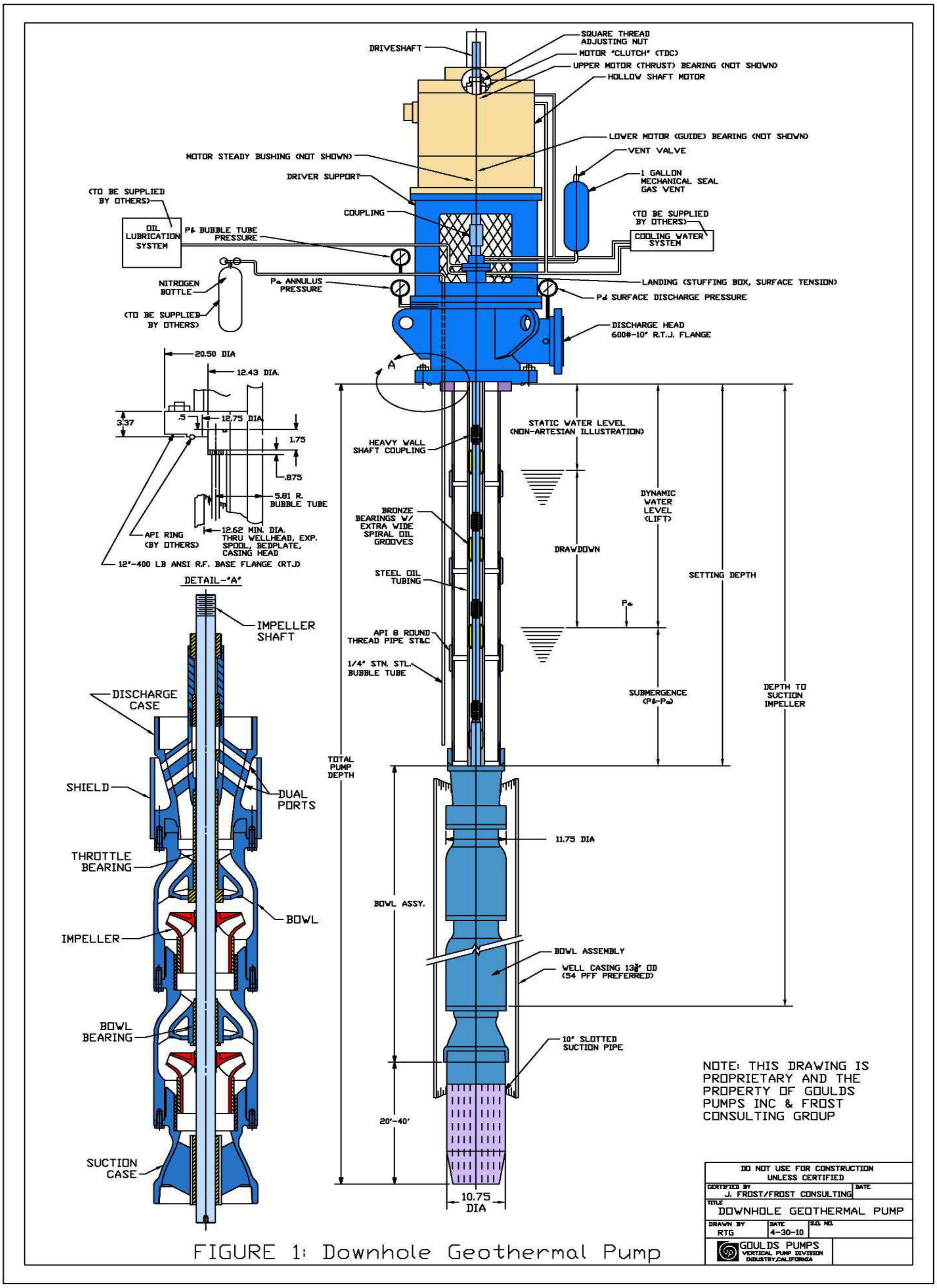


FIGURE 1: Downhole Geothermal Pump

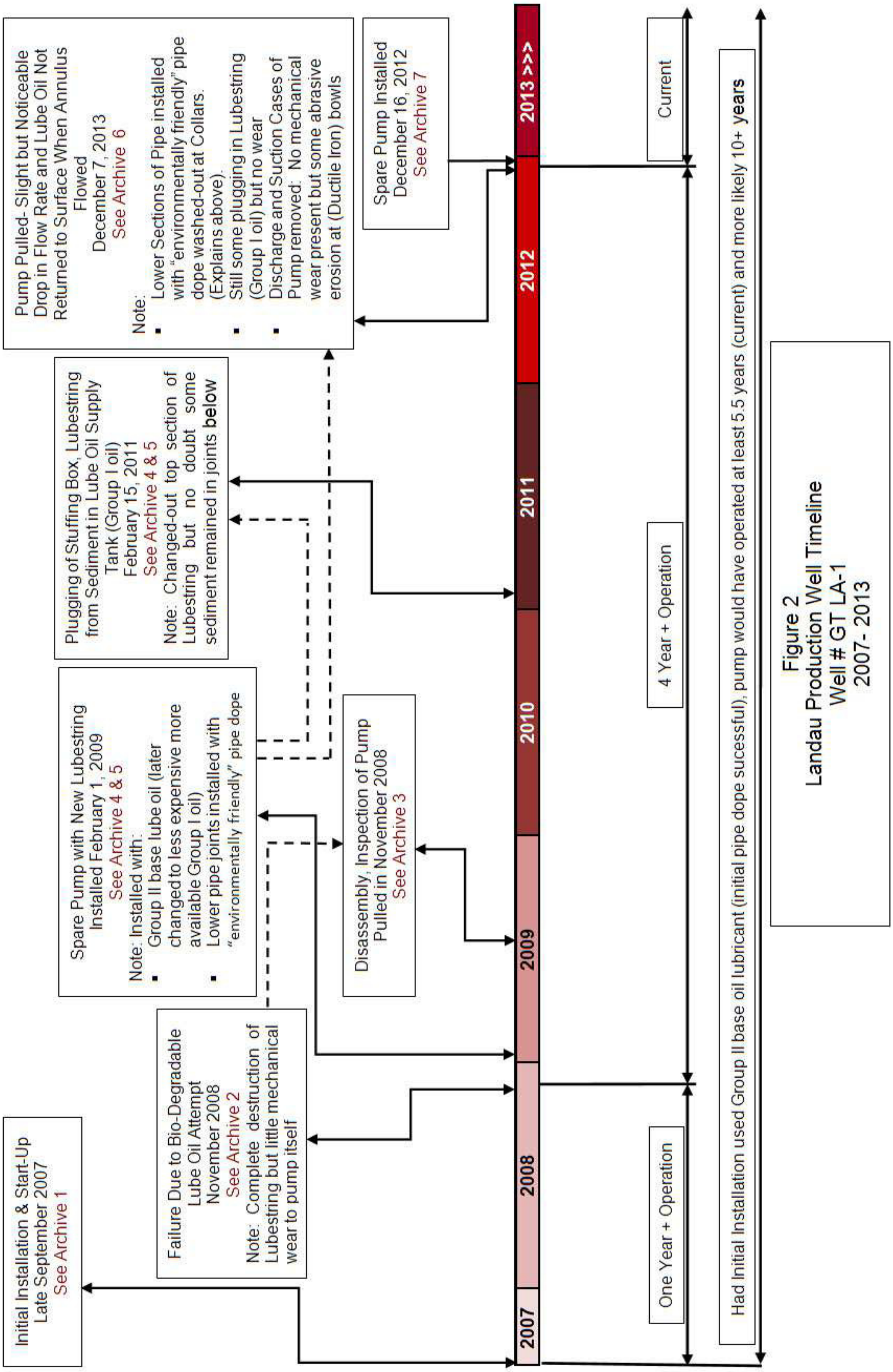
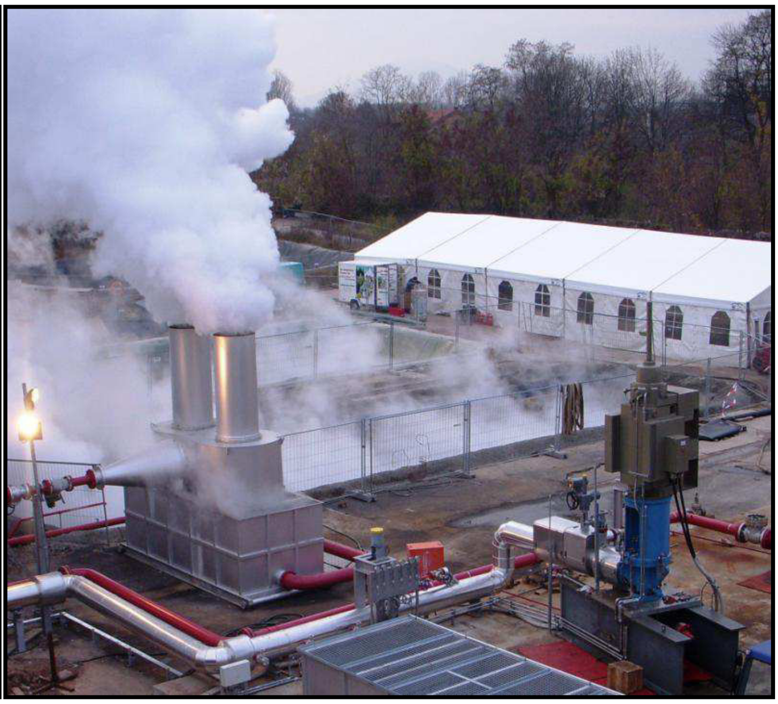


Figure 2
Landau Production Well Timeline
Well # GT LA-1
2007- 2013

ARCHIVE 1	LANDAU INITIAL INSTALLATION & OPERATION: November 2007	
ITEM	DETAILS	
Pump Model	Goulds Pumps geothermal 12EHC-27 Stage	
Pipe	10 ¾" API	
Oil Tubing (surrounding Lineshaft)	22.2 cm	
Lineshaft Diameter	55.6 mm	
Lineshaft Bearing Spacing	Every 1.52 m	
Setting to top of "Pump"	400 m	
Location of brine by-pass and oil outlet ports to annulus	400 m	
Location of bubble tube termination	2-lines to 400 m, 1-line to 452 m	
Depth to pump suction impeller	446 m	
Depth to bottom of Strainer (and chemical line)	452 m	
Motor (Variable Frequency Driven)	559.5 kw Nameplate	
Lubrication oil	In USA, the common lubricant is a base mineral oil such Chevron Bright Stock 150 or a synthetic such as Mobil Super Hecla. A biodegradable oil had never been attempted.	
	For the Landau installation, a **"Biodegradable Oil"** was designed and manufactured per required specifications (viscosity, density, flash point, non-foaming, compound content, etc.)	
	After flooding of string prior to initial start-up: 11-19 liters/day	
Start-Up	Smooth, uneventful; No vibration, run-out, etc.	
Gas Break-Out (tested)	Less than 20 bar @ ~ 161° C	
Typical operation / range	153-160° C	Pump performance per curve
	900-1790 rpm	
	27-75 l/sec	
	8-9.99 bar annulus	
	33-44 bar bubble tube	
	20-22 bar discharge	
	60-300 kw power consumption	
Starts & Stops	50+ in the course of 1 year operation due to Ormat plant, power supply outages, seismicity	

