

Swiss Bulletin

für angewandte Geologie de géologie appliquée di geologia applicata for Applied Geology

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Editorial: Fracking – Segen oder Fluch?

Noch nicht lange ist es her, da wurde über die Peak Oil Frage debattiert, so auch im Swiss Bulletin für angewandte Geologie. Neigen sich die nutzbaren Reserven an fossilen Kohlenwasserstoffen rasch dem Ende zu, wie das im Jahre 1972 der Club of Rome erstmals prognostizierte? – In den letzten Jahren ist indes eine andere Thematik zunehmend in die öffentliche Wahrnehmung geraten, die Technologie des Hydraulic Fracturing (Fracking). Es vergeht kaum eine Woche, ohne dass in den Medien darüber berichtet wird. Eine rasante Entwicklung im geologischen Verständnis der Petroleumsysteme sowie der Bohr- und Fördertechnologie hat in den letzten zwei Jahrzehnten ganz neue Perspektiven eröffnet. Sie ermöglichen die Erschliessung von Kohlenwasserstoffen in Gesteinen, aus denen bislang keine rentable Förderung fossiler Ressourcen möglich war. Sie verändert die Peak Oil Debatte fundamental, weil sich dadurch ganz neue Dimensionen von Gas- und Ölquellen erschliessen lassen. Die Versorgung der Welt mit fossilen Kohlenwasserstoffen scheint plötzlich für viele Jahrzehnte, beim Gas möglicherweise für Jahrhunderte gesichert. Der Peak wird nun zu einem solchen der Nachfrage, und nicht mehr in erster Linie zu einem des geologisch vorhandenen Angebots.

Durch die enormen neuen Gas-Ressourcen, die eine schnelle Substitution von Kohle und Öl in Stromerzeugung und Mobilität ermöglichen, soll auch ein wirtschaftlich und gesellschaftlich verträglicher Übergang zu einer Versorgung durch erneuerbare Energien sichergestellt werden. Nach anfänglicher Euphorie ist klar geworden: erneuerbare Energien sind trotz ihres grossen Wachstums noch weit davon entfernt, auch nur den jährlichen Zuwachs des globalen Energiebedarfs zu decken. Es braucht ver-

mutlich Jahrzehnte, um alternative Energien als tragenden Pfeiler der globalen Energieversorgung zu etablieren.

In den USA hat die Fracking-Technologie im Bereich unkonventioneller Kohlenwasserstoffe einen wahren Boom ausgelöst, die Wirtschaft angekurbelt und die Abhängigkeit der USA von Kohlenwasserstoffimporten fundamental verringert, mit gewaltigen politischen Konsequenzen. Doch Hydraulic Fracturing hat nicht nur Bedeutung bei der Förderung von fossilen Kohlenwasserstoffen, sondern ist auch eine Schlüsseltechnologie in der Tieffengeothermie. Aber sie kann spürbare Erdbeben auslösen, wie die Projekte von Basel (2006) oder Landau im Rheingraben (2013) zeigten. Eine Technologie des Teufels? Das könnte man meinen, wenn wegen der Beben plötzlich zahlreiche Gebäude angeblich frisch entstandene Risse aufweisen oder wenn man den brennenden Wasserhahn im Film «Gasland» (2010) sieht. Obwohl Fachleute schon lange wissen, dass der brennende Wasserhahn nichts mit Hydraulic Fracturing zu tun hat, wirkt das für viele beängstigend. Es verunsichert und schürt Emotionen. Überall, wo Emotionen im Spiel sind, besteht auch die Gefahr der bewussten Desinformation. Leicht können – auch auf der Basis falscher Bilder – Ängste und Aversionen geschürt werden, gerade bei einer für Laien kaum fassbaren, komplexen Technologie und in einem Land, das kaum eine Tradition in der Nutzung des tiefen Untergrundes hat. Hydraulic Fracturing geschieht im Untergrund, in Tiefen von mehreren Kilometern und ist scheinbar der direkten Beobachtung entzogen. Eine ablehnende Haltung solchen Technologien gegenüber ist daher verständlich. Ängste können indes abgebaut werden, wenn eine offene, objektive und sachliche Information und Auseinandersetzung stattfindet.

Wo Risiken sind, sind auch Chancen. Innovation und Entwicklung ohne Risiko ist unmöglich. Wie gehen wir mit diesen Risiken um, wie bewerten und nutzen wir die Chancen, die sich uns bieten?

In diesem Bulletin wollen wir ein breites Spektrum von Aspekten des Frackings behandeln. Spezialisten mit ausgewiesener langjähriger Erfahrung in ihrem Fachgebiet äussern sich dazu:

Einleitend informiert K. M. Reinicke (Prof. TU Clausthal) über die technischen Aspekte des Frackings und dessen Bedeutung bei der Erschliessung von Kohlenwasserstoffen und dem geothermischen Potenzial. R. Jung (Jung Consultant) beleuchtet das Problem der Rissbildung und der induzierten Seismizität und zeigt Lösungsansätze auf. Die Bohrlochintegrität und ihre Bedeutung für einen zuverlässigen Schutz des Grundwassers wird diskutiert von P. Reichetseder (Upstream – Energy Consulting und Prof. TU Clausthal). S. Liermann (Wintershall) zeigt auf, wie Fracking heute in Deutschland verantwortungsvoll und erfolgreich eingesetzt wird.

Die Industrie hat zu den Anfangszeiten des Fracking-Verfahrens Fehler gemacht. T. Engelder (Prof. Pennsylvania State University) nennt die Versäumnisse und nimmt Bezug zur Fracking-Debatte in Europa. M. Stäuble (Shell China) zeigt die Schritte zu einer sicheren operationellen Erschliessung unkonventioneller Öl- und Gasvorkommen in China.

Als Einleitung zur Problematik in der Schweiz informiert R. Wyss (Roland Wyss GmbH) über die Randbedingungen, die Technologie des Frackings und deren Auswirkungen. W. Leu (Geoform Ltd.) und A. Gautschi (Nagra) evaluieren das Potenzial des Opalinustons und der Posidonien-Schiefer als Schiefergasgesteine des schweizerischen Untergrundes. Anschliessend thematisieren D. Hartmann und B. Meylan die Problematik des Grundwasserschutzes in der Schweiz.

Brauchen wir Fracking? Dieser Frage widmet sich E. Grosse Ruse (WWF Schweiz) in seinem Beitrag, mit speziellem energiepolitischem Fokus auf das Zwei-Grad-Ziel. Ist Fracking eine gesellschaftliche Notwendigkeit? W. Wildi (Prof. em. Uni Genève) geht dieser Frage nach und zeigt, wie wir mit verschiedenen Nutzungsansprüchen an den Untergrund umgehen sollten.

Das Thema Hydraulic Fracturing ist auch in der globalen Erdöl- und Gaswirtschaft äusserst prominent. P. Burri (Burri Consulting) resumiert dazu die Erkenntnisse der AAPG-Convention 2014 in Houston und schliesst die Fachartikel mit einer persönliche Einschätzung ab.

Die Auswahl der Beiträge soll dazu beitragen, den Stand des Wissens und die Konsequenzen der Fracking-Technologie aufzuzeigen und dadurch zu einer Versachlichung der oftmals emotionalen oder ideologischen Diskussion beizutragen. Eine objektive Auseinandersetzung auf der Basis von Fakten ist die Voraussetzung für nachhaltige, rationale Entscheide in unserer Energiepolitik. «Whether or not shale gas development will turn out in the long term to have been a positive or negative influence on global well-being will depend on how society understands this technology and manages it.» (Council of Canadian Academies 2014: Environmental Impacts of Shale Gas Extraction in Canada. Ottawa, ON, 262 p).

Daniel Bollinger

The Role of Hydraulic Fracturing for the Supply of Subsurface Energy

Kurt M. Reinicke¹

Presented at the Symposium «Energie aus dem Untergrund – Who cares? (Chancen und Risiken von Hydraulic Fracturing)» der Eidgenössischen Geologischen Kommission, Gurten, Berne, October 7, 2014.

Key words: unconventional gas, deep geothermal energy, hydraulic fracturing, fracturing fluids, fracture growth, fracturing impacts, risk management, multi-frack, horizontal drilling, operational practices, laws and regulations

1 Introduction

Until a decade ago gas liquefaction plants were built in several regions of the world to supply the U.S. market with liquefied natural gas. The boom was sourced by the prediction of an increasing gap between the demand and the supply of natural gas, resulting from a predicted steady decline in domestic production. Things have changed. In 2015 the U.S.A. will start to export natural gas. An oversupply of natural gas has caused prices to fall, leading increasingly to a re-industrialization of the country and can even be recognized in the CO₂ emission of the country, which has significantly decreased in the last years.

Key to this development is the technology of hydraulic stimulation, also known as fracking or hydraulic fracturing. The technology is in use since the 40s of the last century. In the combination of horizontal drilling and multi-fracking the technology has evolved into a tool allowing the development of even shale gas deposits, in rocks so tight, that the concrete pavements of the highways look like kitchen sieves. In the combination of horizontal drilling and multiple fracking the technology is applicable in principle also for

the development of geothermal resources in the deep subsurface, the potential of which is many times larger than the potential of the unconventional oil and gas deposits, at least theoretically.

2 Hydraulic Fracturing

Hydraulic fracturing refers to the process of the generation and propagation of fractures in a rock formation by pumping a liquid under high pressure into this formation. The high pressure liquid enters the formation through holes perforated into the cemented steel pipes, which protect and seal the wellbore, at the level of this formation. Pressure medium (frac-fluid) is in general water. Depending on the application, the water is mixed with proppants to keep the generated fractures open, for example quartz sand, as well as other substances as additives (Emmermann 2014, Reinicke 2012).

In conventional sandstone reservoirs, the treatment usually results in the formation of a two-wing vertical fracture. The entity, which looks much like a butterfly, has a half-length of less than 100 to approximately 300 m in modern applications (Reinicke 2012). As a result of the layering of the geologic subsurface, the fractures are typically longer than higher, because individual sedi-

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mentary layers, like for example clay layers, act as «barrier formations», which impede the growth of fissures in the vertical direction (Fig. 1).

The growth of the fractures is influenced by the geo-mechanical and hydro-mechanical properties of the geologic layers, the stresses acting in these layers, the injected fluid volume, the fluid properties and the pressure at which the fluid is injected. Within these dependencies the extension of the fractures is predictable, in particular their orientation, their geometry and their effect on well productivity, if the properties of the subsurface and the treatment parameters are known (Economides & Martin 2007).

The objective of a hydraulic treatment is the generation of highly conductive flow paths for the transport of fluids (liquids and/or gases) in an otherwise low permeable rock. To have this effect, the generated fractures must remain open. To prevent them from closing and healing, when the pumps stop and the fractures start to close under the influence of the acting rock stresses, proppants are introduced into the fractures, for example sand.

Pure water is not able to carry sand and transport it into the created fractures. To achieve carrying capacity, the water is thickened or gelled by adding viscosifiers (Fig. 2). To clean the created channels, the gels have to be broken subsequent to the treatment, which is why breakers are added. Other additives serve to reduce frictional losses when pumping the viscosified fluid, to avoid the introduction of biological substances into the subsurface, to prevent corrosion, and to stabilize the target formation by, for example, clay stabilizers, etc.

In total, today all additives make up approx. 1% (0.2-3%) of the frac-fluid volume (Fig. 2). The rest is water and proppants. Today's recipes result in mixtures, classified as weakly water contaminating, which means they are in the same category as liquid manure. The classification according to the German *Gefahrstoffverordnung* (hazardous substances ordinance) is not toxic and not hazardous to the environment. Work is under way to further reduce the environmental impact, for example by UV irradiation instead of using biocides (Kassner 2014).

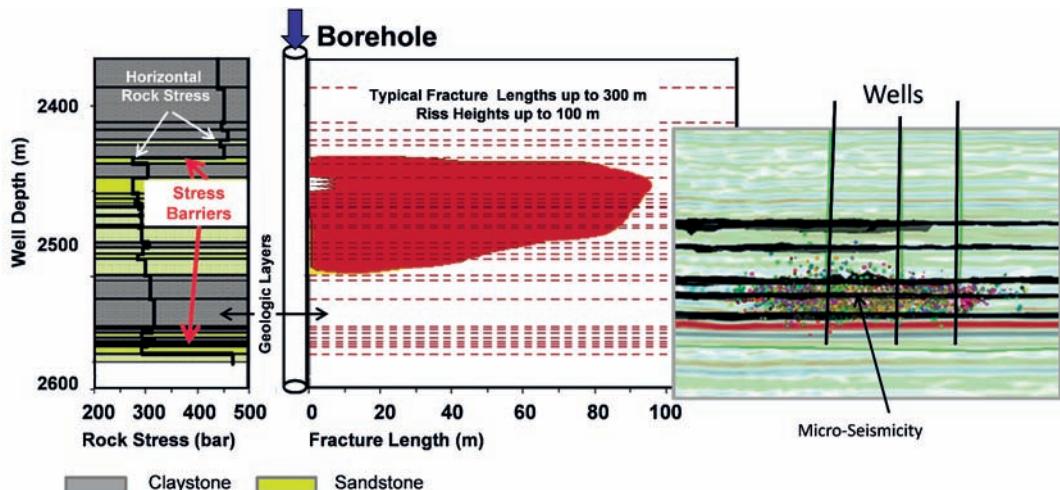


Fig. 1: Fracture propagation in a reservoir: left prognosis, right measurement. The prognosis of fracture propagation is made with recognized methods and commercially available simulators based on the knowledge of the geo- and hydro-mechanical properties of the subsurface and its stress distribution. The measurement is made by monitoring the micro-seismicity associated with the fracture extension (right).

In unconventional (shale and coal bed) reservoirs and geothermal (hot dry rock) reservoirs the process of fracture generation is usually more complex. The reservoir rock often contains natural fissures and fractures. Often the rock is subject to shear stresses like the basement rock in the Upper Rhine valley for example. Both have an influence on the fracture system.

If the reservoir rock contains fissures and fractures, the fracture treatment does usually not result in a two wing fracture system, but in more complex tree-like structures, which follow the zones of weakness in the rock, i.e. the naturally occurring fissures. Under these conditions the injected frac-fluid is distributed over more fractures, which reduces the dimensions of the fracture system. If shear stresses are present and if they are sufficiently high, lateral displacements along the rough fracture surfaces may result. If the rock is sufficiently hard, flow channels remain after fracture closure even without the introduction of proppants, because the fracture faces do no longer fit perfectly into each other. These so-called water fracs are the treatment of choice for petro-thermal energy recovery. The treatments cost less and they are of lower environmental impact, because the frac-fluids require less additives or none at all.

3 Fracking Targets

The targets of hydraulic treatments are at great depths, far below the geologic horizons, which are used or may be used for the withdrawal of drinking water. The water quality does generally not improve with depth. In Northern Germany it is brackish already at depths below 50–400 m. The water contained in the rocks at large depths is heavily loaded with salts and may in addition – albeit at low concentrations – contain heavy metals and naturally occurring radioactive materials. In Northern Germany salt loading of the deep brines is mostly up to saturation. With 200–300 g/l the salt concentration is far above that of our noodle water with 1 tea spoon/l or 8–10 g/l and it is almost a factor of 10 higher than the salt concentration of sea water (35 g/l) (Burri & Häring 2014).

For the only treated well in an unconventional shale reservoir in Germany, treatment depths were larger than 1.200 m. The potable water horizons at the location of the well reached down to approx. 40 m with thick barrier formations from clay between the potable water horizons and the frac horizon. The depth range typically assumed for the exploitable unconventional hydrocarbon deposits in Germany starts at approx. 1.000 m. Shale gas developments shallower than 1.000 m are unlikely, because commercial rates require



Hazardous Substances Rating of Frac-Fluid
not toxic and not hazardous to the environment,
weakly water contaminating



Fig. 2: Frac-fluids.

high reservoir pressures which are not found at the shallower depths, which is also the experience in the U.S.A.

The targets in conventional reservoirs are typically found at depths greater than 3.000 m. Geothermal targets are even deeper, because the desired water temperature of 150 °C or more requires depths of approx. 4.000–5.000 m under average central European conditions. The fracking targets in these reservoirs are overlain not only by clay layers but usually also by several impermeable salt layers, which may reach thicknesses of several 100 m.

4 Fracture Height Growth

According to the myth distributed by the fracking opponents in the internet, the fractures reach from great depths up to the drinking water horizons and create wide flow paths for gas and frac-fluids (Fig. 3, left). For the above described depth ranges and the usual frac-fluid volumes this is physically impossible. The physical balance laws, according to which generated fracture volume can at best be as large as the fluid volume used for its generation, are also valid in the geologic subsurface. In general, the volume will be even smaller, because fluid leaks into the formation as it is fractured and is no longer available for the creation of fracture volume.

The limits to vertical growth are supported by the mapping of real fracture growth data in thousands of fracturing treatments in the U.S.A. by monitoring the micro-seismicity associated with the propagation of fractures in shale gas deposits. Result is, that vertical growth of created fractures is in the order of hundreds of meters at the most with more than 1.000 m of sediments separating the top of the fractures from the drinking water horizons (Fisher & Warpinski 2012) (Fig. 3, right).

5 Methane Emissions

Also, the often implied significant emissions of methane into the atmosphere by natural gas wells and facilities do not represent reality, at least not where best practice is applied like in Europe. According to the German *Umweltbundesamt* (Federal Environmental Agency) and the *Wirtschaftsverband Erdgas und Erdölgegewinnung* (Oil and Gas Producers Association), 53% of the total methane emission in 2012 originated from agricultural sources (UBA 2014a). Only approx. 3% came from energy industry sources with a contribution of the natural gas production of less than 0.1% (WEG 2012). If high standards are applied for the construction and maintenance of natural gas facilities – which can be assumed for the gas

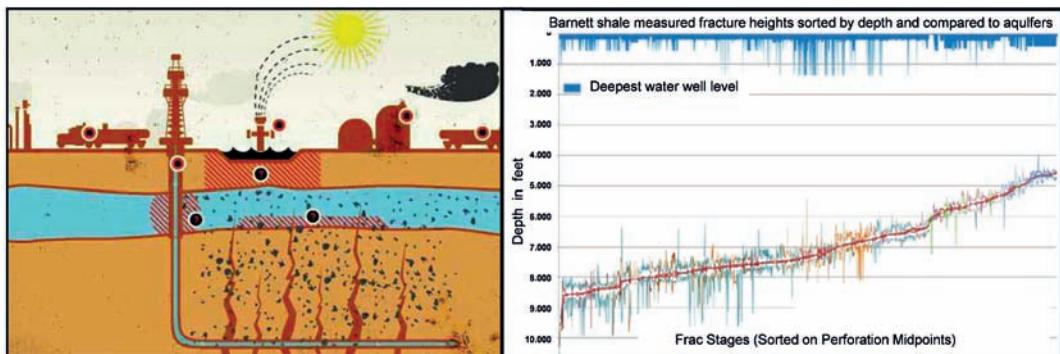


Fig. 3: Fracture vertical growth: Myth and Reality.

operations in Western Europa – methane emissions are not an issue. Climate improvements and avoidance of air pollutions like those for example in China require the substitution of e.g. coal by natural gas.

6 Effect of Hydraulic Treatments

Regardless of the type of fracture system, which is generated in the course of a fracture treatment, it will change the flow pattern in the rock. The reservoir content no longer flows radially to the well bore, to squeeze into a bore of approx. 20 cm diameter, but more or less linear to the significantly larger fracture system, to then flow within this system to the wellbore. For a two-wing system this system has an extension which is mostly a thousand times wider than the wellbore. In a way, the effect resembles that of a highway across a city during the rush hour traffic. It attracts traffic and enables a significantly faster influx and efflux to the central business area(s).

The influence of a hydraulic treatment on the productivity of a well is significant. It is not unusual, that the initial production rate increases by a factor of 5–10 and more to stabilize after an initial strong decline at a significantly higher level than the original flow rate. In the example of a North German gas well, the initial rate could be increased after two hydraulic treatments by a factor of seven (Reinicke et al. 1983) (Fig. 4). The well shown is still producing today after more than 35 years. The example illustrates not only the influence of hydraulic fracturing treatments on the productivity of a well and its development, it documents also that hydraulic fracturing treatments are nothing new even in Central-Europe. The sample well was fracked in 1977 and is part of a major campaign, during which a significant number of gas wells were subjected to major fracturing treatments, so-called MHF treatment, during the end of the 70s/beginning of the 80s. To now suggest, that the technology is something new is not correct. It is in use since the end of the forties and has in the

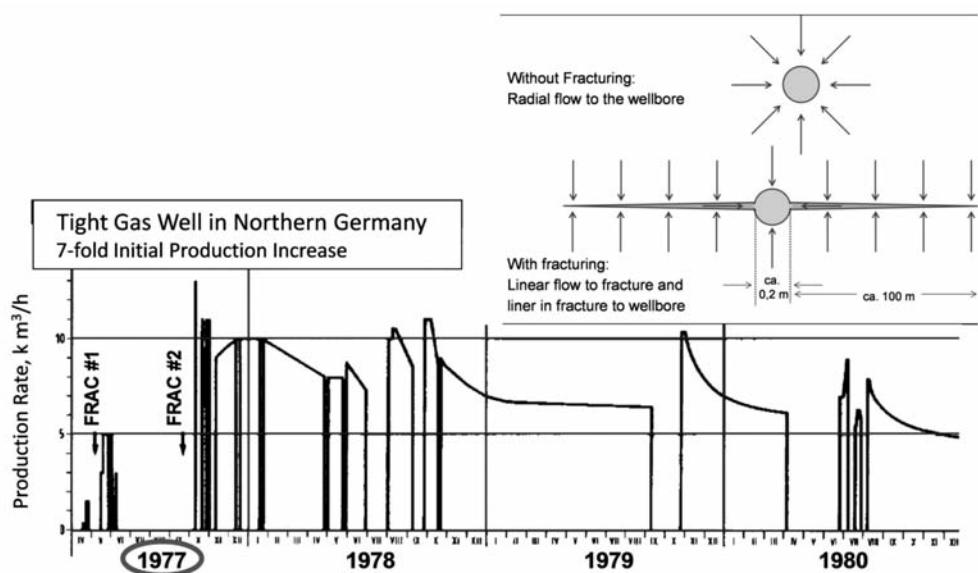


Fig. 4: Effect of a hydraulic fracturing treatment on flow pattern and well productivity (in 1.000 m³/h).

meantime been used worldwide approx. 3 Million times. In Germany approx. 400 fracturing treatments have been carried out since the 60s without any measurable impairment of the environment ever reported.

7 Hydraulic Fracturing and Energy Supply

The influence, which fracking can have on a national economy is represented using the U.S.A. as an example. The U.S.A. has had its peak natural gas production from conventional deposits in the early 70s. The development of tight gas resources with the aid of fracking, starting in the 70s, has reduced the decline of domestic natural gas production to reverse the trend in the 90s. With the development of the shale gas deposits since the second half of the last decade, the U.S.A. have seen a rapid increase in production to a level, which is today already higher than the peak production in the 70s. From a dependent importer, the technology of hydraulic fracturing has enabled the U.S.A. to become an exporter of natural gas. Liquefied natural gas originally developed for the U.S.A in the Middle East and West Africa is now shipped to the Far East and Europe. The development in Germany is completely different. Here domestic production has decreased since 2003 from more than 20 Billion m³ (10⁹ m³) to less than half in 2013. The trend will continue, if the government maintains its «no» to the development of the German shale gas resources. The consequence is the increasing burning of coal.

In North-America the natural gas surplus has led to a significant reduction in the price of natural gas. Prices have declined from 6 to more than 10 \$/Mscf (thousand standard cubic feet [gas]) to actually 3-4 \$/Mscf or approx. 0.9 Euro-cents/kWh. This is a third to a half of the price in Europe and a forth to a fifth of the price in the Far East.

The supply of secure and low-priced hydrocarbons fuels an industrial job machine.

Investments in the U.S.A. are rising. In the chemical industry for example the additional investments up to 2014 are estimated to amount to more than \$ 100 Billion and this in particular by companies headquartered outside the U.S.A. The additional industry production expected from this investment is estimated to be more than \$ 80 Billion, the jobs created exceed 600.000.

Because of the low gas prices, recent developments focus increasingly on wet gas and light oil in the unconventional deposits with impacts for the oil production similar to those for natural gas. The trend of decreasing oil production has been halted. Since 2007, domestic oil production in the U.S.A. is increasing again and was 50% higher in 2013 than in 2007. Production matches for the first time for a long time again the oil imports. In the first half of 2014, the U.S.A were even the largest oil producer worldwide.

The effect of the American shale gas revolution can also be recognized in the development of CO₂ emissions of the country. Since 2005, CO₂ emissions of the U.S.A. have decreased by approx. 600–700 million tons, mainly through substitution of coal in power generation by gas. The decrease represents approx. 70% of the total CO₂ emissions in Germany, which are increasing again since three years – also because of the use of coal – and it is 15 times the annual emissions of Switzerland. It should be kept in mind, that the emission of CO₂ is only one part of the environmental problems. Equally important are pollutants like sulphur, CO, and particulate matters.

8 Is Fracking Needed?

To meet the energy demand provides an increasing challenge. During the last ten years the demand of primary energy has increased by 28%. Key drivers of this development are the ever increasing world population, the increasing prosperity in particu-

lar in the developing countries, and economic growth (Reinicke et al. 2014). As long as there is no change in these drivers, energy demand will further increase. To meet it requires a broad mix in energy. The further development of renewables should be encouraged and supported under all circumstances. But even if this is continued successfully, the world will remain dependent on fossil energy sources for many decades, possibly the whole century, in particular if nuclear energy is no longer an option.

A closer look at the development of the contribution of the individual energy sources shows, that renewables have grown by more than 300% (without hydraulic power) in the last 10 years (BP 2014). This growth nevertheless covers only 7.5% of the total growth in energy demand during this period and contributes today only 2.2% of the worldwide primary energy consumption. Including hydraulic power, the renewables contribute almost 9% to the total consumption. Approx. 86% of the primary energy consumption is still covered by fossil sources with a strongly increasing share of coal. Despite the increase in the contribution from renewable sources, the relative contribution of the fossil energies has remained almost constant compared to 10 years ago, when fossil contribution was 87%. In absolute volumes, the yearly consumption of fossil energies is significantly higher today than it was 10 years ago.

The renewable energies should be encouraged, in particular geothermal energy, but despite the rapid growth of wind, solar energy, etc. the world is far from covering even the global growth in energy consumption, let alone to substitute fossil energies by renewables. If large quantities of fossil energies are needed also in the future, consideration should be given to using the cleanest of these energy forms.

9 Chances and Potential of Fracking

The resources of the subsurface, which can be developed through wells are crude oil and natural gas in conventional and unconventional reservoirs as well as hydro-thermal and petro-thermal energy.

In this context the term conventional reservoir denotes a deposit in a storage rock. In this rock the hydrocarbons are captured by buoyancy forces below an impermeable barrier formation. For the capture, the barrier formation must form a trap, for example a bulge similar to a cheese dome. The trapped hydrocarbons have not been generated in the storage rock, they have migrated to it from a source rock. The permeabilities of storage rocks are usually high enough to allow a development and exploitation by use of classical drilling and production techniques. Under favorable conditions up to 90% and more of the gas in place is recoverable. If the permeabilities are low, as in the case of Tight Gas reservoirs for example, hydraulic fracturing may be used to improve the productivity of the wells, which is done since the middle of the last century.

Unconventional reservoirs are defined as deposits in source rock with oil and gas, which has not yet left the place where it was generated. Pre-requisite for the existence of a deposit is solely a mature source rock, for example a shale, with a sufficiently high content of organic matter, which has been transformed under the influence of pressure and temperature into oil and gas. Because of the low permeabilities of source rocks, which are of similar magnitude as those of barrier formations, a significant amount of the hydrocarbons stays behind in the source rock. It was only in the last ten years, that geologists have discovered that this is often the bigger portion of the generated oil and gas.

To be able to economically utilize unconventional deposits in source rocks with pore throats in the order of nano-meters (1 nm = 1/1.000.000 mm) the use of elaborate hori-

zontal drilling and multi-frac technology is an absolute necessity. By using these technologies it is possible to recover gas volumes in the one digit percentage range up to approx. 20% of the in-place volumes in the subsurface. Despite this low fraction, the incentive for a development of these deposits is large, because other than the «discrete» accumulations of conventional reservoirs, unconventional deposits occur basin-wide with in-place volumes which are enormous.

According to estimates of the U.S. Energy Administration Agency (EIA 2011) and the *Bundesanstalt für Geowissenschaften und Rohstoffe* (BGR 2012) (Fig. 5), the economically recoverable shale gas resources in Europe amount to 10.000–15.000 Billion m³. This is 40 times the current production and 30 times the current consumption in Europe and not much less than that what is estimated for the U.S.A. (15.500 Billion m³). The U.S.A. is no geologic exception. There are significant unconventional resources worldwide.

The world is neither at the end of the oil or the gas age – as predicted by the Club of Rome – nor is there a steep decline of oil and gas production imminent, as propagated by the Peak Oil organization. For both prognoses, previous knowledge of the past has been extrapolated. Over longer time spans, this has never been reliable.

The geologic subsurface does not only contain hydrocarbons, it also contains geothermal energy. To use it economically for the generation of electric power high temperatures ($> 150^{\circ}\text{C}$) and high volume production (several 10 to $> 100 \text{ l/s}$) are required. High temperatures require great depths. In great depths, however, rocks are highly compacted and thus have low permeabilities. The solution is to create permeabilities artificially by hydraulic fracturing.

The theoretical supply potential of hydro- and petro-thermal energy is large and would be able to make a significant contribution to cover the demand, even then when only a fraction of it would be developed. According to estimates published in Ganz et al. (2013),

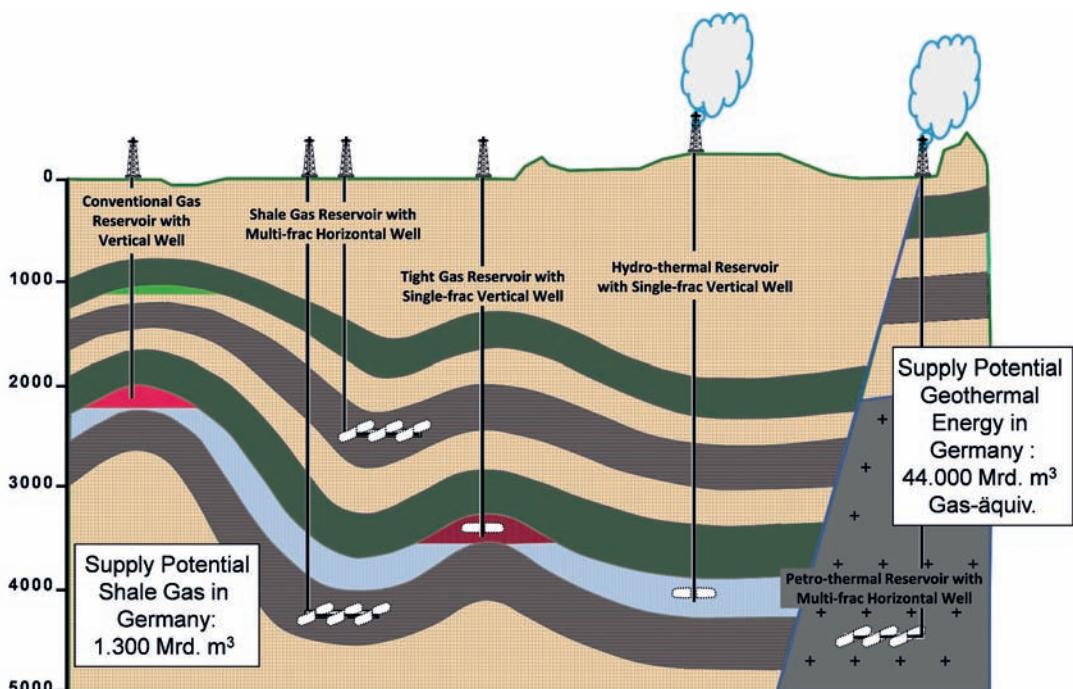


Fig. 5: Potential for energy recovery through wells according to BGR (2012) and Ganz et al. (2013).

the geothermal supply potential for Germany alone amounts to 1.700 EJ or expressed in natural gas equivalents approx. 44.000 Billion m³ (Fig. 5), in comparison to a shale gas potential for all of Western Europe of approx. 10.000-15.000 Billion m³. The question is not, is this potential there? The question is, how much of it can be realized technically and in particular economically? According to the quoted reference, the largest potential is that in crystalline rock, which amounts to 1.150 EJ of so-called petro-thermal energy, i.e. energy which is stored in the rock itself. To develop this potential in the «hot dry rocks» requires the use of the fracking technology. Aside from a few conductive fault zones there is no chance for an economic development without this technology. The deep underground is tight. Its conductivity must at first be generated.

For the generation of this conductivity one can use high-volume fracs as in Basel, Soultz, or Hannover, which is not without seismic risks in tectonically stressed regions. One can also start with proven oil field technology and adapt it for use in geothermal applications, for example the multilateral horizon-

tal drilling technology coupled with the multi-frac technology – already applied to develop shale gas – to construct an Enhanced Geothermal System (EGS) with many small heat exchangers in the hot dry rock (Fig. 6). With such a system, the seismic risk could be greatly reduced, such that tremors of a magnitude as observed in Basel could be avoided. It was one of the essential findings of the frac in Basel, that the magnitude of possible seismic events increases with the volume of the injected fluid and hence with the size of the fracture surface, which has been created. The injected volume in Basel was 11.500 m³. In a system of several much smaller multi-fracs the injection volumes would be in the order of 1.000 m³ per frac or less, which would be injected without proppants and therefore also largely without chemical additives.

It is worthy of note that the noticeable seismicity observed so far in the context of hydraulic treatments was limited to injections of high volumes of fluids in deep horizons in or close to the basement, where they led to the release of existing shear stresses (in Basel for sure, likely also in St. Gallen and in Landau, also for the water disposal-

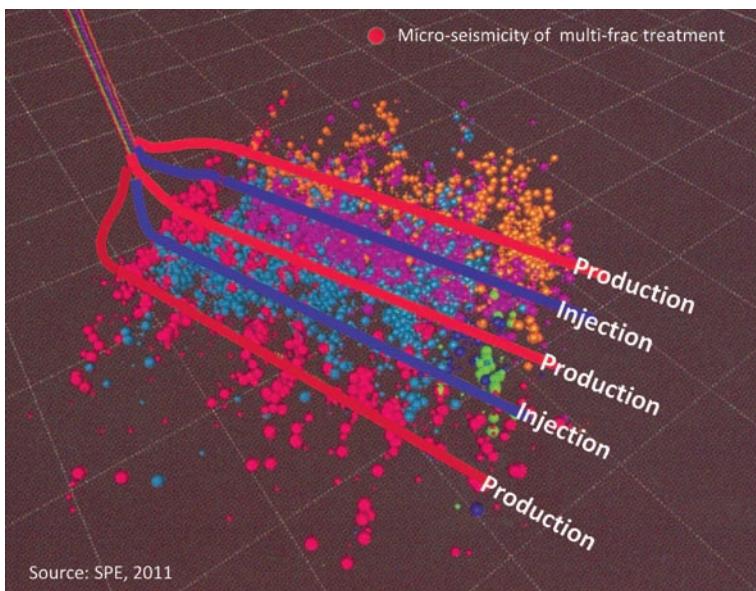


Fig. 6: Possible multi-frac heat exchanger system for the recovery of petro-thermal energy using a shale gas well with five horizontal laterals, fracked 10 times each.

induced tremors in Oklahoma). Contrary to this, no damaging tremors have so far been reported for fracturing treatments in sediments. Noticeable seismicity (up to a magnitude of 2.5) induced by fracturing treatments in shale formations was recorded near Blackpool (2012), which, however, stayed significantly below damage levels (Emmermann 2014).

Granted, it is still a long way until a functioning multi-heat-exchanger system based on multi-fracturing technology can be implemented on a large scale, let alone optimizations thereof. The target horizons are deeper and harder, the necessary wells are more expensive, and the operation of heat exchanger systems is significantly more difficult than draining a hydrocarbon bearing reservoir. But the potential is large and offers a lot of incentives.

In summary, the potential for the recovery of geothermal energy is large and offers chances for implementing a secure and low emission energy supply. However, it requires the use of horizontal drilling and multi-fracturing technology. An economic implementation will likely be possible only when larger numbers of geothermal wells are drilled in a «factory style» process to feed sizeable geothermal power plants. As a first step on the way to this, it is necessary to prove viable technical concepts for a petro-thermal recovery in pilot projects now.

10 Fracking Risks and Possibilities of Risk Management

Like everything in life also the fracking technology is not free of risks. It is the subject of very controversial discussions, which one can read about almost daily. The discussions are dominated by gut feelings and gut reactions. This is true not only for Germany, this is the case internationally. In discussions facts are in most cases of only minor or no importance. The results of reputable investigations, the efforts of industry, and

the evident progress in best practice to manage risks and make the technology environmentally compatible have hardly found their way into the public debate until recently.

With due respect for the concerns raised in the context of the use of the fracking technology, they are often based on images, not representative for the real operations and they do not take into account the measures already implemented to manage risks. The burning water tap in the movie *Gasland* has nothing to do with the production of natural gas and nothing at all with fracking. Also the term «poison cocktail» regularly used to denote frac-fluids, does not represent reality (see also Fig. 2).

The following definitions of the terms risk and environment are the basis of the subsequent elaborations regarding risks and measures to manage risks. Risk is defined as the product of probability that an adverse event occurs multiplied by the severity if the event happens. Environment is defined as the totality of the resources humans-animals-plants, soil, (potable) water, landscape, climate, and cultural assets as well as all interactions.

Of largest concern is quite rightly the preservation of the potable water resources. It is therefore in the focus of the subsequent elaborations. Potential pathways for pollutants to potable water horizons are: substance input from the surface, substance ascent along wells, substance ascent and dispersal through the overburden. Decisive for the severity of a possible event is the damage potential of the contaminants, in particular those contained in the frac-fluids (Fig. 7).

Against this background, there are the following approaches to reduce the probability of an event from occurring and their severity if it occurs. The probability of a water damaging event can be reduced by (1) operations sites and practices on these sites, which prevent inputs from the surface, (2) wells, proven to be tight, (3) a geologic subsurface, proven to contain barrier forma-

tions, and (4) a fracture propagation which does not impair the effectiveness of the overlaying barrier formation. To reduce the severity of a possible damage it is necessary (a) to reduce the damage potential of the substances used (not hazardous to water – no risk), (b) to be able to detect incidents and react immediately, and (c) to provide for unplanned events (Reinicke 2014).

For improved risk management the companies organized in the *Wirtschaftsverband Erdöl- und Erdgasgewinnung* (oil and gas producers association) in Hannover have identified, analyzed, and evaluated the risks associated with hydraulic fracturing and jointly developed «best operational practices» (WEG 2014), and commissioned frac-fluids of improved environmental compatibility. The practices are a voluntary commitment of the industry in addition to the statutory and official requirements, documented in Germany in the *Bundes-Berggesetz* (federal mining law), the *Tiefbohrverordnungen* (deep drilling ordinance) of the *States of Ger-*

many as well as the relevant specialist legal requirement like for example the Water Resources Act. With these practices and requirements there are clear rules in place for the execution of hydraulic fracturing treatments, which ensure, that existing risks are accounted for.

The execution of a wellbore treatment, for example, requires a mining authorization, which can be granted by the mining authorities only to organizations, which have the required technical qualification and the financial resources. The execution of activities requires authorization within the framework of the *Betriebsplanverfahren* (mining operations plan procedure). The admission of the operations plans requires evidence that no damaging effects can be expected, in particular whether the requirements of the Water Resources Act are fulfilled and whether relevant public interests like emmission prevention, soil protection, regional planning, and nature conservation according to the relevant specialist legal requirements have been accounted for.

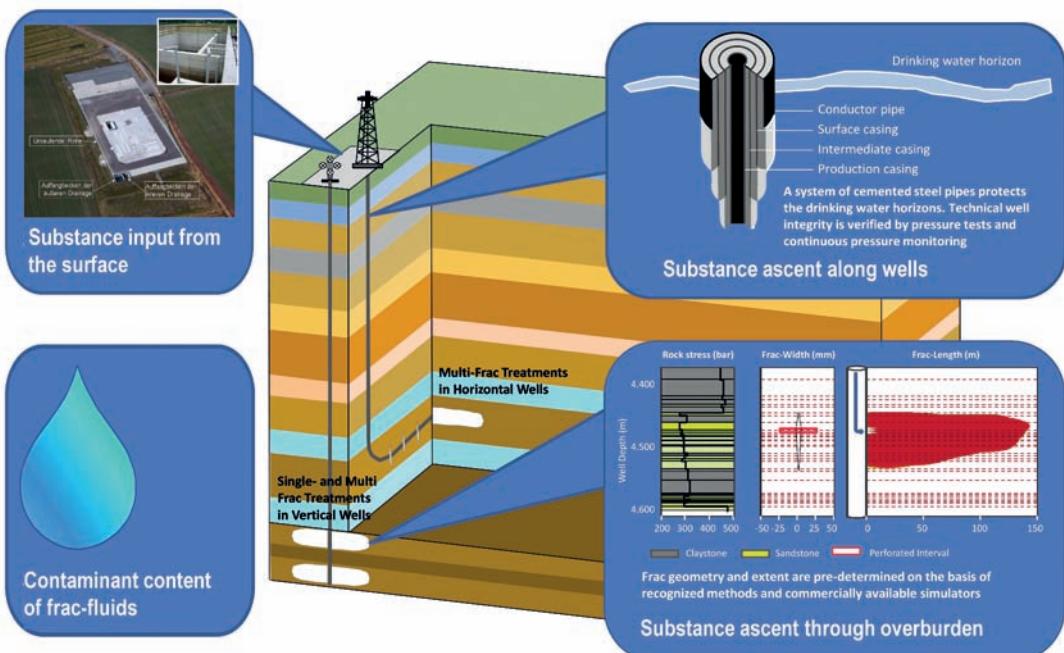


Fig. 7: Potential pathways to potable water horizons and risk management.