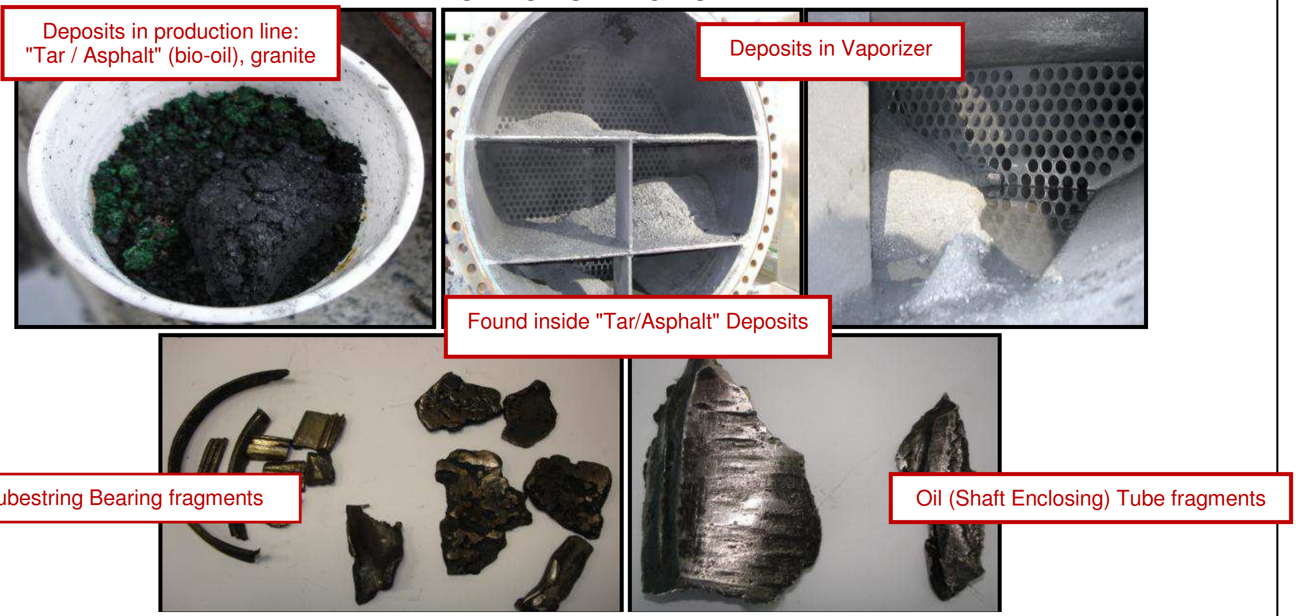


ARCHIVE 2	**FAILURE OF INITIAL INSTALLATION: Pump Pulled After 1 Year Operation**
ITEM	DETAILS
Pump Life Before Failure	12+months (failure November 2008)
Note	Pump still producing / no break in shaft or loss of flow
Warnings of failure	None from a conventional analysis: Head x Flow were still very close to curve
	Lube oil pressure, however, was very sporadic and necessitated a degasser.
	“Sludge” (minerals, granite and undefined material began accumulating at filters, vaporizer).
	At 10-12 months of operation, the power consumption became erratic with increased shaft run-out and vibration at the top of the motor (thrust bearing)
Failure determination	When material from Lubestring appeared in vaporizer, increased mechanical vibration/run-out and fluctuating power albeit pump still within Head x Flow curve
Findings, cause of failure	**“Biodegradable”** lube oil, at least under the temperature and pressures solidified into “asphalt” like material (**coagulated with suspended granite in brine**). This was not known nor confirmed until pump was pulled.
	Once brine & oil ports at top of pump bowls were plugged by solidified bio-oil, brine took the path of least resistance … up the Lubestring. As the bio-oil pumped in came into contact with brine, it too solidified. Oil lubrication of shaft/bearings was instead replaced by this abrasive, solidified “asphalt”.
	Pulling of the pump was extremely difficult as the annulus (between pump and well casing) was essentially solidified. String weight artificially high due to annular “drag”. The Lubestring (shafting, enclosing tube and bearings), all of which were under tension, was fractured into demolished pieces.
	Later, it was also discovered that upper (thrust) Motor bearing was not insulated per specification. Although this was not cause of pump failure (and unrelated to bio-oil solidifying), the Eddy Current created premature wear and eccentric orbiting at the thrust bearing.
Conclusion / Remedy	Eliminate “Bio Oil” and substitute Chevron Bright Stock 150; Run Spare (Model Goulds 12EHC-27 Stage) Pump back in with New Lubestring

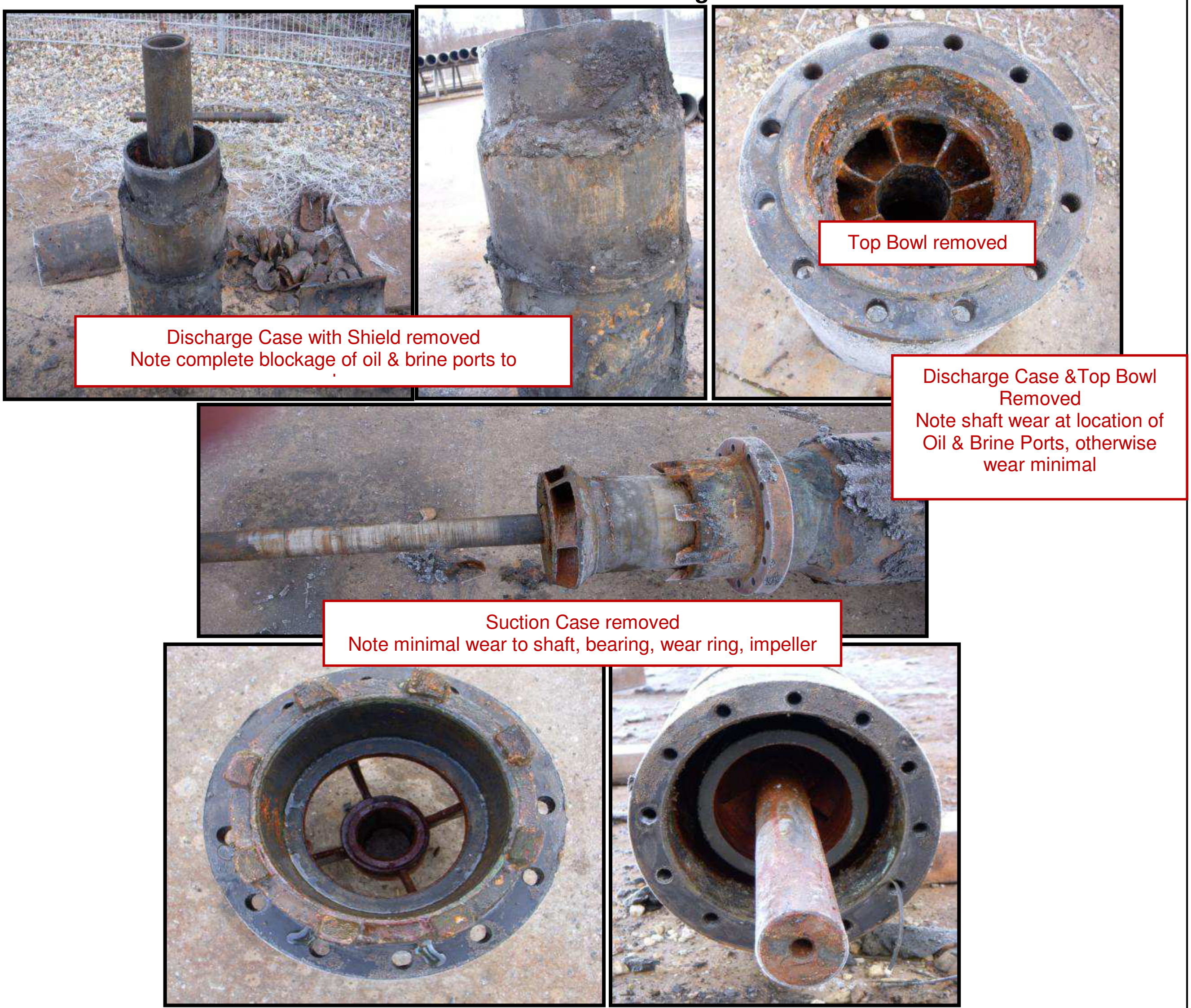
Archive 2 Photos on following page

ARCHIVE 2 Photos: Biodegradable Lube Oil

PRIOR TO PULLING PUMP



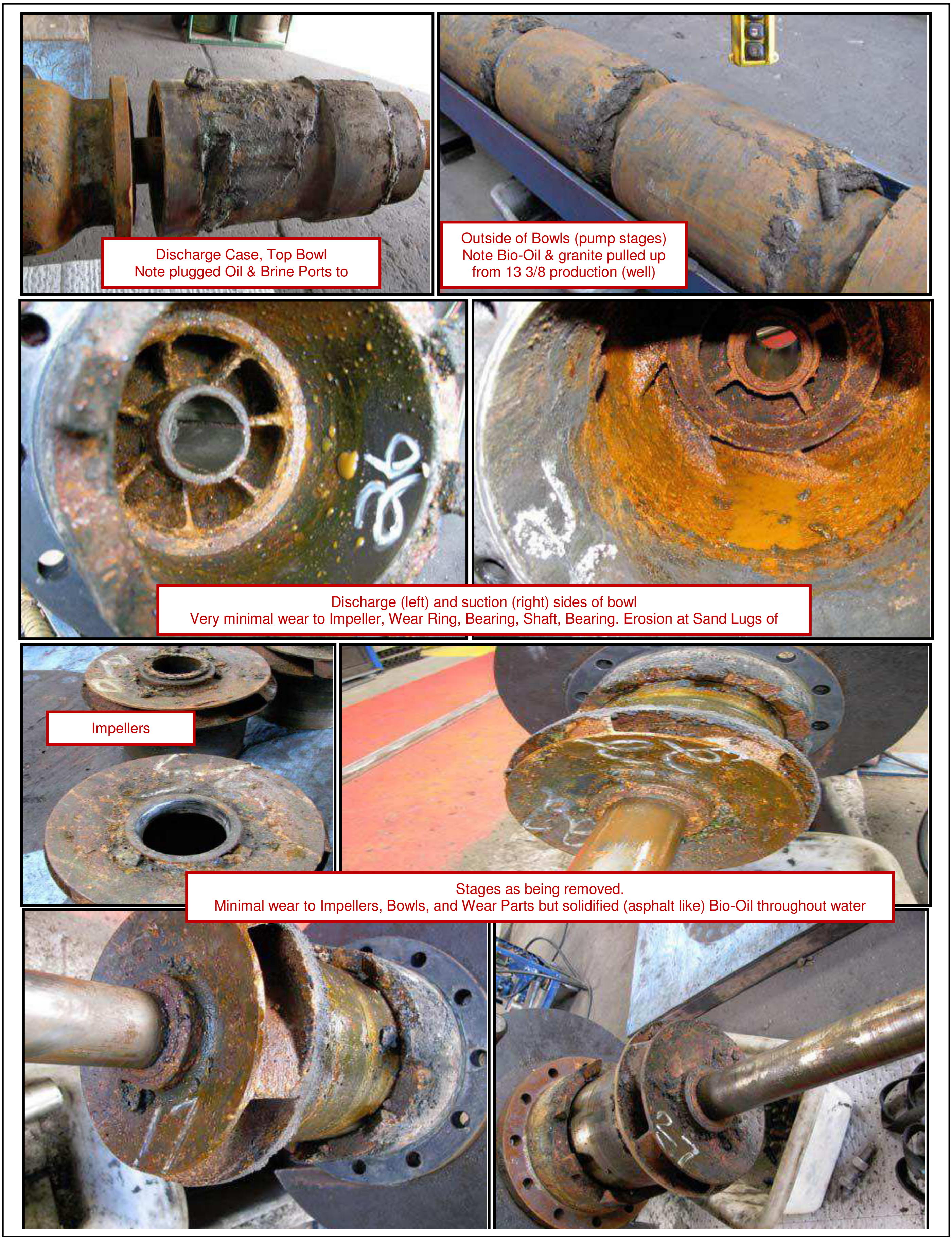
AFTER PUMP PULLED - Removal of Discharge and Suction Ends



ARCHIVE 3	**FACTORY DISASSEMBLY of Model 12EHC-27 Stage pump pulled from initial installation**
ITEM	DETAILS
Disassembly	Labor intensive due to solidified and hardened bio-oil deposition
Corrosion (acidic/caustic, galvanic, other)	None
Erosion / Abrasive wear	Some erosion noted at "Sand Lugs" of Bowls and some entrance side of bowl vanes; random abrasive cuts ("scarring") on Impeller Shaft and Impeller skirts; all of this was attributed to the granite-laced solidified bio-oil.
Wear at Impellers skirts / Bowl Wear Rings	Average 0.18-0.19 mm wear (concentric) but much worse at discharge end (as much as 0.84 mm)
Wear at Bowl Bearings / Shaft	Average 0.10-0.20 mm wear (concentric) but with deep scarring at oil/brine interface (discharge end)
Axial position of impellers during operation	Proper at 2-4 cm off bottom; no topping or bottoming-out
Dye Penetrant examination of castings	Passed
Re-hydrostatic tests of bowls (138 bar)	Passed
Post-disassembly clean-up	Sandblasting had minimal success in removal of deposits necessitating grinding by hand; **some Bowls and Impellers had to be scrapped for no other reason than solidified Bio-oil inside water passages (between) vanes was not accessible for removal.**
Repairs employed	Impeller skirts machined to suit new (oversized) Bowl Wear Rings
	Other new parts: All Impeller Shafting, all Bearings, all Bolting, All 0-Rings
	Some new Bowls and Impellers added where bio-oil was not accessible in water ways for removal
	Added 2 –stages (29 stage) … thought process was to further reduce speed and wear
	Re-assembled / Re-warranted as new equipment

Archive 3 Photos on following page

ARCHIVE 3 Photos: Factory Pump Disassembly after Bio-Oil Failure



ARCHIVE 4 & 5	LANDAU SPARE PUMP INSTALLATION & OPERATION: February 1, 2009 - December 7, 2013	
ITEM	DETAILS	
Pump Model	Goulds Pumps geothermal 12EHC-27 Stage	
Setting to top of "Pump"		
Location of ports to annulus	338.3 m	
Location of bubble tube termination	2-lines to 338.3 m, 1-line to 358.4 m	
Depth to pump suction impeller	352.3 m	
Depth to bottom of Strainer (and chemical line)	358.4 m	
Lubrication oil	**Chevron Bright Stock 150 (typical in USA … ISO 460 Group II Base Oil)**	
	After flooding of string prior to initial start-up: 11-19 liters/day	
	Lube oil later changed to: Texaco Omnis 460 (Group I Base Oil)	
Pipe Dope	**Mining Commission sent a Thread Inspector out for installation and dictated a Lithium-Calcium pipe dope on pipe threads (yellow in color).**	
	After bottom half of joints were installed, we ran out of Thread Inspector's pipe dope and finished the job with a high temperature pipe dope (silver in color).	
Gas Break-Out (tested)	Slightly under 20 bar … no change	
Typical operation / range	$153\text{-}160^{o}$ C	Pump performance per curve
	900-1790 rpm	
	27-75 l/sec	
	8-9.99 bar annulus	
	33-44 bar bubble tube	
	20-22 bar discharge	
	60-300 kw power consumption	
COMMENTS	The switch to Texaco Omnis 460 (from Chevron Bright Stock 150) lube oil presented problems that began somewhere around January, 2010:	
	The oil port entrance and "stuffing box" became plugged with sediment.	
	It was discovered that this sediment was in the oil pump supply tank.	
	Lube oils in the USA and Europe are not the same in spite of similar brand names. It was discovered much later that the Texaco Omnis 460 oil in Europe is a Group I base oil (unfiltered).	
	This sediment caused concentric scars but no wear to the lubestring (shafting, bearings) but plugging was evident.	
	Pump was pulled through uppermost two strings only and put back into service (knowing full well that some sediment may have travel down further into the Lubestring)	
	The motor thrust bearing was eventually discovered as not being insulated (per spec) and was re-installed with proper pre-loading tension.	

<table>
<tr><th colspan="2">ARCHIVE 6</th><th colspan="2">LANDAU SPARE PUMP INSTALLATION & OPERATION: Pipe Dope Failure</th></tr>
<tr><td colspan="2">ITEM</td><td colspan="2">DETAILS</td></tr>
<tr><td rowspan="6">As Mentioned Previously In Artifact 4</td><td rowspan="4">Lubrication Oil</td><td colspan="2">Chevron Bright Stock 150 (typical in USA … ISO 460 Group II Base Oil)</td></tr>
<tr><td colspan="2">After flooding of string prior to initial start-up: 11-19 liters/day</td></tr>
<tr><td colspan="2">Lube oil later changed to: Texaco Omnis 460 (Group I Base Oil)</td></tr>
<tr><td colspan="2">It was not discovered until April 2013 that Texaco Omnis 460 was a Group I ("unfiltered") base oil and the cause of sediment plugging. Prior to that, it was assumed that sediment in the supply tank was due to "dirty/rusty" drums</td></tr>
<tr><td rowspan="2">Pipe Dope</td><td colspan="2">Mining Commission sent a Thread Inspector out for installation and dictated a Lithium-Calcium pipe dope on pipe threads (yellow in color).</td></tr>
<tr><td colspan="2">After bottom half of joints were installed, we ran out of Thread Inspector's pipe dope and finished the job with a high temperature pipe dope (silver in color).</td></tr>
<tr><td colspan="2" rowspan="7">Typical operation / range</td><td>153-160^o C</td><td rowspan="7">Pump performance per curve up until November 2008</td></tr>
<tr><td>900-1790 rpm</td></tr>
<tr><td>27-75 l/sec</td></tr>
<tr><td>8-9.99 bar annulus</td></tr>
<tr><td>33-44 bar bubble tube</td></tr>
<tr><td>20-22 bar discharge</td></tr>
<tr><td>60-300 kw power consumption</td></tr>
<tr><td colspan="2">Problem</td><td colspan="2">After 4 years operation per curve (above) flow rate and head decreased slightly but power consumption remain constant. In concert with this, water level rose slightly without a change in annulus pressure BUT where spent lube oil could be retrieved from periodic flowing of annulus, no oil returned to surface. (Filters, however, not plugging).</td></tr>
<tr><td colspan="2" rowspan="3">Theoretical conclusion</td><td colspan="2">The torque installed to the 10 3/4 API pump casing pipe was verified as accurate and proper, however …</td></tr>
<tr><td colspan="2">Whether by inaccurate casing tong torque (cross-threading, galling of threads which did not show up on gauges) or lack of sealing, it was suspected that the lower pipe joints "washed-out" where Thread Inspector dictated a Lithium based pipe dope.</td></tr>
<tr><td colspan="2">If the lower pipe joints did in fact wash-out, this would fully explain scenario described at Problems (above). That is, pressure from washed-out pipe connections would by-pass flow and pressure to annulus while maintaining horsepower and, further, "push" spent oil downward rather than floating to water level. If pipe was washed-out above the water level (traditional pipe dope used), the same scenario would be present but with an increase in annulus pressure.</td></tr>
<tr><td colspan="2" rowspan="3">Theoretical substantiated when pump was pulled</td><td colspan="2">Only lower pipe joints (Lithium based pipe dope) had leaks</td></tr>
<tr><td colspan="2">Pump Suction and Discharge removed in field … no wear to Wear Parts but some erosion at vanes of Top Bowl (only)</td></tr>
<tr><td colspan="2">Note: Given proper pipe, dope, and torque this pipe (as well as Lubestring) should last many, many years and multiple trips without replacement.</td></tr>
</table>

Archive 6 Photos on following page

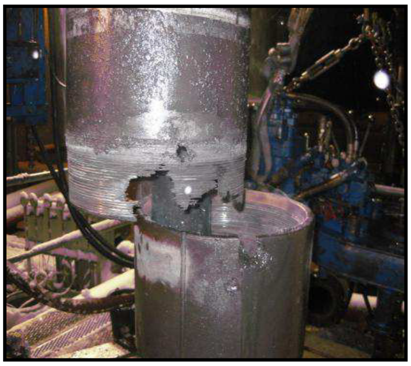
ARCHIVE 6 Photos: Pump pulled for washed-out pipe (pipe dope failure)

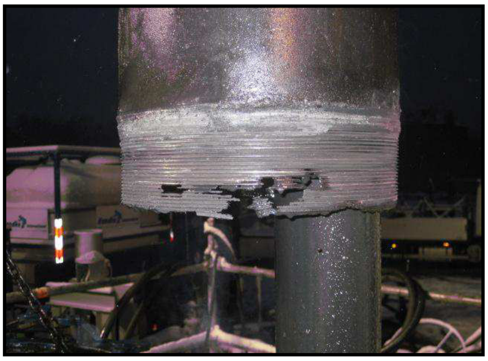
10 3/4 API 8 Round Casing (pump production) Pipe Connections

Pipe washed-out ONLY on joints installed with Lithium based "enviromentally friendly" pipe dope recommended by Pipe Inspector. Upper joints used a more conventional pipe dope and had no such failures.

Because pipe washed-out below water level and close to pump bowls, spent oil vented to annulus was pushed downward and into suction of pump.

It should also be noted that pipe washing-out is NOT typical and in fact is rare. Given proper pipe, dope, and torque this pipe (as well as Lubestring) should last many, many years and multiple trips without replacement.