Whether the existing rules and regulation require modification to even better account for the risks associated with hydraulic fracturing is currently being debated in Germany. In this context an environmental impact assessment for hydraulic treatments is under discussion, addressing in particular the subsurface risks of fracturing in a structured and transparent evaluation process. An environmental impact assessment, which will break new grounds, will come. Its content, procedures, and evaluation criteria are currently being agreed with all stakeholders.

Even now there are no scientific reasons to ban hydraulic fracturing as documented in German and Europe-wide expertises (Emmermann 2014, UBA 2014b, Neutraler Expertenkreis 2012, NRW 2012, UBA 2012). The way forward should therefore be to create the preconditions for scientifically supported demonstration projects executed under special requirements for the recovery of unconventional hydrocarbons and geothermal energy. Such projects would allow proving the technical and environmentally compatible viability of hydraulic fracturing in shale and hot dry rock, improving the technology, further developing standards, rules, and regulations, and earning trust by transparent information of the public. This applies both to the recovery of shale gas and to deep geothermal energy as well.

The companies organized in the German *Wirtschaftsverband Erdöl- und Erdgasgewinnung* (oil and gas producers association) in Hannover have identified, analyzed, and evaluated the risks associated with hydraulic fracturing and have defined additional measures like frac-fluids that are environmentally compatible. The agreed best operational practices represent the minimum standard of the German oil and gas industry for carrying out hydraulic fracturing treatments.

An environmentally compatible use of the technology on the basis of these practices and in compliance with existing laws and regulations is already possible today. The technology is therefore of no greater risk than any other industrial activity.

11 Summary

The development of unconventional natural gas and deep geothermal energy is only possible by employing the technologies of hydraulic fracturing and horizontal drilling. Experience over many decades has shown that the risks associated with hydraulic fracturing can be managed. For the thousands of frac-jobs carried out in Northwest Europe no environmental damages have been reported, in particular in Germany, The Netherlands, the United Kingdom and Norway.

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Application and potential of hydraulic-fracturing for geothermal energy production Reinhard Jung¹

Key words: Hot-Dry-Rock (HDR), Enhanced-Geothermal-Systems (EGS), Hydraulic-Stimulation, Multi-frac-Systems, Waterfrac-Technique

Zusammenfassung

Das grösste Hindernis für die breite Nutzung geothermischer Energie ist die geringe Permeabilität der Tiefengesteine. Dem Hydraulic-Fracturing kommt deshalb eine Schlüsselrolle bei der Erschliessung des riesigen vor allem im kristallinen Grundgebirge gelegenen Potenzials zu. Obwohl seit 1970 ein Dutzend HDR- bzw. EGS-Projekte ausgeführt wurden, ist die Technik nicht ausgereift. Ihre Weiterentwicklung wird derzeit durch die Furcht der Bevölkerung vor induzierter Seismizität behindert. Eine Analyse der Projektergebnisse zeigt, dass die Hauptursache für den schleppenden Fortschritt das Erschliessungskonzept ist, das seit Mitte der 1980er Jahre angewandt wird. Das bis dahin favorisierte Multiriss-Konzept sah vor, zwei geneigte Bohrungen mittels künstlicher Risse zu verbinden. Dieses Konzept wurde nicht zuletzt wegen technischer Schwierigkeiten durch das EGS-Konzept ersetzt. Dieses sieht vor, das natürliche Kluftnetz durch hydraulische Stimulation aufzuweiten. Die Projektergebnisse zeigen jedoch, dass sich stattdessen grosse Einzelrisse ausbilden, bestehend aus natürlichen und künstlichen Riss-elementen. Aufgrund ihrer Grösse und Eigenschaften bergen diese Makro-Risse ein seismisches Risiko. Mit kleineren Abmessungen aber wären sie aufgrund ihrer hydraulischen Eigenschaften für Multiriss-Systeme gut geeignet. Eine Rückkehr zum Ausgangskonzept ist deshalb angeraten. Multiriss-Konzepte werden in den Schiefergas-Projekten erfolgreich eingesetzt und die Technik hat in den letzten 20 Jahren grosse Fortschritte gemacht. Es ist daher wahrscheinlich, dass auch geothermische Multiriss-Konzepte in naher Zukunft realisiert werden können.

Abstract

The main obstacle for a wide application of geothermal energy is the low permeability of the rock at great depth. Hydraulic-fracturing is therefore the key for exploiting this huge resource located predominantly in the crystalline basement. A dozen projects have been performed since 1970. But still the technique, known as HDR- or EGS-technology is not mature. In addition development is now hindered by the risk of induced earthquakes. A review of the projects shows that the poor progress is mainly due to the exploitation concept applied since the early 1980ties. Until then the leading concept was to connect two inclined boreholes by a set of hydraulic fractures. This multi-fracture scheme was abandoned not the least for technical reasons and replaced by the EGS-concept. This intends to enhance the permeability of the joint network by massive water injection. The results of the EGS-projects however show that this is not happening but that a single macro-fracture is created consisting of natural and new tensile fracture elements. Due to their enormous size and their specific properties they bear a seismic risk. Macro-fractures of a smaller scale are less critical and their hydraulic properties are sufficient for multi-fracture systems. These findings suggest a return to the original HDR-concept. Multi-fracture concepts are applied with great success in shale-gas reservoirs and the techniques to establish these systems have improved considerably. So it seems likely that geothermal multi-fracture systems can be realized in the near future.

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1 Introduction

Today, geothermal energy production for direct use and/or power production is restricted to hydro-thermal resources. These are intensely fractured, karstified or highly porous rock-formations with extraordinarily high permeability. Hydro-thermal resources particularly those suitable for power production are rare especially in countries with normal temperature gradients, where one has to drill deep to reach sufficiently high temperatures. The overwhelming part of the heat content of the upper crust accessible by drilling is stored in rock formations with extremely low permeability, particularly in the crystalline basement. The power potential of these petro-thermal resources is by far the biggest energy resource of the upper crust exceeding the power potential of the hydro-thermal and of all hydro-carbon resources by at least two orders of magnitude.

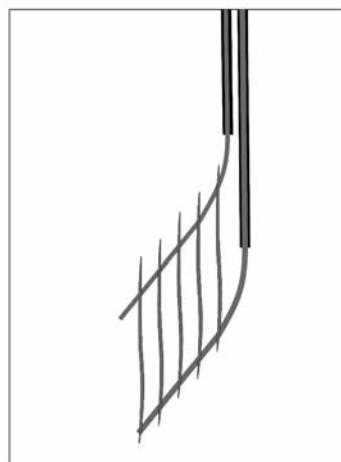
First attempts to access this potential date back to the early 1970s (Brown et al. 2012). The basic idea is to create large fracture systems in the crystalline rock mass in order to hydraulically connect boreholes over great distances. For power production cold water or natural brine injected in one of the wells

heats-up to rock temperature while circulating through the fracture system and is produced in the second well. To prevent flashing an overpressure is maintained in the geothermal loop. Steam for power generation is produced in a secondary loop generally filled with an organic fluid (ORC-Process) or with an ammonia-water mixture (Kalina-Process) as working fluids.

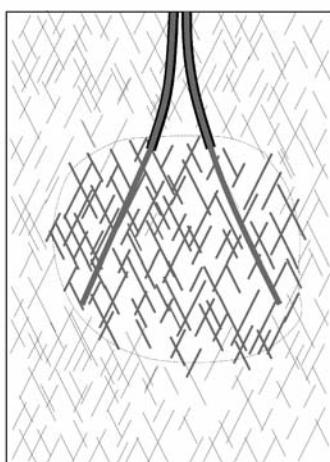
Industrial doublet-systems will have to be designed for an electrical power output of 5–10 MWe and production flow rates in the range of 100 l/s. To ensure a service life of at least 25 years a separation distance of at 0.5 to 2 km between the two wells at depth and a total fracture area of 5–10 km² is required. The volume of rock to be accessed by the fracture system has to be in the order of 0.1 to 0.3 km³. The pumping-power to maintain the geothermal loop can consume a significant fraction of the produced power. For this reason the flow impedance of the fracture system (difference between inlet- and outlet-pressure divided by the flow rate) should not exceed 0.1 MPa/(l/s).

Two concepts had been invented and tested during 40 years of research.

The first regarded the crystalline basement



HDR-Concept



EGS-Concept

Fig. 1: Basic concepts.

as a competent unfractured rock mass and the idea was to connect two inclined boreholes by a number of parallel tensile fractures created by hydraulic-fracturing (Fig. 1). The feasibility of this concept, known as Hot-Dry-Rock-concept (HDR), was proofed by creating and investigating single fracture systems at several locations. Attempts to connect two inclined bore-holes by a multi-fracture system in the Los Alamos-project however failed since the fractures did not propagate in the projected direction and due to technical problems with borehole packers at high temperatures (Rowley et al. 1983, Dreesen & Nicholson 1985, Brown et al. 2012).

Realizing that the crystalline basement contained unsealed natural fractures even at great depth, and that these fractures started to shear before the fluid-pressure reached the level for tensile fracture initiation, the HDR-Concept was abandoned and replaced by the EGS-Concept (Enhanced Geothermal Systems). This concept aims to shear and dilate the natural fracture network by injecting large quantities of water in long uncased borehole sections (Batchelor 1982). In order to distinguish it from hydraulic-fracturing this mechanism was called «hydraulic stimulation» (Murphy 1985). The circulation sys-

tem is completed by drilling a second bore-hole into the region of enhanced fracture-permeability (Fig. 1), as indicated by the spatial distribution of seismic events induced during the stimulation process.

The change in the leading concept had severe consequences:

- Deviated or horizontal wells were no longer required and replaced by more or less vertical wells.
- Development of high temperature packers was no longer important and was disregarded.
- Heat exchanging area as a measure for the service life of a HDR-system was replaced by the stimulated rock volume.
- Geometrically simple fracture mechanical models were replaced by geometrically complex fracture networks lacking fracture mechanical mechanisms.

All projects of the last 30 years followed this concept and fracture systems of enormous dimensions (several square-kilometres) had been created during this period connecting boreholes over distances of up to 700 m. Nevertheless, in several aspects the economic targets defined above have not been met. In particular the flow rates and the power output are still far too low (Tab. 1). The main reason is the high flow-impedance

Project	Average Depth	Temp.	Well distance	Flow rate	Flow impedance	Thermal power	Electric power
	[m]	[°C]	[m]	[l/s]	[MPa·s/L]	[MW _{th}]	[MW _{el}]
Los Alamos I	2.840	190	80	6	1.6	2.9	0.4
Los Alamos II	3.500	230	150	6	2.1	3.8	0.5
Camborne II	2.300	80	250	15	0.6	0.6	n.a.
Hijiori II	2.250	250	90	4	0.6	2.9	0.4
Ogachi	850	240	80	1.7	8	1.2	0.16
Soultz I	3.200	170	450	25	0.23	10	1.2
Soultz II	4.700	200	600	12	0.25	6	0.8
Cooper Basin	4.400	250	700	19	1.8	14	1.9
Target		> 150	> 500	100	0.1	> 40	> 5

Tab. 1: Key-parameters of the major EGS-projects.

in the fracture systems. It will be shown in the next chapters that mainly the change of concept is responsible for the poor progress during the last three decades and that a return to the multifracture-concept as envisaged during the first decade of HDR-research and practiced in the shale gas industry is necessary.

2 Test Performance

2.1 Overview

Nine research projects and three commercial HDR-projects have been performed since the beginning of Hot Dry Rock research at around 1970 (Fig. 2). Some of the early projects investigated fracture propagation and fracture properties at shallow depth in order to gain basic knowledge under well-defined but down-scaled conditions, i. e. Le Mayet de Montagne (Cornet 1989), Falkenberg (Jung 1989), Higashihachimantai (Hayashi & Abé 1989) and Fjällbacka (Wallroth 1992). The majority of the projects however were carried out at greater depth under conditions and on a scale similar to

future industrial systems (MIT 2006). All together more than a billion Euro have been spent in national and international projects. About 20 deep wells with a total length of about 70 km had been drilled and numerous massive waterfrac-tests including pre- and post-frac investigations had been performed at the different locations. The following paragraphs are an attempt to describe and synthesize the main observations and results of these tests.

Almost all stimulation tests of the EGS-projects had been performed with water or brine as frac-fluid. Only in a few cases viscous-gels and proppants had been used. All tests were done in open-hole sections with lengths ranging from about 10 m up to about 700 m. Generally these intervals particularly those with greater lengths contained hundreds of joints, a number of fracture-zones and faults. In addition they comprised long sections with axial or inclined drilling induced fractures and sections with borehole break-outs. Almost all open-hole sections except those in the Fenton-Hill II and the Camborne System were vertical or sub-vertical. The majority of the stimulation tests were performed with only moderate flow rates, ranging from less

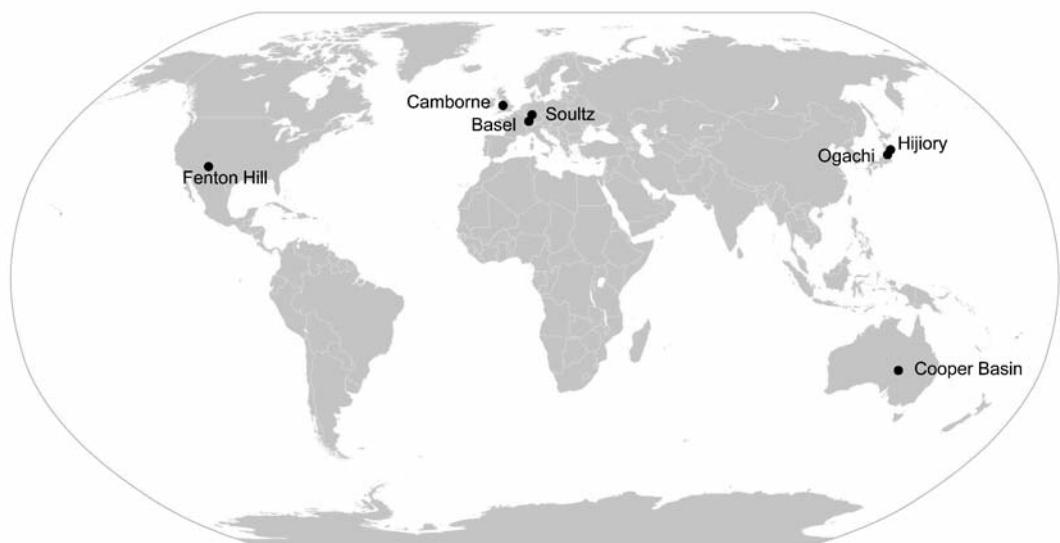


Fig. 2: Locations of the major international EGS-projects.

than 10 l/s to about 50 l/s. Only a few tests were done with flow rates above 100 l/s.

Basically two stimulation-schedules had been applied: the step-rate and the constant-rate injection schedule.

2.2 Example for a constant rate stimulation test

The basic idea behind the constant-rate stimulation schedule was to rise the pressure quickly to a high level so that fractures of various orientation could shear simultaneously. The test was performed in the open-hole section of borehole GPK4 in the Soultz II-system in the depth section between 4.500 m and 5.000 m. The aim was to hydraulically connect the well to the fracture system stimulated earlier in wells GPK2 and GPK3. The distance to the next well GPK3 was about 700 m. The test was started with about 600 m³ of brine followed by 8.500 m³ of water. The well-head-pressure record shows the typical characteristics of a conventional hydraulic-fracturing test with a pressure maximum after start of injection (break-down pressure) and almost constant pressure until the end of injection (Fig. 3). During shut-in the pressure

declined continuously without a sign of fracture closure.

The flow logs recorded during post-frac injection tests showed an almost linear decrease of the flow velocity with depth (Fig. 4). This is typical for axial fractures and is commonly observed after stimulating oil and gas wells in sedimentary rock formations. The logs indicate that the axial fracture extends over the entire length of the open-hole section accessible for logging. The high flow velocity at the lower end of the flow logs and the seismic cloud indicate that it extends further down to the bottom of the well and another 500 m beyond of it.

The seismic cloud was almost planar and was indicative for one through-going fracture. Dip and strike were vertical and N-S respectively. Stress conditions where transtensional with the maximum horizontal stress oriented 170° E. The great number and the character of the seismic signals, as well as the slight deviation of the strike direction from the direction of the maximum horizontal stress indicate that fracture propagation was not in a pure tensile mode but contained a shear-mode component.

These observations proof that large single

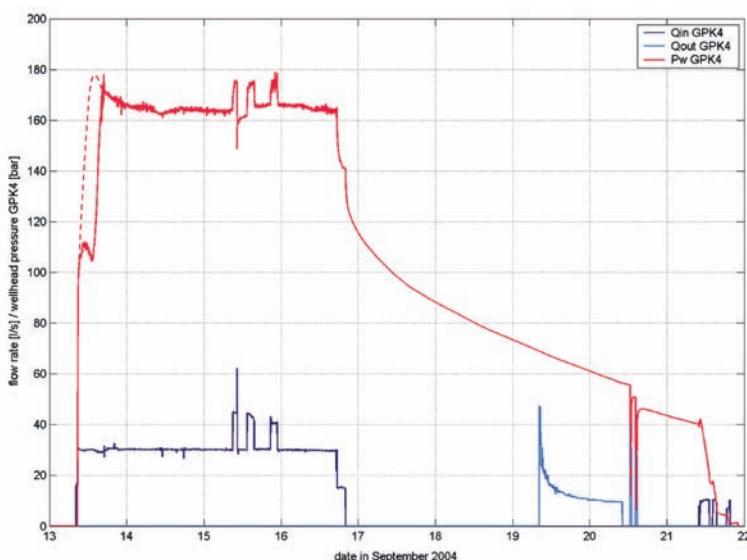


Fig. 3: Flow rate and well-head-pressure record of a constant rate stimulation test in borehole GPK4 (Soultz II-system [Baria et al. 2005]). Dashed line in the pressure record: curve corrected for the density effect of brine injection.

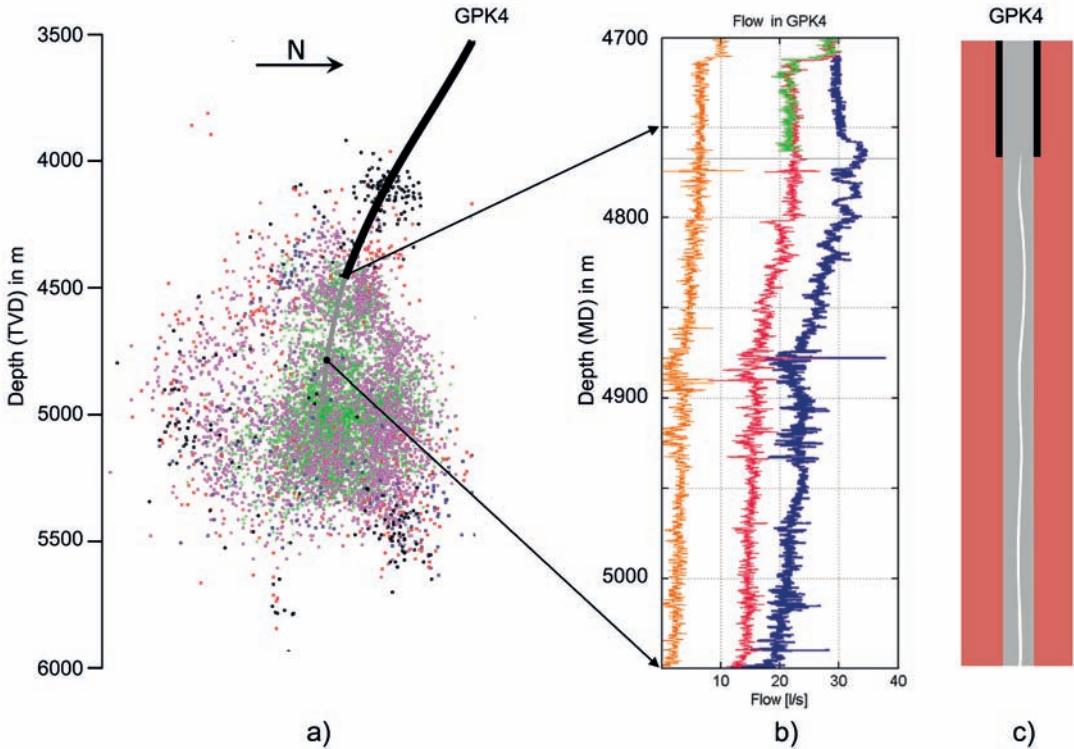


Fig. 4: Left: front-view of the seismic cloud of the stimulation test in borehole GPK4 of the Soultz II-system (view to the east), middle: flow logs recorded during post-frac injection tests, right: scheme of the fracture trace along the borehole wall (right). Sources: seismic cloud (Dyer 2005), flow-log (Schindler et al. 2008).

artificial fractures can be created by hydraulic stimulation in granite despite of the presence of hundreds of natural fractures. The presence of drilling induced axial fractures, the start of the stimulation at relatively high flow rates and an appropriate orientation of the borehole axis with respect to the stress field will favour the initiation of artificial fractures.

2.3 Example for a step-rate stimulation test

The rational of the step-rate stimulation tests was to first activate the fractures most ready for shearing and then activate step by step fractures less favourably oriented for shearing. The exemplary test was performed in the open-hole section of borehole GPK1 extending from 2.850 m to 3.400 m. It was the first stimulation test in the Soultz I-system. In

order to isolate a permeable fault at about 3.500 m depth the bottom part of the well had been filled with sand. Starting flow-rate was 0.15 l/s, the maximum flow rate at the end of the test was 36 l/s (Fig. 5).

The pressure record did not show the typical characteristics of conventional hydraulic-fracturing tests described in the previous example. However the pressure reached a quite high level already during the first step and showed clear signs for a mechanical reaction from the beginning. The pressure increase from step to step was less than proportional to the flow rate steps and pressure remained almost constant for the final steps. This indicates that fractures had been jacked open at this pressure level. As for the constant rate test the pressure declined smoothly during the shut-in period before venting and showed no indication for fracture closure.

The seismic cloud of this test was processed with the so called «collapsing method» (Jones & Steward 1997). This method removes the random location error and leaves a more distinct image of the internal structure of the cloud. The front-view of the cloud (Fig. 6a) shows a quite complex internal pattern with a central patch and lines or stripes of intense seismicity, some of them radiating from the centre at different angles. In several directions the cloud has distinct almost straight boundaries. Views along the strike plane of the cloud as indicated in Fig. 6c and d, show a through-going structure resembling a large wing-crack. The overall strike direction of the vertical cloud is 155°. This is 15° off the direction of the maximum horizontal stress of 170°.

The step-like trace of intense seismicity in the horizontal slice as shown in Fig. 6b indicates that the lines of intense seismicity radiating from the centre are probably identical with the intersection lines of a vertical

N-S striking fracture and some NNW-SSE-striking and ENE-dipping faults. It appears that the fracture is crossing them with a certain offset. The vertical fracture is most likely an artificial fracture created in the well section below the casing shoe that comprised a group of en-echelon drilling-induced fractures (Fig. 7). This fracture consumed or produced 60% of the fluid at the end of stimulation and during post-frac injection and production tests. Three deeper outlets absorbing another 25% of the flow rate were identified by Evans et al. (2005) as hydraulically linked to the main outlet below the casing shoe. This means that 85% of the injected fluid were flowing into the main fracture. The remaining 15% were absorbed by the permeable fault at 3.500 m depth after removing the sand and stimulating this lower part of the well. The pattern of the seismic cloud at this depth indicates that even this fault is connected to the main fracture. A more extensive analysis with a slightly dif-

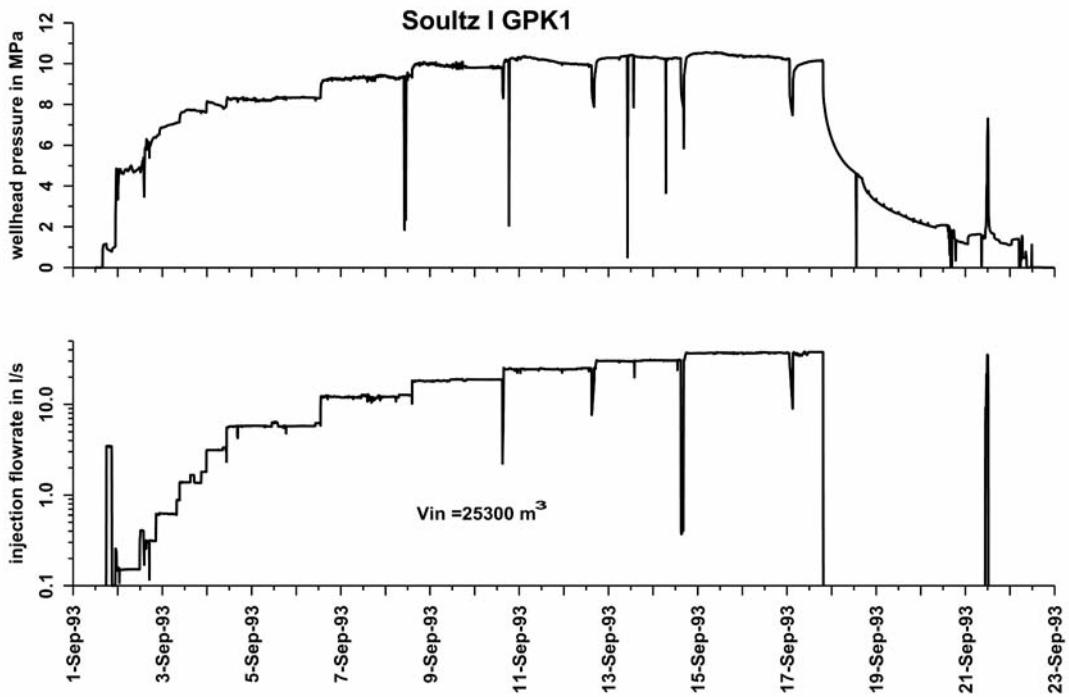


Fig. 5: Flow rate and wellhead-pressure record for the step-rate stimulation test in borehole GPK1 of the Soultz I-system. Note the logarithmic scale of the flow rate axis. Source: Jung (1999).

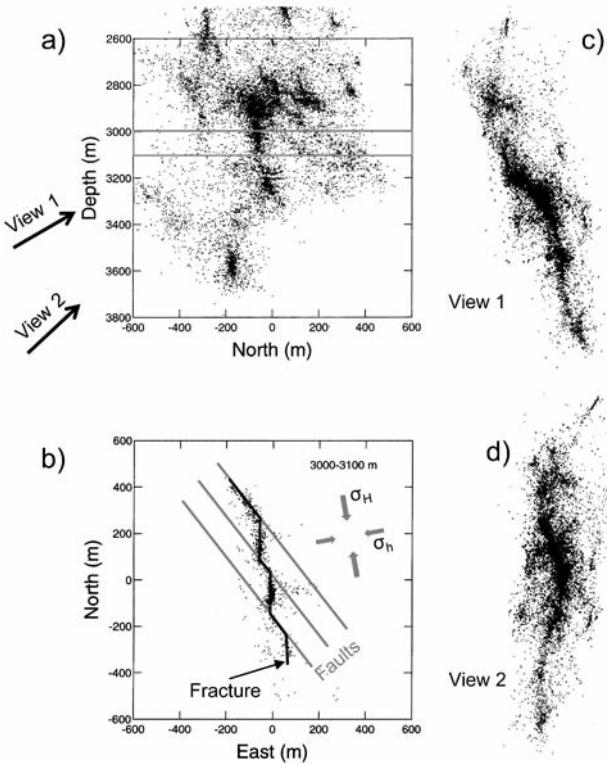


Fig. 6: Processed (collapsed) seismic cloud obtained during the step-rate stimulation test in borehole GPK1 of the Soultz I-system. a] front view [view toward W], b] horizontal slice [3,000–3,100 m] c] & d] views parallel to the plane of a] along indicated directions. Source: Niituma et al. (2004).

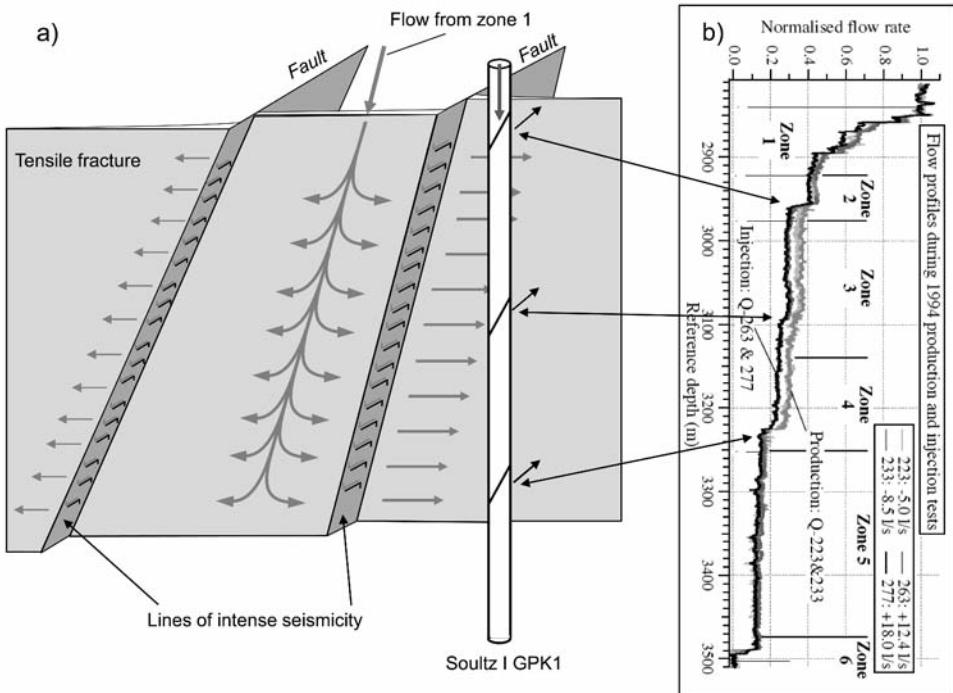


Fig. 7: a) Scheme of the central part of the macro-fracture created in borehole GPK1 of the Soultz I-system, derived from the flow logs and the seismic cloud (Fig. 6). b) flow-logs recorded during post-frac injection and production tests in borehole GPK1 at Soultz. Flow-log from Evans et al. (2005).

ferent interpretation of the seismic data was made by Evans et al. (2005).

In summary one can conclude that the step-rate stimulation test created a wing-crack-like macro-fracture that despite of intersections with faults is mechanically and most likely hydraulically a single large through-going entity.

3 General results and observations

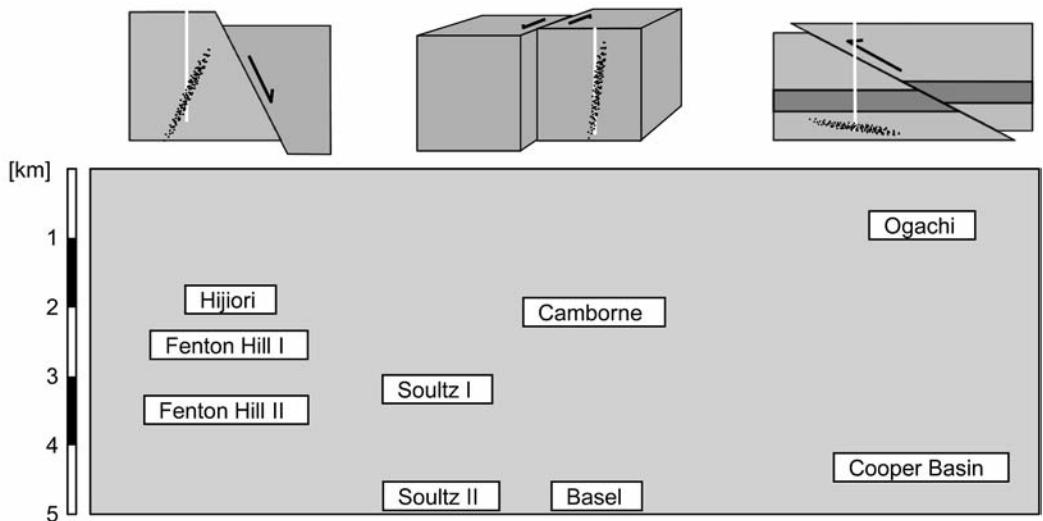
Though the site- and test-conditions of the EGS-projects differed remarkably, an attempt was made to derive results and observations common to all EGS-systems. The only constants were rock type (granite and granodiorite) and frac-fluid (water or brine with one exception) and the fact that all tests were done in uncased borehole sections. All other test parameters and conditions were quite variable: Stress conditions ranged from normal- to thrust-faulting, depth from 800 m to 5.000 m (Fig. 8), temperature from 80 °C to 250 °C, length of frac-interval from 3 m to 750 m, injected volume from 20 m³ to 35.000 m³, and flow rates from

6 l/s to 200 l/s. Furthermore some tests were performed according to the constant-rate schedule, others according to the step-rate schedule. Well trajectories were predominantly vertical to sub-vertical but some tests (Los Alamos II and Camborne) were performed in inclined borehole sections.

3.1 Orientation of the stimulated fractures

It is generally assumed that tensile fractures are oriented perpendicular to the direction of the least compressive stress. Tensile fractures should therefore be vertical for normal and strike-slip stress conditions and horizontal for thrust-fault stress conditions. As mentioned above all basic stress conditions were covered by the major projects. Soultz had trans-tensional stress conditions which is the transition between normal and strike-slip stress conditions.

Investigation of the dip of the seismic clouds of the major EGS-projects showed that the seismic clouds were vertical to sub-vertical for strike-slip and trans-tensional stress conditions, steeply inclined (60–70°) for normal stress-conditions and subhorizontal for



Correspondence of the dip of the seismic clouds with the stress conditions at the major EGS-sites. Scale on the left corresponds to the depth of the EGS-systems. (After Jung 2013).

thrust-faulting conditions (Jung 2013). This indicates that the dip of the stimulated fractures is similar to but not identical with the dip of tensile fractures. The biggest deviation is observed for normal stress conditions. In this case the dip of the fractures is optimal for shearing. For strike-slip conditions the strike of the fractures may also be optimal for shearing. But this was not proved since there is often too high uncertainty in the direction of the principal horizontal stresses. In cases (e.g. Cooper Basin) it was suspected that the seismic cloud corresponds to a pre-existing fault that had been sheared during the stimulation tests. This argument cannot be disproved but it seems unlikely that this is generally the case. One can therefore conclude that the tectonic stresses are the main controlling factor for the overall orientation of the stimulated fractures.

3.2 Size of the stimulated fractures

Because of the 2-dimensional nature of the seismic clouds and the strong influence of the location error on their thickness not the volume but the area of the seismic clouds

was taken as the measure for the size of the stimulated fracture systems similar to an earlier study of Murphy et al. (1983). The area was grossly determined by drawing an envelope around the projection of the seismic clouds on a plane parallel to its main orientation.

Despite of the big variation in test and test-site conditions a clear correlation was found between seismic area and injected volume (Fig. 9). The whole set of data points except that of a gel-frac in the Camborne-project can well be fitted by a power law with exponent $n = 2/3$. This means that the area is increasing with $V_{IN}^{2/3}$. The area did not correlate with flow rate or length of the frac-interval (which could serve as a proxy for the number of natural fractures). These findings and the high coefficient of correlation R^2 of the data points with the fitting line allow establishing the following hypotheses:

- The stimulation process is mainly volume-controlled. Fluid losses have no significant impact. Fluid efficiency η (ratio of created fracture volume and injected volume) is high, at least in the order of 50%.
- Friction pressure losses in the fractures have no significant influence on the area to

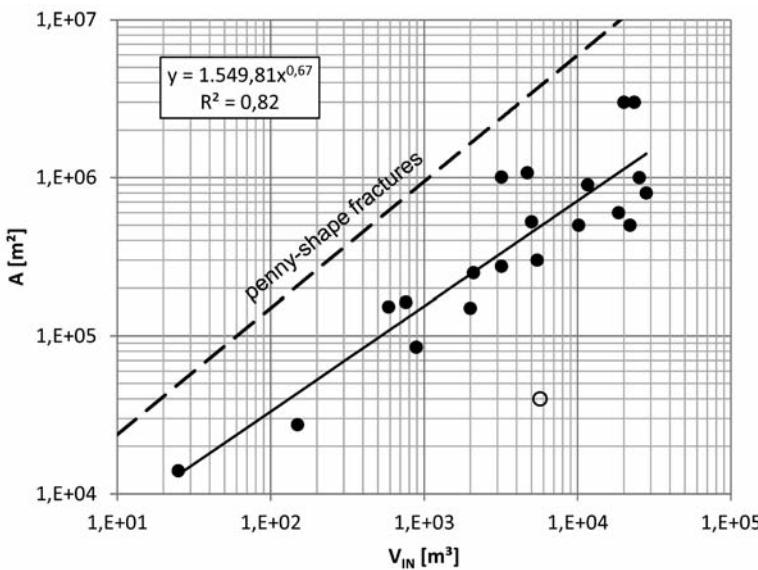


Fig. 9: Area of the seismic clouds of all major EGS-projects vs. injected volume (after Jung 2013). Fitting line and coefficient of determination R^2 is for the solid data points. Open circle: Data point of a gel-frac test in well RH-15 of the Camborne system. Dashed line: Trend-Line for penny-shape fractures for $E' = 50$ GPa and $K_{IC} = 1.5$ MPa·m $^{1/2}$.

volume relationship. Static fracture models should therefore apply.

One of the most popular static fracture model is the circular tensile fracture, the so called «penny-shape fracture». Though it is clear that this model is not applicable for the stimulated fractures a comparison with this model is interesting. For the penny-shape fracture model, which neglects fluid-losses and the vertical stress gradient, the fracture-area is proportional to $V_{IN}^{0.8}$ and even more important it is by about one order of magnitude higher than the area of the seismic clouds (Fig. 9). The major technical consequence is that the fluid volume required for a certain fracture area is about ten times higher than the volume estimated with a penny-shape fracture model. Part of this big discrepancy may be explained by fluid-losses. But as mentioned above fluid losses played not an important role.

3.3 Number of stimulated fractures

Direct information on the number of conductive fractures was obtained from flow and temperature logging during stimulation

and post-stimulation injection or production tests (Jung 2013). In no case was the number of hydraulically significant fractures bigger than five. Furthermore in most cases these fractures were close to each other and there was always a hydraulically dominating fracture among them. As demonstrated in the example above (Fig. 7) it is likely that some of the fractures are only hydraulic links to the main fracture since in most cases the main fracture stays close to the well over a long well section. It may therefore be concluded that the number of hydraulically significant fractures after stimulation was in all cases close to one.

3.4 Fracture aperture

Fracture apertures were determined with three independent methods, first by calculating the ratio of injected volume during stimulation and area of the seismic clouds, secondly by the tracer break-through volume observed during inter-well circulation tests, and third by using the hydraulic impedance measured during interwell circulation tests (Jung 2013).

The apertures determined by the ratio of

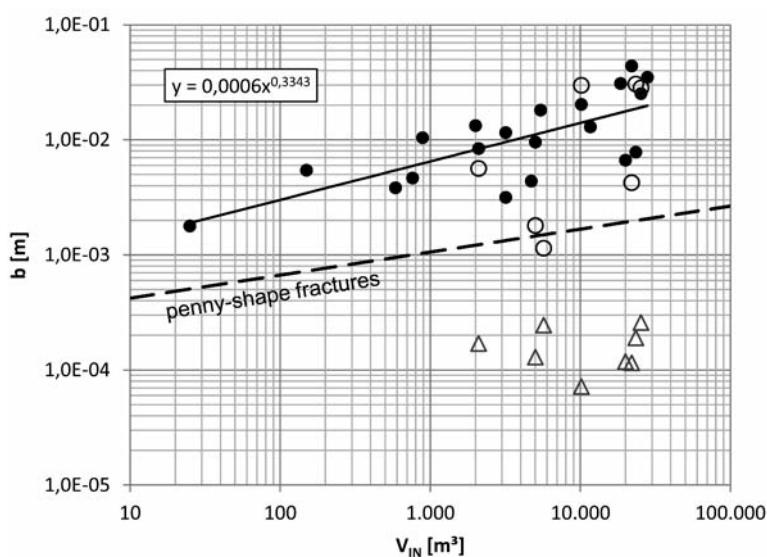


Fig. 10: Fracture apertures determined with different methods. Solid dots: ratio of the injected volume and seismic area, solid line: trend-line for the solid dots, open circles: apertures from tracer break-through volume, open triangles: apertures from hydraulic impedance, dashed line: trend-line for penny-shape fractures with $K_{IC} = 1.5 \text{ MPa}\cdot\text{m}^{1/2}$ and $E' = 50 \text{ GPa}$, data from Jung (2013).

injected volume and area of the seismic cloud increase proportional with $V_{IN}^{1/3}$ and reach values of some centimeters for the largest fractures (Fig. 10). It is not surprising that the apertures determined this way are the highest since they are determined for propagating («inflated») fractures and since fluid losses are included. It is however surprising that most of the apertures determined from the tracer break-through volumes are close to these values. Even more striking is the fact that the apertures determined from the inter-well flow-impedance are by about two orders of magnitude lower than most of the values determined by the two other methods. This means that the hydraulic conductivity of the fractures (which is proportional to the cube of the aperture) are by about 6 orders of magnitude lower than the hydraulic conductivity that one would expect for the apertures determined by the two other methods. This could easily be explained when not a single fracture but multiple fractures were involved in the inter-well flow. But as the flow-logs have shown this was not the case.