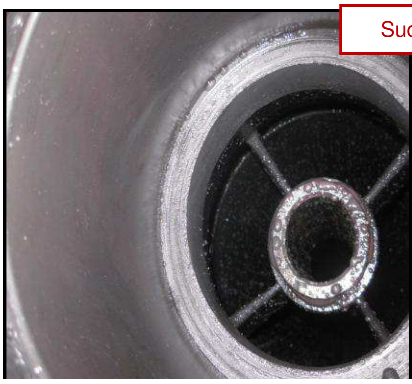


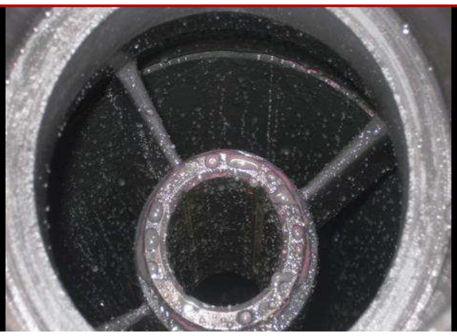


Discharge Case, Top Bowl and Suction Case removed from pump for field inspection

Uppermost Impeller Far left photo: Cuttings, granite, rock, clays and oil; Far right photo: Very minimal wear, erosion to sand lugs

Suction Case and bottom Impeller skirt (washed): No wear





<table>
<tr><td>ARCHIVE 7</td><td colspan="3">LANDAU SPARE PUMP INSTALLATION & OPERATION: December 16, 2012</td></tr>
<tr><td colspan="2">ITEM</td><td colspan="2">DETAILS</td></tr>
<tr><td colspan="2">Pump Model</td><td colspan="2">Goulds Pumps geothermal 12EHC-29 Stage
Refer to Archive 3: Rebuilt pump with 2 stages added</td></tr>
<tr><td colspan="2">Pipe</td><td colspan="2">10 ¾” API</td></tr>
<tr><td colspan="2">Pipe Dope:
Run-N-Seal Extreme (JetLube)</td><td colspan="2"><u>Currently</u> only acceptable alternatives: Steam Chief, Kov'r Kote Geothermal grade; Never use Nikal (now "meeting Cailfornia enviromental standards"), KopperKote or others</td></tr>
<tr><td colspan="2">Oil Tubing (surrounding Lineshaft)</td><td colspan="2">22.2 cm</td></tr>
<tr><td colspan="2">Lineshaft Diameter</td><td colspan="2">55.6 mm</td></tr>
<tr><td colspan="2">Lineshaft Bearing Spacing</td><td colspan="2">Every 1.52 m</td></tr>
<tr><td colspan="2">Setting to top of “Pump”</td><td colspan="2">368.8 m</td></tr>
<tr><td colspan="2">Location of brine by-pass and oil outlet ports to annulus</td><td colspan="2">368.8 m</td></tr>
<tr><td colspan="2">Location of bubble tube termination</td><td colspan="2">2-lines to 368.8 m</td></tr>
<tr><td colspan="2">Depth to pump suction impeller</td><td colspan="2">383.8 m</td></tr>
<tr><td colspan="2">Depth to bottom of Strainer (and chemical line)</td><td colspan="2">389.9 m</td></tr>
<tr><td colspan="2">Motor (Variable Frequency Driven)</td><td colspan="2">559.5 kw Nameplate</td></tr>
<tr><td rowspan="2">Lubrication oil</td><td colspan="3">Pump was installed and has been operating with Texaco Omnis 460 (as a European alternative to commonly used USA Chevron Bright Stock 150. It was only discovered in April 2013 that Texaco Omnis is not an equivalent. That is, as previously mentioned it is a Group I (not Group II) base oil which consequently contains sediments.</td></tr>
<tr><td colspan="3">The Texaco Omnis 460 will be replaced with Shell Morlina S1B (Group II) base oil ... currently in use at Insheim. Time will tell but the Shell grade in spite of specifications does seem to foam.</td></tr>
<tr><td colspan="2">Start-Up</td><td colspan="2">Smooth, uneventful; No vibration, run-out, etc.</td></tr>
<tr><td colspan="2">Gas Break-Out (tested)</td><td colspan="2">Less than 20 bar @ ~ 161° C</td></tr>
<tr><td colspan="2" rowspan="7">Typical operation / range
Note: Gradual production to prevent seismicity</td><td>153-160° C</td><td rowspan="7">Pump performance per curve</td></tr>
<tr><td>900-1700 rpm</td></tr>
<tr><td>27-75 l/sec</td></tr>
<tr><td>8-9.99 bar annulus</td></tr>
<tr><td>33-44 bar bubble tube</td></tr>
<tr><td>20-23 bar discharge</td></tr>
<tr><td>60-300 kw power consumption</td></tr>
</table>



Outline of Japan Beyond-Brittle Project (JBBP) for Development EGS Reservoirs in Ductile Zones

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ABSTRACT

New conventional geothermal energy projects have not been actively promoted in Japan for the last decade because of perceptions of high relative cost, limited electricity generating potential and the high degrees of uncertainties and associated risks of subsurface development. More recently however, EGS (Enhanced Geothermal System) geothermal has been identified as a most promising method of geothermal development because of its potential applicability to a much wider range of sites, many of which have previously been considered to be unsuitable for geothermal development. Meanwhile, some critical problems with EGS technologies have been experimentally identified, such as low recovery of injected water, difficulties in establishing universal design/development methodologies, and the occurrence of induced seismicity, suggesting that there may be limitations in realizing EGS in earthquake-prone compression tectonic zones.

We propose a new concept of engineered geothermal development where reservoirs are created in ductile basement. This potentially has a number of advantages including: (a) simpler design and control of the reservoir, (b) nearly full recovery of injected water, (c) sustainable production, (d) lower cost when developed in relatively shallower ductile zones in compression tectonic settings, (e) large potential quantities of energy extraction from widely distributed ductile zones, (f) the establishment of a universal design/development methodology, and (g) suppression of felt earthquakes from/around the reservoirs.

To further assess the potential of EGS reservoir development in ductile zones we have initiated the “Japan Beyond-Brittle Project (JBBP)”. It is intended that the first few years of the JBBP will be spent in basic scientific investigation and necessary technology development, including studies on rock mechanics in the brittle/ductile regime, characterization of ductile rock masses, development of modeling methodologies/technologies, and investigations of induced/triggered earthquakes. We expect to drill a deep experimental borehole that will penetrate the ductile zone in northeast Japan after basic studies are completed. The feasibility of EGS reservoir development in the ductile zone will then be assessed through observations and experimental results in the borehole. An ICDP supported workshop on JBBP has been held March 12-16 in Sendai, Japan, where feasibility, necessary breakthroughs, and roadmap were discussed from scientific and technological points of view. The output from the WS will be also introduced in the presentation.

The application of the multifrac concept in horizontal wells for deep geothermal energy. A concept study.

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Key Words
Deep geothermal energy, multistage horizontal well fracturing, hydraulic fracturing, drilling of hard rock

ABSTRACT

Nowadays it is state of the art in the oil and gas production to use multifrac technologies in horizontal wells. A new idea is to adapt this concept for deep geothermal energy.

In Germany crystalline rocks have a high geothermal potential, if those reservoirs are developed by hydraulic stimulation. In order to create large heat exchangers in low permeable formations the multifrac concept for horizontal wells might be the best and potentially, the only solution. The basic idea is that two horizontal wells, one for injection and one for production, will be connected by multi-stage fractures. (Figure 1)

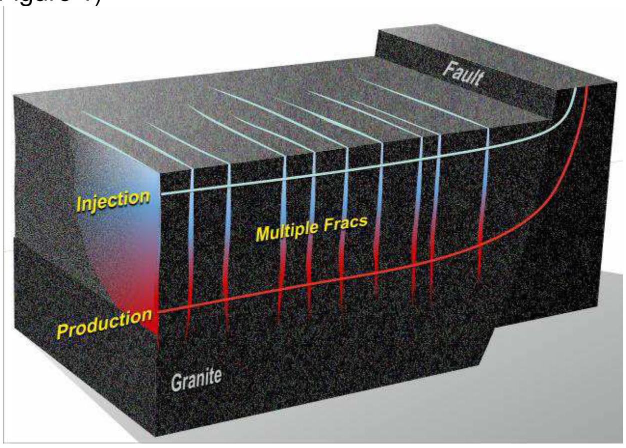

Figure 1: Scheme of the multifrac concept for geothermal energy extraction.

The Federal Institute for Geosciences and Natural Resources examines this concept with respect to technical and scientific aspects. The potential chances and risks of this concept shall be evaluated and recommendations shall be given for its implementation.

The technical part of the study deals with two mayor subjects:

- The drilling technology and directional drilling in crystalline rocks.
- Techniques for multi stage horizontal wells fracturing.

The investigations are mainly based on literature research and on personal experiences from professionals who work with these techniques. In the following a brief overview is given on the first outcomes of our study.

On the one hand there are only few experiences in directional drilling of horizontal wells in crystalline rocks. But on the other hand new developments in the drilling technology show promising results. For example improvements in the used materials show longer persisting bits. New down-hole motors for the rotation of the drilling bit produce higher torque. Hence, it is possible to increase the weight on bit (WOB) and the rate of penetration (ROP). Enhanced directional drilling systems like “Motor powered rotary steerable systems (MRSS)” make it possible to drill with a higher drilling speed. By sharing two types of drives, surface and subsurface, there is an optimal load distribution on the drilling pipe. These developments show significant improvements in drilling performance. A project in granite in Vietnam shows an increase of the durability up to 40 % and the ROP up to 16 %. The down-hole motor could be operated for 10 km in granite without any incident and the costs could be reduced by nearly 30 %.

A lot of experiences in the field of horizontal well fracturing exist from the oil and gas producing industry. Observations have shown some problems which might have a great influence on frac operation performances. For instance, the occurrence of axial fractures can be often observed, even when the horizontal well is correctly drilled in the least minimal stress direction. On the one hand the consequence is a short fracture depth. On the other hand the axial fractures could jump over packers causing bypasses. Reorientation to transverse fractures at some distance to the wellbore could cause high near-wellbore-friction.

High perforation friction is often observed, which causes pressure loss and leads to inefficient frac operations. An option which has been chosen more and more by the industry to reduce the friction is jet-perforation. Compared to explosive perforation, jet-perforation methods create cleaner and deep fracture initiation points.

In general, a short perforation interval seems to be advantageous for the creation of transverse fractures without additional friction losses.

In oil and gas wells, ball-drop tool systems like the “sliding sleeve system” are often used for the creation of multiple fractures. In general, in those operations, not all of the intended fractures can be initiated or several stages are activated at the same time. For oil and gas production these limitations might be acceptable. However, for a geothermal multifrac application stronger requirements have to be made. Here, the aim is to create multiple fractures with nearly the same size and conductivity.