3.5 Hydraulic characteristics of the fractures

Post-frac constant rate injection or production tests always showed a square-root or fourth-root of time-behaviour. This means the pressure in the test-well increases or decreases linearly with the square-root or fourth-root of time. In log-log-plots of the pressure and the logarithmic pressure-derivative this shows up as straight lines with slope $\frac{1}{2}$ and $\frac{1}{4}$ respectively. Pressure-time curves of this type are characteristic for linear (parallel) flow within a fracture of finite hydraulic conductivity imbedded in an impermeable matrix (square-root of time behaviour) or in a permeable matrix (fourth-root of time behaviour). The square-root or fourth-root of time behaviour is commonly observed for hydraulic fractures in stimulated oil- or gas-wells but the duration of these periods particularly of the fracture linear flow-period is generally quite short. In the stimulated EGS-wells however fracture-linear flow-periods of 10 hours or more are not uncommon (Fig. 11). For axial fractures extending over several hundred meters along the borehole wall these long fracture-linear or bilinear flow-periods are reasonable. But the same behav-

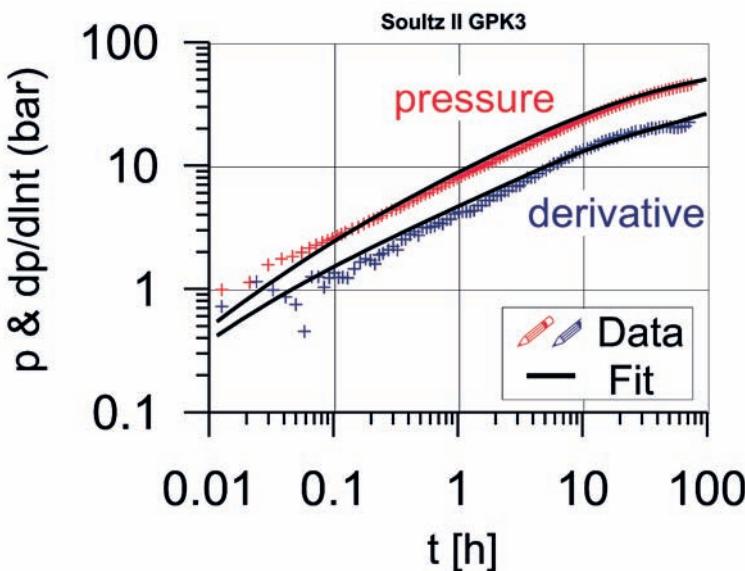


Fig. 11: Log-log-plot of the pressure (upper curve) and of the (logarithmic) pressure derivative vs. time of a post-frac constant-rate injection test at Soultz (Tischner 2013).

iour was also observed for fractures that had a point-like intersection with the borehole. In these cases the most plausible explanation is that the borehole is linked to a very long and highly conductive flow channel within the fractures, which acts as the baseline for the linear or bilinear fracture flow. Another or additional explanation is a strong anisotropy of the fracture-conductivity.

The hydraulic conductivity (transmissivity) of the fractures determined from the square-root or fourth-root of time-curves for single-well tests are in good agreement with the hydraulic impedance measured during inter-well circulation tests. Both values are most likely representative for the hydraulic conductivity normal to the orientation of the channels or normal to the axis of the highest fracture conductivity.

3.6 Thermal Draw-Down

The decline of the production temperature during circulation is the ultimate criterion for the success or the failure of an EGS-system and is a very sensitive indicator for the applicability of the models established for the EGS-system. Unfortunately only a few thermal-drawn curves of EGS-systems are available. In most cases the circulation tests were too short to obtain a thermal-draw down, or the test conditions were not well constrained.

The best examples concerning test conditions and test-duration are the thermal draw-down curves of the Los Alamos I and of the Camborne EGS-system (Fig. 12).

For both cases the temperature decline can well be fitted by single fracture models.

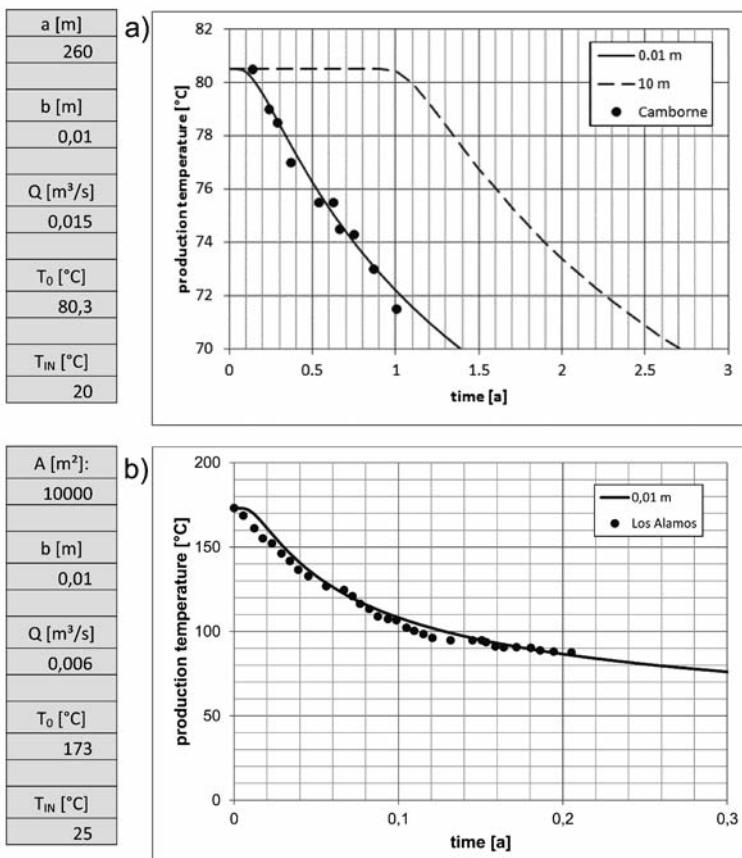


Fig. 12: Temperature decline during constant-rate circulation tests in Camborne II [a] and the Los Alamos I system [b]. Dots: data points, Solid lines: fit curves obtained with analytical single fracture models, dashed line: temperature decline for a doublet in a permeable layer with thickness $b = 10$ m. Data from Brown et al. (2012) and Ledingham (1989). Tables: list of the parameter values used for fitting, a : inlet-outlet distance, b : fracture aperture, Q : flow rate, T_0 : initial reservoir-temperature, T_{r_i} : injection temperature, A : fracture area.

For the Los Alamos I system a good fit was found for a model with parallel fluid-flow in a rectangular fracture accompanied by transient conductive heat flow from the rock toward the fracture plane. The area of the fracture of 10.000 m² determined with this model agrees quite well with the value of 8.000 m² obtained with a similar model by the Los Alamos group (Brown et al. 2012) and corresponds with the inlet-outlet distance of about 80 m of this system.

For the Camborne-system a good fit was found by Ledingham (1989) by using a rectangular fracture model similar to the one above but comprising two fractures with flow-fractions of 79% and 21% respectively. A similar good fit (Fig. 12) is obtained with an analytical model that calculates the decline of the production temperature for a bore-hole-doublet in an infinite fracture with transient conductive heat flow from the rock matrix toward the fracture plane. The inlet-outlet distance of 260 m determined by using this model agrees quite well with the geometrical inlet-outlet distance of the Cam-

borne-system (Tab. 2). If one replaces the discrete fracture in this model by a permeable layer with a thickness of several meters (a proxy for a volumetric system) the temperature decline starts with a significant delay as demonstrated in Fig. 12.

In summary one can conclude that both thermal draw-down curves can well be fitted by a single discrete fracture model. There is no indication for a volumetric or multi-fracture connection between the wells.

3.7 Induced Seismicity

All tests except the gel-frac test in the Camborne-project were accompanied by intense seismicity. The rate of seismic events was proportional to the flow rate but decreased gradually with time for constant flow rate. The number of detectable seismic events was generally in the order of one event per cubic-meter of injected volume. The source radius of the majority of events estimated from the frequency-characteristic (corner-frequency) was in the order of 5-10 m. A rel-

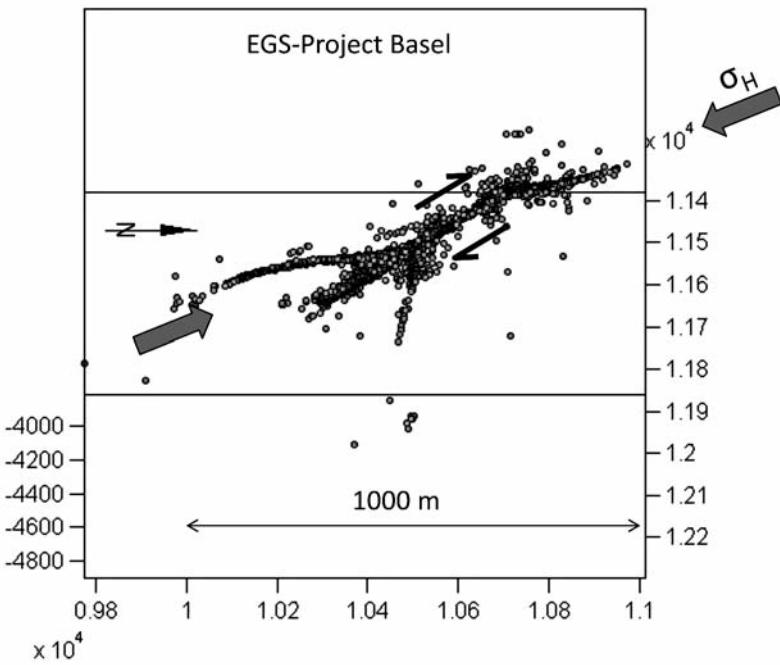


Fig. 13: Processed (collapsed) seismic cloud of the stimulation test in borehole BS-1 at Basel, view parallel to the central plane of the cloud (10° from vertical toward W). Processed Cloud from Baisch & Vörös (2007), stress-direction from Häring et al. (2008).

atively small fraction of events had much bigger source radii and magnitudes and appeared predominantly in the final part of the stimulation tests and during pressure depletion in the subsequent shut-in periods. In the Basel-system some strong events were observed several months after pressure depletion.

All seismic clouds of the major EGS-projects had a disk-like shape with a thickness of up to about 1 to 3 times the location error which was generally between 30 m and more than 100 m. Most of them had areas of intense seismicity in the central part surrounded by a halo of low seismicity. The transition between the two was abrupt and occurred in most cases along straight boundaries. The areas of intense seismicity were often elongated in one direction and in the extreme case almost linear. Similarly there were elongated patches and lines with no seismicity. Many of the regions in the inner part of the seismic clouds showed repeated seismicity. Subsequent stimulation tests in the same well produced almost no seismicity until the injected volume approached the injected volume of the initial test.

The generally diffuse appearance of the seismic clouds was to a main part due to the location error. When this was removed or reduced by applying appropriate processing methods like the so called «collapsing method» (Jones 1997) more distinct images of the fracture systems were produced giving insight into their internal structure. A number of these processed clouds showed the characteristics of a large wing-crack. The most obvious example besides the one in Fig. 6 is the seismic cloud of the Basel-system (Fig. 13).

4 Discussion

The present understanding of hydraulic stimulation as a pressure diffusion process in the natural fracture network accompa-

nied by shearing and dilating of the natural fractures is based mainly on the fuzzy appearance of the seismic clouds, the strong shear wave components of the seismic signals, the great number of natural fractures encountered in granite even at great depth, and the onset of induced seismicity at a fluid pressure lower than the pressure required for the propagation of new tensile fractures. Most of the results and observations described above however do not support this view. The small number of hydraulically significant fractures and the dominance of one in post-stimulation flow-logs, the rapid decline of the production temperature during circulation and the shape of processed seismic clouds indicate that mainly one trough-going macro-fracture is created during the stimulation process. This macro-fracture is oriented almost but not perfectly perpendicular to the direction of the minimum principal stress. At least for a number of cases the macro-fracture resembles a large wing-crack. On this basis it is hypothesized that the wing-crack mechanism plays a key role in the formation of these macro-fractures.

The formation of wing-cracks is one of the micro-mechanisms discussed in material science to explain the inelastic behavior and failure of brittle material under compression. The basic observation is that fractures of finite length failing in shear will not propagate along their own plane but will form tensile wing-fractures (Fig. 13). Referring to results of Coterell & Rice (1980), Lehner & Kachanow (1996) stated that the wings are initiated near the fracture tips at an angle of 70° to the plane of the initial shear fracture and are then bending into the direction of the maximum principal stress.

For natural fractures of the size of joints initiation of the wings start at a fluid pressure only a few bars above the pressure required for the onset of shearing. For natural fractures of a larger scale (fracture zones or faults) the difference is even smaller. This means that natural fractures being sheared

during stimulation will inevitably develop wings. These wings will probably connect to neighboring fractures. The rising fluid-pressure within these fractures will cause them to shear and to develop wings at their tip. As a consequence a through-going fracture will develop consisting of natural and new fracture elements. Its orientation will be slightly off the direction of the maximum principal stress. When the pressure approaches the minimum principal stress large wing-fractures may develop at both ends of this series so that the whole fracture appears as a large wing-crack. It seems that most of the stimulated fractures at Soutz and the stimulated fracture of Basel are of this type. It is likely that the development of the large-scale wings are the reason for the strong seismic events in the final stages of these stimulation tests, since they enable large and simultaneous shear displacements of the whole series of natural and new fracture elements created earlier.

In long uncased borehole sections there are basically two different starting conditions for stimulation (Fig. 14). For step-rate stimulation tests stimulation will most likely start with the shearing of a natural fracture and the process will continue as described above. For constant rate stimulation tests with moderate to high flow rates an axial tensile fracture may be created. This tensile fracture will intersect natural fractures and cause them to shear and to develop wings at

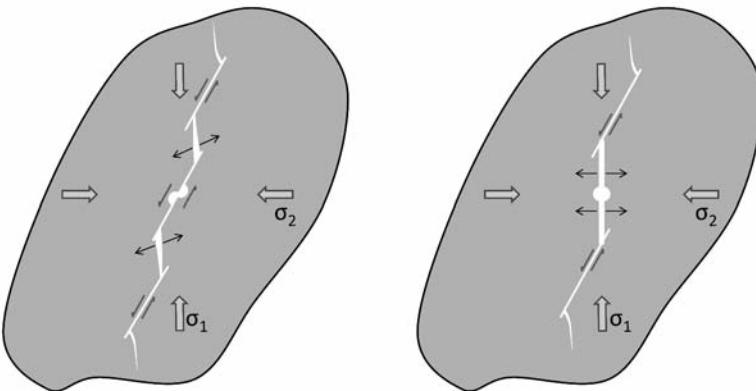


Fig. 14: Scheme of the two basic starting conditions for the evolution of a macro-fracture during hydraulic stimulation in fractured granite. Left: start by shearing of a natural fracture intersecting the well, right: start by creating an axial tensile fracture in the well.

their tips. The process will then continue as in the other case. For very high flow rates or viscous fluids the tensile fracture may cross the natural fractures before the fluid pressure had the time to migrate deeply into the natural fractures and to stimulate shearing. This crossing however happens generally with a certain offset at the interception. So also in this case the macro-fracture contains tensile fracture and natural fracture elements but probably with a smaller proportion of the latter.

In any of these cases the orientation of the macro-fracture is slightly off the direction of the maximum principal stress. As a consequence the maximum principal stress supports the propagation of the macro-fracture and enables fracture propagation at a fluid-pressure below the minimum principal stress.

For fluid flow in the macro-fracture the natural fracture elements act as resistors whereas the tensile fracture elements play the role of capacitors. Accordingly the hydraulic impedance of the macro-fracture is determined by the natural fracture elements whereas its aperture is determined by the tensile fracture elements. In three dimensions this pattern of natural and tensile fracture elements will most likely cause a strong anisotropy of the fracture conductivity with low conductivity parallel to the shear-direction and high conductivity perpendicular to it. Large wings at the tip of large natural frac-

tures or at the ends of a long series of natural and tensile fractures may form long through-going channels after pressure depletion.

During pressure depletion the tensile fracture elements will tend to close but at their roots they are hindered by the friction on the natural fracture elements. Big quantities of elastic energy are therefore temporary or permanently blocked near the roots of the tensile fractures, particularly of the large-scale wings. This energy may be set free explosively by sudden back-sliding of the natural fracture elements. This is a plausible explanation for the observation of strong events during the pressure depletion period and thereafter.

In summary the wing-crack model delivers plausible explanations for almost all observations described in the previous chapters in particular for: the onset of fracture propagation at a fluid pressure lower than the minimum principal stress, the high intensity and mechanism of induced seismicity, the occurrence of lines of intense seismicity in the seismic clouds, the long duration of the fracture-linear or bilinear flow periods during post-stimulation well tests, the occurrence of high magnitude events during and after pressure depletion, the large fracture apertures. It also explains the striking discrepancy between the only moderate fracture transmissibility and the large apertures. It seems therefore justified to use the wing-crack-model and the wing-crack-mechanism as a base for further investigations.

5 Summary and way forward

Observations and results of all major EGS-projects leave no doubt, that hydraulic stimulation cannot be regarded as merely a pressure diffusion process accompanied by shearing and dilating network of natural fractures. The data rather suggest that generally only one macro-fracture was created during the stimulation tests regardless of

the flow rate and the length of the test interval or the number of natural fractures exposed to the fluid-pressure. These macro-fractures were steeply dipping for normal stress conditions, sub-vertical for strike-slip and trans-tensional conditions, and sub-horizontal for thrust-faulting stress conditions. Their area to volume ratio was much smaller than that of tensile fractures. The macro-fractures did not close after pressure depletion but retained a hydraulic conductivity suitable for inter-well flow rates between some l/s and about 25 l/s over well distances of up to 700 m. During single well hydraulic tests the fractures showed long fracture-linear or bilinear flow-periods indicating parallel flow within the fractures emerging from a long highly conductive flow-channel. All seismic events with magnitudes above the perceptible limit occurred in the final state of stimulation but also during or after pressure depletion. It is suspected that most of the macro-fractures created in the EGS-projects are wing-cracks and that the wing-crack mechanism is also acting on a smaller scale by linking adjacent natural fractures via fresh tensile fracture elements.

These findings suggest that the present EGS-concept will never lead to 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 a type of macro-fractures consisting of natural and new tensile fracture elements. Fluid-flow in these macro-fractures is complex due to the presence of flow-channels and anisotropy of fracture conductivity. This poses risks but also offers the opportunity to maximize the heat exchanging area by a proper positioning 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 condi-

tions. 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 would operate for at least 25 years at flow rates of 100 l/s, an electric power output of 5 to 10 MW and a pumping power of less than 1 MW. Directional drilling and high temperature-packer technology have improved significantly during the last three decades (Shiozawa & McClure, 2014) 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.

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Clean Unconventional Gas Production: Myth or Reality? – The Role of Well Integrity and Methane Emissions Peter Reichetseder¹

«Das Antifragile steht Zufälligkeit und Ungewissheit positiv gegenüber, und das beinhaltet auch – was entscheidend ist – die Vorliebe für eine bestimmte Art von Irrtümern. Antifragilität hat die einzigartige Eigenschaft, uns in die Lage zu versetzen, mit dem Unbekannten umzugehen, etwas anzupacken – und zwar erfolgreich –, ohne es zu verstehen. Um es noch schärfer zu formulieren: Wir sind im Grossen und Ganzen besser, wenn wir handeln, als zu denken, und das verdanken wir der Antifragilität.»

[aus: Nassim Nicholas Taleb, «Antifragilität – Anleitung für eine Welt, die wir nicht verstehen», btb, Juli 2014].

Key words: Unconventional gas, methane emissions, well integrity, failure mechanism, barriers, best practice, casing design, well construction, cementing, stray gas

Abstract

This paper is focusing on Well Integrity, because it is an important subsurface element, which is the foundation for reliable and sustainable oil and gas production. Shale gas production in the US, predominantly from the Marcellus shale, has been accused of methane emissions into the atmosphere or contaminating drinking water under the suspicion that this is caused by hydraulic fracturing in combination with compromised leaking wells. Several scientific studies seemed to prove this hypothesis mainly by geochemical and statistical analysis over the last 4 years.

A multiple line-of-evidence approach (isotope analysis in combination with complex analysis of geology and broad inventory of gas and water well data) has helped to distinguish different possible sources and identify shallow gas formations («stray gas») below the groundwater formations as main methane source, whereas the studies did not find any link between hydraulic fracturing and water contamination! Too slim well design and compromised well integrity (cement, casing) are more likely the enabler for possible gas migration behind casing.

This paper is attempting a critical review and reinterpretation of the wealth of available information and opinions. If a best practice approach based on recent experience and standards is applied for proper well design, construction and operations, methane emissions into groundwater or atmosphere can be avoided. The main barriers against any leakage are proper casing design and cementing. Baseline studies and monitoring of groundwater quality need to be an integral part of shale gas developments.

1 Methane Emissions – the «Achilles' heel» of Unconventionals?

Shale gas has been in the focus of discussion in recent years and months because of many economical and also technical concerns. While this business has dramatically changed and pushed both domestic gas and oil production in North America, and in the US alone 30.000 wells are drilled every year, most of them multi-fracked, Europe is torn between negative opinions (ban/moratorium in e.g. France, Germany) and early activities towards unlocking the potential for unconventional gas production (Poland, UK). In the media mainly negative cases from US are reported and dominate, while the huge benefits do not get much attention. Very slowly a more rational approach is growing.

One of the main concerns is the question, if shale gas production can be considered as favorable as conventional gas with respect to Greenhouse Gas (GHG) Emissions.

Shale gas production in US has grown enormously and the Marcellus Shale in Pennsylvania (Fig. 1) presently contributes 40% of US shale gas production (EIA 2014).

However, the Marcellus region, because of special geological and historic reasons, has also become a hotspot for problems with contaminated drinking water. McKay & Salin-

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ta (2011) are referring to legal claims of 13 families in Lenox township having filed a lawsuit in Susquehanna County Court (in the NE of Pennsylvania) in which «they allege that fracking contaminated their drinking water supply and made them ill». Like the lawsuits, some media reports imply that Marcellus Shale drilling and production operations have caused widespread problems.

In a study from Duke University, Osborn et al (2011) argue quite firmly «In aquifers overlying the Marcellus and Utica shale formations of northeastern Pennsylvania and upstate New York, we document systematic evidence for methane contamination of drinking water associated with shale gas extraction.» The authors are considering three possible mechanisms for fluid migration in the shallow drinking-water aquifers:

- a. Displacement of gas-rich deep solutions from deep target formation.
- b. Casing leaks from production wells, in combination with lateral and vertical fracture systems – which the authors consider the most likely case.
- c. Enhanced migration of gas via newly created fractures.

Groundwater contamination in water wells from natural gas sources was not considered.

Molofsky et al. (2011) published the results of a comprehensive investigation of more than 1.700 water wells sampled and tested prior to proposed gas drilling in the Susquehanna County, PA; this study concludes methane to be ubiquitous in shallow groundwater with a clear correlation of methane concentrations with surface topography. Specifically, water wells located in lowland valley areas seem to exhibit significantly higher dissolved methane levels than water wells in upland areas, with no relation to proximity of existing gas wells. The correlation of methane concentrations with elevation would indicate that, on a regional level, elevated methane concentrations in groundwater are a function of geologic features, rather than shale gas development.

Potential sources of this naturally occurring methane include thermogenic gas-charged (from underlying Devonian layers) sandstones in the Catskill formation, which are tapped by most water wells in this region. These sandstones exhibit an extensive net-

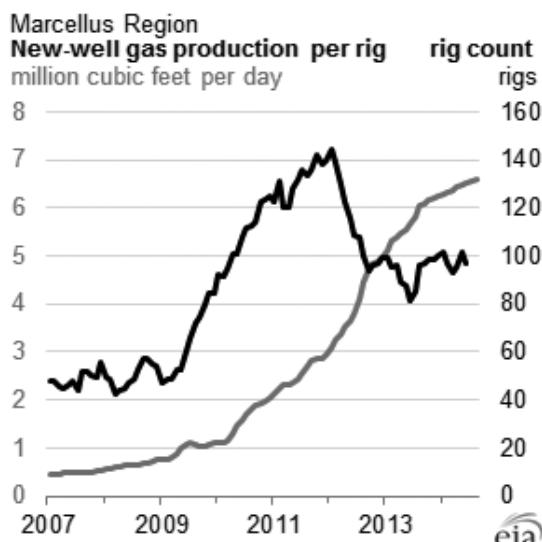
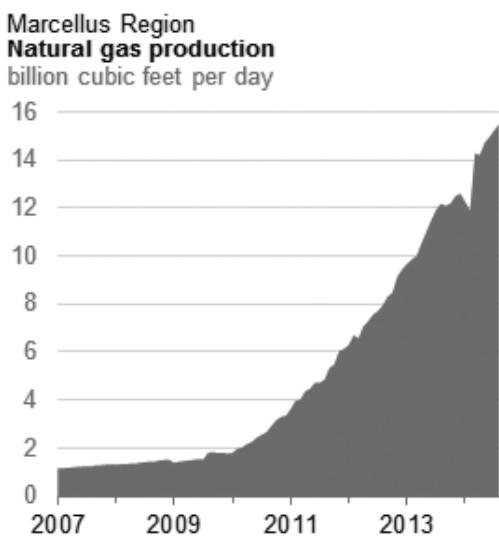


Fig. 1: Marcellus Gas Production and Drilling per 8/2014 (EIA 2014).

work of fractures, joints and faults that serve as principle conduits of groundwater flow and potential pathways for the movement of shallow-sourced dissolved methane (Fig. 2).

Biogenic methane, which is produced by the natural decomposition of organic material within thick valley alluvium and glacial drift deposits in the area, may also be found in water wells that draw water from shallower sediment deposits. The source of this dissolved methane is important with regard to understanding the potential effects of ongoing shale gas development and appropriate measures for protection of water resources. Fig. 3 depicts a possible situation where methane from different sources may be found in contaminated water wells. Forensics using isotopes and noble gases give the ability to unambiguously distinguish between biogenic and also different thermogenic gases (Sueker et al. 2014).

This has important implications with regards to the findings of the recent study from Duke University (Osborn et al. 2011), which suggested that the thermogenic sig-

nature of elevated methane concentrations in water wells in Susquehanna County was consistent with an origin in deep shale gas deposits, such as the Marcellus and Utica formations.

Molofsky et al (2011), however, show that the isotope signatures of the Duke study's thermogenic methane samples were more consistent with those of shallower Upper and Middle Devonian deposits overlying the Marcellus shale. These findings indicate that the methane could have originated entirely from shallower sources above the Marcellus that are *not related to hydraulic fracturing activities*.

The apparent misinterpretation of the origin of the observed thermogenic methane underscores the need of the multiple lines-of-evidence approach for proper characterization of methane gas sources, with careful integration of the relevant geologic, historical, *well construction*, and isotopic data. Duke University conducted a follow-up study (Jackson et al. 2013) of their 2010/2011 study based on a more extensive dataset for

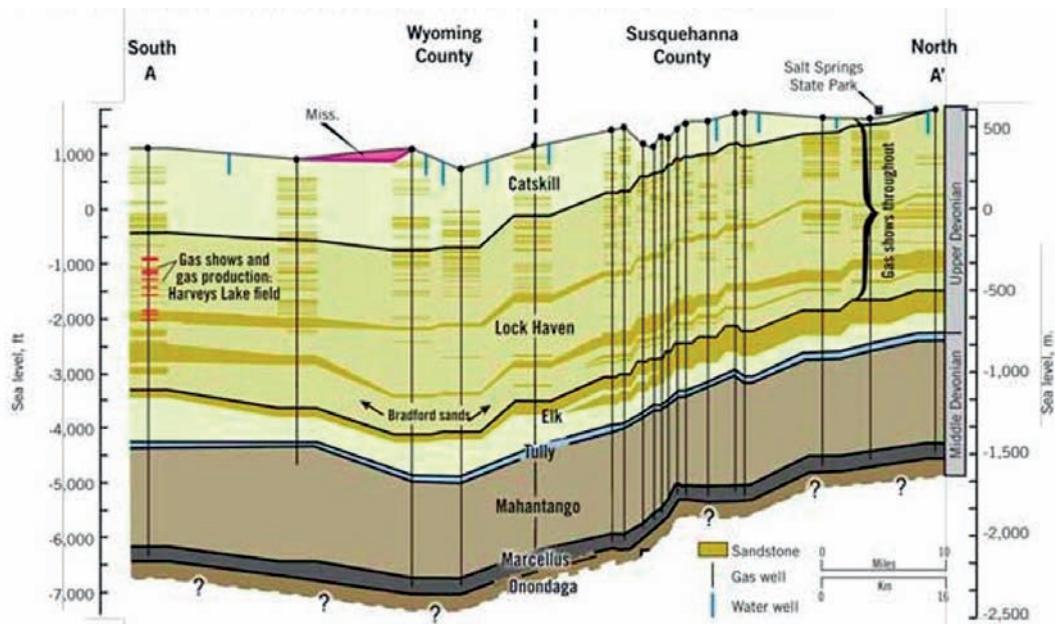


Fig. 2: Generalized Cross Section of Upper Devonian and Marcellus Formations (Molofsky et al. 2011).

natural gas in shallow water wells in NE Pennsylvania, comparing sources of thermogenic methane, biogenically derived methane, and methane found in natural seeps. The team expanded the analysis by investigating also ethane and propane concentrations to distinguish thermogenic from biogenic sources and using isotopic data for methane, ethane and inorganic carbon, and helium analysis to reach better differentiation between different sources.

Among the different parameters investigated: distance to gas wells, proximity to both valley bottom streams (potential discharge areas), and the Appalachian Structural Front (ASF; an index for the trend in increasing thermal maturity and degree of tectonic deformation), *distance to gas wells* (Fig. 5) was the *dominant* statistical factor for both methane and ethane. The authors did not investigate naturally occurring contaminations in water wells.

If hydraulic fracturing was not related to methane contamination of drinking water wells, what could be a plausible mechanism?

The authors were immediately pointing towards well integrity problems (casing leaks or imperfections of cement) also triggered by the fact that in 2010 PADEP (Pennsylvania Department of Environmental Protection) had already issued 90 violations for faulty casing and cementing on 64 Marcellus shale gas wells, 119 similar violations were issued in 2011. Are these only symptoms or do they prove the cause?

Of course, the NE sector of Pennsylvania – different to many other sedimentary basins where conventional and unconventional gas is produced – is characterized by many shallow gas layers located between the deep Marcellus (> 2.000 m) and the groundwater formations (< 300 m). Duke researchers, not being very positive towards shale gas production in general, continued to follow this track with more research – and heavy statistics.

Driven by strong suspicion that integrity of cement must be the weak link of the system the Duke researcher Ingraffea et al (2014) published a paper in May 2014 based on the

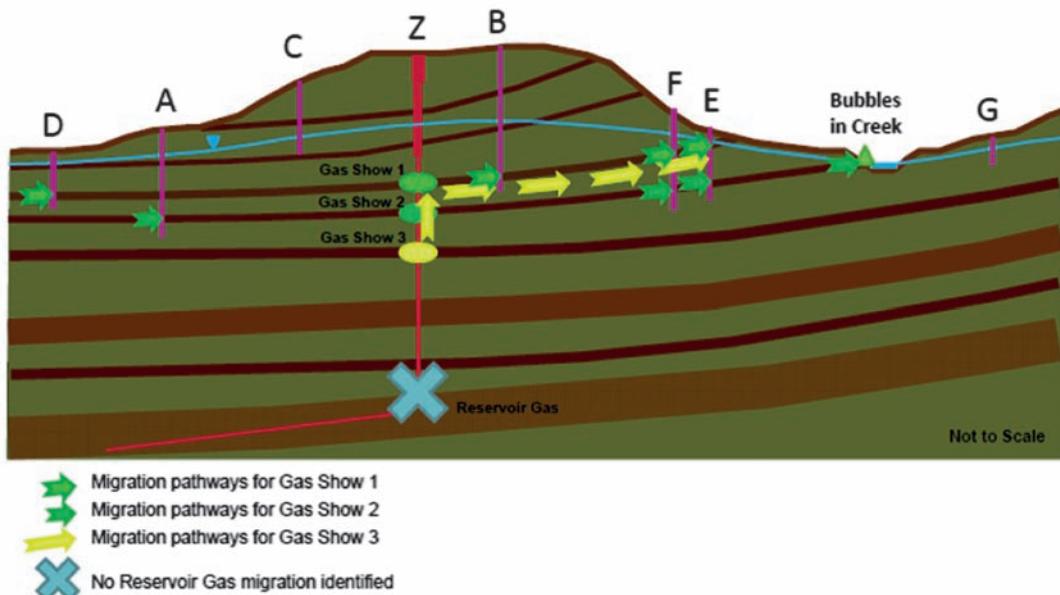


Fig. 3: Stray Gas Forensics to distinguish methane in water well sample from multiple unrelated methane sources (Sueker et al. 2012).

hypothesis «Leaking oil and gas wells have long been recognized as a potential mechanism of subsurface migration of thermogenic and biogenic methane, as well as heavier n-alkanes, to the surface». Quoting all potential failure cases of the casing/cement system known in literature it must be THE main problem zone, if hydraulic fracturing has to be ruled out.

«An analysis of 75.505 compliance reports for 41.381 conventional and unconventional wells in Pennsylvania drilled from January 1, 2000 – December 31, 2012, was performed with the objective of determining complete and accurate statistics of casing and cement impairment» (Ingraffea et al. 2014). It remains to be demonstrated, how compliance reports should be able to prove cement impairment?

Pennsylvania state inspection records – according to (Ingraffea et al. 2014) – show «compromised» cement and/or casing integrity in 0.7–9.1% of the active oil and gas wells drilled since 2000, with a 1.6–2.7 fold higher risk in unconventional wells spudded since 2009 relative to conventional well types. Ingraffea et al. (2014) further conclude: «Hazard modeling suggests that the cumulative loss of structural integrity in

wells across the state may be actually higher than this, and upward 12% for unconventional wells drilled since January 2009. This wide range of estimates is influenced by the significantly higher rates of impairment in wells spudded in the NE counties of the state (average 12.5%, range 2.2–50%), with predicted cumulative hazards exceeding 40%.» We have to differentiate between indicators (e.g. pressure) at the wellhead/annulus of a well and the immediate conclusion, that these indicators would already be a proof of loss of integrity or relevant impairment of a well. These indicators are symptoms, but not real causes themselves (see also EnergyInDepth 2014), they are symptoms for potential weaknesses or a barrier defect. However, further tests and analysis are necessary to reveal their significance.

Another aspect is the supposed cumulative risk of unconventional wells in comparison with conventional wells. Unconventional wells are generally characterized by good initial production, followed by a strong decline of production and pressure after the first year. This does not increase the risk of leakages, rather the contrary. Because of that it is hard to believe that unconventional wells should be more often «compromised»

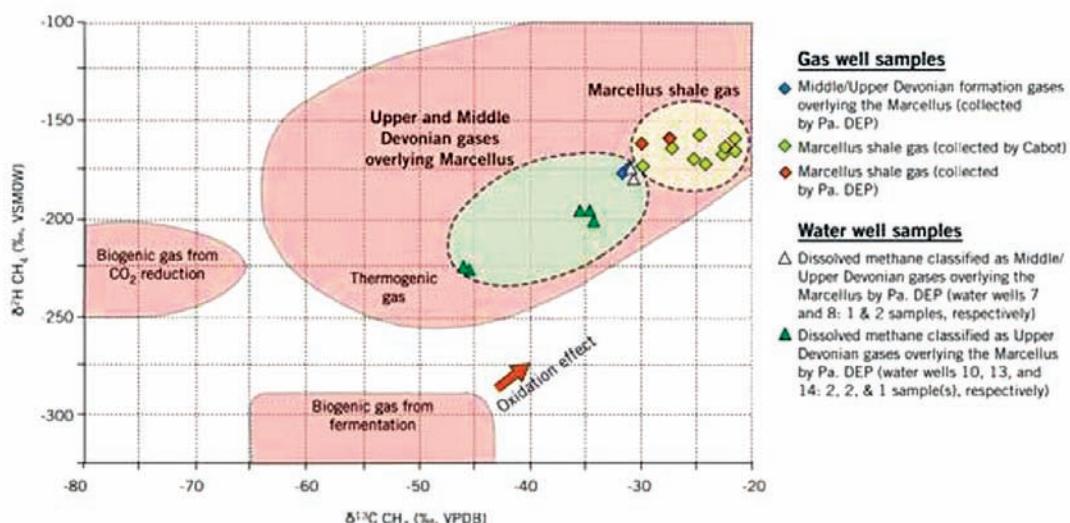


Fig. 4: Comparison of Susquehanna County Methane Isotopic Signatures (Molofsky et al. 2011).

than conventional wells. Many wells in the initial phase of the shale gas boom were drilled by smaller companies and a strong need of low cost drilling with two casing strings only: surface casing and production casing, but no intermediate casing. Conventional wells were the domain of the established players who had followed more conservative designs.

The statistics at least correlate with the higher number of methane problems in the NE of the Marcellus region with a known strong presence of «stray gas» and in combination with a slim well design this is not surprising.

Recent investigations from Darrah et al. (2014) from Duke University on 113 drinking-water wells in Pennsylvania and 20 samples from the Barnett area in Texas, found methane contamination in ground water table caused by impaired well construction, however, «not fracking».

According to their analysis gas geochemistry data would implicate leaks through annulus cement (4 cases), production casings (3 cases), and underground well failure (1 case) rather than gas migration induced by hydraulic fracturing deep underground.

Darrah et al (2014) feel quite confident according to Snow (2014): «our data clearly show that the contamination in these clusters stems from well-integrity problems such as poor casing and cementing».

Discussion

- This report clearly states that the researchers (who initially related ground-water impairment to hydraulic fracturing) did after further studies not find any link between hydraulic fracturing and water contamination, which is a very strong result in itself.
- Did the study find evidence of well integrity failure? Despite the strong conviction of the researchers questions remain. The sample in the Barnett area is challenged by a study of the Texas Railroad Commission (RRC 2014), which did not find any well in the Parker County with well integrity problems, which could be the cause for methane contamination in ground water.
- Are the statistics of «compromised» wells plausible at all? Information from EnergyIn-Depth (2014) raises concerns about the plausibility of numbers in the studies of

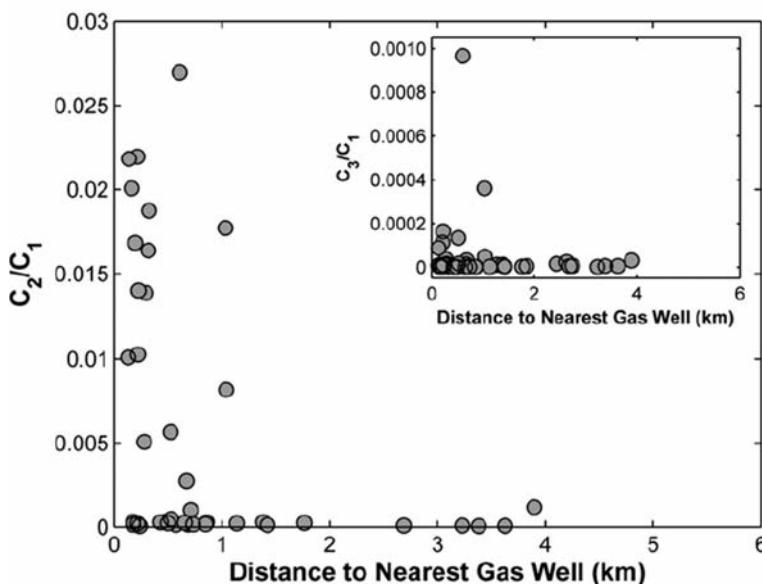


Fig. 5: The ratio of ethane/methane (C_2/C_1) and (inset) propane/methane (C_3/C_1) concentrations in drinking water wells as a function of distance to natural gas wells (kilometers) (Jackson et al. 2013).

Duke University (Ingraffea et al. 2014) which supposedly support very high failure rates of wells. In 2011 the Ground Water Protection Council looked at more than 34.000 wells drilled in Ohio from 1983 to 2007 and more than 187.000 wells drilled in Texas between 1993 and 2008. The GWPC data reveal a well failure rate of 0.03% in Ohio and only 0.01% in Texas (GWPC 2011).

We can draw several conclusions from these investigations:

Before embarking in heavy shale drilling campaigns with many wells it is crucially important to understand the local/regional geology also above the targeted shale formations. If shallow gas (or «stray gas») is present (something that has to be expected in large parts of Pennsylvania), extensive work has to go into baseline studies to provide a robust foundation for the design and execution of wells.

Well integrity has to be in the focus, especially in geological settings with stray gas concentrations. Well design, construction and monitoring have to be performed with high degree of professionalism. This is the purpose of «Well Integrity Management».

While ensuring that well integrity is a universal obligation for all oil and gas (production) wells, the author selected to focus on issues and solutions in the Marcellus area, because it shows a hydrocarbon province with higher challenges than most other shale gas production areas and also demonstrates industry's best practice dealing with this issue.

2 Well Integrity: Definition and Standards

Norway: In the Norwegian system for standards for the petroleum sector Well Integrity is defined in Norsok D-010 (2013) as «application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well».

Norsok D-010 is a functional standard and sets the minimum requirement for the equipment/solutions to be used in a well, but it leaves it up to the operating companies to choose the solutions that meet the requirements. It also specifies that «there shall be *two well barriers available during all well activities and operations*, including suspended or abandoned wells, where a pressure differential exists that may cause uncontrolled outflow from the borehole/well to the external environment». This sets the foundation for how to operate wells and keep the wells safe in all phases of the development.