In general, the sliding sleeve technology seems to be a good option for the use in geothermal circulation concepts because of the ability to close or to reopen ports manually and to separate individual fractures from the well. At this point of the study the long time reliability of sliding sleeve technology is not investigated and needs more research. In connection with proppants there are experiences that the sliding sleeve might stick and the fractures cannot longer be separated.

There will be more comprehensive investigations in the field of mud systems and loading capacities of materials. Further, methods of well completion and simulations of fracture propagation and dimensions will be part of our investigation, too.

Beside, GeoForschungsZentrum Potsdam (GFZ) and TU Bergakademie Freiberg (TUBAF) are partners in the overall project.

The GFZ is responsible for designing a reservoir model and the investigation of thermo hydraulic mechanisms of the heat exchanger.

TUBAF is simulating processes during the fracture propagation and investigates by using 3-D modeling the interaction of multiple fractures. Furthermore the TUBAF investigates the induced seismicity for such concepts.

Both partners perform their investigations with respect to a reference size. At the end it should be possible to give a development scenario and a possible frac operation design for a reference size.

Acknowledgement

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Wing-cracks – the key for understanding the stimulation process in fractured rock

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ABSTRACT

The heat content of the crystalline basement is by far the biggest energy resource of the earth crust. First attempts to access this resource date back to the early 1970´th and more than a dozen research and industrial projects have been performed since than in various countries. But still the technique, known as HDR (Hot-Dry-Rock) or EGS (Enhanced-Geothermal-Systems) is not mature and further development is now hindered by the risk of strong induced seismicity.

A critical review of results and observations shows that the main reason for the poor progress is the exploitation concept being applied in all major projects since the early 1980´th. Until than the basement had been regarded as a competent rock mass and the leading exploitation scheme was to connect two inclined boreholes by a number of parallel fractures created by hydraulic fracturing in short insulated borehole sections. Realizing that the basement contains open natural fractures even at great depth this multi-fracture-concept was abandoned and replaced by the EGS-concept. The intent of this concept is to enhance the permeability of the natural joint network by massive water injection in very long uncased borehole sections. This process known as hydraulic stimulation is regarded as a pressure diffusion process accompanied by shearing and widening of the joint network.

Observations and results of all major EGS-projects however suggest that this is not happening but that generally one large fracture is created during massive stimulation tests regardless of site- and test-conditions. The formation of these single fractures can well be explained by the wing-crack model. The basic finding under-laying this model is that natural fractures of finite extent failing in shear will not propagate in their own plane but will develop tensile wing-cracks at their periphery. The wing-crack model delivers plausible explanations for almost all observations of the major EGS-projects in particular for the onset of fracture propagation at a fluid pressure much lower than the minimum principal stress, the high intensity and mechanism of induced seismicity, the occurrence of channel-like features in the seismic clouds, the long lasting fracture linear or bilinear flow periods during post-stimulation hydraulic testing, the occurrence of high magnitude after-shocks, the large fracture apertures derived from tracer break-through volumes and from the ratio of fracture area and injected volume. It also explains the striking discrepancy between the only moderate fracture transmissibilities and the large apertures as well as the rapid thermal draw-down observed during circulation tests.

Theses findings suggest that the present EGS-concept will never lead to EGS-systems of industrial size and performance. It has to be abandoned and be replaced by a multi-fracture scheme as it was foreseen in the original Hot-Dry-Rock concept with the main difference that the tensile fractures of this concept have to be replaced by wing-cracks. This requires a more sophisticated design and planning in particular for the positioning, completion and treatment of the second well. Industrial systems of this type require wells being drilled parallel to the axis of the minimum principal stress, i. e. horizontal wells for normal and strike slip stress conditions and vertical wells for reverse faulting conditions. An industrial system may consist of about 30 to 40 equidistant fractures connecting two 1 km long parallel well sections with a well separation of about 500 m. Systems of these dimensions should operate for at least 25 years at flow rates of 100 L/s, an electric power output between 5 and 10 MW and a pumping power of less than 1 MW. Directional drilling and packer technology have improved significantly during the last three decades and multi-fracture concepts are applied with great success in unconventional gas reservoirs. Though the conditions and requirements in geothermal applications are more demanding in various aspects it seems almost certain that geothermal multi-fracture-systems of this type can be realized in the near future.

Concern regarding induced seismicity: Observations and possible ways forward

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ABSTRACT

Generally speaking, hydrothermal systems are located where the crust is relatively thin which offers the advantage of having higher temperature at shallow depth and thus economically attraction. One of the disadvantages of this type of system is that it has to accommodate some of the pressure built up and movement in the upper crust which can manifest itself as seismic events. On the other hand experienced gained from over 40 years of fluid injections in crystalline basements have shown that there are some parameters which may help to reduce or control the generation of induced seismicity.

A brief historical review of the data from all EGS projects in the world (there have been something like 20 or more to date set in various stress and geological conditions) may provide a better understanding of parameters which may be contributing to the generation of larger induced seismic events. These projects should have information on stress orientation and gradient, geology with depth, fracture distribution and orientation, existence of faults, a number of hydraulic tests to characterise the in-situ permeability, a good high resolution seismic network to extend the seismic analyses other than just produce pictures of the seismic locations, flow logs to characterise the flow distribution with the well etc. These type of projects give a more precise information on how the rock mass react when hydraulic injection or circulation is carried and thus a better understanding on what is happening. A brief evaluation of the data from some of these EGS projects show that:

1. The influence of stress, both direction and gradient is very important or one could say is crucial to the understanding of induced seismicity. Observations indicate that in

   i) Normal faulting regime the reservoir will grow horizontal to upward, depending on the stress ratios.
   ii) In a strike slip regime it will grow horizontal to downwards, again depending on the stress rations.
   iii) Stress migration takes place as the reservoir grown and the permeability is enhanced.

   Observations show that for some reason there is a stress build up on these pre existence faults and then is released as larger bang. Using source parameter calculations it can be shown that the large energy can have relatively small fault lengths and therefore are for unlikely to cause any structural damage.

2. Induced seismicity and volume injected. There are a number of examples available which shows that the total seismic energy release is directly proportional to the total volume injected.

3. Induced seismicity and water losses in the formation. There are examples which show that seismicity will continue occurring if the injected water is not recovered as the reservoir expands continuously i.e. reservoir management is essential.

4. Induced seismicity and use of higher viscosities (jells) instead of just fresh water. Observations show that there is significantly reduction in seismicity when jells are used instead of fresh water or brine. These were tested at the Rosemanowes project (UK) for the development of an EGS project. Viscosities varied from 30 1-1000 cp. This had additional advantage in that the total volume injected relatively low thus introducing less total mechanical energy in to the system.

5. Diagnostic techniques: A number of diagnostic techniques are essential for us to understand the generation and control of induced seismicity. These include numerical stimulation & circulation models, tracer studies, production logging, high resolution seismic network (preferably downhole with broad bandwidth (5-500Hz and high sensitivity) etc.

6. Public acceptance: The reason one is discussing how to control induced seismicity is because of the lack of public acceptance and not that there is likely to be catastrophe and tens of people will die. A protocol and a white paper have been established under the International Energy Agencies'

Geothermal Implementing agreement and this needs reinforcing or updated. Additionally, "earthquakes" the term used for quantifying these induced tremors are not helpful as it generates a picture in the public that the world is falling apart and this needs to replaced with a more engineering or structural damaged based which relies on the dominant frequency and peak particle acceleration as used in the mining industry.

How to minimize seismic activity during geothermal exploitation? The Soultz experience.

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ABSTRACT

After the construction of the Soultz geothermal power plant completed in 2008, several circulation tests have been performed to test electricity production as well as downhole pumping technologies. Different production/injection strategies, involving 2, 3 or 4 boreholes were tested with different production / injection flowrates. The induced seismicity was continuously monitored with a surface seismological network of 8 permanent stations.

In 2008, two 2-months circulation were performed. The first involved one production well, GPK2, and one reinjection well, GPK3. Around 190 microseismic events were recorded and seismic activity started only when the reinjection pressure reached ~60 bar. The maximum observed magnitude was 1.4. The second 2008 test was performed using 2 production wells, GPK2 and GPK4, and one reinjection well GPK3. Again, microseismic activity was observed when reinjection pressure reached 60 bar, and a total of 50 events could be detected. The largest magnitude event (M=1.7) occurred 5 days after the end of the test.

In 2009, the 9-months circulation test involved the 4 deep boreholes, GPK2/GPK4 as production wells, and GPK3/GPK1 as reinjection wells. But because of pump failures, they only operated in the same time for a short period. ~200 microseismic events were observed and the largest activity occurred when GPK3 reinjection pressure was above 50 bar. When the pressure was decreased below 30 bar, only a few events were detected. Maximum magnitude was 1.7.

In 2010 was carried out the longest circulation test (11 months) ever performed at Soultz. Production was performed with GPK2 only and reinjection was done first into GPK3 only, then after 5 months, into both GPK3 and GPK1. Around 400 events were recorded. The largest microseismic activity was observed in the first part of the test, when GPK3 reinjection pressure was around 50 bars. But, when reinjection was shared between GPK3 and GPK1, (for a small volume only) limiting GPK3 injection pressure to 30-35 bar, the seismic activity decreased to a very low level. It rose again by the end of the test, because of the continuous, slow increase of GPK3 injection pressure to 50 bars. 4 events reached magnitude higher than 2, the maximum magnitude being 2.3. Fortunately, none was felt by the local population.

In 2011, two circulation tests were performed with GPK2 as production well. Here the reinjection strategy was adapted: it was decided to let the surface pressure (~20 bar), given by the production pump, control the reinjection into GPK3. The remaining volume was thus reinjected into GPK1 with a very low injection pressure. The main consequence is the spectacular decrease of the seismic activity, as only 5 events were induced (1 during the first test, 3 during the shut in period of the first test and 1 during the second test.)

In 2012, the same strategy was applied during the short circulation test and no event was detected.

Thus, the strategy which consists in sharing the reinjection between 2 wells, so as to lower the injection pressure seems to be a very efficient way to reduce the induced microseismic activity. However, this was proven on relatively short-term circulation tests and further long-term observation is needed to see if a larger circulated volume of geothermal fluid could generate the opposite effect. Finally, we noticed that the increase of volume reinjected into GPK1, which is at a shallower depth than the other boreholes, led to a negative impact on GPK2 production temperature, as it decreased by about 3-4°C. Thus, for the current circulation test, we decided to share the reinjection between GPK3 and GPK4. As the pressures are still low, only one single event of low magnitude has been detected up to now.

Monitoring induced seismicity from geothermal and gas production in Germany

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ABSTRACT

Induced seismicity from geothermal sites, often related to the stimulation of the reservoir, and from gas production with or without fracking poses a previously unknown threat to population, and is a serious obstacle for political acceptance. The first step in mitigating this challenge is to monitor natural and induced at production sites. FKPE has issued recommendations of how to perform this monitoring based on proven technologies, and with classical seismic networks. Here we introduce studies from planned geothermal sites in Germany (Groß-Gerau, Mauerstetten), and gas production in northern Germany (Rotenburg) where this concept is complemented, and compared to Nanoseismic Monitoring. NM uses surface arrays, and error-tolerant processing software to achive high monitoring performance in industrial and urban, noisy environment. First quantitative results from comparing both monitoring approaches will be presented.