UK: UK Oil & Gas has updated its «Well Integrity Guideline» by July 2012 (Oil&GasUK 2012) and developed a new comprehensive regulative framework which is called «UK Onshore Shale Gas Well Guidelines» (UKOOG 2013) and specifies in a similar manner all relevant aspects of «good industry practice and reference to relevant legislation, industry standards and practices»: Well Design and Construction (Casing, Cementing, Barrier Planning), Management Supervision and Competence, as well as Well Examination during Design and Construction (also «well examiners visiting the well site to examine certain well integrity and fracturing operations on site in real time» – to build trust) and Abandonment.

US: The most comprehensive and also in the oil and gas industry widely used system of standards stems from the American Petroleum Institute (API), which has developed standards for oil and natural gas operations since 1924. API's formal consensus process is accredited by the American National Standards Institute (ANSI). API-standards are developed in an open process that requires regular review of its more than 600 standards (Emmert 2012).

API has issued the following main guidelines and recommended practices (RP) for Hydraulic fracturing operations especially relevant to well integrity:

- API Guidance Document HF1: Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines (API 2009)
- API Standard 65-Part 2, Isolating Potential Flow Zones During Well Construction (API 2010)

API states in the Guidance Document HF1 (API 2009) that «Maintaining well integrity is a key design principle and design feature of all oil and gas production wells. Maintaining well integrity is essential for the two following reasons:

1. To isolate the internal conduit of the well from the surface and subsurface environment. This is critical in protecting the environment, including groundwater, and in enabling well drilling and production.
2. To isolate and contain the well's produced fluid to a production conduit within the well.»

«Although there is some variability in the details of well construction because of varying geologic, operational settings, the basic practices in constructing a reliable well are similar. These practices are the result of operators gaining knowledge based on years of experience and technology development and improvement.»

The general principles (Sec. 3) describe the main steps as follows:

«Groundwater is protected from the contents of the well during drilling, hydraulic fracturing, and production operations by a combination of steel casing and cement sheaths, and other mechanical isolation devices installed as part of the well construction process.»

«The primary method used for protecting groundwater during drilling operations consists of drilling the wellbore through the groundwater aquifers to a depth sufficient to protect the groundwater, immediately installing a steel pipe (= casing) and cementing this steel pipe in place. This surface casing will be cemented normally from bottom to the top, completely isolating groundwater

aquifers. Similar regulations are in effect in all countries and normally enforced rigidly.» The steel casing protects the zones from material inside the wellbore during subsequent drilling operations and, in combination with other steel casings (intermediate and production casing) and cement sheaths that are subsequently installed, protects the groundwater with multiple layers of protection for the life of the well.

«The subsurface formation containing hydrocarbons produces into the well, and that production is contained within the well all the way to the surface. This containment is what is meant by the term *well integrity*.» Design and execution are then followed by regular monitoring during drilling and production operations, further periodically testing to insure that integrity is maintained. The standards are describing the main elements of the well design program, which are most relevant for hydraulic fracturing and establishing well integrity in Sec. 3 (*Well design and Construction*).»

In 12/2010 API released Standard 65-2, a special standard dealing with practices for isolating potential flow zones (API 2010). This standard refers not only to possible blowout situations threatening loss of well control, safety of personnel, the environment, and drilling rigs themselves. They also point towards the typical geological situations described in chapter 1 in the Marcellus region. A second objective is to help prevent Sustained Casing Pressure (SCP), also considered a serious industry problem.

API 65-2 defines barrier elements as either physical or operational. Physical barrier elements are classified as hydrostatic (fluid columns), mechanical (e.g. seals, packer, plugs), or solidified chemical materials (= usually cement). Operational barriers are practices that result in activation of a physical barrier (e.g. flow detection devices). While physical barriers dominate the process, the total system reliability of a particular design is dependent on the existence of both types of barriers.

It is worth mentioning that both the casing design and process of setting casings, and the process of cementing design and

cementing are interdependent. The quality of the cement sheath depends very much on the design and running & cementing execution operations of the casing strings and the associated equipment.

However, both elements individually and in combination have to create sustainable barriers for the lifetime of the well to avoid any fluid leakage and migration outside of the well system.

3 Best Practice to Avoid Methane Leaks

For cementing not only accepted *design best practices* are relevant, but also accepted *execution best practices*. The cementing practices are specified in great detail in API 2010, outlining all activities to be considered to be important for good cementation, e.g.: Engineering Design, Wellbore Preparation and Conditioning, Cement Job Execution, Casing Shoe Testing, Post-cement Job Analysis and Evaluation.

Prohaska & Thonhauser (2012) are discussing the main failure scenarios (Fig. 6), if barriers against inflow and upward flow/migration are not intact after cementing: Leaking tubings and casings (connection), poor cement allowing gas migration behind casing, (partly) missing cement allowing fluid inflow into annulus and upward migration to wellhead or between individual formations or into groundwater, etc.

However, Prohaska & Thonhauser (2012) conclude: «If existing standards and current best practice are followed, groundwater contamination, resulting from well integrity failure, is very unlikely to happen.»

Meanwhile several states in the US (Ohio 2014) have adapted their guidelines for design and construction of shale gas wells in order to improve well integrity (Pennsylvania «Chapter 78 Oil and Gas Wells» early 2011, Texas «Well Integrity Rule» May 2013, Ohio early 2014).

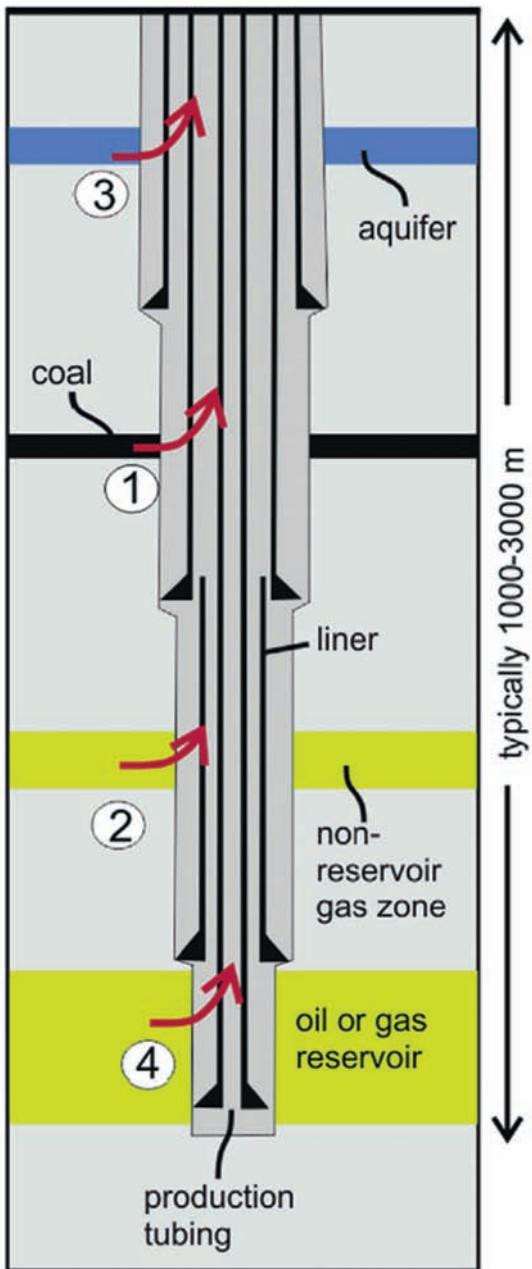


Fig. 6: Schematic diagram of typical sources of fluid that can leak (via failure mechanisms) through a hydrocarbon well. 1 - gas-rich formation such as coal, 2 - non-producing gas or oil formation, 3 - biogenic or thermogenic gas in shallow aquifer, 4 - oil or gas from oil/gas reservoir (Davies et al. 2014).

Major changes have been introduced for cementing surface casing (casing setting depth, cementing to surface, minimum cement volume, use of centralizers, minimum thickness of cement sheath, etc.) **and for casing design.** New regulations are requiring an *intermediate casing string*.

As mentioned above, previously shale gas wells in the Marcellus region did not have intermediate casing strings, which was very likely the reason for gas migration from stray gas accumulations.

The typical design of well integrity for unconventional onshore wells (Fig. 7) is shown by Cuadrilla Resources – the front runner of UK shale gas development. It requires always at least three layers of steel casing at depths penetrating the aquifer. The surface casing, the intermediate casing and the production casing are cement-sealed and extend below the aquifer. The

intermediate casing is an integral part of well design to establish a second steel, cement-sealed layer of well protection extending well below the level of the aquifer, which creates a barrier against a possible leakage path from the shale reservoir (or other lateral gas inflow) up to the aquifer. The difference between the new and old («inferior») design is shown in Fig. 8. Prohaska & Thonhauser (2012) are presenting a comprehensive list of typical Best Practices for establish effective cement barriers. Besides important general rules, the selection of the right cementing process is depending on specific requirements for geology, purpose and design of the well and specific experience.

One very relevant example of cement design is given by McDaniel & Watters (2014) for the Marcellus Shale. The cyclic hydraulic fracturing process after cement has set and the challenge of stray gas migration are

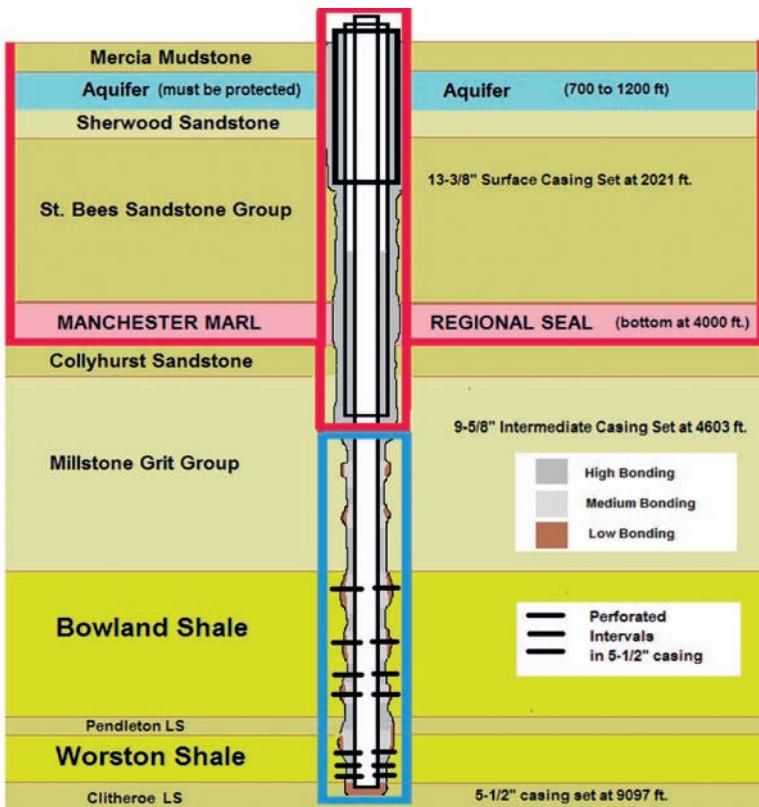


Fig. 7: Wellbore Integrity Design for Cuadrilla Preese Hall#1 (Cuadrilla 2014).

important design criteria. There are proven cement compositions available which can cope with multi-fracturing applications (additives, such as polymers, bentonite, gypsum, foam). Instead of its traditional brittleness and high compressive strength, cement should allow some (elastic) deformation to withstand pressure fluctuations during multi-fracturing operations.

The paper shows that cement integrity of the intermediate casing may be caused by mechanical damage to cement seal rather than through unset cement. Compressive strength is therefore not a good indicator for seal durability, the latter can be reached by different cement compositions. Cement durability can be correlated to inelastic strain potential, mechanical properties and tensile strength of the cement system. Further work will be directed towards correlation between «Applied Energy vs. Energy Resistance».

For the given situation with combination of cyclic stresses (short term) and resisting gas migration long term both aspects need to be considered. Special cement testing is

under development with parameters such as tensile strength, inelastic strain, flexural strength, impact strength and mechanical properties to determine the cement's ability to resist energy applications.

Evaluation techniques are also needed to investigate, if well integrity has been reached and is still maintained, focusing on the main failure scenarios for any possible leakage. Which specific method or tool is effective in proving cement isolation of a zone? Which method or tool should be required on the surface casing cement or other cement strings as a part of initial well construction (or, if not required, when it may provide useful information)? API Standard 65-2 (2010) gives guidance on different tools and their results.

King (2012) gives a very useful and pragmatic summary on cement evaluation by pointing out, that «*The only cement test method that can confirm zone-to-zone isolation is a pressure test.*» Pressure tests are mandatory before drilling fresh formation after cement has set. This formation integrity test is paramount to prove that there is a seal.

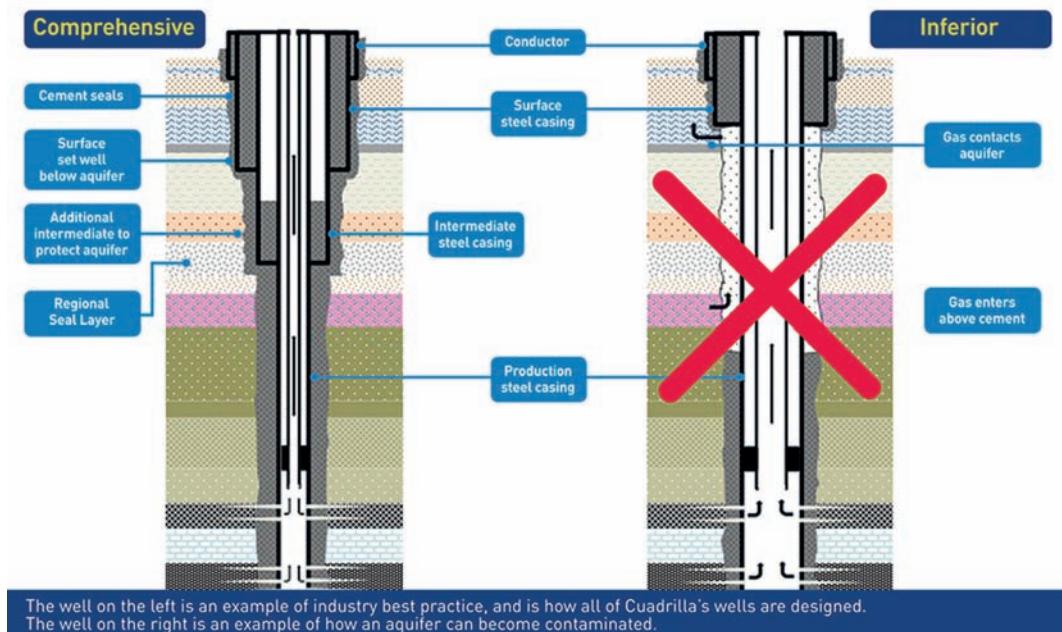


Fig. 8: Well design with and without intermediate casing (Cuadrilla 2014).

Temperature logs are run usually to determine the top of cement within a time-window. It is important to know, if the cement has been placed where it should be.

Cement bond logs (CBL) have proven to be a widely used and accepted method. Cement bond logs can give a reasonable estimate of bonding and a semi-quantitative idea of presence or absence of larger cement channels, but will not certify pressure or fluid isolation of a zone. To provide an effective seal and isolation of a zone, only part of the total cement column must be channel free. Cement channels may be present in parts of the cement, but as long as there are one or more significant, continuous sections of channel-free cement, isolation of the zone along the wellbore will be adequate.

Finally, we have to mention situations during the operations phase of a well, when pressure is emerging in the annuli of a well, which may eventually be considered Sustained Casing Pressure (SCP). Do these situations mean that a vital barrier in the well is broken or impaired?

While improved design has been updated in regulations, there is strong activity at present in API but also in the industry and regulatory bodies of states with emphasis on testing and, if deviations exist, re-establishing the integrity of wells which have critical pressure in the annulus. API has not yet published Guidelines on SCP. Valuable guidance is given by Norsok (2013) and Oil&GasUK (2012) under Sec. 9 «Annulus Management». Monitoring and analysis is important to ensure a leak or breach of a well barrier is detected early and that corrective action can be taken before the problem escalates (Norsok 2013).

At the Stray Gas Incidence and Response Forum 2012 in Cleveland, Ohio, Arthur et al (2012) presented «holistic well evaluation» methods with the focus on testing the annulus situation of shale gas wells showing annulus pressure: Pressure build-up testing, External Well Integrity testing (visual inspection, venting rate testing, volumetric analy-

sis, geology review, assessing casing & cement: CBL, temperature & noise logging). A combination of testing methods and analysis can be used effectively to assess well integrity, but most testing methods do not offer an absolute and definitive answer regarding well integrity. Regulatory agencies tend to seek methods that provide a black & white answer, but tend to recognize the complexities.

Physical remedial activities, such as perforating the production casing and squeezing cement or other products are challenging. Often, specialty products, such as micro-fine cement, resins, etc. may be required, and assuring perforations are sealed for purposes of production operation must also be considered.

4 Conclusions

In the early phase of shale gas production, especially in the northeastern part of the Marcellus region in Pennsylvania, US, methane contamination of groundwater has been recognized and quickly attributed to hydraulic fracturing.

Investigations revealed that many water wells in the region were containing natural gas contaminations from direct communication with the ubiquitous stray gas formations, even without the presence of any gas production well. A best practice approach clearly calls for comprehensive baseline studies and close monitoring during shale gas drilling and development.

Both for conventional and unconventional oil and gas production, well integrity is a prerequisite for safe long-term production. While hydraulic fracturing could NOT be proven to be the cause of methane contamination of groundwater formations, several US-states (e.g. Ohio, Pennsylvania, Texas), as a consequence of the lessons learned, have been tightening the regulations for oil and gas wells, among others demanding an intermediate casing string in combination

with strict rules for cementing the surface casing string. Evaluation methods are available to investigate the quality of these vital barriers in oil and gas wells. If necessary, repair methods have to be applied or as a last resort the well to be abandoned.

With proper barriers in place groundwater formations can be safely protected and leakage of methane into the atmosphere avoided. European countries (e.g. UK, Norway, Germany) have regulations in place which already require best practice solutions to maintain well integrity for the lifetime of a well.

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Hydraulic Fracturing – Application of Best Practices in Germany

Steffen Liermann¹

Key Words: Hydraulic fracturing, best practices, barrier, gas, tight gas, sweet water aquifer, Düste Z10, fracturing fluid, well design, well site, permit

Abstract

Today, many oil and gas fields would not be economically viable without hydraulic fracturing. For more than 50 years, the technology has been applied by the oil and gas industry in Germany without any negative impact to the environment (WEG 2013). However, due to an increasingly critical public perception, the approval of recent oil and gas projects requiring hydraulic fracturing has been adversely affected by a political de-facto moratorium. Best practices have been developed for planning, permitting and execution of projects involving this technology including active stakeholder engagement. The Düste Z10 Tight Gas Project, operated by Wintershall, is currently idle as the approval of required hydraulic fracturing operations is outstanding. Best practices applied in the project are described and discussed.

Zusammenfassung

Seit 1949 wird Hydraulic Fracturing in mehr als drei Millionen Bohrungen weltweit angewendet. Allein in Deutschland ist das Verfahren seit 1961 mehr als 300-mal ohne negative Auswirkungen auf das nutzbare Grundwasser zum Einsatz gekommen. Die Technologie ist ausgereift und stellt bei Einhaltung betrieblicher Best Practices kein Risiko für die Umwelt dar. Diese sind im Wesentlichen: 1. die sichere Prognose dichter Deckgebirge, 2. die Vermeidung des Eintrags von Schadstoffen von der Erdoberfläche in das Grundwasser, 3. die Gewährleistung integrer Bohrungen, 4. die sichere Prognose und Steuerung der Ausbreitung hydraulisch induzierter Risse, 5. die Verwendung von Frac-Fluid-Additiven mit maximal WKG 1-Einstufung und Offenlegung dieser, 6. die sichere Entsorgung von rückgeförderten Flüssigkeiten sowie 7. die Vermeidung spürbarer, ausgelöster seismischer Erschütterungen. Anhand des aktuellen Tight-Gas Projektes Düste Z10 in Norddeutschland werden Beispiele für die Anwendung dieser Best Practices aufgezeigt und diskutiert.

1 Introduction

Since its first application in the 1940's (Montgomery & Smith 2010), oil and gas companies have been using hydraulic fracturing as the technology of choice for production enhancement. Originally developed to bypass drilling induced near-wellbore damage, it has been continuously refined to effectively increase the drainage area of a well. Hydraulic fracturing improves recovery factors from conventional reservoirs, especially those in decline, and is the key technology enabling commercial production from unconventional reservoirs. To date, close to three million wells worldwide have been hydraulically fractured and the technology is applied to 60% of all newly drilled oil and gas wells (Montgomery & Smith 2010). About 35.000 new wells are drilled in unconventional reservoirs in the USA per year alone (WEG 2014). In Germany, hydraulic fracturing has been applied by oil and gas companies since the 1960's with more than 300 operations carried out to date (WEG 2014).

2 Tight Gas Project Düste Z10

Wintershall Holding GmbH, a 100% oil and gas subsidiary of BASF SE initiated the Düste Z10 Tight Gas Project in Northern Germany in 2011. The gas well location is in Wintershall's 100% production license Ridderade-Ost in the State of Lower Saxony, about 50 km south of the city of Bremen. The project is mainly comprised of the following stages:

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- Drilling and completing a vertical well into the tight Carboniferous sandstones;
- Carrying out a comprehensive data acquisition program;
- Hydraulically fracturing gas bearing sands within the Carboniferous;
- Carrying out a long term production test to determine the commercial production potential.

The target formation in Ridderade-Ost is known to Wintershall from two previous wells. The well Düste Z7 was drilled in 1966 and proved gas in the Carboniferous. However, only sub-commercial production rates could be achieved from a vertical open-hole test. The well was therefore plugged back. In 1995 Wintershall started another attempt at the Carboniferous. The well Düste Z9 explored the formation at a different location of the reservoir. A total of five hydraulic fracture treatments were carried out across

different sands. Due to a variety of geological and technical reasons, production performance was sub-optimal and the well had to be shut-in after a few years.

The subsurface target of Düste Z10 was chosen based on a structural high of the Carboniferous and the proximity to Düste Z9 to benefit from near offset geological data. The project planning process incorporated lessons learned from offset wells and the latest developments in tight gas production technology including data acquisition along with well and hydraulic fracturing designs. Düste Z10 was planned as a vertical well to determine the lowest gas bearing sand and gas-water contact and to provide the maximum flexibility for hydraulic fracture design.

The subsurface target coordinates determined the general area of the surface well site location. The detailed selection of the well site took into account the legally required minimum distances to communi-

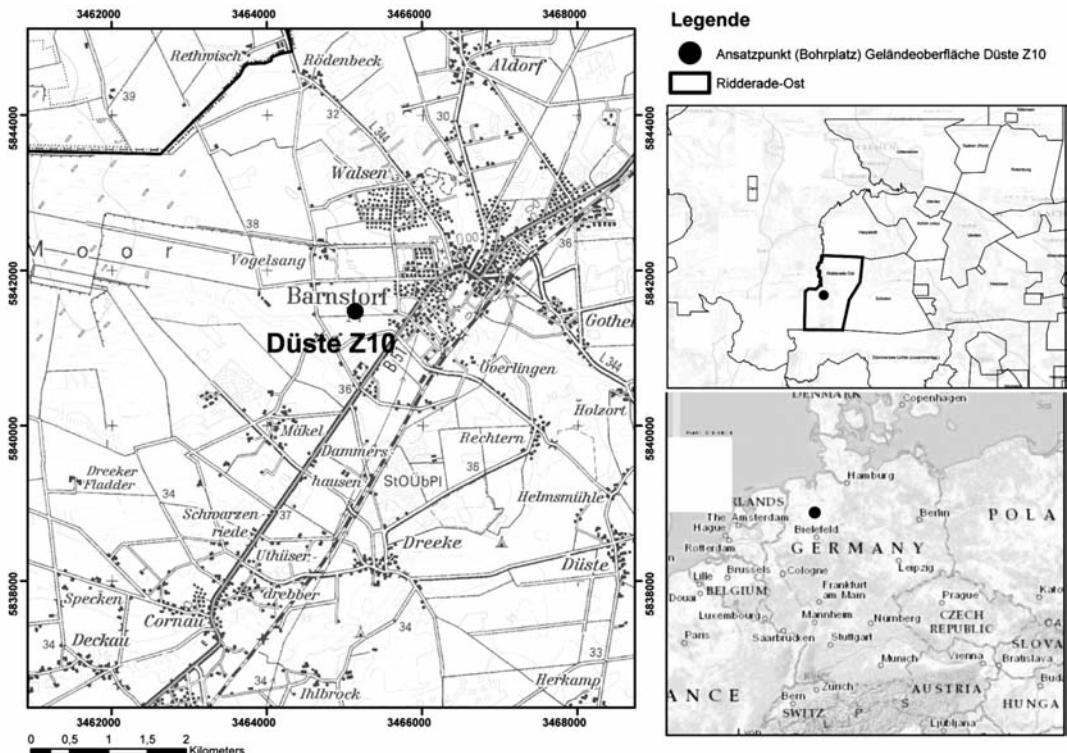


Fig. 1: Düste Z10 well location in production license Ridderade-Ost.

ties, single houses, infrastructure and environmental protection areas. The technical and economical reach to subsurface target coordinates as well as the requirements for surface space for further wells (cluster drilling) including a gas dehydration facility also had to be balanced.

3 Permitting

Wintershall commenced the Düste Z10 project in early 2011, when hydraulic fracture treatments were still permitted and carried out in Germany. However, at that time, the subject of hydraulic fracturing just started to be viewed critically by the German public. Therefore, Wintershall planned the execution of the project to be closely accompanied by a stakeholder engagement strategy, which called for early and complete involvement of all relevant authorities, local politicians, the public and immediate neighbors. Prior to any official permit applications the contents were presented to and discussed with relevant authorities and local politicians. Multiple public events with more than 1.000 visitors complemented the strategy in the community adjacent to the operation. Wintershall also created a special internet site for German operations, closely informing the public on the progress at the Düste Z10 project.

Due to the increased public perception of hydraulic fracturing, the Mining Authority required application for a General Permit («Rahmenbetriebsplanantrag») for the entire project, which is possible under the existing mining law. In the past, General Permits were only mandatory for large facilities but not for single wells, even if hydraulically fractured. This General Permit required broad technical descriptions of the different operational stages:

1. Site construction;
2. Drilling and completion operations including water usage;
3. Hydraulic fracturing and well test operations.

In addition an Environmental Impact Assessment Study of the planned operations had to be performed by a third-party.

The General Permit application, as opposed to a normal permit application («Sonderbetriebsplanantrag») is distributed for endorsement to other relevant authorities, most importantly to the Water and Environmental Protection Authority of the county. Therefore these authorities were formally included into the permitting process. The Düste Z10 General Permit was approved in summer 2011.

As per the mining law, Wintershall also applied for separate permits for each of the different operational stages. These permit applications included detailed technical descriptions of the planned operations. The applications for construction of the well site and drilling and completion operations were both submitted to the Mining Authority in summer and fall 2011 respectively and subsequently granted. The well site was constructed in fall 2011 and drilling and completion operations were carried out from January to beginning of May 2012.

The last hydraulic fracturing operations in Lower Saxony were permitted in summer 2011. Thereafter, the Mining Authority did not process any new permit applications. At the beginning of 2012 the authority issued a new directive on structure and minimum content requirements for new hydraulic fracturing permit applications, which was made a prerequisite for the acceptance of new applications. Wintershall applied for the permit in July 2012, with detailed descriptions of:

- Hydraulic fracturing operations;
- Composition of frac fluid and additives;
- Well site selection and construction;
- Well and completion design;
- Well test operations;
- Barrier formations above reservoir formation;
- Hydrogeological situation in the influence area of well site;

- Environmental impact assessment of the operations.

The Mining Authority accepted the Frac Permit application (incl. well test operations) as submitted by Wintershall. After additional questions were answered to satisfaction, the Mining and local Water Authorities technically approved the Frac Permit early 2013. However, the final approval was blocked at the political level in Lower Saxony (which had undergone a change of government in 2013), arguing that more public participation is required in the approval process. Full approval of the frac permit is therefore outstanding. A new regulation, specifically governing hydraulic fracturing operations has been drafted, but not been enacted yet.

4 Technical Work

4.1 Geophysical Analysis and Geological Modeling

During the planning stage of Düste Z10, data from an existing 3D seismic survey from 1985 was reprocessed. The new data resulted in a qualitative better characterization of the reservoir and was used to build a new static geological model. Three offset wells, two from within the production license and one from outside were used for calibration. The target coordinates for Düste Z10 were determined based on the structural high, preferable reservoir characteristics and relative proximity to the target coordinates of Düste Z9.

4.2 Well Design

The Düste Z10 well design has been optimized for hydraulic fracturing operations. Geophysical and geological data, offset

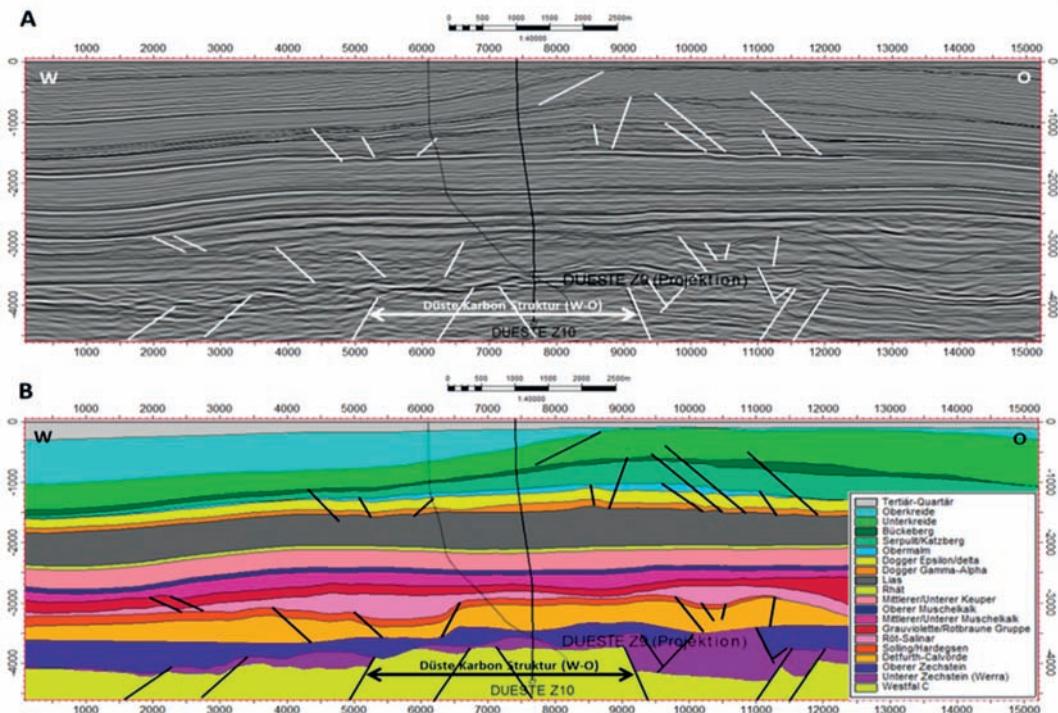


Fig. 2: Seismic X-Section with Düste Z9 and Z10.

drilling and production data, especially from Düste Z9 and other wells in the area served as the main input with respect to general casing design and corrosion aspects. Latest hydraulic fracturing parameters (mainly pumping rates and pressures) as applied in offset wells and comparable settings around the world defined minimum well design parameters, which in practice were inner diameters, pressure ratings and material strengths of production liner, production tubing, completion components, tubing head and X-mas tree.

The intermediate liner and casing sizes had to be designed around these minimum design requirements. Selected tubulars and components have to withstand all major load cases that are possible throughout the life of the well. These are simulated with standard well and completion design software programs. Generally, the most severe load cases throughout the life of the well include pressure tests, early life production and shut-in scenarios, late life production scenarios and fluid injection scenarios.

Hydraulic fracturing, for example, repre-

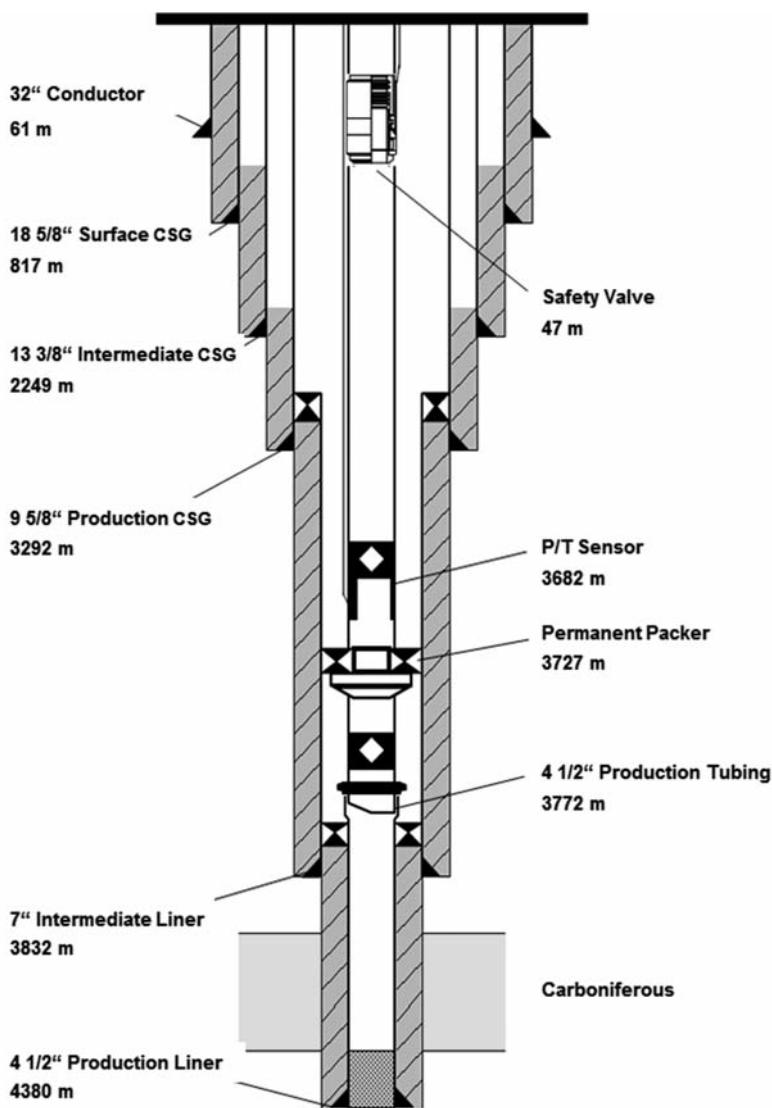


Fig. 3: Well design Düste Z10.

sents a fluid injection case. The simulator takes into account induced temperature and pressure changes and simulates corresponding material forces and stresses, which have to stay within 80% of the material specific maximum yield strengths. The well design process is iterative and ends when suitable size and material combinations are found for the entire well.

A permanent down-hole pressure and temperature gauge was selected for the production tubing close to reservoir depth to allow real-time pressure and temperature control during the hydraulic fracturing treatments and long-term reservoir monitoring. A permanent packer is required at the bottom of the completion string. It creates an annulus between production casing and production tubing (annulus #1, see Fig. 4). This annulus is needed for well integrity monitoring and pressure support, for example during hydraulic fracturing operations. Anchoring the tubing with a permanent production packer is part of the double barrier principle.

All fluids injected into or produced from the reservoir are forced through the inner production tubing and production liner. The flu-

ids cannot get into contact with the production casing or any other parts of the well. The production tubing can therefore be viewed as a «wear part», which could be replaced any time in case of an integrity issue. The Düste Z10 well design foresees five concentric tubulars across the depth interval of the fresh water aquifer (0–50 m) providing total protection from inner well fluids (Fig. 4).

4.3 Site Construction

In Germany, drilling sites are constructed according to guidelines as set out by the WEG (Wirtschaftsverband Erdöl- und Erdgasgewinnung e. V.), which are some of the most stringent worldwide. All surface areas of the well site, which may get in contact with fluids used during drilling, hydraulic stimulation and production tests, must be built «leak tight» (WEG 2006).

Prior to well site construction for Düste Z10, the conductor pipe was driven to a depth of more than 60 m, protecting the fresh water aquifer (0–50 m) from future drilling work (Figs. 3 and 4). Only afterwards construction of the roughly 10.000 m² large site com-

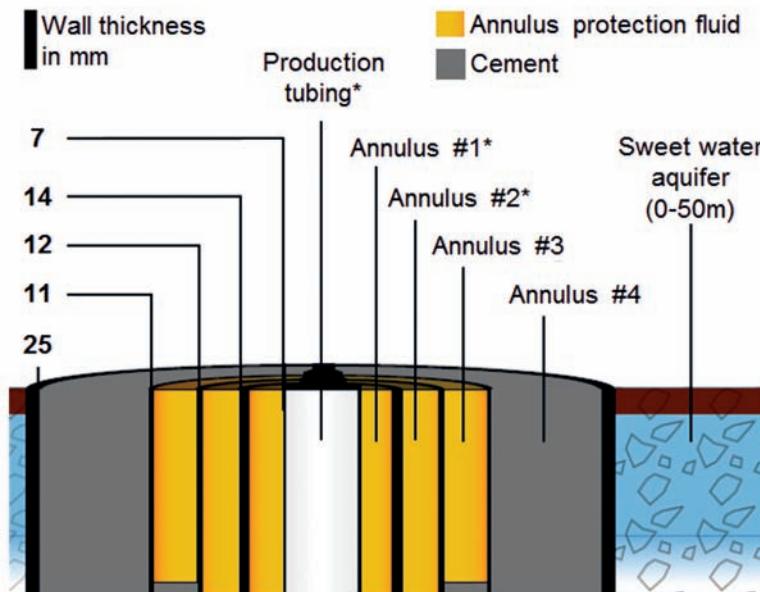


Fig. 4: Düste Z10 design across fresh water aquifer; [*] permanently pressure and temperature controlled.

menced, which was sealed against the conductor pipe. The inner area is equipped with a surrounding fluid barrier and an independent drainage system to a double hulled tank. The outer area is equipped likewise.

In order to take baseline analyses and perform long term monitoring of the fresh water aquifer in the proximity of the well site, three water wells were constructed. Data taken from these wells was also used for the hydrogeological expertise, which was a required input for the frac permit application.

4.4 Drilling and Completion

The drilling rig was mobilized to the well site in December 2011. After drilling to the first casing section depth, the surface casing was run and cemented to surface. The cement quality was independently checked by wire logging methods and pressure tests before drilling of the next section commenced. Each following casing and later the liners were checked for cement quality and pressure integrity in the same manner.

Each well section was logged before (open-hole logging) and after casing and cementing

it off (cased-hole logging). Most of the measurements run in the upper hole-sections were standard logs for stratigraphic description and determination of cement and casing quality. Standard mud logging was performed during the entire drilling operations at shortened intervals across the reservoir section. In the target formation, several cores were taken to be able to carry out routine and special core analysis. This data was used to calibrate the following well logging measurements and provided geologists with actual reservoir rock samples for improved geological modelling.

A specially tailored logging program was carried out in the reservoir section to allow for thorough tight gas reservoir characterization and hydraulic fracturing design. Additionally, a special VSP (Vertical Seismic Profile) log was run to be able to accurately tie Düste Z10 into the existing 3D seismic survey. Cased logging finally confirmed cement quality and provided a baseline measurement for later planned log based frac-height determination.

Before running of the well completion, the well was pressure tested to maximum anticipated annulus pressures during the



Fig. 5: Drilling rig on Düste Z10.

hydraulic fracturing process. Afterwards an inflow test confirmed pressure containment from the reservoir. Afterwards the well completion components including the down-hole pressure and temperature sensor and permanent packer were installed such to ensure mechanical continuity to the production liner (mono-bore concept, Fig. 3). Following X-mas tree installation, pressure tests confirmed pressure integrity and readiness of the entire well construction for the hydraulic fracturing operations.

After demobilization of the drilling rig, the wellhead was equipped with pressure and temperature sensors on the tubing head and on annulus #1 (between production tubing and production casing) and annulus #2 (between production casing and intermediate casing). These sensors together with the permanent down-hole pressure and temperature sensor on the production tubing were connected to the distributed control system providing a means for continuous pressure integrity monitoring of the well (see Fig 4). This system will be used for real-time monitoring of well integrity during the frac operations and for long term monitoring of reservoir and well performance.

4.5 Frac Design

The hydraulic fracturing design was carried out in different stages. Before Düste Z10 was drilled, a general design was drafted based on data from offset wells, namely Düste Z9. This data included stratigraphy, pore pressures, rock mechanics, local stress field and job data from the five hydraulic fractures pumped in 1995. The fracture orientation in this area is well known from offset data from several wells. Fractures in the Düste Reservoir at this depth develop vertically along the maximum horizontal stress direction, which is roughly North-Northwest – South-Southeast.

As new data became available from Düste Z10 (logging data, core measurements, actual well orientation, geometry and design), a

detailed frac design was carried out as per the actual stratigraphy in the reservoir. It specifically determined the number of required frac treatments, perforation design, frac treatment sizes per gas bearing sand, fluid types and resulting formulations, fluid volumes, proppant types and volumes, pump rates and pressures.

Wintershall carried out special regained conductivity tests to determine optimal fracturing fluid formulations using chosen proppants under in situ conditions (reservoir pressure and temperature). This involved optimization of polymer-breaker and high-temperature stabilization concentrations in the fluid.

Generally, no single concentrated frac fluid additive of the planned fluid formulation rates higher than water hazard class 1 (WHC 1 = low hazard to water) according to the VwVwS (Verwaltungsvorschrift wassergefährdende Stoffe). For example, the fluid which forms on streets during winter, when sodium chloride is used as the de-icing agent, already is classified WHC 1. In the frac fluid the additives are highly diluted. In the Düste Z10 frac fluid formulation, water and proppants (both not WHC rated) make up 99.2% and additives only 0.8% (max. WHC 1 rated) of the frac fluid. Nevertheless, since the additives are rated WHC 1, the frac fluid mixture in total automatically rates WHC 1.

4.6 Frac Operations (Outstanding)

The detailed frac design determined the necessity of seven frac treatments for Düste Z10. These were planned to be conducted over a two-month period, averaging about one frac treatment per week including mobilization, all required auxiliary operations, well clean-up and demobilization.

There is no risk of fracturing fluid unintentionally leaking into the fresh water aquifer during these operations. The following theoretical leak paths were examined and discussed:

- Surface leakage at the well site;

- Lateral leakage through the well;
- Vertical leakage up along the outside of the wellbore;
- Vertical leakage up through the formations from the reservoir.

Surface leakage of fracturing fluid during operations are highly unlikely, since fracturing fluid is not stored at the location, but only mixed «on-the-fly» immediately before being pumped into the well. The entire fracturing equipment is located within the leak tight inner area of the well site. Only municipal water is stored in tanks before the operation starts. A frac fluid additive truck trailer contains all required liquid additives, which are stored according to the double barrier principle. It has to be noted that even the concentrated frac additives are within the WHC 1 rating. In the unlikely case of leaking surface equipment downstream of the mixing equipment, a maximum of about 2 m³ of frac fluid (incl. additives) could reach the leak tight inner surface area of the well site

without control systems and operator personnel taking notice of it. The 10 cm high fluid barrier around the inner area has a fluid containment capacity of 200 m³ with an independent 100 m³ double hulled tank connected to the drainage system. Therefore it is impossible for the frac fluid mixture to leak into the fresh water aquifer. Additionally, as confirmed by the findings of an independent hydrogeological specialist, the fresh water aquifer in the area of the well site is naturally protected by 8–15 m thick natural clays. This type of hydrogeological setting is e.g. a prerequisite for the construction of municipal garbage disposal dumps in the state of Lower Saxony in order to protect the fresh water aquifer.

Lateral leakage of fracturing fluids through the well is technically impossible. As described above, production tubing, annuli #1 and #2 pressures are constantly monitored. In case of a pressure integrity issue, hydraulic fracturing operations would not be carried out. A pressure integrity issue

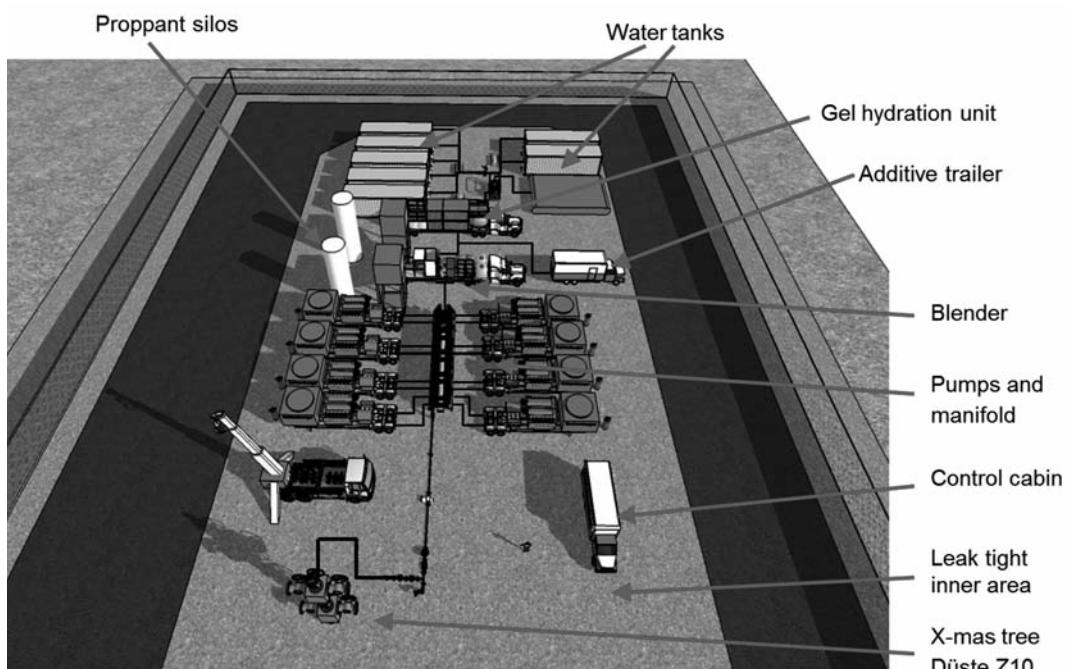


Fig. 6: Layout of fracturing equipment in inner area of Düste Z10 well site.

during fracturing operations would instantaneously lead to opening of a pressure relief valve and to pump shut down. Since a total of five steel barriers exist, there is no direct leak path of the fracturing fluid from the production tubing to the fresh water aquifer (Fig. 4).

Vertical leakage from fractures created in the reservoir at more than 3.800 m depth up along the outside of the well is impossible as two (Zechstein- and Muschelkalksalinar)

several hundred meters thick salt formations are located above the reservoir. Special thick-walled casings had to be set across these salt formations in order to keep the salt from deforming the casings, as it is mobile under the existing pressures and temperatures. Salt formations are therefore «self-healing» and often provide the main barrier above hydrocarbon reservoirs in Northern Germany.

Vertical migration of fluids from the reser-

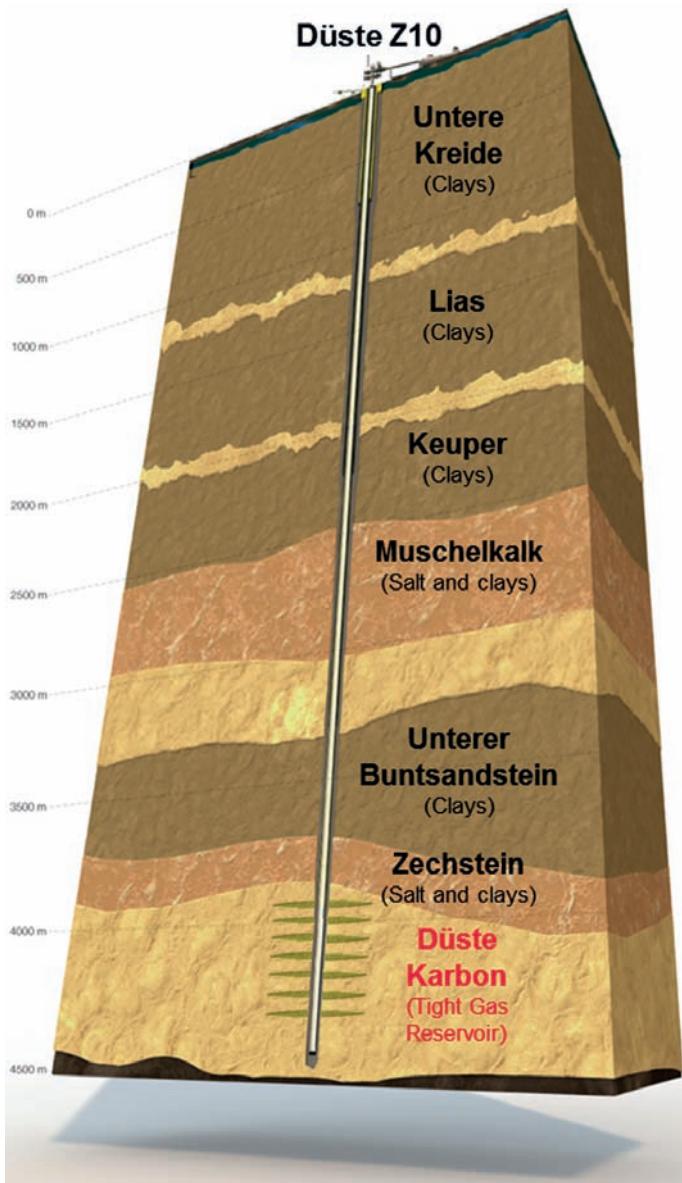


Fig. 7: Salt and clay barriers above Düste Carboniferous tight gas reservoir.

voir across more than 3.800 m of various impermeable barrier formations into the fresh water aquifer is impossible. Next to the salt formations, several thousand meters of impermeable clay formations exist. Additionally, hydraulic fracs, designed for the Düste tight-gas reservoir, ideally will reach half lengths of up to 150 m and heights up to 100 m but normally less as they are constrained by shale barriers within the reservoir.

The larger the frac, the more reservoir rock is exposed, into which frac fluid leaks off. Therefore there is a maximum frac size which can be reached, which is defined by the balance of fluid leak-off and maximum fluid pump rate, which is constrained by maximum allowable pressures. Additionally there are rock mechanical-, stress field-, lamination- and fluid-related effects impacting the maximum size of hydraulic fracs just to name a few.

Conductive faults across the barrier formations above the reservoir do not exist. If they would exist and they would be conductive, the target gas reservoir would not exist. Moreover, frac fluids are heavier than hydrocarbons, i.e. if hydrocarbons do not migrate up from the reservoir (in this case the target reservoir would not exist) water will also not migrate up against gravity.

During the frac-operations in the Düste Z10 well, which only last 1-2 hours per treatment, control systems and operations personnel monitor all relevant pressures and volumes constantly. If any abnormal pressures or volumes are observed, the pumps are immediately shut down.

For Düste Z10 it was additionally planned to carry out micro seismic monitoring of the created fracture geometries. The offset well Düste Z9, which is only about 500 m away at reservoir depth, was specifically prepared for placing geophone receivers. Also, it was planned to use special proppants in some of the treatments to be able to carry out fracture height logging at the wellbore. These measurements were only intended to improve the accuracy of the simulation

models in the order of 10s of meters for future frac operations.

The operations are not expected to induce any seismicity at the surface that can be felt by humans or cause damage to buildings ($M_L > 2.5$). During several recent hydraulic fracturing treatments of the same formation in a near offset well no induced seismicity at the surface has been measured by the German Regional Seismic Network (operated by the Bundesanstalt für Geowissenschaften und Rohstoffe).

A long-term production test was planned following the completion of hydraulic fracturing operations. One of Wintershall's own well test equipment packages will be utilized for this test and installed within the inner area of the well site. The pipeline tie-in to an existing raw gas production gathering system was already constructed as part of the well site preparation. Part of the hydraulic fracturing treatment fluids will be produced back with the gas and reservoir water. The fluids will be separated by the well test equipment and temporarily stored at the well site in closed tanks. Safe fluid disposal will either be organized by approved specialized companies or injected into approved disposal wells within depleted oil and gas reservoirs.

5 Conclusions and Outlook

Hydraulic fracturing operations have been applied in Germany more than 300 times since 1961 without any harm to the environment. The strict regulatory framework has ensured that operations are carried out consistently to high safety standards. Moreover, in light of the critical perception of the technology, the German oil and gas industry has developed a catalogue of best practices that is also publically accessible (WEG 2014).

The Düste Z10 Tight Gas Project in Lower Saxony has been planned, permitted and executed in accordance with these best practices, key elements of which are:

1. Evidence of effective geological barriers above the reservoir;
2. Prevention of surface spill risk by adequate well site construction;
3. Prevention of subsurface spill risk by adequate well design;
4. Full understanding and control of created frac dimensions;
5. Safe disposal of produced fluids after hydraulic fracturing operations;
6. Prevention of damaging induced seismicity at the surface.

However, the hydraulic fracturing permit for Düste Z10, despite the fact of being technically approved, was blocked at the political level in early 2013. The project is therefore on hold since that time.

In 2014, the state of Lower Saxony drafted a new regulation concerning the approval process of hydraulic fracturing, which distinguishes between operations in conventional reservoirs (including tight gas) and operations in unconventional reservoirs (Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2014). Generally, environmental impact assessments will become mandatory for all hydraulic fracturing operations and have to be made publicly available including permitting documentation. The new regulation mainly aims at providing a solid legal foundation for more public involvement. However, this new regulation has not yet been enacted by Lower Saxony. In parallel, Germany is working at the national level to adapt the existing legal framework to the new public perception.

In the summer of 2014, the first hydraulic fracturing operation since three years has been approved and executed in Germany in the state of Mecklenburg-Western Pomerania. Assuming that the new regulation will be enacted in Lower Saxony by the end of 2014 and taking into account all statutory periods, work on Düste Z10 realistically might only resume in early 2016.

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The Fracking Debate in Europe – An Assessment of the History behind the European Bans on Hydraulic Fracturing

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Introduction

During a recent four-week AAPG Distinguished Lecture Tour in Europe, my most popular lecture was an analysis of the fracking debate; «The Environmental Realities of Hydraulic Fracturing: Fact versus Fiction» – unsurprising considering the sensitivity to the prospect of shale gas exploration in much of Europe. My objective was to address the public fears that drove moratoria and bans on fracking in places as different as New York, the UK, and France. Central causes of public fear in America were a combination of early mistakes by industry and purposeful disinformation from activists, especially those seeking to profit from such anxieties. This fear has now spread beyond America to places with nothing more than a modest gas industry experience.

My «environmental realities» lecture was a clash between the recalcitrant notion that the worst will happen when the gas industry shows up and my American optimism that gas can be produced at maximum benefit and minimum risk. Several people stated that Europeans do not want fracking until they are sure it is safe. While everyone wants a safe industry, safety is never absolute. In Pennsylvania, for example, where more than 3.000 people are killed annually in automobile accidents, only a handful have died in fracking related accidents since the start of

horizontal drilling in 2006. Yet a poll among Pennsylvanians would probably identify driving as the safer activity!

The lecture started with a discussion of my research on natural hydraulic fracturing in gas shale dating back to the 1970s, which was concurrent with both the first horizontal drilling of shale source rocks and the initial use of massive hydraulic fracturing in the US. Although both techniques date back 35 years in the USA, none of this early work on fracking made much of an impression on the public.

Surprising Research

The process by which fracking entered the general consciousness may have started about 2007 with my calculation of the technically recoverable reserves in the Marcellus gas shale of the Appalachian Basin. In 2007 shale was not widely discussed as a source of gas reserves and few people had any idea what the extraction process involved. I slowly began to understand that gas shale production would become a significant foundation for «new» gas reserves globally, pushing «Hubbert's peak» for gas production well into the future. My calculation was so much larger than current estimates (25 times larger than the USGS number) that several things came to mind. If people took me seriously and I was wrong, the industry and the economy could lose billions of dollars; however, if my estimate was right, this new-found reserve would

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slow the march towards a low carbon energy portfolio and reduced carbon footprint. Even if the estimate was accurate, speculators were still going to lose money. Either way seemed like a net loss. However, all natural systems, including the human economy, grow and thrive only in proportion to their access to abundant energy, so it seemed to me that shale gas was that next source of relatively inexpensive energy for us. Ideally it would backup those notoriously unreliable but carbon-neutral renewables, wind and solar, until smart grids and long-term energy storage for electrical generation were developed.

Risks and Rewards

In late 2007 I went to the news media with my results, receiving a great deal of public attention. At that time the term fracking was not part of the English language; within a year it had become shorthand for gas extraction by horizontal drilling and high-volume hydraulic fracturing, and most people now know what fracking is.

In Europe, I was frequently asked, «How can you be so certain [about fracking]?» My American optimism must have been shining through, because I point out in the lectures



Fig. 1: Terry Engelder is Professor of Geosciences at Pennsylvania State University and a leading authority on the Marcellus gas shale play.

that shale gas comes with risk along with reward. As Voltaire said: «doubt is not a pleasant condition, but certainty is absurd.» Science is not capable of certainty beyond having a sense of when others are mistaken. As the automobile fatalities example shows, people don't do a very good job of normalizing risk. When asked for absolute numbers on risk, all I can do is point to the millions of hydraulic fracture treatments and stimulations undertaken already, resulting in a modest number of examples of groundwater contamination from subsurface sources, virtually all from methane leaking along the cement-bedrock contact inside a borehole. Risks outside methane leakage come from poor surface management of fluids in the form of spills and leaks.

Air quality is at risk and ultimately, burning methane leaves a carbon footprint. These are concerns. The leaks need be found and fixed – but replacing coal-fired power plants with natural gas led to a significant reduction in America's carbon footprint over the past five years, according to the EIA. This good news does not mean that mankind should discontinue its march toward a larger renewable energy portfolio.

A Number of Mistakes

Industry was responsible for six major «mistakes» during the early days of high-volume horizontal hydraulic fracturing in the Appalachian Basin. I use the term mistake, because each might have been anticipated, but only by someone with great clairvoyance. None were a manifestation of single events like the engineering carelessness of the Macondo well blowout. However, they did create a breeding ground for amplifying public fear of the unknown.

Arguably, the most serious one was the failure to establish baseline water chemistry before drilling campaigns. Many chemical elements, (e.g. iron, magnesium, potassium) and compounds (e.g. methane) are dissolved in drinking water, but when water

chemistry is measured after the arrival of industry, there is a belief that these chemicals, particularly methane, result from drilling.

Traditionally, the first oil wells in a region were drilled where oil is leaking to the surface. Likewise, gas leaks are associated with the great gas basins on the world, including the Appalachian Basin where there are several towns named Burning Springs. Methane was there all along but industry failed to present these details to the public prior to drilling. Through the history of the O&G industry in the US, regions that leaked gas exclusively were not nearly as interesting as those that leaked both oil and gas. Pennsylvania, for example, had a long history of flaming faucets and bubbling stream beds, although the gas was not usually concentrated sufficiently in groundwater to manifest itself in drinking water. Intensified drilling in 2008 produced a heightened sensitivity to methane in groundwater, but with no baseline, it was impossible to know whether and how much methane resulted from this drilling. Pennsylvania law held operators responsible for the methane in groundwater within 1.000 ft of a gas well, regardless of whether it was their fault.

The second industry mistake involved the extent to which casing was cemented. Early on, surface and intermediate casing was completely cemented but as much as 5.500 ft of open hole was left outside the production casing, as traditionally done in sparsely populated parts of the country with few water wells near gas ones. This is fine if the overburden section is not gas charged – but in north-eastern Pennsylvania the overburden contains Upper Devonian coals, full of methane gas, which flowed into the open holes and in some cases likely increased groundwater concentration by leaking along poorly cemented gas wells. Industry no longer leaves open-hole production casing, at least below the intermediate casing string.

Secrecy and Earthquakes

The use of air-drilling to penetrate the vertical legs of Marcellus gas wells was another error. The pressure of air blowing into more permeable aquifers was sufficient to drive methane towards nearby water wells. It also increased the natural turbidity in groundwater, which often worries people.

A fourth mistake was to lobby for elements in the Energy Policy Act of 2005 that allowed fracking companies to keep their additives proprietary. The public feared that groundwater would become contaminated by unknown, possibly toxic, chemicals, and wanted to understand exactly what and how much was being pumped into the ground. There was also the (inaccurate) perception that this act exempted the industry from Clean Water and Clean Air Acts. The industry elected to reveal the details of additives on a website, «Frac Focus», and, while posting volume and chemical composition was voluntary, most operators in the Appalachian Basin have joined in an attempt to become more transparent.

The industry disposed of flowback in large enough volumes to trigger minor earthquakes in Ohio and Texas, which naturally played into the public fear. Water under pressure flowing along faults reduces the frictional strength sufficiently to cause slip; triggering a large earthquake by injecting water was even the plot of a James Bond movie. USGS studies confirmed that there is a relationship between the injected volume of water and earthquake size, but showed that it was not possible to trigger a destructive earthquake with the amount of water used during fracking – incidentally proving the implausibility of the James Bond plot.

The sixth mistake involved management issues associated with potentially leaking open pits, leading to the fear that groundwater could be contaminated if a lined pit was punctured or seals failed. Presently, only fresh water is stored in open pits. Any flowback is contained in enclosed frack tanks where the chance of leaking is near zero.

Purposeful Disinformation?

Public anxiety arising from these very real mistakes was easily manipulated and magnified by activists who either did not know better or sought to profit by playing to this fear. The most egregious case of purposeful disinformation being used to manipulate the public is found in the closing scene of the movie «Gasland», where a tap is lit. The owner's water well was drilled through a coal bed giving off methane, and the film's producer admitted knowing that the methane had nothing to do with fracking.

Public fear can also be manipulated by famous people. Movie star Matt Damon was quoted as saying that «Everyone knows that fracking poisons the water and air», adding that fracking, «[...] tears apart local communities and subverts democracies [...].» Yoko Ono was quoted in the media as stating categorically that «Fracking kills». Subsequently, signs declaring that fracking kills have shown up regularly at protest rallies in many places worldwide.

The most common prop at protest rallies has been the jug of rusty, brown water – easily transported and, unlike the flaming faucet, looking nasty enough to amplify fear of fracking. Rusty, brown water is a natural product of the oxidation of dissolved iron. Tests suggest that nearly half the water wells in parts of Pennsylvania have enough dissolved iron in the groundwater to make it turbid when exposed to atmospheric oxygen, a process accelerated by pumping wells dry. In fact, the US EPA tested one water well repeatedly and found the water safe to drink. Later, the owners admitted pumping their water well dry to supply turbid water when visitors came knocking.

In summary, public pressure was largely responsible for political decisions to place moratoria or bans on fracking. In a sense, industry was directly responsible for these political decisions because of early mistakes, making it easy for activists using purposeful disinformation to further cement a negative public position relative to fracking.

Unconventionals in China – Shell's Onshore Oil and Gas Operating Principles in Action Martin Stäuble¹

Key words: China, unconventional oil and gas, hydraulic fracturing, operating principles

Abstract

Shell is operating four production sharing contracts (PSC's) targeting a variety of unconventional onshore tight gas and shale plays in the provinces of Sichuan and Shaanxi, all in partnership with Petrochina. Three offshore PSC's are also being executed in partnership with CNOOC targeting conventional gas in China.

Initial production started in 2007 in the Changbei field, which, with 3.3 Bcm yearly gas production, today delivers ca. 40% of Beijing's gas demand. The more recent acreage additions in Sichuan (Jinqui, Fushun and Zitong) are in appraisal stage, with over 50 wells drilled since startup of operations in 2010. Sichuan is home to a prolific conventional hydrocarbon system with multiple high quality source rocks and reservoir levels. Generally, reservoirs are very tight and hence Basin Centre Gas plays are possible in addition to Shale Gas and Shale Oil plays. Currently long term testing is progressing, aiming to prove that viable options exist to profitably produce this resource.

Drilling and fracing (hydraulic fracturing) in densely populated areas requires a high degree of care and sensitivity. Shell has introduced five operating principles that address safety and well integrity of drilling and completions, water use and disposal, safeguarding air quality, the footprint of our operations, and interaction with neighboring communities. Experience shows that achieving the quality that the five operating principles demand is equal in importance to finding the right geology or being cost competitive.

Unconventionals in China

Unconventional gas is a key component of the energy reform of China – a country whose energy demand will nearly double by 2030.

Related to energy, the Chinese government recognizes three strategic drivers: 1] ensure the economic prosperity of its 1.3 billion people by supplying affordable energy, 2] improve domestic energy production and thereby reduce dependency on imported energy and 3] drive environmental improvement by substituting coal with gas (Fig. 1). While these strategic drivers are of great importance to the Chinese people, their implication in particular on the environmental and climate agenda have global reach: substituting coal with gas as the primary energy supplier can reduce the CO₂ footprint by up to 50%. For these reasons, China has set ambitious targets for unconventional gas production.

The China oil and gas scene is dominated by the three large national companies: CNPC (Petrochina), SINOPEC and CNOOC. Oil and gas infrastructure is installed and is being expanded at a relatively fast pace. China has excellent manufacturing capabilities and a long oilfield tradition, which means that drilling and fracing equipment as well as oil field services are readily available. China has many prolific hydrocarbon basins (Fig. 2) in often fairly complex settings and a predominance of lacustrine source rocks. The latter are also the focus of the emerging unconventional oil and gas activities.

Developing unconventional oil and gas as a

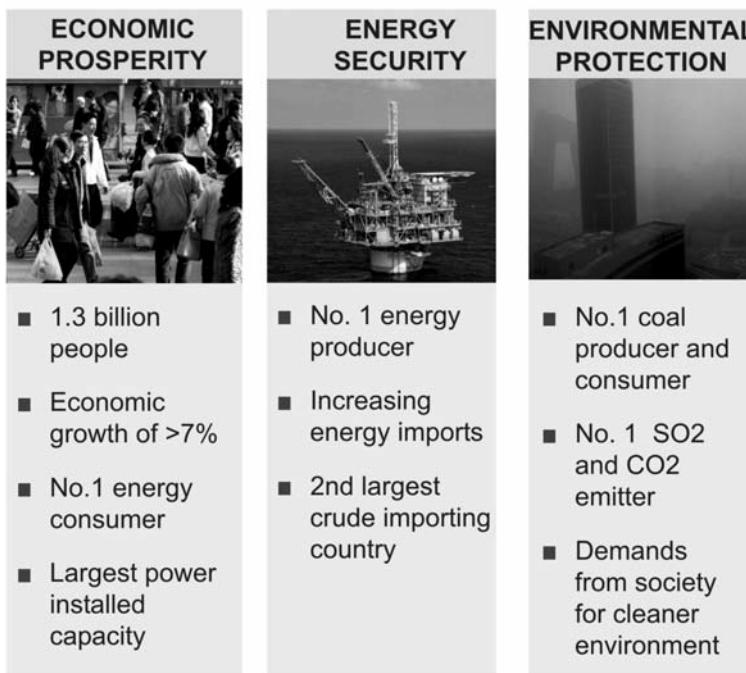
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new resource has been a slow process with few foreign players acquiring acreage and only Shell being an active operator. The main reason for this slow pace lies in uncertainties as to the viability of the unconventional plays, immaturity of the regulatory framework, lack of freely available data, the high cost of the exploration and appraisal phase and finally, limited access to bidding rounds. To date, approximately 200 wells have been purposely drilled into unconventional targets with even fewer long term tests. This contrasts with over 10.000 wells drilled on a yearly basis in North America. Many of the ingredients to make unconventional resources a success are present in China with good government support, a good supply chain and an active oil and gas industry. However, it is an industry in its infancy, with few players and so far limited experience.

Onshore operating principles

2012, Shell published its Onshore Oil and Gas Operating Principles. The company is making all of Shell's operated onshore projects where hydraulic fracturing is used to produce gas and oil from tight sandstone or shale, consistent with these principles and with local rules and regulations. The reason for making these public was in response to concern around the development of unconventional resources, especially with regard to the practice of hydraulic fracturing. It creates transparency as the public today demands and allows Shell to share «how we do our business». It also demonstrates confidence, which is based on 60 years of onshore operational experience, including the use of hydraulic fracturing, and underpins how the company works today and how it aspires to improve. The operating princi-



Social Harmony

Fig. 1: The strategic drivers for China policy makers.

ples comprise five elements, each complemented with detailed and auditable instructions (not shown in this paper):

- Principle #1: Shell designs, constructs and operates wells and facilities in a safe and responsible way.
- Principle #2: Shell conducts its operations in a manner that protects groundwater and reduces potable water use as reasonably practicable.
- Principle #3: Shell conducts its operations in a manner that protects air quality and controls fugitive emissions as reasonably practicable.
- Principle #4: Shell works to reduce its operational footprint.
- Principle #5: Shell engages with local communities regarding socio-economic impacts that may arise from its operations.

The operating principles in action

In the following, two examples of applying the Shell operating principles in China are highlighted: Footprint reduction and community engagement.

Footprint reduction

Sichuan has a population density of about 600 people per km². The terrain in the operating area is hilly with small villages, minor roads and an abundance of small and medium rivers. As one of the most fertile regions of China, Sichuan hosts intense agriculture and is considered the bread basket of China. For drilling and fracturing operations, a well pad approximately the size of a football field (ca. 4.500–6.000 m²) needs to be constructed. This area provides room for the rig, crew accommodation and fracking equipment. Following successful testing, the well pad is converted into a production station, and

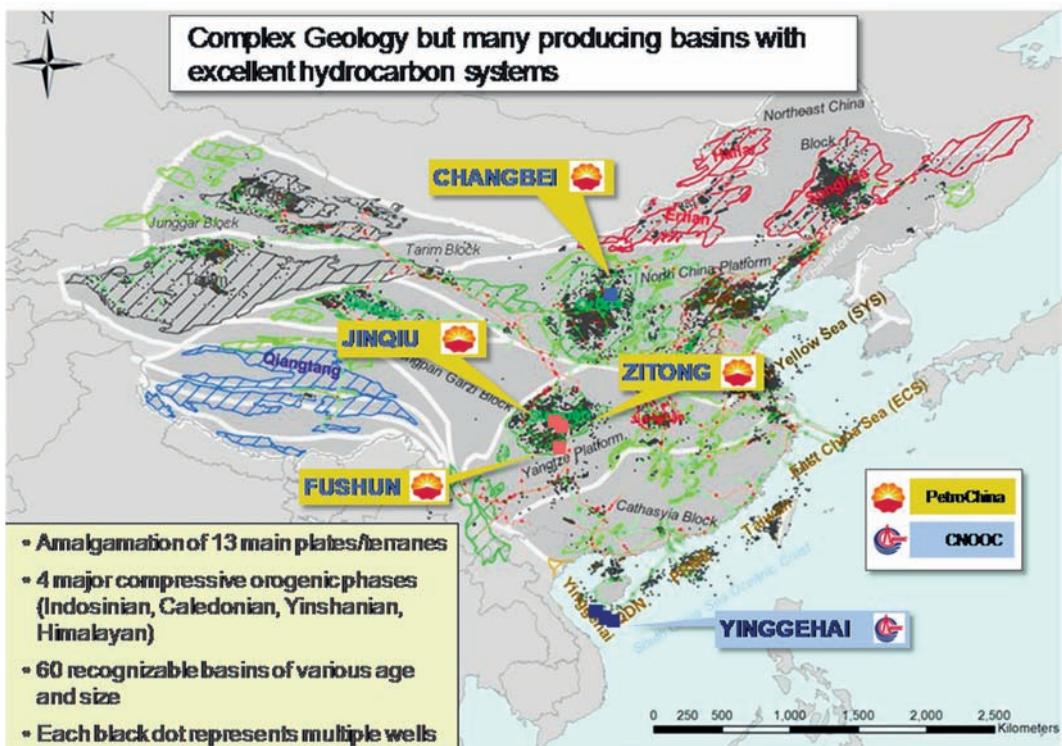


Fig. 2: Simplified tectonic map of China overlain with existing drilling locations and Shell's operating locations (modified from IHS data).



Fig. 3: The challenge of land acquisition in a densely populated province like Sichuan.

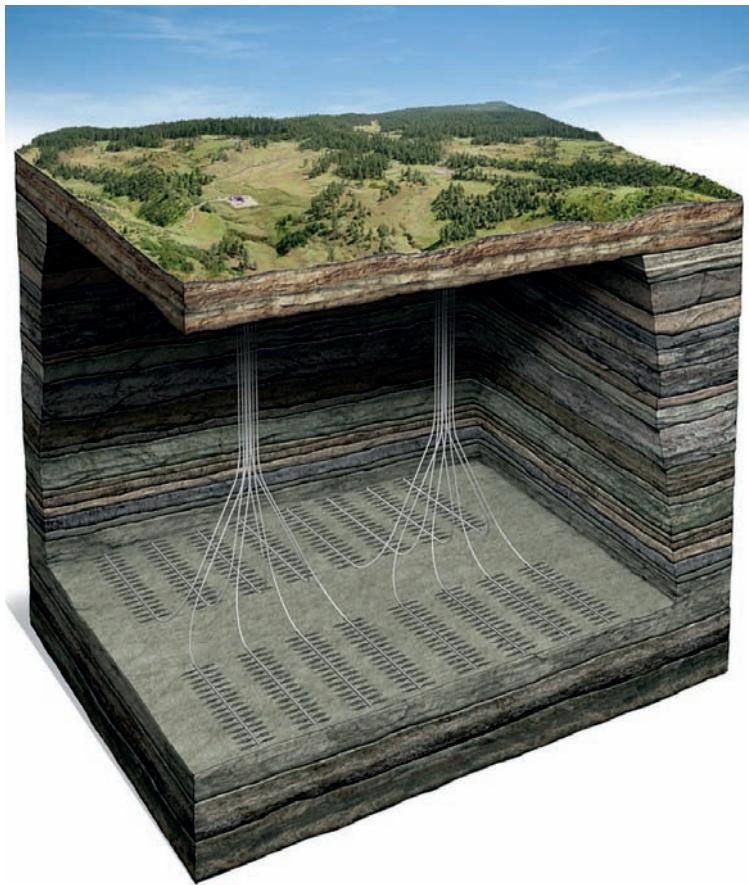


Fig. 4: Multiple horizontal wells from each location dramatically reduce the operational footprint.

excess land restored to vegetation. Finding appropriate well locations can be a challenging exercise in heavily populated areas, as can be seen in Fig. 3. Many farm houses, terraced fields and steep sided hills dominate the picture. In addition to the well pad itself, sufficient safety distance from the nearest house must be maintained.

As unconventional developments can typically comprise hundreds, if not thousands of wells, minimizing the footprint not only is an important operating principle but is a key ingredient for success. The solution is to use the same well pad for multiple wells – up to 32, and use horizontal, far-reaching wells to drain a large subsurface area during development as is shown in Fig. 4.

Community engagement

Entering a new location requires diligent work with the community ahead of any engineering activity. Community liaison officers are the first on the scene to engage the village inhabitants, especially the village leadership and anyone living near to the intended operational area. The officers' task is to generate an understanding of what a site construction and drilling operation entails, thus giving the community the opportunity

to voice both concerns and needs. Thanks to the feedback from the community, the impact of operation can more effectively be minimized. In addition, Shell aims at creating win-win situations where the community gains long-term benefit from the company's presence in the area. This can take the form of employment opportunities, social investment focused at improving people's livelihood or the purchase from the community of goods and services to support the operations.

Similar to the previously mentioned footprint reduction, successfully working with the community is understood by Shell as a prerequisite for success. People will make their sentiment felt by opposing an activity or blocking progress. Hence, regardless how good the geology is, if the relationship between community and company is not sustainable, the company will not be able to operate efficiently. Fig. 5 shows how easily operations are stopped when a community disagrees with a certain activity – in this case what was considered excessive trucking activity passing through a small village road. Likewise, when the relationship is based on mutual respect and trust, it can be



Fig. 5: Peaceful community protest.

beneficial for both parties. The example in Fig. 6 shows the community close to the well site celebrating the completion of an irrigation project that Shell put in place.

In summary

The exploration and production of unconventional resources in China are in their infancy, with relatively few wells drilled, an immature regulatory framework and a contractual regime designed for conventional oil and gas. However, several unconventional plays are producing first gas, government support is strong and an excellent supply chain is emerging.

Having strong operating principles in place has proven essential for progressing Shell's operations in China. Adherence to these principles minimizes impact of the company's operations on environment and people and also serve as a foundation for a sustainable interaction with the community. In short, demonstrable adherence to the Onshore Oil and Gas Operating Principles is considered to be of equal importance as for instance a good hydrocarbon system or a cost effective drilling operation.



Fig. 6: Celebrating the completion of an irrigation project that was executed for a local farming community by Shell and PetroChina.

Die Erschliessung und Nutzung der Energiequellen des tiefen Untergrundes der Schweiz – Risiken und Chancen

Roland Wyss¹

Stichworte: Geothermie, Erdgas, Potenzial, hydraulische Stimulation, Fracking, Grundwasser

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Zusammenfassung

Aufgrund der derzeit laufenden Energiediskussion gilt es abzuklären, welche Anteile der grossen Potenziale von Erdgas und Geothermie in der Schweiz künftig nutzbar sein werden. Die Schweiz hat ausreichende rechtliche Grundlagen zum Schutz von Umwelt und Wasser (u. a. Grundwasser, Trinkwasser), diese lassen sich aber nicht auf die Nutzung des tiefen Untergrundes direkt anwenden, da z. B. Tiefengrundwasser nicht Wasser im Sinne der heutigen Gesetze ist. Bei Tiefengrundwasser handelt es sich meist um saline Wässer mit für die Lebenswelt unerwünschten Inhaltsstoffen. Bei der Tiefenerkundung und -erschliessung muss in erster Linie verhindert werden, dass durch Tiefengrundwasser unsere Schutzgüter Wasser und Boden beeinträchtigt werden. Tiefbohrungen erfordern den Einsatz einer Spülung mit Additiven. Der Einsatz von Hydraulic Fracturing (Fracking) für die Schiefergasgewinnung ist wegen der Verwendung von Zusatzstoffen (Additiven) in der Öffentlichkeit stark umstritten. Mit heutigen Additiven kann eine Beeinträchtigung von Wasser und Boden aber ausgeschlossen werden. Studien zeigen, dass

eine sichere Anwendung von Fracking möglich ist. Für die hydraulische Stimulation in der Tiefengeothermie wurden bis heute keine Additive verwendet, es ist jedoch wahrscheinlich, dass solche in Zukunft nötig werden.

Zwischen der Schiefergasnutzung oder der Nutzung von Tight Gas und der Tiefengeothermie gibt es grosse Ähnlichkeiten, aber auch deutliche Unterschiede. Die operationelle Erfahrung in der Tiefengeothermie ist im Vergleich zur Schiefergasnutzung noch gering.

Jede Erschliessung und Nutzung des tiefen Untergrundes stellt einen Eingriff in den Untergrund dar. Erfahrungen zeigen, dass es möglich ist, ohne Beeinträchtigung der Trinkwasserressourcen und ohne Gefährdung von Mensch und Infrastruktur den tiefen Untergrund zu nutzen. Es braucht klare Regeln ohne unnötige Hürden für die Branche und eine transparente Information der Öffentlichkeit. Es braucht aber auch innovative Projekte, sachliche Diskussionen und unternehmerischen Weitblick, einheimische Ressourcen des tiefen Untergrunds vertieft zu erkunden und zu nutzen.

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Résumé

Dans le cadre des discussions en cours en matière de politique énergétique, il s'agit de déterminer la part des ressources géothermiques et de gaz naturel qui pourront être mises en valeur à l'avenir en Suisse. La Suisse dispose d'une législation adéquate en matière de protection des eaux (nappes phréatiques, eau potable) et de l'environnement en général. Pourtant, cette législation ne s'applique pas directement aux eaux issues des profondeurs du sous-sol, car, par exemple, ces eaux ne sont pas de l'eau au sens des lois en vigueur. Les eaux des profondeurs sont le plus souvent salées et contiennent des substances qui ne doivent pas entrer en contact avec le monde vivant. Lors de forages profonds, qu'ils soient exploratoires ou servent à l'exploitation d'une ressource, il faut surtout éviter que nos biens protégés – l'eau et le sol – en subissent l'impact. Les forages profonds nécessitent le recours à des liquides de transport contenant des additifs. La fracturation hydraulique (fracking) est très contestée par le public à cause de l'utilisation de ces additifs. Toutefois, les additifs actuellement utilisés permettent d'affirmer qu'aucun effet néfaste pour l'eau ou le sol ne s'ensuivra. Des études montrent qu'il est possible de mettre en œuvre la fracturation hydraulique de manière sûre.

En géothermie profonde, aucun additif n'a été utilisé à ce jour pour la stimulation hydraulique. Il est cependant probable qu'à l'avenir, il sera également nécessaire de recourir à des additifs pour les forages et l'exploitation de la géothermie profonde.

Il y a de grandes similitudes entre l'exploitation des gaz de schistes ou l'utilisation du «tight gas», d'une part, et la géothermie profonde, d'autre part. Mais il y a aussi des différences importantes. En géothermie profonde, on ne dispose pas encore, et de loin, de la même expérience qu'en matière d'exploitation des gaz de schistes.

Toute mise en valeur ou utilisation du sous-sol représente une atteinte à l'intégrité de celui-ci. Sur la base de l'expérience acquise, il est prouvé qu'il est possible d'utiliser le sous-sol profond sans porter atteinte aux ressources en eau potable ni mettre en danger l'homme et les infrastructures. Des règles claires qui ne créent pas d'obstacle inutile pour la branche, ainsi qu'une information transparente du public sont nécessaires. Mais il faut aussi des projets novateurs, des discussions objectives et une vision entrepreneuriale à long terme qui permettent d'explorer le sous-sol profond et de le mettre en valeur.

Summary

In light of current energy discussions clarification is necessary on the question of which proportion of the high potential for natural gas and geothermal energy in Switzerland can, in the future, be used. Switzerland has adequate fundamental legal principles concerning the protection of the environment and water (including groundwater and drinking water): These principles, however, cannot be directly applied to the utilisation of low-lying substrata since, for example, deep groundwater is not «water» in terms of current legislation. Deep groundwater, for example, is usually saline water which contains substances that are not compatible with the living environment. Primarily, when performing deep exploration and exploitation, it must be prevented that commodities such as earth and water are not compromised by the exploitation of deep groundwater. Deep boring requires the use of drilling fluids and additives. The use of Hydraulic Fracturing (Fracking) for the extraction of shale gas is highly controversial in the general public because of the use of additives. However, with today's additives, an influence on water and the ground can be ruled out. Studies show that the safe application of Fracking is possible.

Although no additives have been employed up to now for hydraulic stimulation in deep geothermal energy operations, it is probable, however, that in the future additives will also become necessary for the development and use of deep geothermal energy resources.

There are great similarities between the use of shale gas or the use of «Tight Gas» and deep geothermal exploitation, but there are also important differences. Operational experience in deep geothermics is still low in comparison with the exploitation of shale gas.