EGS subsurface seismic hazard assessment

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Key Words
EGS Microseismic Seismicity Hazard Probabilistic

ABSTRACT

Probabilistic based approaches to EGS seismic hazard have been receiving increased interest, both in terms of estimating the size of the maximum probable induced event and also implementing adaptive “traffic light” systems. Probabilistic based approaches are of practical interest to developers because they do not demand a highly detailed knowledge of fault parameters, and the uncertainties associated with hydro-mechanical interactions and the microearthquake rupture process. However in order to use probabilistic approaches developers need to be confident that large induced events are not “anomalies” or somehow “special” events, but are part of a statistical and scalable seismicity distribution. EGS Energy has incorporated a probabilistic element into its hazard assessment for the Eden EGS development. This is based on the use of the nearby CSM Hot Dry Rock (HDR) Project at Rosemanowes as an analogue. Rosemanowes itself experienced several large induced events ($M_L \leq 2$) during the main circulation phase of the project. These have been considered somewhat “anomalous“ in terms of the bulk of the seismicity. However recent re-analysis of the Rosemanowes data suggests that these large events are consistent with the general relationship between seismic eneregy release and injected fluid volume, and also consistent with the range of focal mechansims expected due to the interaction of the injected fluid, stress regime and fracture distribution. This supports the approach adopted in the Eden assessment and also provides an illustration of where apparently anomalous events do seem consistent with the use of a probabilistic approach.

Introduction

As part of the Eden EGS development EGS Energy Ltd has conducted a subsurface seismic hazard study. The study has investigated the potential for large-scale seismicity (ie felt or larger) resulting from the proposed EGS development and circulation operations. A key component of the study the use of the experience at the nearby Camborne School of Mines (CSM) Hot Dry Rock (HDR) Project at Rosemanowes as an analogue for the anticipated behaviour at Eden.

This assumption appears reasonable for several reasons: SW England is a region of relatively low tectonic strain; it has low levels of natural seismicity; both sites are within the same uniform granite batholith that extends to surface; available evidence indicates a relatively uniform regional in situ stress regime. Furthermore, even though the Rosemanowes boreholes only extended to around 2.2km depth the EGS seismicity was observed to >3.5km depth, which is similar to the depths anticipated for the Eden EGS project (~4->4.5km).

Although the analogue seems reasonable EGS Energy nonetheless recognise the need to validate this assumption during the early stages development.

This validation approach also raises a broader question concerning the scalability of probabilstic relationships developed during small volume tests to large fluid volumes, and hence the use of these as predictive tools.

This paper presents the results of a recent re-assessment of the seismic behaviour of the Rosemanowes system udertaken as part of the EU FP7 GEISER Project. It has particular relevance for the use of historic EGS seismicity catalogues as a hazard assessment tool. In the case of Rosemanowes it addresses the statistical and geomechanical relationship between the few, apparently anomalous, large ($M_L \leq 2$) induced seismic events and the bulk of the microseismic activity.

Following the termination of the Rosemanowes project there remained some uncertainty about whether these large events were anomalies, for example “triggered” seismicity on some unknown large-scale structure, or whether they formed part of a continuous distribution of microseismicity and were a statistically quantifiable consequence of the sustained injection operations.

This question is of general importance for EGS seismic hazard assessment. If large-scale induced seismicity is found to represent part of a continuum of induced seismicity then it may be appropriate to consider a probabilistic approach to hazard assessment. However if large-scale events are consistently found to be anomalous in terms of their size, focal mechanism or stress drop, it may be more appropriate to adopt a deterministic approach that would take into account local geological and tectonic conditions, as well as operational parameters.

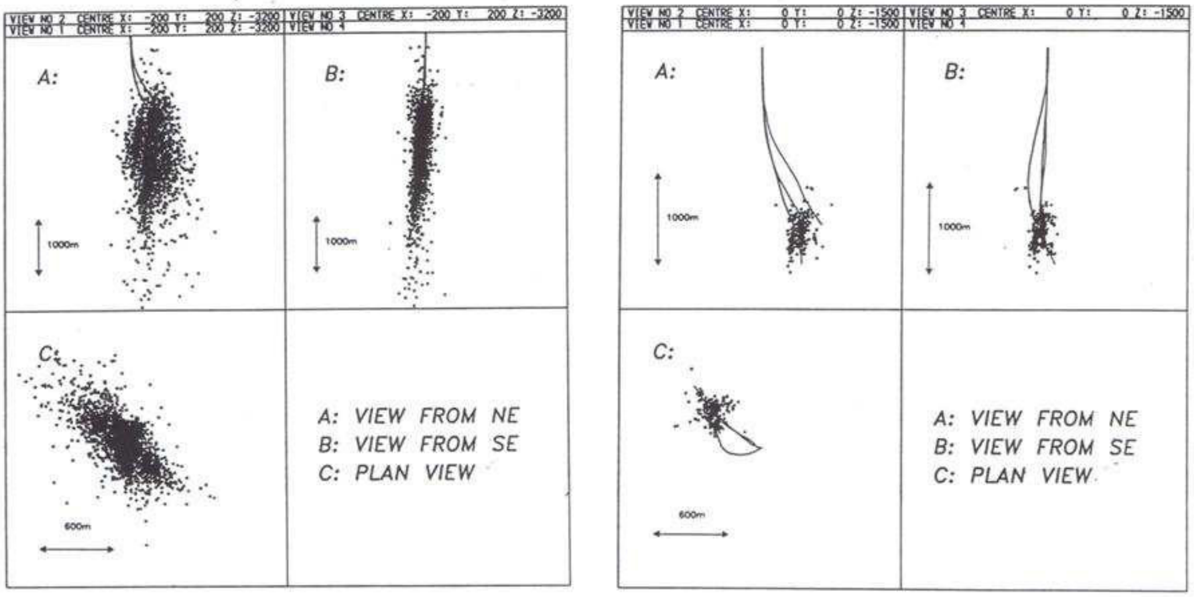

Figure 1: Side and map views of the boreholes and seismicity during Phase 2A and 2B of the Rosemanowes geothermal experimentation. A) Left - Phase 2A seismicity and RH11/RH12 boreholes, B) Right - Phase 2B seismicity showing additional borehole RH15.

Seismicity at the CSM Rosemanowes Project

Large-scale EGS experimentation was undertaken at the CSM HDR Project between 1980 and 1991. There were 3 main Phases, with a series of sub-phases. Briefly:

- *Phase 1:* Experiments at shallow depth (300 m) to assess the feasibility of enhancing the permeability of the rock
- *Phase 2:* Studies at intermediate depth (2500 m) to determine the feasibility of creating a viable HDR subsurface heat exchanger. This was the main experimental phase at Rosemanowes and is of most relevance to this study
- *Phase 3:* Design and concept testing aimed an HDR prototype at commercial depth (6km)

The first part of Phase 2 (ie Phase 2A) lasted from 1980 to 1983. This involved the drilling of two boreholes deviated from the vertical by *30°* to a depth of 2km (Figure 1). Hydraulic stimulation was carried out with water from the lower borehole to try to open up the near vertical fractures rising to and intersecting the upper borehole. When circulation started, the system did not behave as predicted: water losses were large (~70%) and the pumping pressures required for circulation were found to be too high.

During Phase 2A approximately 30,000 microseismic events were detected and more than 5,000 were located. The net fluid injection was ~230,000 m^3, with an overall net return of ~30%. The largest event reported by the British Geological Survey (BGS [1]) was an M_L=1.0 in 1983.

The microseismic data obtained during the Phase 2A stimulation and circulation indicated that a large microseismic 'cloud' had developed beneath each borehole (Figure 1). It was believed that the majority of the injected water migrated into this zone below the boreholes and hence was not recovered by the second borehole.

Phases 2B and 2C were undertaken between 1983 and 1988. A third borehole (RH15) (Figure 1) was drilled at the end of 1984 to a measured depth of 2600m and along a helical path crossing the microseismic 'cloud' obliquely to the vertical plane of the first two boreholes. The aim was to maximize the number of fracture intersections.

The Phase 2B programme began with a medium-viscosity gel stimulation to try to open up the volume between this new borehole and the deeper of the original boreholes. The injected volume during the stimulation was around 6000 m^3. During Phase 2B overall the total net injection volume was around 120,000m^3, with an overall net recovery of over 70%. Approximately 1300 microseismic events were detected and more than 500 located (Figure 1). The largest event in Phase 2B had an M_w ~0.0 (CSM [2]).

The main phase of reservoir circulation at Rosemanowes was Phase 2C. During the Phase 2C circulation experiments the reservoir was operated at high flowrates and pressure for sustained periods.

Measurements in Phase 2C established that impedance fell as the injection pressure and flow rate increased. However the higher operational pressures resulted in further seismicity, indicating further stimulation of the reservoir and continued growth. Amongst this low magnitude seismicity three larger seismic events occurred, with M_L=2.0, 0.7, and 1.7 (BGS [3],[4],[1]). The M_L=2.0 event was felt at the surface by a number of local residents, albeit in extremely calm weather and quiet environmental conditions. The injection flowrate was subsequently reduced in order to prevent further felt seismicity. The M_L 1.7 event occurred in January 1988 but was not felt at ground surface. No further events of $M_L \geq 1$ occurred in the Phases 2C and 3A experimentation.

As noted earlier an important question remains as to whether these large events should be considered anomalous, or whether they form part of a continuous distribution, or spectrum, of microseismic activity resulting from the EGS experimentation.

This has been investigated by firstly considering the relationships between net fluid injection and seismic energy release, and secondly by examining the focal mechanisms in terms of the expected geomechanical behaviour of the Rosemanowes subsurface.

Relationship between seismicity and fluid volume

In this section we consider the relationship between the seismicity observed at the Rosemanowes project and the net injected fluid volumes. Models are developed using the Rosemanowes data from Phases 2A and 2B and then used to make predictions concerning the large events in Phase 2C. The success of these predictions then provides some insight into the nature of the large events.

McGarr [5] proposed the following relationship between the cumulative seismic moment (M_o) and the injection (or extraction) of a fluid volume $|\Delta V|$.

$$\sum M_o = K\mu \, |\Delta V| \qquad (1)$$

where μ is the rock mass rigidity and K is a constant which McGarr [5] estimates to be ~1.0, but depends on the specific site and unit system employed.

In this study we have obtained empirical estimates of the constant K for Phase 2A and 2B, and used these to make predictions about the Phase 2C events. Figure 2 presents an example of a cumulative seismic moment against net injected volume curve for the main stages of Phase 2A. Two curves are shown: one is the original data digitised from plots in the Rosemanowes reports (solid line); the other is calculated from new seismic moment estimates obtained from the historic digital waveform data recovered during the course of the GEISER Project work (dashed line). The curves are very similar indicating successful recovery of both the waveform and hydraulic data.