Every development and use of low-lying substrata represents an intrusion in the underground. Experience shows that it is possible to make use of the underground without having an influence on drinking water resources and without endangering human beings and the underground infrastructure. It is necessary to define clear rules for this sector of business without any unnecessary hindrances and to provide transparent information for the general public. However, innovative projects and objective discussions are also needed, as well as entrepreneurial farsightedness in order to investigate and benefit from local deep subsoil resources.

1 Einleitung

In der aktuellen in der Schweiz laufenden Energiediskussion spielt die Energie aus dem Untergrund eine zunehmende Rolle. In der Energiestrategie des Bundes ist einerseits der Tiefengeothermie eine wesentliche Rolle zugedacht, andererseits sollen auch Gaskombikraftwerke eine solche übernehmen. Aus Geothermie werden heute in der Schweiz rund 2'400 GWh Wärme gewonnen, jedoch noch kein Strom produziert. Sämtliches in der Schweiz verbrauchtes Erdgas, rund 32'000 GWh (etwa 13% des Gesamtenergieverbrauchs der Schweiz), wird importiert. Neue Möglichkeiten der Untergrunderschliessung durch abgelenkte Bohrungen und hydraulische Stimulation/Fracking bieten sowohl für die Geothermie als auch für die Kohlenwasserstoffproduktion in der Schweiz neue Perspektiven.

Die Tiefengeothermie besitzt trotz bisher ausbleibender kommerzieller Erfolge und negativen Schlagzeilen wegen schwacher Erdbeben in der öffentlichen Wahrnehmung eine grosse Zustimmung. Demgegenüber ist bezüglich der Erdgasnutzung, insbesondere wegen des «Frackings», eine starke Ablehnung vorhanden.

Die Erdgasversorgung in der Schweiz wird heute über Lieferverträge mit Firmen aus dem angrenzenden Ausland sichergestellt. Rund drei Viertel des in der Schweiz verbrauchten Erdgases wird in Westeuropa gefördert, vorwiegend in Norwegen, Deutschland und Dänemark, 20% stammt aus Russland.

Um mittel- und langfristig die schweizerische Energieversorgung auf eine solide Basis zu stellen und die strategischen Optionen zu kennen, ist es wichtig abzuklären, welche einheimischen Energieressourcen aus dem Untergrund künftig einen Beitrag leisten können und wie gross dieser Beitrag sein kann. Dabei müssen sowohl Umweltaspekte als auch wirtschaftliche Faktoren berücksichtigt werden. Beide spielen über unsere Landesgrenze hinaus eine Rolle.

Die nachfolgenden Ausführungen sollen einen Beitrag zur laufenden Diskussion liefern und beleuchten vorwiegend die geologisch-technischen Aspekte der Untergrunderkundung und -nutzung.

2 Umwelt, Grundwasser und der tiefe Untergrund

2.1 Rechtliche Grundlagen

Gemäss Bundesverfassung (Bundesverfassung 1999), Art. 74, Abs. 1, erlässt der Bund Vorschriften über den Schutz des Menschen und seiner natürlichen Umwelt vor schädlichen oder lästigen Einwirkungen.

In Art. 76, Abs. 1 wird ausgeführt, dass der Bund im Rahmen seiner Zuständigkeiten für die haushälterische Nutzung und den Schutz der Wasservorkommen sowie für die Abwehr schädigender Einwirkungen des Wassers sorgt. In Abs. 2 wird weiter dargelegt, dass der Bund Grundsätze über die Erhaltung und die Erschliessung der Wasservorkommen, über die Nutzung der Gewässer zur Energieerzeugung und für Kühlzwecke sowie über andere Eingriffe in den Wasserkreislauf festlegt.

Zur Energiepolitik heisst es in Art. 89, Abs. 1: «Bund und Kantone setzen sich im Rahmen ihrer Zuständigkeiten ein für eine ausreichende, breit gefächerte, sichere, wirtschaftliche und umweltverträgliche Energieversorgung sowie für einen sparsamen und rationellen Energieverbrauch.» Weiter steht in Abs. 2: «Der Bund legt Grundsätze fest über die Nutzung einheimischer und erneuerbarer Energien und über den sparsamen und rationellen Energieverbrauch.»

Artikel 1 des Umweltschutzgesetzes (Umweltschutzgesetz 1983) definiert den Zweck des Umweltschutzgesetzes:

Abs. 1: «Dieses Gesetz soll Menschen, Tiere und Pflanzen, ihre Lebensgemeinschaften und Lebensräume gegen schädliche oder lästige Einwirkungen schützen sowie die natürlichen Lebensgrundlagen, insbesonde-

re die biologische Vielfalt und die Fruchtbarkeit des Bodens, dauerhaft erhalten.»

Abs. 2: «Im Sinne der Vorsorge sind Einwirkungen, die schädlich oder lästig werden könnten, frühzeitig zu begrenzen.»

Im Gewässerschutzgesetz (Gewässerschutzgesetz 1991) werden in Art. 4, Bst. b., unterirdische Gewässer als «Grundwasser (einschl. Quellwasser), Grundwasserleiter, Grundwasserstauer und Deckschicht» erläutert.

In der Wegleitung Grundwasserschutz (BUWAL 2004) wird Grundwasser wie folgt definiert: «Das Grundwasser füllt die natürlichen Hohlräume (Poren, Spalten, Klüfte) des Untergrundes zusammenhängend aus und bewegt sich entsprechend der Schwerkraft. Grundwasserleiter können aus Lockergesteinen (z. B. Kies, Sand) oder aus Festgesteinen (z. B. Kalkstein, Granit) bestehen. Deren Durchlässigkeit ist ein entscheidender Faktor für den unterirdischen Wasserfluss.

Im neuen, noch nicht in Kraft getretenen, «Gesetz über die Nutzung des Untergrundes (UNG)» des Kantons Thurgau wird in §7, Abs. 4 festgelegt: «Frackingverfahren [...], welche die Umwelt, insbesondere ober- und unterirdische Gewässer gefährden, sind verboten. Der Regierungsrat bestimmt, welche Chemikalien verwendet beziehungsweise nicht verwendet werden dürfen.» (Kanton Thurgau 2014).

2.2 Der Begriff Umwelt

Gemäss Duden steht der Begriff Umwelt für 1) die auf ein Lebewesen einwirkende, seine Lebensbedingungen beeinflussende Umgebung und 2) Menschen in jemandes Umgebung (mit denen jemand Kontakt hat, in einer Wechselbeziehung steht).

Das Umweltlexikon (<http://www.umweltlexikon-online.de>) gibt folgende Definition:

«Der Begriff der Umwelt ist geprägt durch die anthropogene Sichtweise des Menschen. Umwelt ist danach definiert, als einem Lebewesen umgebende Medien (Wasser, Boden,

Luft usw.) und aller darin lebenden Organismen sowie deren Wechselwirkungen in und mit dieser Umgebung. Mit Umwelt verstehen wir hier nicht nur alle auf die Natur wirkenden Einflüsse, sondern auch die sozialen, kulturellen, ökonomischen und ökologischen Bedingungen und Einflüsse unter denen Menschen und Lebewesen leben.»

2.3 Die Umwelt, das Grundwasser im tiefen Untergrund?

Die Begriffe Umwelt und Grundwasser haben im Gesetz eine andere Bedeutung, als im naturwissenschaftlich-technischen Sinn. Bei dem in der Bundesverfassung und der Gesetzgebung verwendeten Begriff «Umwelt» handelt es sich um die Lebenswelt des Menschen. Die rechtliche Definition von Wasser bzw. Grundwasser hat die Nutzung des Wassers als Trinkwasser im Fokus. Naturwissenschaftlich gehört aber die gesamte Erde zur Umwelt.

Im tiefen Untergrund herrschen Bedingungen, die der Lebenswelt des Menschen jedoch sehr entgegengesetzt sind. Insbesondere das vorkommende Tiefengrundwasser (Kap. 4) hat einen Chemismus, der eine Gefährdung für unsere Schutzgüter Grundwasser und Boden darstellt. Zwar kann das genutzte Grundwasser mit den heutigen rechtlichen Grundlagen genügend geschützt werden, jedoch können diese Grundlagen nicht auf das Tiefengrundwasser extrapoliert werden, da dieses, obwohl grundsätzlich zusammenhängend, sich stofflich meist deutlich vom oberflächennahen Grundwasser (Trinkwasser) unterscheidet.

Für die Erschliessung und Nutzung des tiefen Untergrundes können die Begriffe «Umwelt» und «Wasser», wie sie im bestehenden Recht verwendet werden, nicht einfach auf den tiefen Untergrund ausgedehnt werden. Die bestehenden Grundlagen gelten jedoch für Einflüsse, welche sich durch die Tiefennutzung auf unsere Lebenswelt auswirken können.

3 Kurze Einführung in die Tiefbohrtechnik

3.1 Einleitung

Zentrales Element der Erkundung, Erschließung und Nutzung des tiefen Untergrundes sind Tiefbohrungen.

Das Bohren in grössere Tiefen ist ein komplexer Vorgang. Es handelt sich nicht einfach um die mechanische Erstellung eines Hohlraumes im Gestein, sondern um einen komplexen hydraulisch-mechanischen Vorgang, bei welchem neben Gesteinsparametern auch Gebirgseigenschaften (z. B. Spannungen) und die im Gebirge enthaltenen Fluide eine wichtige Rolle spielen.

Tiefbohrungen werden in der Regel im Rotationsspülverfahren abgeteuft.

Die wesentlichen Elemente einer Tiefbohranlage sind: Der Bohrturm, die Antriebsaggregate (Diesel oder elektrisch), das Hebewerk, der Drehtisch (bzw. der Kraftdrehkopf oder der Spülungsmotor), das Bohrgestänge, die Bohrwerkzeuge und das Spülungssystem. Ein Blowout-Preventer verhindert im Bedarfsfall den unkontrollierten Austritt von Fluiden (Wasser, Öl, Gas) am Bohrlochkopf. Das Bohrgestänge beziehungsweise der Bohrmeissel (drill bit) wird bei der Rotationsspülbohrung mittels Drehtisch (rotary table), Kraftdrehkopf (top drive) oder mit Spülungsmotor (mud motor) angetrieben.

3.2 Spülungssystem

Ein zentrales Element einer Tiefbohrung ist die Spülung. Sie wird in der Regel durch Spülungspumpen über das Bohrgestänge in die Tiefe gepumpt. Via Bohrmeissel reinigt sie die Bohrlochsohle und strömt über den Ringraum nach oben. Dort gelangt sie über die Bohrspülungsrückleitung (flow line) in die Spülungsaufbereitung (Schüttelsiebe, Entsanter, Entfilter, Spülungsbecken). Die Spülung hat im Bohrloch vielfältige Aufgaben:

- Hydraulische Stabilisierung des Bohrlochs.

- Kontrolle des Druckes von Formationsfluiden (Wasser, Gas, Öl).
- Bildung eines Filterkuchens zur Abdichtung des Bohrlochs vor Zu- und Abflüssen.
- Reinigung der Bohrlochsohle und Austrag des Bohrkleins (cuttings).
- Physikalische und chemische Stabilisierung des Bohrlochs.
- Reibungsverminderung des Bohrgestänges an der Bohrlochwand.
- Kühlung des Bohrmeissels.
- Korrosionsschutz von Verrohrung und Bohrgestänge.

Die Grundlage der Spülung bildet in der Regel Wasser. Ohne Zusätze wird Wasser als Spülung meist bei untiefen Grundwasserbohrungen verwendet (Klarwasserspülung). Mittels verschiedener Zusätze können die chemischen und physikalischen Eigenschaften des Wasser bzw. der Spülung beeinflusst werden. Als Spülungszusätze dienen:

- Bentonite: Bildung einer Gerüststruktur, erhöht die Viskosität und das Austragevermögen der Spülung. Führt zur Bildung eines Filterkuchens auf der Bohrlochwand.
- Polymere und CMC (Cellulose): ergibt minimalen Filterkuchen mit erhöhter elastischer Abdichtung,
- Kreide, Baryt: Beschwerung der Spülung bei Gefahr von Fluid-Überdrücken.
- Bakterizide: Verhinderung der Zersetzung von CMC.
- Sägemehl, Zellophan, Muschelschrot, etc.: Bekämpfung von Spülungsverlusten.

Weitere Spülungszusätze (Additive) sind: Leichtzusätze, rheologische Zusätze, Korrosionsinhibitoren, anorganische Zusätze, Biocide, Entschäumer, Tonstabilisatoren.

Als Bohrspülungen bei Tiefbohrungen werden thixotrope Flüssigkeiten verwendet. Eine Spülung wird entsprechend dünnflüssiger, wenn man sie bewegt. Bei Stillstand verfestigen sie sich wieder. Ihre Zusammensetzung und ihre rheologischen Eigenschaften

werden ständig den Bohrumständen und den geologischen Gebirgseigenschaften angepasst. Die thixotrope Eigenschaft der Bohrspülung verhindert dabei im Falle von Pumpenstillständen das Sedimentieren des im Ringraum befindlichen Bohrkleins, was zu einem Festwerden und schlimmstenfalls zum Verlust des Bohrstranges führen könnte.

Mit der Zugabe von Bentoniten können die chemischen und die physikalischen Eigenschaften der Spülung beeinflusst werden. Insbesondere bilden Bentonite eine Gerüststruktur, die zum Wachstum eines Filterkuchens auf der Bohrlochwand führt. Auch Zusätze von Polymeren und Zellulose ergeben Filterkuchen mit erhöhter elastischer Abdichtung der Bohrlochwand (Rota et al. 2007).

Die Eigenschaften der Spülung werden während den Bohrarbeiten laufend überwacht, damit Veränderungen erkannt und die Spülung entsprechend aufbereitet werden kann. Eine optimale Spülung trägt stark zur Verbesserung des Bohrfortschritts bei.

In besonderen Fällen können salzgesättigte Spülung, Ölspülung oder Schaumspülung eingesetzt werden (z. B. Bohren in Salz).

3.3 Verrohrung

Um das Bohrloch über längere Strecken zu stabilisieren, wird es abschnittsweise und entsprechend den geologischen und hydraulischen Bedingungen der durchbohrten Gesteinsformationen teleskopartig mit Futterrohren (casing) ausgebaut. Das Verrohrungsschema hat sich nach den Anforderungen der Bohrung zu richten (siehe auch Fig. 2).

Üblicherweise werden die aufeinanderfolgenden Rohrtouren folgendermassen bezeichnet:

- Standrohr: Wenige Meter tief, zur Absicherung der obersten Lockergesteinszone, Schutz der Fundamente vor Unterspülung, dient als Führung.
- Ankerrohrtour: Einzementierte Rohrtour zur Aufnahme der Sicherheitsarmaturen (BOP), Führung zur Einhaltung der vorgegebenen Bohrrichtung.
- Technische Rohrtouren, Zwischenverrohrung: Zementation bis in vorhergehende Rohrtour oder bis zu Tage.
- Endverrohrung, Produktionsrohrtour: Evtl. mit Filterstrecke versehene Rohrtour, zementiert oder frei.
- Verlorene Rohrtour, Liner: Wird nicht bis zutage geführt sondern in die letzte Verrohrung eingehängt.
- Förderrohrtour, Tubbing: wird in Produktionsrohrtour eingebaut und dient zu deren Schutz.

Die Zementation der Futterrohre (Ringraumzementation) soll folgende Aufgaben erfüllen:

- Verankerung der Rohre im Gebirge durch Haftung bzw. mechanische Verkeilung von Zement an Rohrtour und Gebirge.
- Abdichtung des Ringraumes gegen eindringende Fluide (Wasser, Sole, Gas) und Verhinderung des Eindringens dieser Fluide in benachbarte Horizonte oder nach übertage.
- Mechanischer Schutz der Verrohrung bei drückendem Gebirge (Ton, Salz, Gebirgsspannungen).
- Chemischer Schutz der Verrohrung vor Korrosion durch aggressive Wässer.

3.4 Blow Out Preventer

Ist beim Bohren mit erhöhten Formationsdrücken zu rechnen (Wasser, Öl, Gas) muss die Bohrung schnell geschlossen werden können, damit ein Eindringen von Fluiden in das Bohrloch (Kick) kontrolliert werden kann und es nicht zu einem unkontrollierten Ausbruch (Blow out) von Fluiden kommt. Dazu wird ein Blow Out Preventer (BOP) auf der letzten, zementierten Verrohrung aufgebaut. Dieser ermöglicht, eine Bohrung hydraulisch zu kontrollieren. Er besteht aus folgenden Komponenten:

- Ringpreventer (annular blow out preventer);
- Backenpreventer (blind ram, shear ram, pipe ram);

- Anlage zur hydraulischen Preventersteuerung (accumulator system);
- Ausbruchverhütungssystem (choke and kill manifold).

3.5 Bohrloch-Havarien

Trotz fachgerechtem Einsatz von gutem Material kann es bei einer Tiefbohrung zu Havarien kommen. Typische Havarien können sein:

- Festwerden des Bohrgestänges/des Meissels;
- Bruch des Bohrgestänges;
- Bruch oder Festwerden der Verrohrung;
- Probleme beim Zementieren;
- Fremdkörper im Bohrloch;
- gerissene Seile/Kabel (z. B. bei Bohrlochmessungen).

Massnahmen zur Beseitigung von Havarien sind zum Beispiel:

- Bei Festwerden: Bestimmung der Lokation (Dehnungsmessung), Freischlagen, Freivibrieren, Freiziehen mit Verrohrungseinrichtung, Wechsel der Spülung, Überbohren, notfalls Abschrauben oder Absprengen des Gestänges → Bohrung ablenken.
- Beim Bruch des Bohrgestänges: Fangarbeiten mittels geeigneter Fangwerkzeuge: Fangdorn (tap), Fangglocke (overshot) etc.
- Bei Fremdkörper im Bohrloch: Einsatz von Sohlenreinigungswerkzeugen: Magnetfänger, Fangspinne, Fangvorrichtung (junk basket) etc.

Eine erfahrene Bohrunternehmung kennt den Umgang mit Havarien. Entsprechende Vorgehensweisen sind bekannt und erprobt, das notwendige Material ist auf dem Bohrplatz vorhanden. Die Ursachen von Bohrlochhavarien sind vielfältig (geologisch, technisch, operationell) und können, trotz z. T. aufwendigen Gegenmassnahmen, zum Verlust des Bohrlochs führen, was eine Ablenkung der Bohrung (side track) oder ein Neuansetzen der Bohrung zur Folge haben kann.

4 Zur Hydrogeologie des tiefen Untergrundes

4.1 Begriffe

Grundwasser wird nach DIN 4049 definiert als «unterirdisches Wasser, das die Hohlräume der Erdrinde zusammenhängend ausfüllt und dessen Bewegung ausschliesslich oder nahezu ausschliesslich von der Schwerkraft und den durch die Bewegung selbst ausgelösten Reibungskräften bestimmt wird.» Diese naturwissenschaftlich-technische Definition umfasst somit alle im Untergrund vorkommenden Wässer und unterscheidet sich vom Begriff «Grundwasser» wie er in der schweizerischen Gesetzgebung verwendet wird (Kap. 2).

Felsgrundwasser und *Lockergesteinsgrundwasser* bilden zusammen das Grundwasser im naturwissenschaftlich-technischen Sinne. Der Begriff *Bergwasser* oder *Grubenwasser* wird typischerweise im Untertagbau bzw. im Bergbau verwendet. In einem Tunnel abfließendes Bergwasser wird auch *Tunnelwasser* genannt.

Formationswasser oder *Tiefengrundwasser* können als synonyme Begriffe verwendet werden. In den Berichten der Nagra wird für die Nordschweiz in der Regel der Begriff «Tiefengrundwasser» verwendet (Schmassmann 1990, Schmassmann et al. 1992). Bei *Lagerstättenwasser* handelt es sich um Wasser, das sich natürlicherweise in einer Lagerstätte befindet und durch die Förderung von Erdöl oder Erdgas zutage gefördert wird. Wir verwenden im Weiteren den Begriff Tiefengrundwasser für Wasser aus Festgesteinen des schweizerischen Mittellandes.

4.2 Tiefengrundwasser im schweizerischen Molassebecken

In der *Molasse* sind die obersten paar 100 m durch Ca-Mg-HCO₃- und Na-HCO₃-Wässer geprägt, während darunter zunehmend Na-Cl-Wässer zu erwarten sind.

Grundsätzlich ist mit zunehmender Tiefe

eine Zunahme der Mineralisation zu erwarten, welche mit einer längeren Verweildauer des Wassers im Untergrund einhergeht. Gemäss einer Studie der Nagra (Schmassmann 1990) können für die Molasse der Nordschweiz drei Hauptwassertypen unterschieden werden, deren Abgrenzungen diskordant zu den geologischen Schichtabfolgen verlaufen. Von oben nach unten sehen sie wie folgt aus (Fig. 1):

- **Ca-Mg-HCO₃-Wässer** mit verhältnismässig kurzer Verweilzeit (< 35 Jahre) im Untergrund, welche oberflächennah meist in weniger als 100 m Tiefe anzutreffen sind.
- **Na-HCO₃-Wässer**, welche in erster Linie auf kaltzeitliche, pleistozäne Infiltration zurückzuführen sind und im Raum St. Gallen vermutlich bis in mehrere 100 m Tiefe charakteristisch sind.
- **Na-Cl-Wässer**, bei welchen es sich um mit infiltrierten Wässern verdünnte Formationswässer marinen oder brackischen Ursprungs handelt. Sie bilden die tiefen Wässer, welche nicht oder kaum in Wechselwirkung mit jüngerem Wasser stehen. In grösseren Tiefen bestimmen in Na-Cl-Wässern die Na-Cl-Gehalte weitgehend die Gesamtmineralisation.

Die Gesamtmineralisation der Tiefengrund-

wässer der Molasse liegt in der Grössenordnung von wenigen 100 bis um 1'000 mg/l. Es handelt sich somit um Süßwasser.

In den *mesozoischen Schichtreihen* findet im süddeutschen Raum mit dem Abtauchen ins Molassebecken nach unten rasch ein Wechsel von Ca-SO₄-HCO₃- zu Na-Cl-Wässern statt. In Tiefbohrungen wurden nördlich des Bodensees verbreitet Na-Cl-Konzentration von 10-80 g/l festgestellt. Es wird angenommen, dass diese Solen im Tertiär infolge tektonischer Bewegungen eingeschlossen wurden (Bertleff et al. 1988). Der Sulfatgehalt nimmt in der Regel mit der Tiefe verhältnismässig wenig zu.

In Benken wurden im Malm 10 g/l gelöste Stoffe gemessen. Im Trigonodus-Dolomit des *Oberen Muschelkalkes* wurde in 813-826 m Tiefe Wasser vom Ca-Mg-SO₄-(HCO₃)-Typ angetroffen mit einer totalen Mineralisation von rund 2.4 g/l (Nagra 2001). In seinen Hauptkomponenten ist in Benken das beprobte Wasser typisch für den Muschelkalk-Aquifer und vergleichbar mit anderen Muschelkalkwässern aus der Nordschweiz. Im *Permokarbon* wurden in der Schweiz von der Nagra hochsaline Wässer durchbohrt (36-120 g/l in rund 1'100-1'420 m Tiefe) (Nagra 1989).

Im *Kristallin* ist mit heterogenen Wässern ohne eine gesetzmässige Zunahme der Salinität

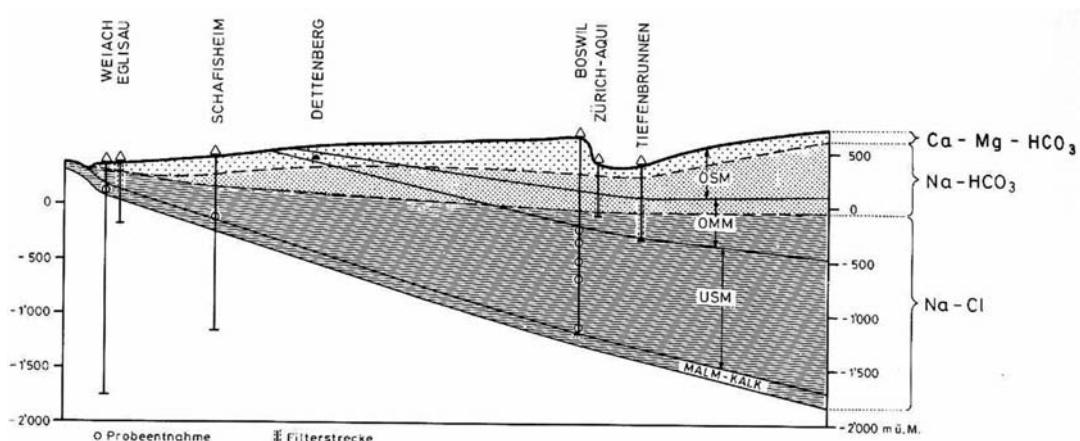


Fig. 1: Verbreitung der Wässertypen im schweizerischen Molassebecken (Schmassmann 1990).

nität mit der Tiefe zu rechnen. In den Bohrungen der Nagra der Nordschweiz sind Anzeichen erkennbar, dass die Chemie je nach Durchlässigkeit des Gesteins ändert. Demnach sind in weniger durchlässigen Bereichen tendenziell höher mineralisierte Wässer zu erwarten (Kanz 1987). In den besser durchlässigen Bereichen sind Mischwässer aus den überliegenden Sedimenten und aus tieferliegenden Bereichen des Kristallins wahrscheinlich. In der Nagra-Bohrung Weilach wurden in rund 2'200–2'300 m Tiefe Na-Cl-Gehalte von 6.4–8.0 g/l und in Schafisheim in 1'500–1'900 m Tiefe 7.9–8.0 g/l gemessen (Pearson et al. 1989). Hochsaline Tiefenwässer sind auch aus Tiefbohrungen im Kristallin in Deutschland bekannt. So wurden in der Kontinentalen Tiefbohrung in der Oberpfalz in rund 4 km Tiefe 63 g/l (Möller et al. 1997) und in Soultz-sous-Forêts 97.6 g/l (145 °C) Gesamtmineralisation gemessen (Aquilina et al. 2000).

Von der Geothermiebohrung St.Gallen GT-1 wurde für das aus dem Malm geförderte Wasser eine Gesamtmineralisation von ca. 20 g/l rapportiert.

5 Hydraulic Fracturing

5.1 Der Begriff Hydraulic Fracturing (Fracking)

Im Wikipedia ist der Begriff «Fracking» wie folgt definiert: «Hydraulic Fracturing oder kurz Fracking (von englisch to fracture «aufbrechen», «aufreissen»; auch «Hydrofracking», «Fracking», «Fraccing» oder «Frac Jobs» genannt, deutsch auch hydraulische Frakturierung, hydraulisches Aufbrechen, hydraulische Risszerzeugung oder auch hydraulische Stimulation) ist eine Methode zur Erzeugung, Weitung und Stabilisierung von Rissen im Gestein einer Lagerstätte im tiefen Untergrund, mit dem Ziel, die Permeabilität (Durchlässigkeit) der Lagerstättengesteine zu erhöhen. Dadurch können darin befindliche Gase oder Flüssigkeiten leichter und

beständiger zur Bohrung fliessen und gewonnen werden» (Wikipedia: Hydraulic Fracturing, 2014).

Diese Definition hat offensichtlich den Einsatz in der Kohlenwasserstoff(KW)-Industrie im Fokus. Jedoch ist darin auch der Begriff der «hydraulischen Stimulation» enthalten, wie er in der Tiefengeothermie verwendet wird. In der derzeit laufenden Diskussion, auch in Fachkreisen, wird der Begriff «Fracking» als Begriff für die unkonventionelle Erschließung von KW gesehen, und die «hydraulische Stimulation» als Methode in der Tiefengeothermie. Aus unserer Sicht mag diese Unterscheidung heute noch gelten. Es stellt sich aber die Frage, ob mit der Entwicklung in der Tiefengeothermie nicht auch hier der Einsatz von Additiven notwendig sein wird, um erfolgreich künstliche Wärmetauscher zu erzeugen und diese effizient betreiben zu können.

5.2 Hydraulic Fracturing zur Kohlenwasserstoffförderung

Diese Technologie wurde erstmals in den 1940er Jahren von der Kohlenwasserstoff(KW)-Industrie zur Erhöhung der Ausbeute von Erdgas und Erdöl aus konventionellen Lagerstätten eingesetzt, d. h. aus KW-Vorkommen in porös-permeablen, von undurchlässigen Barriere-Formationen abgedichteten Speichergesteinen. Hydraulic Fracturing hat sich seitdem zu einer Schlüsseltechnologie zur Erschließung von Erdgas und Erdöl aus relativ dichten Sandsteinen oder karbonatischen Speichergesteinen (sogenanntes Tight Gas) sowie aus Schiefern (shale gas) entwickelt. Weltweit sind inzwischen rund drei Millionen Fracking-Massnahmen in Bohrungen durchgeführt worden. In Deutschland wird die Fracking-Technologie seit 1961 – ohne messbare Beeinträchtigungen der Umwelt – zur Steigerung der Produktionsrate von weniger ergiebigen KW-Lagerstätten und insbesondere zur Gewinnung von Tight Gas eingesetzt (Deutsche Akademie der Technikwissenschaften 2014).

5.3 Hydraulische Stimulation in der Tiefengeothermie

In derselben Publikation (Deutsche Akademie der Technikwissenschaften 2014) wird die hydraulische Stimulation in der Tiefengeothermie als «... vergleichsweise junges, inzwischen aber weltweit etabliertes...» Verfahren für die Erschliessung von Erdwärmeverreservoiren im tieferen Untergrund zur Energiegewinnung (Tiefengeothermie) bezeichnet. Es wird weiter ausgeführt, dass dazu in der Regel keine chemischen Additive verwendet würden.

Auf Additive kann verzichtet werden, da davon ausgegangen wird, dass bei der Öffnung bestehender Klüfte bzw. bei der Entstehung neuer Risse die auf Rissflächen wirkende Scherspannung zu einem Versatz entlang der Rissfläche führt, was bewirkt, dass sich die raue Rissfläche nicht mehr schliesst («self-proping Effekt», GtV - BV 2012). Wenn das Gestein nur geringe Scherspannungen aufweist oder nur Zugrisse parallel zur Hauptspannung erzeugt wurden, so dass kein Versatz der Rissflächen zu erwarten ist, und die Risse sich wieder schliessen wür-

den, wird der Einsatz von sogenannten Stützmitteln (Proppants) als Möglichkeit dargestellt (GtV - BV 2012).

Bei den bis heute in Deutschland durchgeführten hydraulischen Stimulationen wurden Drücke von 100-400 bar (am Bohrlochkopf) angewandt. Es wird davon ausgegangen, dass mit hydraulischer Stimulation horizontale Risse von mehreren hundert Metern Länge erzeugt werden können.

Bei der Geothermiebohrung Basel wurde bei der hydraulischen Stimulation ein maximaler Kopfdruck von 300 bar bei einer Fliessrate von rund 55 l/s während rund eines halben Tages angewandt. Insgesamt wurden während der gesamten hydraulischen Stimulation in 6 Tagen 11'600 m³ Wasser ohne Additive verpresst. Bei den derzeit in Planung befindlichen EGS-Projekten der Geoenegie Suisse AG wird davon ausgegangen, dass bei der Erzeugung eines Wärmetauschers eine Fläche von insgesamt ca. 4 km² erschlossen werden muss. Bei einer theoretischen Rissgrösse von 200 × 200 m entspricht dies 100 Rissebenen.

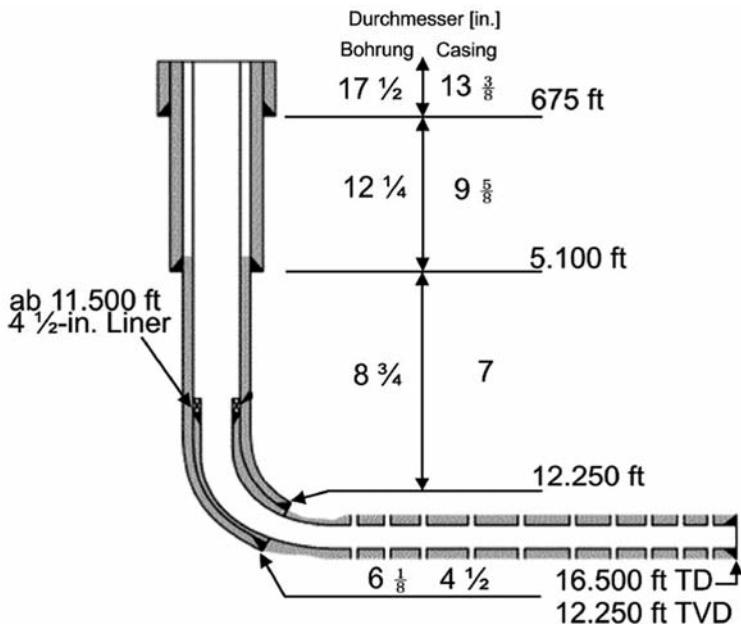


Fig. 2: Beispielhaftes Verrohrungsschema einer Horizontalbohrung (nicht massstäblich). TD: Länge der Bohrung gemessen vom Bohrungsanzpunkt (total depth); TVD: Vertikaler Abstand des Bohrlochtiefsten zum Bohrungsanzpunkt (true vertical depth); Massangaben: 1 ft = 0.3048 m; 1 in. = 2.54 cm (aus Meiners et al., 2012, nach Rohwer et al. 2006).

5.4 Ablauf einer hydraulischen Stimulation / Fracking-Massnahme

Nachdem eine Bohrung den entsprechenden Zielbereich erreicht hat, wird diese vollständig verrohrt und zementiert (Fig. 2). Mit der Verrohrung und der Zementation wird sichergestellt, dass aus der Bohrung keine Fluide in die Formationen gelangen können (und umgekehrt) und dass außerhalb der Bohrung im Ringraum keine Fluidzirkulation zwischen verschiedenen Formationen oder nach Übertrag möglich ist. Der Erfolg dieser Massnahmen muss mit geeigneten Mitteln geprüft werden (Drucktest, cased hole logging).

Der folgende Ablauf einer hydraulischen Stimulation / Fracking-Massnahme ist nach Meiners et al. 2012 beschrieben.

Perforation: Ein erster Schritt für eine hydraulische Stimulation ist die abschnittsweise Perforation der Verrohrung im Zielbereich. Dabei kommt üblicherweise ein Hohlladungsperforator zum Einsatz. Dieser enthält Aussparungen, welche mit Sprengstoff und Hohlladungen bestückt sind. Bei der Zündung durchschlagen Projektille mit hoher Geschwindigkeit die Rohrtour und den Zement und dringen in das Gestein ein. Die Energie wird durch das konische Gehäuse in einer Richtung konzentriert und durch die resultierende Verformung entsteht ein Projektil aus verflüssigtem Metall. Auf diese Weise werden mehrere Perforationen gleichzeitig pro Meter erzeugt. Um die Gesteinsbruchstücke und Überreste des Projektils aus der Perforation zu entfernen, wird das Perforieren meist unter Spülungsdrücken unterhalb des Porendrucks der Formation durchgeführt.

Fracking: Grundsätzlich wird beim Fracken abschnittsweise ein Fluid mit einer höheren Rate in das Bohrloch gepumpt als durch Infiltration in das Gestein die Bohrung wieder verlässt. Dadurch erhöht sich der Druck bis zu dem Punkt, an dem ein Riss im Gestein

entsteht. Kreiselpumpen kommen zum Mischen und Befördern der Fracking-Fluide bei niedrigen Drucken zum Einsatz. Hochdruck-Verdrängerpumpen befördern das fertig gemischte Fluid (Suspension) in das Bohrloch.

Der Ablauf einer Frack-Massnahme gliedert sich in folgende Phasen:

1. Säure-Phase: Verdünnte Säure (HCl) dient der Säuberung des Bohrlochs von Zementrückständen im Bereich der perforierten Verrohrung sowie dem Lösen von Karbonaten und der Erweiterung und dem Aufbrechen bereits bestehender Klüfte im Nahbereich der Bohrung.
2. Füll-Phase (pad stage): Frack-Fluid, u.a. mit reibungsmindernden Zusätzen, wird ohne Stützmittel unter stufenweise erhöhtem Druck und Verpressraten eingepresst. Die Rissbildung wird dadurch eingeleitet.
3. Stütz-Phase (prop stage): In dieser Phase wird nach eingeleiteter Rissbildung dem Fluid unter stufenweise erhöhter Konzentration Stützmittel in Suspension zugegeben. Aufgrund der Infiltration von Fluid in das Gestein erhöht sich die Konzentration der Suspension, während sie durch den Riss strömt, da das Stützmittel in der Suspension verbleibt.
4. Ziel ist ein gleichmässiges Füllen des Risses mit dem Stützmittel. Die Suspension mit geringer Stützmittelkonzentration, mit welcher die Stütz-Phase eingeleitet wird, legt die längste Strecke im Riss zurück und verliert somit am meisten Fluid durch Infiltration in das Gestein. Zum Ende der Stützphase wird Suspension hoher Konzentration verpresst.
5. Spül-Phase (flush stage): Diese Phase dient dazu, in der Bohrung verbliebenes Stützmittel in den Riss zu spülen. Dazu wird Wasser verwendet.

Danach wird das Einpressen von Fluid beendet und die Bohrung für einige Zeit verschlossen (shut-in). Durch die anhaltende Infiltration in das Gestein sinkt der Druck all-

mählich ab und der erzeugte Riss schliesst sich, soweit es das Stützmittel zulässt. Der Zusatz und der Einsatz von Frack-Fluiden erfolgen lagerstättenspezifisch und werden an den Frackverlauf angepasst.

Der beim Fracking maximal angewendete Druck richtet sich nach den Spannungsverhältnissen im Gebirge, die unter anderem von der Tiefenlage abhängig sind.

5.5 Rissbildung

Entscheidend für die Orientierung der Rissausbreitung ist das im Reservoir vorherrschende Spannungsfeld. Die Rissausbreitung erfolgt bevorzugt senkrecht zur Richtung der geringsten Spannung.

Gemäss einer amerikanische Studie von 44 Regionen, in denen Horizontalbohrungen mit Fracking durchgeführt wurden, konnte eine Rissausbreitung im Untergrund von 12 bis 295 m aufwärts und 10 bis 190 m abwärts festgestellt werden (Maxwell 2011, zitiert in Dannwolf et al. 2014). Eine weitere Studie von 1'170 Bohrungen in den USA zeigte eine hydraulische Rissausdehnung nach oben

von maximal 588 m (Barnett Shale). Nur sehr wenige hydraulische Risse können sich zufolge über mehr als 500 m ausbreiten, da geschichtete Sedimentgesteine eine natürliche Barriere bilden (Davies et al. 2012 zitiert in Dannwolf et al. 2014). Fracs (Risse) aus mehr als 1'000 m Tiefe bis an die Oberfläche sind daher nicht möglich.

5.6 Fracking-Fluide

Bei der Schiefergas-Gewinnung wird in die im Gebirge erzeugten Risse mit dem Frack-Fluid im Allgemeinen Stützmittel eingebracht (sog. Proppants, z. B. Quarzsand oder keramische Partikel). Diese halten die Risse gegen den Gebirgsdruck offen und sorgen dafür, dass die geschaffenen Wege samkeiten auch in der Förderphase erhalten und damit dauerhaft bessere Fliessbedingungen für das Erdgas zur Förderbohrung hin bestehen bleiben.

Weitere dem Frack-Fluid zugesetzte Additive haben u. a. den Zweck, den Transport des Stützmittels in die Risse zu gewährleisten, Ablagerungen, mikrobiologischen Bewuchs,

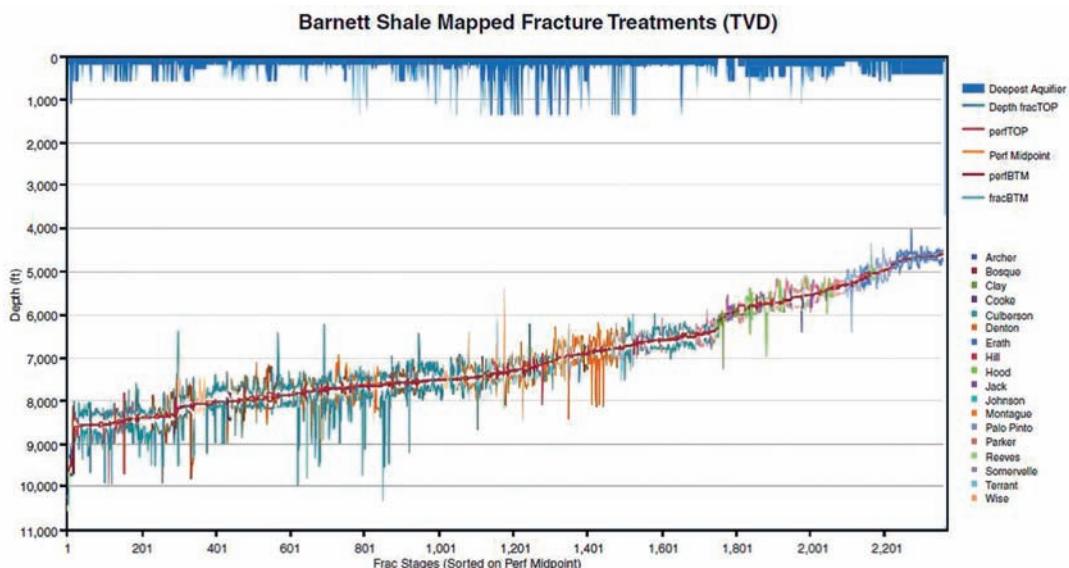


Fig. 3: Rissausdehnung in «Barnett Shales», Texas (Fisher 2010). Mit mikroseismischen Messverfahren bestimmte Ausdehnung von Fracrisen in den Barnett Shales in the Fort Worth Basin in Texas (rund 2'400 Fracs).

die Bildung von Schwefelwasserstoff und ein Quellen der Tonminerale im Frack-Horizont zu verhindern, Korrosion zu vermeiden und die Fluidreibung bei hoher Pumpleistung zu minimieren (Meiners, et al. 2012). Neben Stützmittel sind weitere Additive von Frack-Fluiden: Ablagerungshemmer, Biozide, Gelbildner, Hochtemperaturstabilisatoren, Kettenbrecher, Korrosionsinhibitoren, Lösungsmittel, pH-Regulatoren, Quervernetzer, Reibungsverminderer, Säuren, Schwefelwasserstofffänger, Tenside/Netzmittel, Tonstabilisatoren. Wie bei der Bohrspülung haben die Fracking-Fluide vielfältige Eigenschaften aufzuweisen, damit sichergestellt ist, dass die Fracking-Massnahme sicher abläuft und die gewünschte Wirkung erzielt wird.

Moderne Fracking-Fluide bestehen aus ca. 70% Wasser und 29% Stützmittel. Die Additive machen in Deutschland einen Anteil von ca. 1% aus. Als Additive stehen dabei etwa 50 Inhaltsstoffe zur Verfügung, von denen keiner die Wassergefährdungsklasse 1 (WGK 1 = schwach wassergefährdend) übersteigt. Für die Zubereitung eines Frack-Fluids werden in der Regel 5 bis 15 dieser Stoffe verwendet (Deutsche Akademie der Technikwissenschaften 2014).

Das eingesetzte Fluidvolumen pro Frackphase richtet sich nach den lokalen Gegebenheiten. Pro Frackphase betragen die eingesetzten Volumen in der Größenordnung von 1'000–1'500 m³, pro Bohrung sind es Volumen von 10'000–20'000 m³.

Die Stabilität von modernen Fracking-Fluiden ist in mittleren Tiefen bei mittleren Temperaturen gewährleistet. Bei hohen Temperaturen, wie sie in der Tiefengeothermie angestrebt werden, bestehen diesbezüglich noch keine Erfahrungen. Fracking-Fluide basierend auf Stickstoff (N₂), Kohlenstoffdioxid (CO₂) oder Propan (C₃H₈) sind möglich, in Tight Reservoirs erprobt und bieten gegenüber wasserbasierten Fracking-Fluiden gewisse Vorteile, sind aber in der Schiefergasnutzung nicht im industriellen Einsatz.

6 Risiken der Untergrundverschlusung und -nutzung

Im Zusammenhang mit der derzeit intensiven Diskussion zum Thema Fracking werden die Risiken der Methode im Zusammenhang mit der Schiefergasförderung in verschiedenen Studien und Berichten dargestellt und erläutert. Im Folgenden wird insbesondere auf die Risiken im Untergrund eingegangen. Detaillierte Darstellungen der Umweltrisiken finden sich in umfassender Form in den beiden Berichten des deutschen Umweltbundesamtes, des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit (Meiners et al. 2012 und insbesondere Dannwolf et al. 2014).

Bezüglich der Risiken von Tiefbohrungen und Fracking werden verschiedene Wirkungspfade analysiert (Fig. 4): Schadstoffeinträge von der Oberfläche (0), Schadstoffaufstiege und -ausbreitung ausgehend von der Bohrung (1), Wirkungspfade entlang von geologischen Störungen (2) und flächenhafte, diffuse Aufstiege bzw. deren laterale Ausbreitung durch geologische Schichten ohne bevorzugte Wegsamkeiten (3).

Trotz rund drei Millionen Frac-Operationen weltweit gibt es keine Beispiele von Fracs in Schiefergas-Fördergebieten oder in der Tiefengeothermie, bei denen künstliche Risse die Oberfläche oder Trinkwasserhorizonte erreicht hätten (Deutsche Akademie der Technikwissenschaften 2014). Verunreinigungen von Oberflächen- oder Grundwasser sind jedoch aufgetreten, wobei der Grund beim Transport, unsachgemäßem Umgang auf dem Bohrplatz oder bei defekten Bohrungen (Leckagen in der Verrohrung, Ringraumzementation) zu suchen ist, beziehungsweise im Zusammenhang mit der Entsorgung von Flowback steht (Transport, Handling). Die bei der Gewinnung von Erdgas aus konventionellen und unkonventionellen Lagerstätten anfallenden Formationswässer und Flowback werden in Deutschland derzeit primär in sog. Versenkbohrungen/Disposalbohrungen entsorgt.

Die seismologische Gefährdung bei der Gewinnung von Schiefergas ist gering. Dies gilt insbesondere für die Betriebsphasen Bohren, Fracken, Produktion und Rückbau. Bei der Betriebsphase Reinjektion von Flowback/Produktionswasser, also bei Verpressbohrungen ist jedoch eine seismologische Gefährdung grundsätzlich nicht auszuschliessen (Dannwolf et al. 2014). In Prague, Oklahoma, kam es in einem Gebiet mit zahlreichen Reinjektionsbohrungen zu einer Zunahme der Erdbebenaktivitäten, wobei auch Schadenbeben zu verzeichnen waren (USGS 2014). Schadenbeben, die dem eigentlichen Fracking zugeordnet werden können, sind weltweit keine bekannt.

Für die Tiefengeothermie gelten grundsätzlich dieselben Ansätze wie bei der Kohlenwasserstoffexploration und -produktion im Allgemeinen bzw. bei der Schiefergasnutzung im Speziellen. Es gibt grosse Ähnlichkeiten bei beiden Gebieten, jedoch auch deutliche Unterschiede. Wegen der vergleichsweise geringen Erfahrung in der Tiefengeothermie gibt es aber auch noch zahlreiche offene Fragen. Wichtigste Aspekte sind:

- Bei der Tiefenerkundung und -erschließung muss verhindert werden, dass Tieffengrundwässer aufsteigen und das nutzbare Grundwasser und den Boden verunreinigen können.
- Bei der Schiefergasnutzung ist das Thema der induzierten Seismizität vorwiegend bei Injektionsbohrungen von Bedeutung.
- Bei der Tiefengeothermie, insbesondere bei EGS, ist die induzierte Seismizität während der Erschließung und der Nutzung des Reservoirs ein wichtiges Thema.
- Die bei einer Geothermie-Tiefbohrung eingesetzten Fluide (Spülung) sind mit denjenigen in der KW-Industrie vergleichbar bzw. identisch.
- Sowohl beim Schiefergas wie auch bei der Tiefengeothermie werden vom selben Standort aus mehrere, abgelenkte Bohrungen (cluster) gemacht. Der Landverbrauch pro Anlage für beide Technologien dürfte somit etwa in derselben Größenordnung liegen.
- Auch der Wasserverbrauch für das Fracking/die Stimulation dürfte sich bei der Schiefergas-Nutzung und der Tiefengeothermie etwa in denselben Dimensionen bewegen.

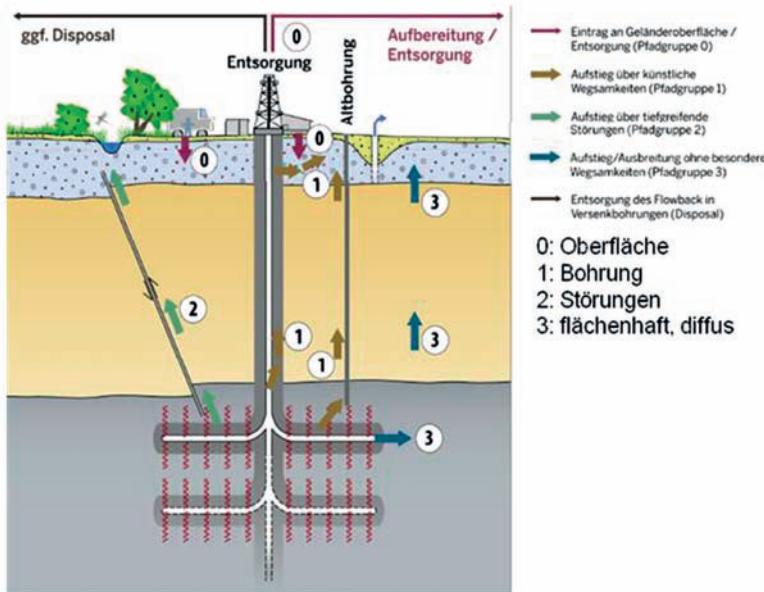


Fig. 4: Schematische Darstellung potentieller Wirkungspfade (Meiners, et al. 2012).

- Bei der Erschliessung und Nutzung von Tight Gas dürfte der Stimulationsaufwand und damit der Wasserverbrauch geringer sein als bei Schiefergas.
- Die Tiefenlagen für die Tiefengeothermie, insbesondere für künftige EGS-Systeme, dürften grösser sein als z. B. bei der Schiefergasnutzung.
- In der Tiefengeothermie (EGS) wurde bis heute für die hydraulische Stimulation praktisch ausschliesslich Wasser eingesetzt.
- Der künftige Einsatz von Additiven bei hydraulischen Stimulationen in der Tiefengeothermie kann nicht ausgeschlossen werden.
- Bei der Nutzung der Tiefengeothermie dürften Fragen wie Korrosionsschutz, Ausfällungen, Bakterienwachstum etc. die Behandlung des zirkulierenden Fluids erfordern.
- Die notwendige Fläche eines geothermischen Wärmetauschers ist erheblich und mit Drainageflächen in der Schiefergasnutzung vergleichbar.
- Wärmetauscher für EGS-Systeme der Tiefengeothermie werden voraussichtlich vorwiegend im kristallinen Grundgebirge erstellt werden (Schweiz). Dieses besitzt andere felsmechanische Eigenschaften als Formationen, die sich für die Produktion von Schiefergas eignen.

Die Energiedichte bei der Nutzung der Geothermie ist im Vergleich zur Energiedichte bei der Gasnutzung vergleichsweise gering. Entsprechend könnte der «ökologische footprint» im Untergrund bei der Tiefengeothermie pro produzierter Kilowattstunde vergleichsweise grösser sein als bei der Gasproduktion. Demgegenüber ist der CO₂-Ausstoss pro kWh bei einem Tiefengeothermiekraftwerk um ein Vielfaches kleiner als bei einem Gaskraftwerk.

7 Chancen der Untergrunderschliessung und -nutzung

7.1 Potenziale

In der Kohlenwasserstoffindustrie sind *Ressourcen* nachgewiesene, aber derzeit technisch und/oder wirtschaftlich nicht gewinnbare sowie nicht nachgewiesene, aber geologisch mögliche, künftig gewinnbare Energierohstoffmengen. *Reserven* sind nachgewiesene, zu heutigen Preisen und mit heutiger Technik wirtschaftlich gewinnbare Energierohstoffmengen.

Bei «possible reserves» besteht eine Gewinnwahrscheinlichkeit von mindestens 10%, bei «probable reserves» eine solche von mindestens 50%. Für «proved reserves» muss eine Wahrscheinlichkeit für deren Gewinnung von 90% gegeben sein. Der Ausdruck «proved reserves» beinhaltet sowohl die bereits produzierten wie auch die noch nicht produzierten Reserven.

In der Geothermie ist das technische Potenzial jene Energiemenge, die mit bekannten Methoden nutzbar ist. In Anbetracht der noch jungen Technologie wurde entsprechend dieser Ausdruck in Anführungszeichen gesetzt.

7.2 Potenzial Erdgas

Die aktivste Phase der Erdöl- und Erdgasexploration in der Schweiz war in den Jahren 1960 bis 1989. Verschiedenste Seismikkampagnen wurden durchgeführt und insgesamt 18 Tiefbohrungen nach Erdöl und Erdgas abgeteuft (Lahusen & Wyss 1995). Mangelnde Erfolge in dieser Zeit hatten zur Folge, dass die Kohlenwasserstoffexploration in der Schweiz im Vergleich zum Süddeutschen Raum vergleichsweise wenig intensiv betrieben wurde.

In zahlreichen Tiefbohrungen wurden Erdöl- und Erdgasindikationen festgestellt. Einzig aus der Bohrung Entlebuch-1 (1980) konnte in den Jahren 1985–1994 74.3 Mio. Kubikmeter Gas gefördert und in die Transitgaspipeline eingespeist werden.

Die Resultate dieser KW-Exploration in der Schweiz lassen sich wie folgt zusammenfassen (Brink et al. 1992):

- Reife Muttergesteine sind vorhanden.
- Migration hat stattgefunden.
- Fallenstrukturen sind vorhanden (kompressives Regime).
- Reservoirhorizonte sind vorhanden, jedoch ist die Reservoirqualität eher bescheiden.

Die Gas-Reserven (proved reserves?) wurden auf ca. 0.1 Mrd. Kubikmeter Gas geschätzt, etwas mehr, als in Entlebuch gefördert worden war. Dass Erdgas im schweizerischen Untergrund vorhanden ist, lässt sich auch aufgrund der zahlreichen oberflächennahen Erdgasindikationen feststellen (Fig. 5).

Auch der kurze Gas-Fördertest an der Geothermiebohrung St.Gallen GT-1 war mit über 5'000 m³ pro Stunde sehr eindrücklich. Die initiale Förderrate in Entlebuch (nach dem Produktionstest, im ersten Jahr der Produktion) lag bei ca. 3'500 m³ pro Stunde.

Aufgrund tiefer Erdgaspreise kam die Erdgasexploration Anfang der 90er Jahre praktisch zum Erliegen. Auch wurden «unkonventionelle» Projekte wie die Gasproduktion aus Kohleflözen, die Entwicklung von «low

porosity/low permeability» Reservoiren (Tight Gas) oder von tiefen Erdgaslagerstätten im Bereich der alpinen Decken nicht weiter bearbeitet (Lahusen & Wyss 1995). Dank neuer Technologien in der KW-Exploration und der nicht nachlassenden Nachfrage nach Energie in der Schweiz im Kontext der dynamischen Entwicklung auf dem Energiesektor in Europa und der Welt ist das Thema einheimischer Ressourcen nach wie vor aktuell. Neuste Schätzungen zeigen, dass unter dem mittleren und dem südlichen schweizerischen Mittelland ungefähr 50–150 Mia. Kubikmeter förderbares Schiefergas vorhanden sein könnten (Leu 2014). In Relation zum heutigen jährlichen Gaskonsum der Schweiz von ca. 3.5 Mia. m³ ist dies eine signifikante Ressource. Für Tight Gas liegt das Potenzial in der Größenordnung von 150–300 Mia. m³, für Kohleflözgas liegen keine Zahlen vor (Leu, mündl. Mitt.). Zum Vergleich: 1 Mia. m³ Erdgas entsprechen einer Energie von rund 10'000 GWh, was ca. einem Drittel des heutigen jährlichen Gasverbrauchs in der Schweiz entspricht. Es ist abzuklären, ob und in welchem Ausmass diese Potenziale nutzbar sind.

Potenzial	Kohlenwasserstoffe	Geothermie
Theoretisches Potenzial	Ressourcen und Reserven «gas in place» «proved, probable and possible reserves»	Heat in Place, im Gestein enthaltene Wärme
Technisches Potenzial	Ressourcen «technically recoverable» «proved and probable reserves»	Technisch nutzbarer Wärmeinhalt, mit «bekannten» Methoden nutzbare mögliche Wärme
Wirtschaftliches Potenzial	Reserven «economically recoverable» «proved reserves»	Wirtschaftlich nutzbarer Wärmeinhalt

Tab. 1: Potenziale von Kohlenwasserstoffen und geothermischer Energie.

7.3 Potenzial Tiefengeothermie

Eine Studie des Paul Scherrer Instituts (Hirschberg et al. 2005) schätzt für die Schweiz in 3–7 km Tiefe ein theoretisches Potenzial von 15'900'000 TWh_{th}. Bei einem Gewinnungsfaktor von 4% und, je nach Tiefenlage bzw. Temperaturniveau, einem elektrischen Wirkungsgrad von 10–14% lässt sich daraus ein «technisches» Potenzial von 82'500 TWh_e abschätzen. Bei einem Stromverbrauch in der Schweiz von rund 60 TWh_e pro Jahr ist dies eine bedeutende Ressource. Die in der Energiestrategie des Bundes vorgenommenen Schätzungen für die Geothermie beziehen sich nicht auf die effektiv vorhandene Ressource, sondern auf einen möglichen Zuwachs und somit auf das Wachstum der Branche von ca. 10% pro Jahr. Bis 2035 wird eine Stromproduktion von 1'100 GWh/a erwartet. Dies entspricht einer installierten Leistung von ca. 135 MW (zum Vergleich: im KKW Mühleberg ist eine Leistung von 450 MW installiert). Bei einer Anla-

gengrösse von 5 MW_{el}, eine Dimension, wie dies für Basel oder St.Gallen angedacht war, wären dies 27 Anlagen, wobei dazu jeweils 2–3 Bohrungen notwendig sind.

Bis 2050 wird in der Energiestrategie von der Geothermie eine Stromproduktion von 4'400 GWh/a erwartet, was einer Leistung von 550 MW entspricht. Bei 5 MW-Anlagen wären dies 110 Anlagen. Sollten mit zunehmender Reife der Technologie in Zukunft auch grössere Anlagen möglich sein, würde sich die Anzahl der (Oberflächen-)Anlagen reduzieren, nicht jedoch die Anzahl der für diese thermische Leistung notwendigen Bohrungen.

Es ist davon auszugehen, dass die an die Geothermie gestellten Erwartungen nur erfüllt werden können, wenn es gelingt, die EGS-Technologie in einem entsprechenden Ausmass zu entwickeln. Dazu müssen ebenfalls die Kosten erheblich gesenkt werden, was nur durch das Abteufen von grossen Serien von Bohrungen möglich sein wird (economies of scale).

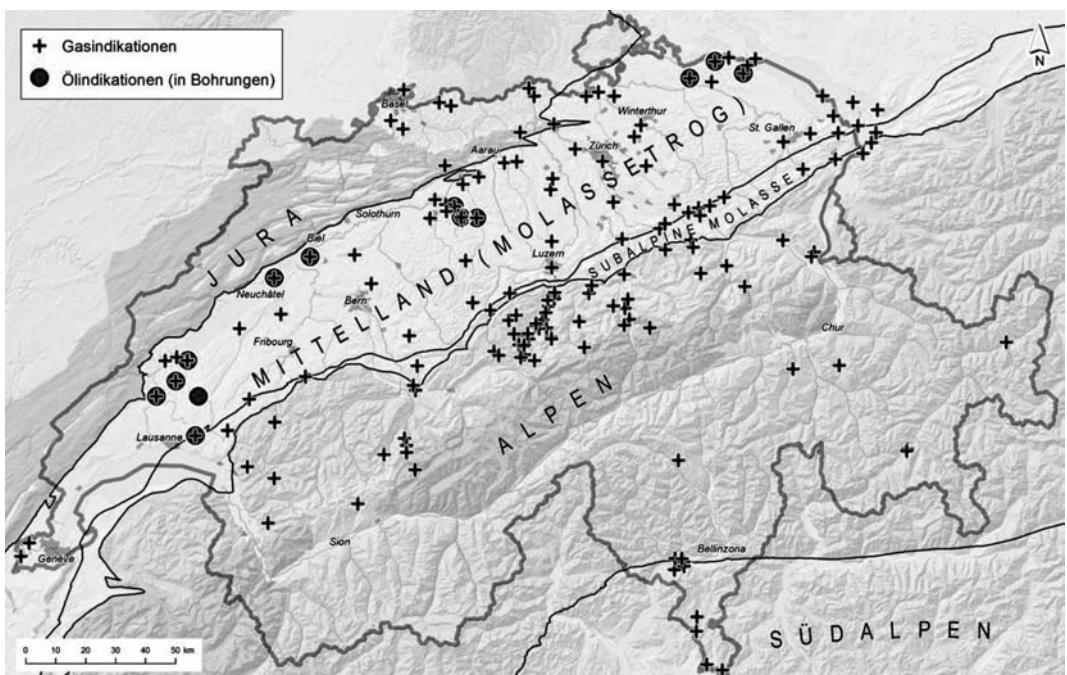


Fig. 5: Erdöl- und Erdgasindikationen in der Schweiz. An der Oberfläche, in Tunnels, untiefen Bohrungen (< 400 m) und Tiefbohrungen gibt es zahlreiche Hinweise auf Erdöl und Erdgas in der Schweiz.

8 Schlussbemerkungen

In der Energiestrategie 2050 des Bundes spielen neben Energieeffizienz und neuen erneuerbaren Energien u. a. auch Gaskraftwerke eine Rolle. Weltweit nimmt die Nachfrage nach Energie zu. Daher ist es für die Schweiz wichtig, die Frage nach der künftigen Energieversorgung, auch aus eigenen Quellen, breit zu diskutieren. Durch neue Methoden in der Untergrunderkundung scheinen sich für die Schweiz Möglichkeiten zu eröffnen, eigene Energieressourcen zu erkunden und zu erschliessen.

In Anbetracht der sehr grossen vorhandenen Potenziale an Erdgas und Geothermie im Untergrund müssen diese untersucht werden. Dazu braucht es neben Forschung an den Hochschulen insbesondere auch konkrete Projekte: Seismische Untersuchungen und Tiefbohrungen. Damit kann abgeklärt werden, welche Rolle diesen beiden Energierohstoffen in Zukunft zukommen kann. Dazu sind aber auch unternehmerischer Weitblick und Innovationsgeist notwendig.

Durch die medial geführte Diskussion über das Fracking ist nicht nur die Ressource Erdgas in Verruf geraten, sondern indirekt auch die Zukunft der Tiefengeothermie in Frage gestellt. Die Wortklaubereien über Fracking in der Schiefergasnutzung und hydraulische Stimulation in der Geothermie sind dazu wenig hilfreich. Spitzfindige Argumentationen sind in der Öffentlichkeit kaum zielführend.

Jede Erschliessung und Nutzung des tiefen Untergrundes stellt einen Eingriff in den Untergrund dar. Mannigfaltige Erfahrungen zeigen, dass es möglich ist, ohne den Schutz unserer Trinkwasserressourcen (Grundwasser, Quellen und Oberflächengewässer, Seen) zu beeinträchtigen und ohne Gefährdung für Menschen und Infrastruktur, sowohl Erdgas und als auch Geothermie zu erschliessen und zu nutzen. Allfällige Nutzungskonflikte im Untergrund zwischen einer Gasexploration und -produktion und der Tiefengeothermie sind in der Schweiz

nicht erheblich und können geregelt werden. Die Entwicklung beider Technologien dürfte für beide wichtige Synergien bringen. Für die Branche braucht es klare, verlässliche Regeln, die auf der Basis wissenschaftlicher Erkenntnisse und Erfahrungen sachlich fundiert sind. Unnötige Hürden und Erschwernisse erhöhen die Kosten einer Technologie und vermindern somit deren Potenzial. Die Öffentlichkeit ist über die Chancen und Risiken klar und transparent zu informieren.

Das Thema der Untergrunderkundung und -nutzung muss über die weltanschaulichen Grenzen hinweg diskutiert werden. Die Schweiz hat Geologinnen und Geologen mit guten Kenntnissen über den tiefen Untergrund und über die Methoden, die Energie aus der Tiefe zu gewinnen. Sie können zur Frage der Energiezukunft der Schweiz einen kompetenten und wichtigen Beitrag leisten.

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The Shale Gas Potential of the Opalinus Clay and Posidonia Shale in Switzerland – A First Assessment

Werner Leu¹, Andreas Gautschi²

Keywords: Shale gas, Opalinus Clay, Posidonia Shale, Switzerland, Molasse Basin, organic richness, thermal maturity, recoverable gas resources

Abstract

There has been recent interest in the shale gas potential of the Opalinus Clay and Posidonia Shale (Middle and Lower Jurassic) below the Swiss Molasse Basin in the light of the future role of domestic gas production within the expected future energy shift of Switzerland and possible conflicts in underground use. The Opalinus Clay of northern Switzerland is a potential host rock for repositories of both high-level and low-to-intermediate level radioactive waste and the exploitation of shale gas resources within or below this formation would represent a serious conflict of use.

Well data from northern Switzerland shows that these two formations are unsuitable for future shale gas recovery. They never reached the gas window during their burial history (maturity values are $\leq 0.6\% R_o$) and as a consequence never generated significant quantities of thermogenic gas. Geochemical data further shows that the average TOC values are in the range of 0.7%, i.e. clearly below accepted values of more than 1.5% for prospective shales.

A review of available exploration data for the Opalinus Clay and Posidonia Shale in the deeper and western part of the Swiss Molasse Basin indicate that their shale gas potential may be substantial. The gross Posidonia Shale thickness increases from central Switzerland from less than 10 m to over 100 m in the Yverdon-Geneva area and is characterised by numerous bituminous intervals. A simplified shale gas resource calculation results for a geologically likely scenario in a technically recoverable gas volume of ~120 Mrd. m³. The current database for such estimates is small and as a consequence, the uncertainties are large. However, these first encouraging results support a more detailed exploration phase with specific geochemical and petrophysical analysis of existing rock and well log data.

1 Introduction

Recently, the Opalinus Clay (Middle Jurassic, Aalenian) and the underlying Posidonia Shale (Lower Jurassic, Toarcian) of the Swiss Molasse Basin have been mentioned in connection with the search for shale gas (Chew 2010, Leu 2014a). Also the *European Shale Gas Map* (JPT 2012) shows two potential resource plays in Switzerland: Jurassic Shales (probably the Opalinus Clay and the Posidonia Shale) to the north of Lake Geneva and Permian Shales in the eastern part of the Molasse Basin.

The shale gas potential of these formations is currently being discussed in Switzerland because of two reasons: a] domestic natural gas resources, if present, could play an important role in the envisaged energy transition and b] conflicting interests in the future use of the deep underground (natural resources, storage, water, geothermal energy etc.).

In particular, the Opalinus Clay in northern Switzerland is a potential host rock for repositories for both high-level and low- to intermediate-level radioactive waste (Nagra 2008). The conceptual part of the *Sectoral Plan for Deep Geological Repositories* sets out the procedure and criteria for selecting sites for repositories for all waste categories in Switzerland (SFOE 2008). One of the criteria to be evaluated (criterion 2.4) relates to conflicts of use. Within and beneath the host rock, there must be no natural resources that would be worth exploiting in the fore-

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seeable future with the potential for conflict of use. Exploiting such resources within or beneath the host rock formation of a radioactive waste repository could compromise the long-term stability of the barrier system, either by damaging the geological barrier or by drilling directly into disposal caverns. The shale gas potential of the Opalinus Clay and the Posidonia Shale [corresponds to Rietheim Member of the Staffelegg Formation (Reisdorf et al. 2011)], as one possible conflicting natural resource, has been evaluated as part of stage 2 of the Sectoral Plan process (Leu 2014b, Leu & Gautschi 2012). The objective of this paper is to provide a first assessment of the shale gas potential of these Jurassic formations and its distribution within the entire Swiss Molasse Basin. The analysis differentiates between northern Switzerland (wider area surrounding the potential siting areas for radioactive waste repositories) and the more southern parts of the Molasse Basin (Central/Western Switzerland).

2 Shale gas: origin, recovery technology and rock parameters

2.1 Origin of shale gas

Besides coal bed methane and oil shales, gas shales are part of the group of unconventional resource plays (EIA 2011).

Shale gas consists principally of methane stored in micropores and in fractures within an organic rich shale formation (bituminous shale). Part of the gas is further adsorbed on organic components and clay minerals within fine-grained sediments (Passey et al. 2010, Jarvie et al. 2007, Curtis 2002, Canadian National Energy Board 2009). The gas is generated by biogenic (early diagenetic and recent; see below) and thermogenic processes during geological burial and in situ heating within the source rock.

The term *shale gas* originates from the common use of the term *shale* to describe the

group of extremely fine-grained sedimentary rocks like clay- and mudstones composed of particles like clay, quartz, feldspars, organic matter and heavy minerals (Passey et al. 2010). The particle size is generally in the range of < 2 microns up to 62.5 microns (clay and silt fraction).

Part of the hydrocarbon gases that are generated within the organic particles escapes from the source rock rock (primary migration) and migrates into more porous, generally overlying reservoir layers that are sealed at the top with a tight barrier (classical or conventional gas plays). Shale gas is the gas component that remains trapped in the tight, fine-grained rock and cannot normally escape without artificial stimulation by fracturing technology and preferably drilling of horizontal wells. These reservoir rocks have permeability's in the micro- to nanodarcy range (BGR 2012). A gas shale is therefore a source rock, a reservoir and a seal in one and the same formation (*resource play*). Today it is well known that often the greater part of generated gases remains trapped within the source rock (Burri et al. 2011, Burri 2010).

It has only been recognised in recent years that biogenetically generated methane can form economically viable gas deposits in argillaceous rocks. Examples of this are the New Albany Shale (Tab. 1; Devonian, Illinois Basin, USA) and the Antrim Shale (Devonian, Michigan Basin USA; Martini et al. 1996 and 1998). Two types of biogenic methane formation are distinguished: a) early diagenetic biogenic processes related to alteration and decomposition of organic material that begins shortly after deposition of the sediment and b) relatively recent (last 1 to 2 million years) methanogenesis related to bacterial activity associated with the infiltration of meteoric waters into near-surface decompression and fracture zones. Theoretically it is possible to distinguish between the two biogenic and the thermogenic gas fractions, using carbon and hydrogen isotopes of methane, ethane, propane and CO₂. Com-

plex mixing processes, however, often make the distinction not very straight forward (Shurr & Ridgley 2002, Martini et al. 2003, Curtis 2002 and 2010).

2.2 Typical rock characteristics of proven shale gas resource plays

Successful shale gas formations that have been proven to be capable of producing gas at commercial rates can be characterised using typical values for specific rock parameters. However, experience over the last ten years has also shown that economic recovery is often dependent on a combination of these rock parameters that are very specific for one region. This clearly indicates that there is no unique «recipe» for exploration of shale gas resources and each basin and stratigraphic unit has its own learning curve. Several tens of specifically designed exploration wells are normally necessary to assess the technical and economic potential. As part of a broad based comparative study, Gilman & Robinson (2011) showed that the minimum values that are generally published for typical rock parameters are often too pessimistic and that other factors such as stimulation technology, reservoir temperature or natural fracture intensity also play an important role.

The following key rock parameters have to be investigated when exploring shale gas plays:

- *Organic richness* (TOC, total organic carbon): Determines the amount of hydrocarbons that can be formed by the transformation of kerogen. TOC has also a positive correlation with the total gas filled porosity in shales (micro pores and adsorption in organic particles, Passey et al. 2010).
- *Thermal maturity*: Measure for the degree of transformation of kerogen into hydrocarbons (Fig. 1; early biogenic or thermogenic formation during burial; oil window, gas window).
- *Rock mineralogy*: The fractions of clay minerals, quartz and carbonate and organic

matter determine the microporosity, and hence the possible total storage volume of free gases. The mineralogy also influences the brittleness of the rock for hydraulic stimulation (Fig. 2).

- *Thickness* of the shale formation: Determines the overall gas in place per unit area.

Examples of typical rock characteristics for historical shale gas formations with economic production in the USA are summarised in Table 1 (Curtis 2010, see also EIA 2011).

Formation depth is only a relevant factor for economic consideration because it influences the necessary drilling costs to reach the target formation. Prospective areas should have shale resources in the depth range of 1.000 m to 5.000 m (EIA-ARI 2013). Porosity, permeability and the density and type of the natural fracture network are also important, but are secondary parameters that determine the production rate and recovery factor. Regions with intense and deep reaching fault tectonics are normally avoided because of the increased risk of triggered earthquakes and possible inflow of formation waters from over or underlying formations.

The depositional environment determines the kerogen type (I-II-III) in sedimentary rock. Valid shale gas formations could have been deposited either in a marine, a lacustrine or a terrigenous (swamp) environment, as long as the organic richness is high (Fig. 2). Marine and lacustrine shales have a greater potential to produce also oil before the gas. But marine shales tend to have a lower clay content with a higher proportion of brittle minerals such as quartz, feldspar or carbonates (EIA-ARI 2013).

The key rock parameters organic richness, thermal maturity, hardness and formation thickness (discussed above) should generally lie at least within the ranges compiled in Table 2.

If reference wells are available in an exploration area, various parameters like TOC,

mineralogy or porosity can be estimated or calculated using geophysical measurements from wireline logs (e.g. Passey et al. 2010). To optimise the hydraulic stimulation parameters, geomechanical properties and local stress states are increasingly being determined from well data (borehole wall breakouts, analysis of dipole sonic and image logs).

3 The shale gas potential of the Opalinus Clay and the Posidonia Shale in Northern Switzerland

3.1 Key shale rock properties (Northern Switzerland)

The Opalinus Clay, together with the directly underlying Posidonia Shale (Toarcian) has been considered in the context of the conventional hydrocarbon exploration as a potential source and cap rock (Brink et al.

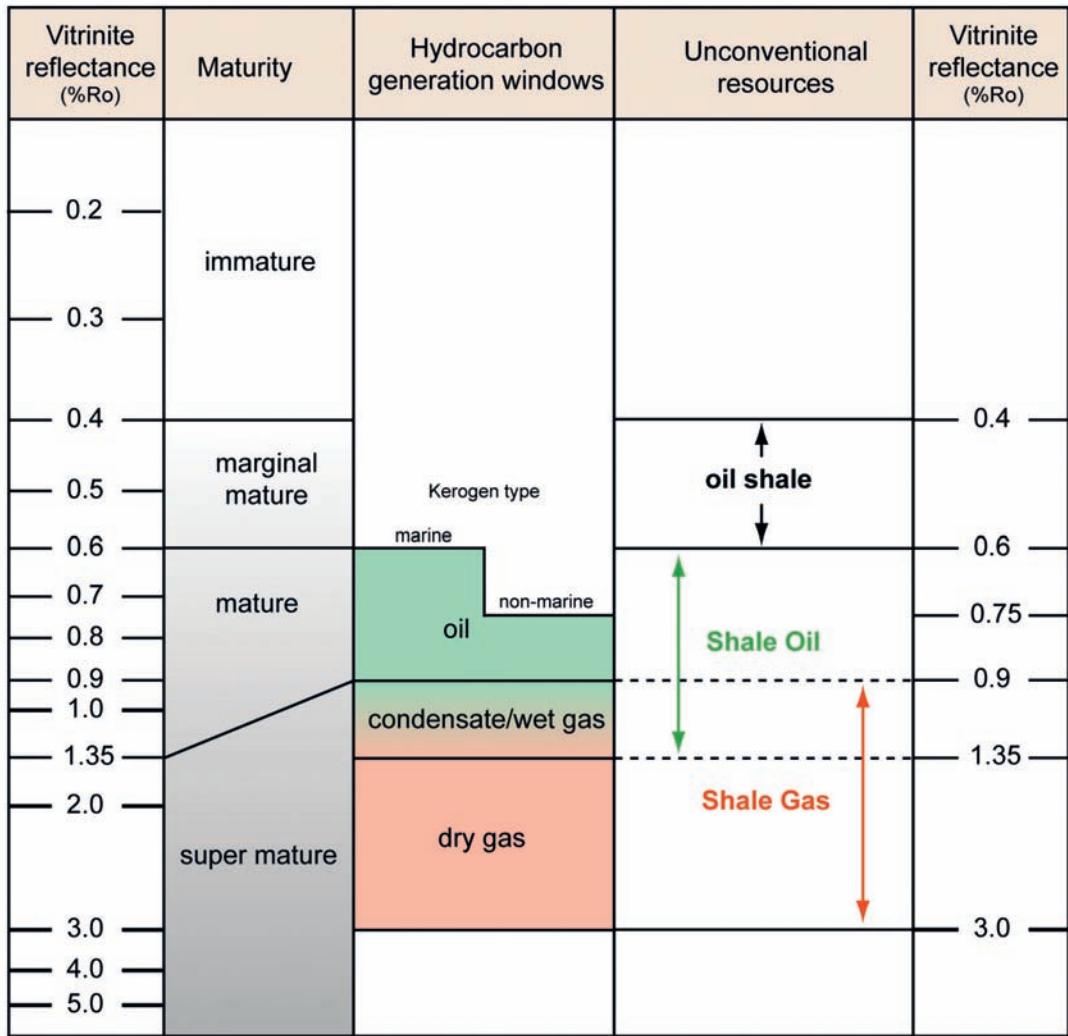


Fig. 1: Thermal maturation scale (vitrinite reflectance) with typical values for oil shale, shale oil and shale gas rocks (modified after EIA-ARI 2013, BGR 2012).

1992, Greber et al. 1997, Schegg et al 1999). Boyer et al. 2011 include also the Swiss/German Molasse Basin in their global shale gas review and Chew (2010) mentions explicitly the Jurassic shale formations in Switzerland in connection with the shale gas exploration activities of the company Schuepbach Energy LLC in Cantons Fribourg and Vaud. Although the Toarcian Posidonia Shale in northern Switzerland may reach up to 10 wt.% TOC (Todorov et al. 1993, Bitterli 1960) its overall thickness remains less than 10 m in the potential siting areas of Northern Switzerland (Kiefer et al. 2014) and any assessment of the shale gas potential has to concentrate in this area on the Opalinus Clay. Related to its shaly lithology with elevated organic contents (grey to brownish/black colours) this Middle

Jurassic unit has some similarities to known historic shale gas formations (Tab. 1) but also very distinct differences.

A detailed compilation of key rock parameters of the Opalinus Clay for northern Switzerland based on ten Nagra exploration wells and further data from the Mont Terri underground rock laboratory (Mazurek 2011, Nagra 2002) have been summarized in Table 3.

Very low organic richness values of ~0.7 wt.% TOC indicate that the Opalinus Clay is a rather lean source rock in this area and stays clearly below accepted minimum values of ~1.5 wt.%. Other formations that are also being investigated by Nagra as potential host rocks (e.g. «Brauner Dogger» and Effingen Member) have even lower values for TOC

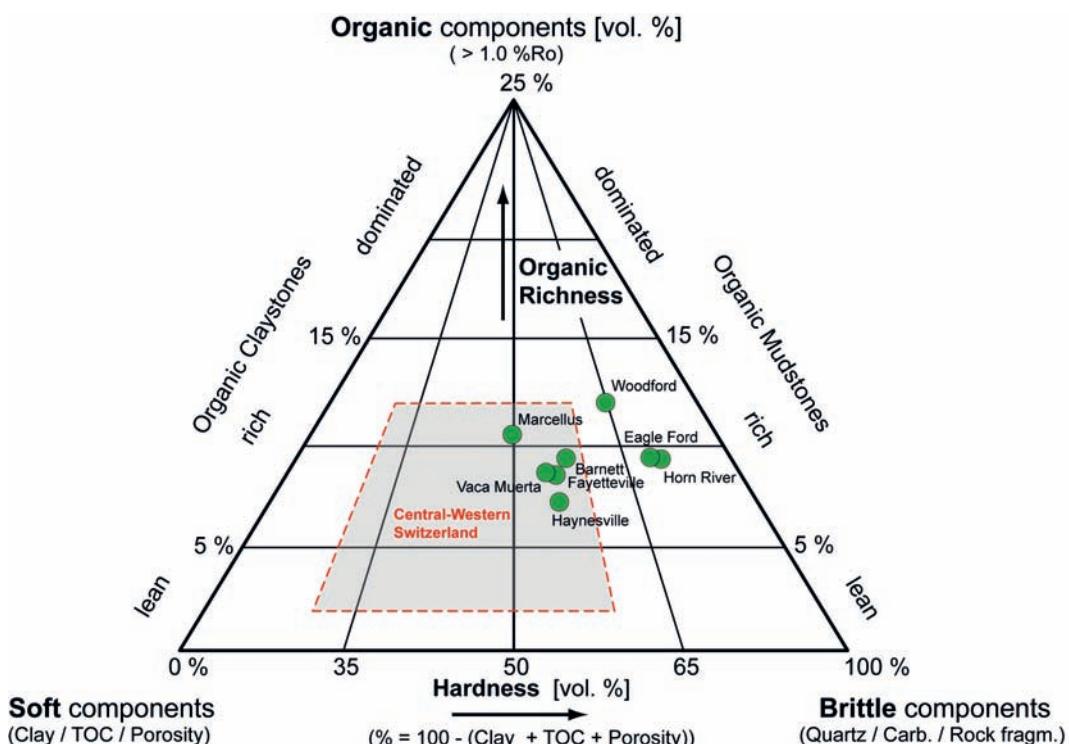


Fig. 2: Characterization by compositional properties of shale reservoirs (modified from Ottmann & Bohacs 2014). The horizontal axis is a measure of the rock hardness, differentiating between soft and more brittle components. The vertical axis describes the organic richness (total organic content). Note that all units are in volume percent. Successful US shale reservoir rocks are indicated with green circles and potential shale gas reservoirs (Opalinus Clay and Posidonia Shale) of Western-Central Switzerland plot within the stippled outline.

Property	Barnett Shale	Ohio Shale	Lewis Shale	Antrim Shale	New Albany Shale
Basin	Fort Worth	Appalachian	San Juan	Michigan	Illinois
Age	Mississippian	Devonian	Cretaceous	Devonian	Devonian
Lithology	Black/grey shale	Black/grey shale	Siltstone	Black shale	Black shale
Kerogen transformation	Thermogenic	Thermogenic	Thermogenic	Biogenic	Thermogenic /biogenic
Maturation [VR%]	1.1–1.4	0.6–1.9	1.6–1.9	0.6–0.7	0.6–1.2
Richness [wt.% TOC]	2–5	2–6	0.5–1.75	5–15	5–20
Porosity [%]	3–7	2–6	2–5	5–12	5–12
Mineralogy [% non-clay]	45–70	4–60	50–75	55–70	50–70
Thickness [m]	60–120	90–300	150–580	50	55
Depth [m]	2.100–2.600	760–1.830	1.370–1.830	150–760	300–760
Natural fractures	Critical to product./faults into lower water beds	Critical to productivity	Important	Critical to productivity	Critical to productivity

Tab. 1: Examples of rock characteristics of historic shale gas plays exploited economically in the USA today (Curtis 2010, modified).