Similar analyses were performed for all the main stages in Phase 2A and 2B to obtain a distribution of values for the constant K. These values were then used to make a prediction of the expected maximum magnitude for Phase 2C. The conservative assumption is made that all energy is released in a single event.

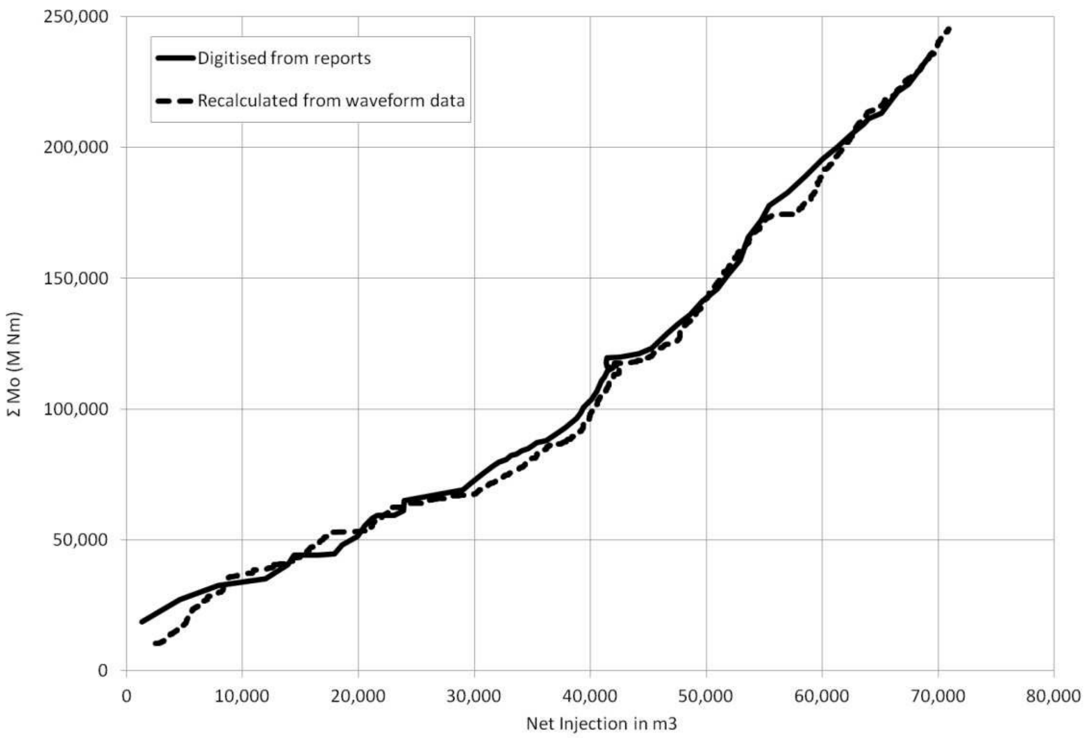

Figure 2: Cumulative seismic moment against net injected volume for Rosemanowes Phase 2A. Black line digitised from reports, Red line recalculated from waveform data

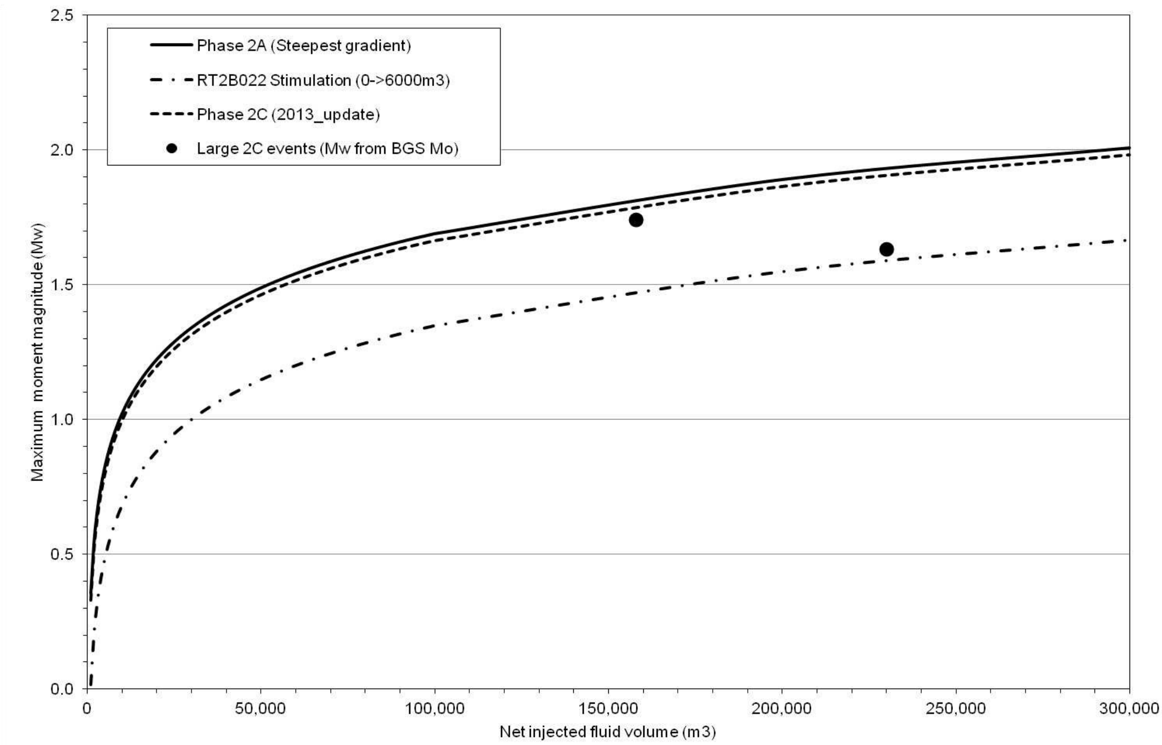

Figure 3: Predicted maximum moment magnitude against net injected fluid volume based on analysis of Phase 2A and Phase 2B Rosemanowes results. Black points are the occurrence of large magnitude events on 12 July 1987 (M_L 2) and 7 January 1988 (M_L 1.7).

Figure 3 presents estimates of the maximum expected M_w against net fluid volume for the overall range of K values obtained for Phase 2A and 2B. The M_w for the two largest Phase 2C events are plotted against the net fluid volume corresponding to their occurrence time (CSM [6]). It can be seen that two large events plot well within the bounds of the K value estimates. This indicates that the energy release for these two events is consistent with the general trend estimated from the Phase 2A and 2B data. In other words the large 2C events do not exceed the cumulative energy release predicted by the McGarr [5] model. Hence we can conclude that at least in terms of the McGarr model the Phase 2C events do not appear anomalous in terms of the cumulative net injected volume.

A second approach was used in which the distribution of event magnitudes was taken into account. Dinske [7] proposed the concept of the seismogenic index (∑). It had been shown that the number of earthquakes having a magnitude larger than a given size increases proportionally with the injected fluid volume, and that this is also affected by the seismotectonic state of the specific site. In order to characterise this state Dinske [7] introduced the concept of the seismogenic index (∑). This combines several, generally unknown, site-specific properties. However it is relatively simple to evaluate ∑ from microearthquake catalogues using the relationship:

$$\Sigma = \mathrm{Log}_{10} N_{\geq M}(t) - \mathrm{Log}_{10} V_i(t) + bM \qquad (2)$$

where b is the b-value slope obtained from the classic Gutenberg-Richter magnitude frequency distribution, N is the cumulative number of events greater than or equal to a specific magnitude M, and V_i is the net injected fluid volume. Therefore the seismogenic index can be estimated for various values of M by analysing the relationship between injected volume and N. In the case of the main Phase 2A stimulation a b-value estimate of 1.9 was obtained based on an analysis of the recalculated M_w distribution using the maximum-likelihood approach. This gives a seismogenic index of -3.65.

This value has been compared to the results obtained by Dinske [7] for a number of injection projects, including geothermal. It was found that Rosemanowes is on the low side of the seismogenic indices obtained for EGS systems around the world. It is similar to the value obtained for the Soultz shallow reservoir and is consistent with the idea that Rosemanowes was a site of relatively low level seismicity and hazard.

Having estimated the seismogenic index from Phase 2A we can use it to estimate the largest event that might have been expected during Phase 2C. We do this by rearranging the above equation and evaluating M_w for a range of fluid volumes, where N=1. The results of this analysis are shown in Figure 4. This shows the expected maximum event magnitude (N=1 event) plotted against net injected fluid volume. Also shown are 95% error bars. Based on this curve the N=1 event corresponding to the fluid volume injected prior to the M_L 2 event (~158,000m^3) is approximately

M_w 1.55. This estimate is close to the BGS observed M_w ~1.7 and indicates that this large event falls well within the 95% confidence limits for the seismogenic index based estimate.

As with the McGarr [5] approach this indicates that the energy release for the large event is consistent with the general trend estimated from the Phase 2A data. Hence the Rosemanowes Phase 2C large events do not appear anomalous in terms of the cumulative net injected volume.

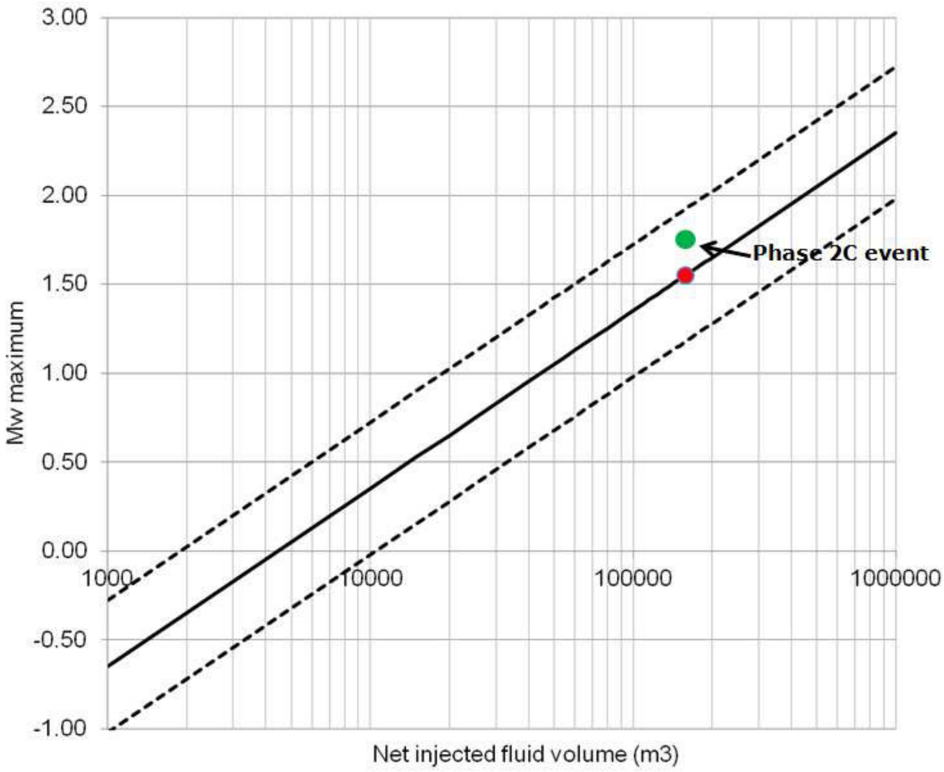

Figure 4: Plot of maximum expected M_w for N=1 probability events using the Rosemanowes RT2A046 derived seismogenic index, compared with the actual occurrence of the 12 July 1987 (M_L 2) event. Dashed lines are 95% confidence limits on seismogenic index.

Focal Mechanism Analysis

Analysis of the magnitude-fluid volume relationship suggests that the large events are consistent with the bulk of the Rosemanowes seismicity in terms of the cumulative energy release (ie McGarr [5]) and also the expectations based on the Gutenberg-Richter magnitude-frequency model (ie Dinske [7]).

Therefore unless the Rosemanowes large-events demonstrated some anomalous focal mechanism it would be hard to clasify them as anomalies, and not some part of the overall continuous distribution of microseismicity at the Rosemanowes site.

Detailed focal mechanism analysis is difficult with the Rosemanowes data because the sensors were mainly single component (vertical sensors), there is amplitude saturation of large events and also because of the relative sparseness of the array geometry. Nonetheless reanalysis of focal mechanisms data during the GEISER Project has provided some insight into this question.

Figure 5 presents a summary of composite focal mechanisms obtained during this study, and also a focal mechanisms obtained by the BGS for the M_L 2 event BGS [1]). In all cases the projections are upper hemisphere. The top two mechanisms show the BGS solution for the M_L 2 event and a GEISER solution obtained for a nearby smaller event. These mechanism are consistent and show a normal faulting component on relatively shallowly dipping failure planes, which strike close the orientation of the maximum principal stress (NW/SE).

These mechanisms were initially considered anomalous by CSM because the vast majority of the solutions obtained at Rosemanowes indicated strike-slip on sub-vertical fractures (left-hand-bottom solution Figure 5). However more detailed analysis suggests that a range of failure mechanisms are present. The vast majority are the pure strike-slip mechanisms, but there are also a much smaller number of mechanisms that include moderate to large normal faulting components. This spectrum of solutions incorporates the BGS obtained solution for the M_L 2 event. Furthermore the frequency of non strike-slip solutions also appears to increase with depth within the reservoir, which is consistent with the location depth of the larger events. Therefore this suggests that the mechanism for the large event is not a complete anomaly, but part of a spectrum of focal mechanisms.

Rosemanowes benefits from quite extensive in situ stress data and it is believed that the stress field is well characterised to at least 2.5km depth and can be reasonably extrapolated for at least another kilometer (CSM [6]). This has allowed us to make some predictions concerning the likely range of focal mechanisms that might be expected during the Rosemanowes injection operations.

A Mohr-Coulomb failure analysis has shown that the minimum fluid pressure required for shear slip occurs for vertical fractures striking approximately 20°->25° from the maximum horizontal stress. This is consistent with the bulk of the focal mechanisms observed at Rosemanowes. However there is a fairly broad minimum in the critical pore pressure distribution that extends towards the strike of the maximum horizontal stress for shallower dipping fractures. This exists at both 2.5km and 3.5km depth, but the minima becomes more significant at greater depths. This is because of the divergence of the maximum and minimum horizontal stress with depth at Rosemanowes. Hence we find that shear slip may be possible on fracture planes with shallower dips (~60°->70°) and that the frequency of these mechanisms might increase with depth.

This analysis can be further expanded to consider the sense of shear slip predicted on planes of any orientation. At both 2.5km and 3.5km depth it has been found that there is a transition from strike-slip to normal-faulting mechanisms that corresponds with the shape of the minima in the pore pressure plots. This is also consistent with the observation that the more shallowly dipping fractures striking closer to the maximum horizontal stress will exhibit an increasing normal faulting component.

In summary it appears that the observed focal mechanisms for the large events are entirely consistent with the overall spectrum of focal mechanisms that might be expected based on the measured in situ stress field at the Rosemanowes site. Furthermore the analysis also suggests that the relative frequency of mechanisms with a normal faulting component will increase with depths due to the known divergence of the two horizontal stresses. Therefore the mechanisms for the relatively deep large events appear predictable as part of the overall microseismic event population.

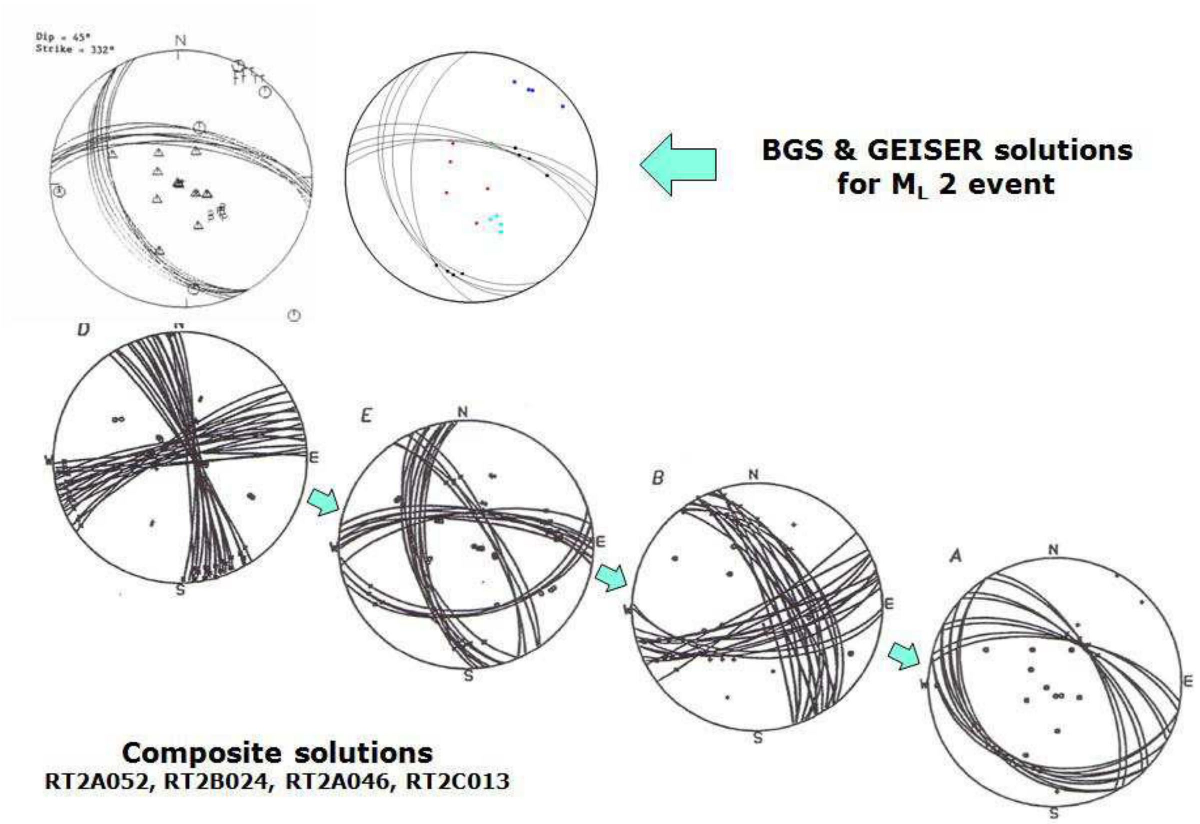

Figure 5: Summary of the range of focal mechanisms observed at Rosemanowes. All mechanisms are shown as upper-hemisphere projections. Top - BGS published mechanisms for the 12 July 1987 (M_L 2) event and GEISER derived solution for a nearby event. Bottom - range of focal mechanisms observed at Rosemanowes with decreasing event frequency to right.

Results and Conclusions

The key question addressed in this study has been whether the large events observed at Rosemanowes were truly anomalous, or whether they formed part of a continuous distribution of microseismicity. The significance of this point is that if the large-scale induced seismicity does not form part of a continuum of induced seismicity then it may be inappropriate to adopt a probabilistic hazard assessment approach based on magnitude-frequency statistics. It may necessitate the need for a purely mechanistic approach that would take into account accurate local geological and tectonic conditions, with its associated requirements for exploration.

This is of general importance to EGS hazard assessment, as well as the proposed Eden EGS development where it is assumed that Rosemanowes is a reasonable analogue for the expected behaviour during the Eden EGS development.

The results of the study show that:

- The large events (M_L 2) observed during Phase 2C of the Rosemanowes project appear statistically consistent with the observed magnitude-injected fluid volume relationships observed during previous Phases. This supports the argument that the events are part of a continuous distribution of seismicity, rather than anomalous one-off events.

- The focal mechanisms observed for the large events are also consistent with the predictions of the geomechanical interaction between the injected fluid and the in situ stress field. This suggests the dominance of pure strike-slip on vertical fractures, but also the likelihood of more normal faulting mechanisms on more shallowly dipping fractures. The relative frequency of mechanisms with a normal faulting component is likely to increase with depth, which is also consistent with the occurrence of the larger events

- It appears that the large events observed at Rosemanowes should not be considered anomalous, but are a statistical and geomechanical consequence of net fluid loss within the subsurface at Rosemanowes. This result is significant as it indicates that, at least in this example, a probabilistic hazard assessment approach based on magnitude-frequency statistics may be justifiable.

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Induced Seismicity: Towards Real Time Probabilistic Seismic Risk Assessment – Case study for Basel 2006 and associated uncertainties

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ABSTRACT

Almost seven years after the enhanced geothermal system (EGS) project in Basel (2006) has been abandoned, Induced Seismicity (IS) is still considered to be one of the major obstacles for future EGS projects. Since the Basel EGS project was canceled in 2006 due to concerns about too high financial losses, risk assessment of IS is strongly needed, from the planning until the post-operational phase.

We present an induced seismicity risk assessment tool (ISRA) which is able to forecast probable loss time-dependent. Loss estimation in terms of financial loss, number of damaged houses and possible casualties is integrated with seismic hazard forecast models. The tool uses well-established methodologies, while its core is the damage grade estimation of buildings based on the predicted ground shaking level given in intensity units. Based on a risk study (SERIANEX risk study, Baisch et al., 2009) conducted after the Basel EGS in 2006, the technical functionality of the model is verified. New estimates of the financial loss caused by the Basel EGS (which are lower than insurance payouts) are used to perform a model calibration.

Further we explore uncertainties linked to key model parameters such as seismicity forecast model, maximum magnitude, intensity prediction equation, site amplification or not, vulnerability indexes of buildings and cost functions. Uncertainty is implemented using a logic tree composed of a total of 324 branches.

Although the tool has been developed in the context of deep geothermal energy, it is also applicable to other issues such as CO_2 storage, waste water injections, mining or any kind of hydraulic fracking. However, the project at its actual stage needs further development and better implementation into the ISRA framework to become ready for operational use.

Figure 4: Possible applications for the development of an induced seismicity risk assessment tool in the context of different interest groups

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