Rock property	Range	Comments
Organic Richness [wt.% TOC]	> 1.5	The higher the better
Maturation [VR%]	(0.6) – 1.2 – 3.0	Secondary for biogenic transformation (oil/gas window see Fig. 1)
Mineralogy [% non-clay]	> 30 – 50	Quartz + carbonate + other rock fragments, brittleness
Thickness [m]	> 20 – 50	

Tab. 2: Key shale rock properties and their minimal requirements for potentially economic shale gas plays (compiled after Jarvie et al. 2007, Gilman & Robinson 2011, Curtis 2010).

and maturity than the Opalinus Clay (Mazurek 2011).

The relatively low maturity values (immature to lower boundary for the oil window, Tab. 3, Fig. 1) of the Opalinus Clay in northern Switzerland is well documented with data from detailed analysis in wells Benken, Weiach, Herdern-1 and the Mont Terri rock laboratory (Fig. 3). These values are in good agreement with the regional coalification trend of increasing maturity values of this stratigraphic interval towards the Alpine front (Fig. 4).

3.2 Observed gas occurrences in the Opalinus Clay in northern Switzerland

In Nagra's deep boreholes in northern Switzerland, continuous gas measurements were carried out as part of the drilling fluid monitoring programme (Hinze et al. 1989, Jäggi & Steffen 1999). The measured gas concentrations were always very low when drilling through the Opalinus Clay, with methane concentrations < 100 ppm (< 0.01 vol.%). No trip gas peaks were observed, with the exception of a small peak (< 100 ppm) in the lowermost clayey facies in the Riniken borehole. In comparison, the methane concentrations in the Muschelkalk and the Permo-Carboniferous

were several orders of magnitude higher and marked trip gas peaks were observed regularly.

In connection with stress measurements, two multiphase hydro-fracturing tests with repeated cycles were carried out in the Opalinus Clay in the Benken borehole (Nagra 2001). Well stimulation of this type generates fractures with surfaces in the order of one to a few square meters. None of these tests indicated the presence of a free gas phase. This is further confirmed by investigations on numerous core samples, where combined porosity/water content and hydrochemical analysis resulted in 100% water saturation in the Opalinus Clay. It can be concluded that the mud gases observed during drilling are dissolved in pore water under in situ downhole conditions.

Similar observations were made in the Mont Terri underground rock laboratory: during tunnel excavation gas measurements in the tunnel atmosphere showed only very low methane concentrations (i.e. below the detection limit of 0.05 vol.%; written communication, Dr. Paul Bossart, swisstopo). Methane influx into sealed test boreholes monitored over longer times under high hydraulic gradients was also very low (methane flux 1.7×10^{-5} mol/day/m 2 ; written

Rock property	Opalinus Clay (Northern Switzerland)	Accepted minimum values (see Tab. 2)
Organic Richness [wt.% TOC or C _{org}]	0.7 ± 0.4	> 1.5
Maturation [VR%]	0.5 – 0.6	(0.6) – 1.2 – 3.0
Mineralogy [% non-clay]	35 ± 10	> 30 – 50
Thickness [m]	80 – 140	> 20 – 50

Tab. 3: Average rock property values for the Opalinus Clay in Northern Switzerland (Mazurek 2011, Nagra 2002) compared to accepted minimum values (Tab. 2).

communication Dr. Agnès Vinsot, Andra). Also gas migration experiments, including numerous hydro-fracturing tests gave no indication of a free gas phase (Bossart & Thury 2008).

The isotopic ratios of methane, ethane, propane and carbon dioxide of the headspace gases in boreholes in the Opalinus Clay at the Mont Terri further indicate that the formation of gases is complex. Thermogenic gases generated at temperatures above 60 °C are subsequently altered by bacterial processes. In addition diffusive migration from underlying layers cannot be ruled out (Eichinger et al. 2011). None of the known economic shale gas plays indicate gas migration from underlying, more mature source rocks.

4 The shale gas potential of the Opalinus Clay and the Posidonia Shale in Central and Western Switzerland

4.1 Formation thickness, organic richness and thermal maturity

The question remains if the Opalinus Clay and the Posidonia Shale in the central and western part of the Swiss Molasse Basin could have some relevant shale gas potential. Data remain scarce with only a few deep wells that indicate that the Liassic in general is thickening towards the west with a basin centre in the Besançon-Geneva area (e.g. Röhl & Schmidt-Röhl 2005, Bitterli 1972, Büchi et al. 1965, Sommaruga 1996, Sommaruga et al. 2012). In well Essertines-1 (Schegg et al. 1997) in the north-western part of the Molasse Basin the Opalinus Clay has a thickness of over 150 m and the Toarcian Shales 93 m, respectively.

The organic richness (TOC) is likely to increase towards viable levels in the range of 1–4 (max. 10) wt.% in the Posidonia shale along the basin axis towards the southwest, as indicated by some data in wells

Essertines-1 and Treycovagnes-1 (see also Schegg et al. 1999 and Todorov et al. 1993). The organic content in the overlying Opalinus Clay is expected to remain below 1.0 wt.%, related to a lithological transition from shale dominated to more carbonate rich platform facies towards the west (Nagra 2008).

Despite these large uncertainties a comparison with successful shale formations of the US in a rock hardness/organic richness triangular plot (Fig. 2) indicates that some of the characteristics could overlap. The available data for the Molasse Basin (not including northern Switzerland) plot in a hardness range of 20–60% and an organic richness range of 2–12 vol.%.

The maturity of the Opalinus Clay to Posidonia Shale interval (Fig. 4) is clearly increasing from oil window levels ($0.6\text{--}0.9\% R_o$) into the gas window ($> 0.9\% R_o$) towards the Alpine front. The iso-reflectance lines run slightly oblique to the Molasse Basin axis with generally higher maturities further north and at shallower depth towards the western part of the basin. Hence, an interesting corridor for potential shale gas resources (maturity range of 0.9 to $1.35\% R_o$, condensate/wet gas, Fig. 1) with a width of 15–30 km extends from Lake Constance over Lucerne-Berne towards Lausanne and across Lake Geneva below the Molasse Basin (see also Leu 2014b). The potential clearly increases from central to western Switzerland related to more favourable rock characteristics (see above) and generally shallower depth. The northern edge of the potential trends lies in depths of at least 2.000 to 2.500 m, whereas the southern limit reaches ~5.000 m (economic floor) in the east and 3.500–4.000 m in the west. The depths are extrapolated from the available deep well information and depth maps based on seismic data (e.g. Sommaruga et al. 2012).

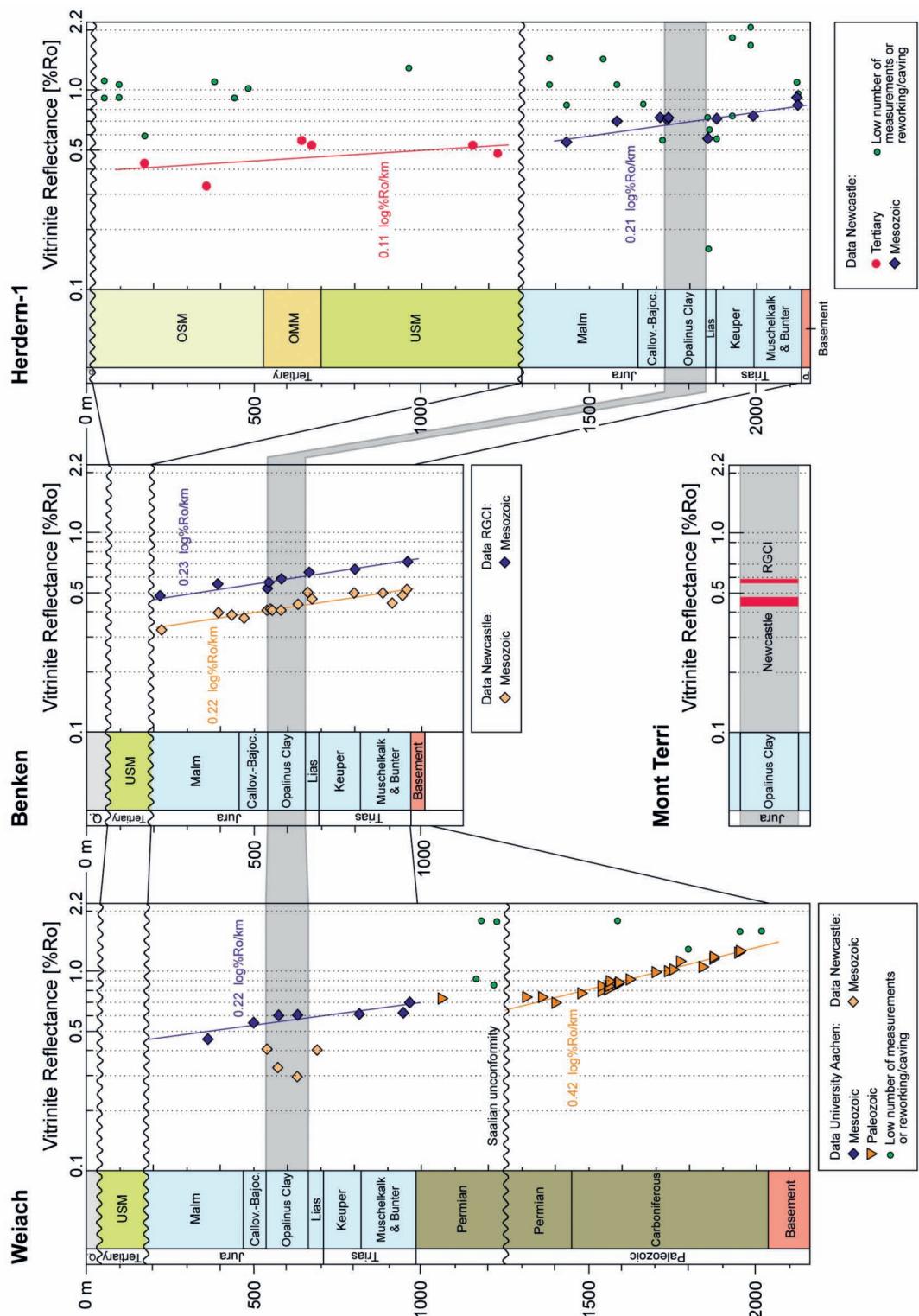


Fig. 3: Maturity profiles in Northern Switzerland based on cores and cuttings from wells Benken, Weiach and Herdern-1. For comparison also data of the Mont Terri underground rock laboratory are shown (Nagra 2002).

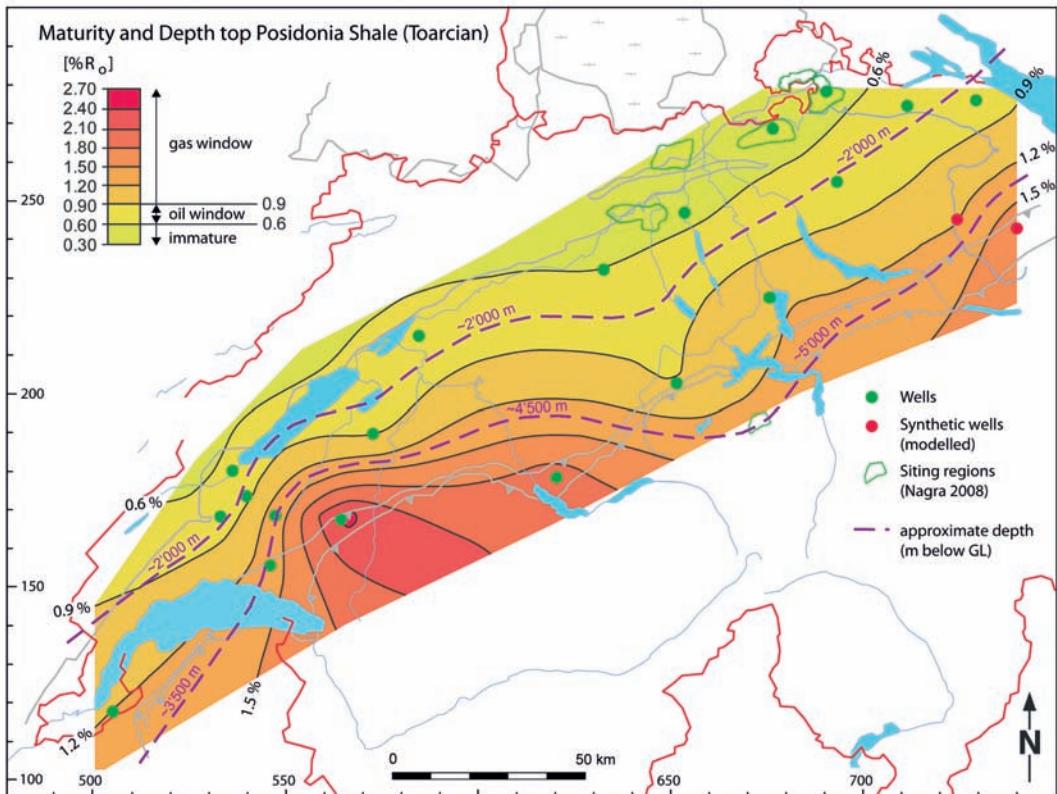


Fig. 4: Maturity map of the transition Base Opalinus Clay/Top Toarcian (Posidonia Shale) with approximate depths below ground level. Map constructed using borehole data and synthetic basin modelling points (after Greber et al. 1997, modified). The geological siting regions in northern Switzerland (Nagra 2008) are outlined in green and the depths were estimated from Sommaruga et al. (2012).

	Low	Likely	High
Gas in place GIP/unit rock [m³/m³]	7	10	30
Thickness shale [m]	20	40	100
Area shale play (depth ~2.000 – 4.500 m) [km²]	1.000	3.000	5.000
Recovery factor [%]	5	10	20
Recoverable shale gas [Mrd. m³] [TCF]	7 0.2	120 4.2	3.000 106

Tab. 4: Estimate of technically recoverable shale gas volume of the compound Opalinus Clay/Posidonia Shale interval in Central and Western Switzerland. Gas volumes are given for standard temperature and pressure conditions. See text for explanations for the three scenarios.

4.2 Estimate of technically recoverable gas volumes

Keeping in mind the above discussed uncertainties, it is possible to estimate the technically recoverable shale gas potential for the Swiss Molasse Basin for the Opalinus Clay and the underlying Posidonia Shale (Tab. 4). Detailed procedures for the calculation of recoverable shale gas reserves are described in BGR (2012) or EIA-ARI (2013). As no specific data are currently available for several parameters used in the Molasse Basin we have chosen the following simplified approach:

$$\text{Recoverable gas [m}^3\text{]} = \text{GIP/unit rock [m}^3/\text{m}^3\text{]} \times \text{thickness [m]} \times \text{area [m}^2\text{]} \times \text{recovery factor [%]}$$

Three individual scenarios were calculated: a] «Low» case, where all four parameters are unfavorable, b] «Likely» case representing median values (P_{50}) and c] «High» case, where all four parameters would be very favorable.

For the GIP (gas in place per rock unit) norm values we took the assumptions for the Posidonia Shale as proposed by BGR (2012). A likely value of $10 \text{ m}^3/\text{m}^3$ is conservative compared to their range of 7 to $38 \text{ m}^3/\text{m}^3$ (P_{05} to P_{95}). Productive shale gas plays in the US have values in the range of 5 to $25 \text{ m}^3/\text{m}^3$ (e.g. Curtis 2002).

For the net prospective shale thickness a likely value of 40 m and for the likely prospective region an area of roughly $20 \times 150 \text{ km}$ is assumed. Depending on the lithological characteristics of the shale formation and assuming today's state-of-the-art production technology (drilling and stimulation) only a fraction of the GIP volume can be produced. In the US such recovery factors are in the range of 5 to 25% with some exceptionally high values of up to 60% in the Antrim Shale of Michigan (Tab. 1, Curtis 2002, EIA-ARI 2013). For the Posidonia Shale assessment of Germany a likely value of 10% was assumed (BGR 2012).

In the likely scenario a technically recoverable shale gas volume of 120 Mrd. m^3 results (Tab. 4). In comparison, the current annual gas consumption of Switzerland is 3.5 Mrd. m^3 and 100 Mrd. m^3 for Germany. The wide range between the low scenario (7 Mrd. m^3) and the high scenario (3.000 Mrd. m^3) reflects the uncertainties at this early stage of exploration in the Swiss Molasse Basin.

5 Conclusions

The Opalinus of Clay and Posidonia Shale of northern Switzerland are characterised by two parameters that are unsuitable in terms of future shale gas recovery: TOC and maturity. These formations did not reach the gas window during their burial history (maturity values are $\leq 0.6\% R_o$) and as a consequence significant thermogenic gas generation never occurred.

Geochemical data for northern Switzerland further show that the average TOC values are in the range of 0.7%, i.e. clearly below an accepted value ($> 1.5\%$) for prospective shales.

A review of available exploration data for the Opalinus Clay and Posidonia Shale in the deeper and western part of the Swiss Molasse Basin indicate that their shale gas potential may be substantial. Especially, the gross Posidonia Shale thickness increases from central Switzerland to over 100 m in the Yverdon-Geneva area.

A simplified calculation of the technically recoverable shale gas indicates that for a geologically likely scenario a volume of around 120 Mrd. m^3 is possible. The current data base for such estimates is small and as a consequence the uncertainties large. However, these first encouraging results support a more detailed exploration phase with specific geochemical and petrophysical analysis of existing rock and well log data.

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Fracking in der Schweiz aus der Sicht des Grund- und Trinkwasserschutzes Daniel Hartmann¹, Benjamin Meylan²

1 Einleitung

Die Autoren möchten mit diesem Artikel zur Versachlichung der Diskussion über Fracking in Bezug auf den Grund- bzw. Trinkwasserschutz beitragen. Vor allem relativieren sie die aus politischen Kreisen und den Umweltorganisationen beschworene Gefahr einer Grundwasserverunreinigung durch Fracking und weisen darauf hin, dass wesentlich akutere, aktuelle und flächendeckende Probleme für die Wasserqualität, wie beispielsweise von den in der Landwirtschaft verwendeten Pestiziden ausgehen. Medienberichten zur Folge kam es in den USA wegen Fracking mehrmals zu Umweltverschmutzungen. Am 20. Juni 2014 haben die Grünen Kanton Bern zusammen mit Pro Natura Bern, Greenpeace Regionalgruppe Bern und der EVP (Evangelische Volkspartei) die Stopp-Fracking-Initiative eingereicht. Diese verlangt, dass die Förderung von Erdgas und Erdöl aus sogenannt nicht-konventionellen Lagerstätten im Kanton Bern verboten wird. Ähnliche Absichten, Moratorien oder gar Verbote bestehen auch in anderen Kantonen.

2 Argumente der Stopp-Fracking-Initiative

Die Stopp-Fracking-Initiative wird im Wortlaut folgendermassen begründet (<http://www.stopp-fracking.ch>):

1. *Fracking vergiftet Boden und Wasser: Der beim Fracking verwendete Chemikaliencocktail bedroht die Qualität der Grund- und Oberflächengewässer und damit des Trinkwassers.*
2. *Fracking untergräbt die Energiewende: Mit der Förderung von Schiefergas wird ein zusätzliches Potenzial an fossilen Ressourcen erschlossen. Die Abhängigkeit von fossilen Ressourcen wird verlängert – und der Umstieg auf erneuerbare Energien damit torpediert. Das ist weder energiepolitisch noch volkswirtschaftlich sinnvoll.*
3. *Fracking belastet das Klima: Schiefergas ist nicht nur deshalb klimaschädigend, weil bei der Verbrennung von Gas CO₂ freigesetzt wird, sondern auch, weil die Förderung und der Abtransport überdurchschnittlich viel Energie benötigen. Beim Fracking entweichen grössere Mengen an Methan in die Luft und ins Grundwasser; Methan ist 25 Mal klimaschädiger als CO₂ und heizt das Klima an. Schliesslich: Die Schiefergasförderung führt nicht zum Ersatz von Kohle und Erdöl, sondern zu einer Ausweitung des Verbrauchs fossiler Ressourcen.*
4. *Fracking führt zu Landverschleiss: Der für die Erschliessung der Bohrfelder erforderliche Landbedarf ist enorm (Strassen, Tanks, Abwasserbecken, Lagerplätze, Stellplätze usw.). Der Umstand, dass wegen der raschen Erschöpfung der Lagerstätten immer neue Bohrlöcher erschlossen werden, verschärft den Landverschleiss zusätzlich.*

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lich. Neben dem Landverbrauch erzeugt Fracking eine hohe Lärm- und Verkehrsbelastung, da das geförderte Gas in der Regel nicht per Pipeline, sondern per Lastwagen abtransportiert wird.

5. *Fracking produziert gefährliche Abfälle: Das beim Fracking verwendete Wasser-Sand-Chemikaliengemisch muss speziell entsorgt werden. Ähnlich wie bei den radioaktiven Abfällen besteht keine Lösung für die Entsorgung dieses Flowbacks. Bei Lecks am Bohrloch drohen unkontrollierte Vergiftungen und Verschmutzungen durch die giftigen Flowbacks.*
6. *Fracking nützt nur ausländischen Grossfirmen: Im Gegensatz zu erneuerbaren Energien profitieren vom Fracking-Boom allein wenige multinationale Grosskonzerne – und nicht die einheimische, regionale Wirtschaft.*

Ähnliche Befürchtungen finden sich in der Bevölkerung. Die Argumente der Initiative möchten wir im Folgenden aus Sicht des Grund- und Trinkwasserschutzes kurz diskutieren, da die Rahmenbedingungen für Fracking, insbesondere die gesetzlichen Bestimmungen des Umweltrechts, in der Schweiz wesentlich einschränkender und präziser sind, als in den umliegenden Ländern und in den USA.

3 Gesetzesvollzug

Umweltverträglichkeitsprüfung

In der Schweiz benötigen Anlagen zur Gewinnung von Erdgas gemäss der Verordnung über die Umweltverträglichkeitsprüfung vom 19. Oktober 1988 (Anhang 21.7 UVPV, SR 814.011) eine kantonale Bewilligung. Bei der Prüfung der Umweltverträglichkeit stellt die zuständige Behörde aufgrund des Umweltverträglichkeitsberichts des Gesuchstellers fest, ob das Projekt den bundesrechtlichen und kantonalen Vorschriften über den Schutz der Umwelt entspricht. Dazu gehören das Umweltschutzge-

setz und die Vorschriften, welche den Natur- und Heimatschutz, den Landschaftsschutz, den Gewässerschutz, die Walderhaltung sowie die Jagd und die Fischerei betreffen. Das Ergebnis der Prüfung bildet eine Grundlage für den Bewilligungsentscheid. Werden nicht sämtliche Vorschriften eingehalten, darf die Behörde keine Bewilligung erteilen. Sie hat zudem dafür zu sorgen, dass der Bericht und der Entscheid öffentlich zugänglich sind. Somit können sich Interessierte informieren und allenfalls gegen das Vorhaben Rekurs einlegen. In der Schweiz besteht zudem das Verbandsbeschwerderecht. Es ist deshalb zu erwarten, dass insbesondere Umweltverbände bei einem Fracking-Projekt von dieser Möglichkeit konsequent Gebrauch machen werden.

Gewässerschutzrechtliche Bewilligung

In der Schweiz benötigen Bohrungen in besonders gefährdeten Bereichen, das heisst in sämtlichen Gebieten mit nutzbaren Grundwasservorkommen, eine gewässerschutzrechtliche Bewilligung nach Artikel 32 der Gewässerschutzverordnung vom 28. Oktober 1998 (GSchV, SR 814.201) und den kantonalen Bestimmungen. Um eine solche Bewilligung zu erhalten, müssen die Gesuchsteller nachweisen, dass die Anforderungen zum Schutz der Gewässer erfüllt sind und die dafür notwendigen Unterlagen einreichen. Dafür sind gegebenenfalls auch hydrogeologische Untersuchungen notwendig. Die zuständige Behörde darf die Bewilligung mit den entsprechenden Auflagen und Bedingungen nur dann erteilen, wenn sichergestellt ist, dass ein ausreichender Schutz der Gewässer gewährleistet werden kann (siehe folgendes Kapitel). Die Behörde legt dabei auch die Anforderung an die Stilllegung der Anlage fest (Art. 32 GSchV).

Anforderungen zum Schutz der Gewässer nach Gewässerschutzrecht

Gemäss Artikel 3 des Gewässerschutzgesetzes vom 24. Januar 1991 (GSchG, SR 814.20) ist jedermann verpflichtet, alle nach den

Umständen gebotene Sorgfalt anzuwenden, um Verunreinigungen und andere Eingriffe, welche die Funktion des Grundwassers beeinträchtigen, zu vermeiden. Die Kosten für die Sanierung einer allfälligen Beeinträchtigung muss der Verursacher tragen (Art. 3a GSchG). Insbesondere dürfen keine Stoffe, die Wasser verunreinigen können, mittelbar oder unmittelbar ins Grundwasser eingebracht werden.

Bei der Prüfung eines Gesuchs wird die kantonale Behörde daher alle genannten Punkte prüfen. Die Gesuche müssen so dokumentiert sein, dass sie den zuständigen Behörden eine ordnungsgemäße Prüfung erlauben. Nötigenfalls müssen diese ergänzende Untersuchungen verlangen (Art. 32 Abs. 3 GSchV), beispielsweise durch ausgewiesene SpezialistInnen. Falls nötig, wird die Meinung des Bundesamtes für Umwelt eingeholt. Die Behörde wird eine Bewilligung für ein Fracking-Projekt nur erteilen, wenn nachweislich ein ausreichender Schutz der Gewässer gewährleistet ist. Die Anforderungen an inhaltlich umfassende und fachlich einwandfrei fundierte Nachweise zur Erfüllung der genannten rechtlichen Vorschriften sind entsprechend gross.

Das Gewässerschutzgesetz gilt für alle unter- und oberirdischen Gewässer (Art. 2 GSchG), wobei es keine Tiefenbeschränkung für nutzbares Grundwasser gibt. Alle nicht bereichs- oder zonenspezifischen Bestimmungen gelten flächendeckend und jederzeit, wie z. B. die Sorgfaltspflicht nach Art. 3 GSchG, das Verursacherprinzip nach Art. 3a GSchG oder die Behandlungspflicht für verschmutztes Abwasser (inkl. jenes von Bohrstellen) nach Art. 7 GSchG. Grundwasser, das nicht genutzt werden kann, ist im Sinne von insbesondere Art. 2 und Art. 3 GSchG geschützt. Auch ausserhalb der besonders gefährdeten Bereiche, welche in der Schweiz ungefähr 30% der Landesfläche umfassen, gelten grundsätzlich die Anforderungen des Gewässerschutzschutzgesetzes. Davon sind alle potenziell wassergefährdenden Anlagen

(z. B. Tankstellen, Pipelines, Abwasseranlagen, Wärmenutzungsanlagen aus dem Untergrund, Anlagen zur Lagerung nuklearer Abfälle usw.) betroffen. Die Behörden haben, in Abwägung aller Anliegen, das Recht und die Pflicht, je nach Situation und Anlage entsprechende Auflagen zu verfügen. Mehrere Kantone haben denn z. B. bezüglich Wärmenutzung bereits entsprechende Vorzugs- bzw. Ausschlussgebiete in ihren Gewässerschutzkarten festgelegt.

4 Gegenargumente zur Stopp-Fracking-Initiative

Fracking vergiftet Boden und Wasser: In der Schweiz muss der Gesuchsteller der Behörde offenlegen, welche Stoffe zur Anwendung gelangen. Chemikaliencocktails aus wassergefährdenden Stoffen sind klar verboten. Der Gesuchsteller muss nachweisen, dass er ausschliesslich mit unbedenklichen Stoffen (in erster Linie mit Wasser und Sand) arbeitet. Zur Sicherheit wird die Behörde entsprechende Kontrollen durchführen und bei Verstössen die Anlage schliessen. Eine Sanierung allfällig verschmutzten Grundwassers würde zu Lasten des Gesuchstellers gehen. Die pauschale Behauptung, dass Fracking Boden und Wasser vergiftet und dass der beim Fracking verwendete Chemikaliencocktail die Qualität der Grund- und Oberflächen Gewässer und damit des Trinkwassers bedroht, ist unqualifiziert und bei Beachtung der geltenden rechtlichen Bestimmungen falsch. Das Grundwassergefährdungspotenzial der schweizweit nach wie vor im unmittelbaren Umfeld von Trinkwasserfassungen eingesetzten Pestizide ist nachweislich wesentlich problematischer.

Fracking produziert gefährliche Abfälle: Für die Entsorgung von belasteten Materialien gelten die bestehenden Regeln des Umweltrechts sowie allfällige präzisierende Vorgaben aus der Bohrbewilligung. Gefährliche, nicht behandelbare Abfälle dürfen beim Fracking schon darum nicht entstehen, weil

sonst das Gesuch abgelehnt werden müsste. Der Gesuchsteller muss deshalb in seinem Umweltverträglichkeitsbericht auch nachweisen, dass er sein Abfallproblem umweltverträglich lösen kann. Das benutzte Wasser sollte im Kreislauf verwendet und kontinuierlich gereinigt werden. Beispielsweise mit der Umkehrsmose kann das verwendete Wasser wieder Trinkwasserqualität erreichen. Der Vergleich der Abfallproblematik beim Fracking-Verfahren mit derjenigen von radioaktiven Abfällen dient daher primär der Angstmacherei. Eine Verschmutzung von Boden und Grundwasser kann bei fachgerechter Ausführung weitestgehend ausgeschlossen werden. Selbstverständlich kann ein Hydraulikschlauch platzen, aber dies kann auf jeder Baustelle passieren.

Zu den andern Argumenten der Stopp-Fracking Initiative:

- Wie manch andere Treibhausgase generierenden Tätigkeiten des Menschen kann Fracking das Klima belasten. In der Schweiz mittels Fracking gewonnenes Erdgas dürfte jedoch eine mit durch die Verbrennung von Kohle produziertem Importstrom oder unter zweifelhaften Rahmenbedingungen gewonnenem, über Meere und Flüsse verschifftem Erdöl durchaus konkurrenzfähige Umweltbilanz aufweisen (Anm.: die Schweiz importiert aktuell rund 80% ihrer Energie. Der Anteil fossiler Brennstoffe beträgt 66%, der Anteil des mehrheitlich importierten Erdgases am Endenergieverbrauch 13%).
- Tatsächlich würde mit der Förderung von Schiefergas ein zusätzliches Potenzial an fossilen (einheimischen) Ressourcen erschlossen. Dass dies, wie in der Stopp-Fracking-Initiative behauptet wird, «weder energiepolitisch noch volkswirtschaftlich sinnvoll» ist, kann bezweifelt werden.
- In der Schweiz würde Fracking kaum zu einem wesentlichen Landverschleiss führen. Der grösste Teil der Anlagen ist temporär und die Behörden würden vom Gesuchsteller verlangen, dass nach Abbruch der Anla-

gen der ursprüngliche Zustand wieder hergestellt wird, wie dies in der Regel auch bei allen anderen Bohrungen, beispielsweise zwecks Energiegewinnung, verlangt wird.

- Dass Fracking nur ausländischen Grossfirmen nützen würde, ist nicht nachvollziehbar. Schliesslich bietet die Erschliessung einer einheimischen Ressource die Chance, die Abhängigkeit vom Ausland zu verringern.

5 Allgemeine Betrachtungen zum Fracking

Wie oben aufgezeigt, muss jeder Gesuchsteller in der Schweiz nachweisen, dass er sämtliche umweltrechtlichen Bestimmungen einhält. Der vertikale Abstand zwischen den Gesteinen, die gefractt werden sollen und den Grundwasservorkommen muss genügend gross sein, um zu gewährleisten, dass die künstlich erzeugten Risse nicht bis in nutzbare Grundwasservorkommen hinaufreichen können. In einem Gebiet, dessen tiefer Untergrund geologisch wenig bekannt ist, wird die Behörde daher den Nachweis verlangen, dass durch das Fracking keine nutzbaren Grundwasservorkommen betroffen werden.

Ein generelles Verbot von Fracking in der Schweiz ist daher aus der Sicht des Grund- und Trinkwasserschutzes wenig sinnvoll. Ein solches Verbot würde zudem auch die geothermische Nutzung des Untergrundes in Frage stellen. Viel problematischer für das Grundwasser sind ohnehin die zahllosen Erdwärmesonden, die momentan – unter Kostendruck und in teilweise krasser Unkenntnis der lokalen Gegebenheiten im Untergrund – erstellt werden. Bei unsachgemässer Hinterfüllung des Bohrlochs entstehen präferenzielle Fliesswege, durch welche Schadstoffe ungehindert von der Oberfläche in den Untergrund gelangen können und verschiedene Grundwasserstockwerke in unkontrollierter Weise miteinander verbunden werden. Da eine korrekte Hinterfüllung

des Bohrlochs Zeit beansprucht, wirkt sich der Kostendruck verheerend auf die Qualität dieser Erdwärmesonden aus, wodurch für das Grundwasser die Gefahr einer Verunreinigung entsteht. Aus Sicht des Grundwasserschutzes wäre es daher wünschenswert, wenn zur Gewinnung der Erdwärme ausschliesslich grosse Anlagen gebaut würden, die eine grössere Anzahl Haushalte mit Wärme versorgen. Solche Anlagen werden professioneller erbaut, betrieben und gewartet. Vor allem sinkt die Anzahl der für die Erdwärmevernützung notwendigen Bohrungen und somit die Anzahl Perforationen des Untergrundes, durch welche Schadstoffe ins Grundwasser gelangen können.

Das grösste Problem beim Fracking sehen wir in den Erdbeben, die dabei ausgelöst werden können. Ob in Anbetracht der Siedlungsdichte der Schweiz ohne schwere Mängel in Bezug auf Erdgas, solche Beben von der Bevölkerung in Kauf genommen würden, erachten wir als eher unwahrscheinlich. Trotzdem sollte jedoch die Erkundung des tiefen Untergrunds in der Schweiz vorangetrieben werden. Damit sollen vor allem Erkenntnisse zur Errichtung von petrothermalen Geothermieanlagen gewonnen, aber auch das Potenzial an nutzbarem Schiefergas abgeklärt werden. Es ist bedauerlich für ein Land, das lange in der Geologie führend war, dass die Kenntnisse über den eigenen Untergrund und den Umfang allenfalls vorhandener natürlicher Ressourcen so gering sind. Ohne die Untersuchungen der NAGRA und der Erdölindustrie wäre die Kenntnis des geologischen Untergrunds der Schweiz noch dürftiger.

6 Defizite des Grundwasserschutzes in der Schweiz

Die Grundwasservorkommen in der Schweiz sind quantitativ gut geschützt. Mit der Qualität des Grundwassers gibt es indes Probleme, insbesondere wegen der Landwirtschaft. In der Schweiz dürfen Landwirte

Pestizide bis 10 Meter neben einer Trinkwasserfassung ausbringen. Dass diese dabei ins Trinkwasser gelangen, ist nicht weiter verwunderlich.

Eigentlich müsste der Öffentlichkeit – im Hinblick auf die Gesundheit der Schweizer Bevölkerung – ein Pestizid freies Trinkwasser so viel Wert sein, dass auf eine intensive Landwirtschaft im unmittelbaren Vorfeld von Trinkwasserfassungen verzichtet würde. Biolandwirtschaft oder besser noch Graswirtschaft wären ja weiterhin möglich. Im Einzugsgebiet von Trinkwasserfassungen würde der Landwirt damit auch zum Trinkwasserproduzenten.

Mit dem Vergleich zur Landwirtschaft möchten wir bewusst auf die effektive Tragweite verschiedener Gefährdungspotenziale für das Grund- und Trinkwasser hinweisen, da wir in den letzten Jahren die zunehmende Fokussierung auf «trendige», sprich «medienträchtige Nebenschauplätze» wie den Nachweis von Assugrin in Gewässern, brennende Wasserhähne, Dünger auf Skipisten, Wasserknappheit und andere «Schauerlichkeiten» feststellen mussten, bei gleichzeitig völliger Gleichgültigkeit gegenüber realen und problemlos vermeidbaren Beeinträchtigungen (z. B. Landwirtschaft oder Eingriffe in Oberflächengewässer im unmittelbaren Vorfeld von Trinkwasserfassungen).

7 Fazit

Fracking in der Schweiz ist, wenn die geltenden Vorschriften und der Stand der Technik strikte eingehalten werden, im Hinblick auf die Sicherstellung der Qualität des Grund- und Trinkwassers eine verantwortbare Technologie. Der Schutz von Mensch und Umwelt kann gewährleistet werden, wenn die geltenden Vorschriften und die Technikstandards eingehalten und konsequente, regelmässige Kontrollen durchgeführt werden. Gravierend ist indes das Problem der Pestizide im Grund- und Trinkwasser als Folge intensiver landwirtschaftlicher Nutzung.

Unkonventionelle Gasförderung im Klimaschutz: Teil der Lösung oder Teil des Problems? Elmar Grosse Ruse¹

Stickworte: CCS, Energiewende, Erdgas, Fracking, Geothermie, Klimapolitik, Kohlenstoffbudget, Methan, Schweiz, USA

Zusammenfassung

Der vorliegende Artikel bewertet die Hydraulic Fracturing Technologie (Fracking) aus der Perspektive der globalen Klimapolitik. Die genannten Argumente zeigen, dass aus dieser Sichtweise Fracking in den allermeisten Fällen nicht Teil der Lösung, sondern Teil des Problems ist. Allein die Tatsache, dass zwei Drittel aller schon bekannten fossilen Energiereserven im Untergrund verbleiben müssen, damit die Zwei-Grad-Grenze eingehalten werden kann, verbietet es, politische, technologische und finanzielle Ressourcen in Praktiken zur Erschliessung der bekannten und künftigen Erdgas-Reserven zu investieren. Dies gilt umso mehr, als die investierten Ressourcen meist de facto in Konkurrenz zu einem verstärkten Engagement für Energieeffizienz und erneuerbare Energien stehen. Und kapitalintensive Fracking-Infrastruktur führt in ein Kohlenstoff-Lock-in: Um Investitionsruinen zu vermeiden, müsste in grossem Ausmass und über ausreichende Zeit unkonventionell gefördertes Erdgas energetisch genutzt werden. Das wiederum heizt den Klimawandel an bzw. schränkt den Spielraum für Klimaschutzmassnahmen weiter ein. Diese Argumentation gilt umso mehr, wenn sich die wachsende Evidenz bestätigt, dass Fracking deutlich höhere Methanemissionen mit sich bringt als bislang vermutet bzw. als aus der konventionellen Erdgasförderung bekannt. Als politische Konsequenz dieser Erkenntnisse wird ein generelles Verbot für die Förderung jeglicher Kohlenwasserstoffe in der Schweiz empfohlen.

Abstract

In this article the hydraulic fracturing technology (fracking) is assessed from the perspective of global climate change mitigation policy. The presented arguments show that from this perspective fracking is in most cases part of the problem and not part of the solution. Simply the fact that two thirds of all known fossil fuel reserves must remain in the ground in order to comply with the two-degree-limit bans the investment of political, technological and financial resources in projects to exploit the known and future reserves of natural gas. This is all the more true as the invested capital de facto competes with increased investments in renewable energies and energy efficiency. In addition, capital-intensive infrastructure for fracking leads to a carbon-lock-in: in order to prevent decaying hulks of abandoned projects, natural gas would have to be exploited and used energetically to a great magnitude over a long period of time. This in turns fosters climate change und minimizes the scope for climate change mitigation. This is all the more true, in case the growing evidence is confirmed that fracking goes with much higher methane emissions than previously thought resp. than conventional exploitation of natural gas does. As a political consequence of these findings a general ban of the exploitation of all hydrocarbons in Switzerland is recommended.

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1 Einführung

Die massive Förderung von unkonventionellen Erdgasvorkommen mithilfe der Hydraulic Fracturing Technologie (im Folgenden vereinfacht «Fracking» oder «Schiefergasförderung») in den USA und entsprechende Vorhaben in Europa haben umfassende Diskussionen in Medien und Zivilgesellschaft ausgelöst. Gegenstand dieser Auseinandersetzungen sind meist die Auswirkungen von Fracking für gesellschaftliche Anliegen wie Boden- und Gewässerschutz, Luftreinhaltung, Erdbebenschutz, Landschaftsschutz, Lärmschutz und Verkehrsvermeidung. Da Fracking lokal bzw. regional vor allem auf die genannten Schutzgüter einwirkt, ist diese Schwerpunktsetzung aus Sicht der vor Ort (potenziell) Betroffenen nachvollziehbar. Aus einer globalen Perspektive ist jedoch ein anderes von Fracking betroffenes Schutzgut mindestens ebenbürtig: die Einräumung der globalen Klimaerwärmung. Im Folgenden wird daher die Förderung unkonventioneller Gasvorkommen mittels Fracking aus der Perspektive der nationalen und internationalen Klimapolitik bewertet. Aus der Analyse werden Empfehlungen für die politische Steuerung der Schiefergasförderung abgeleitet. Diese beziehen sich auf das politische System der Schweiz, sind aber verallgemeinert auch auf andere Staaten übertragbar.

2 Die klimapolitischen Auswirkungen von Fracking

2.1 Das Kohlenstoffbudget als zentrale Grenze für die Energierohstoffförderung

Meinshausen et al. (2009) haben mithilfe probabilistischer Modelle aus dem politisch gesetzten Ziel einer Begrenzung der durchschnittlichen Erderwärmung auf maximal zwei Grad Celsius gegenüber dem vorindustriellen Temperaturniveau – die sogenannte Zwei-Grad-Grenze – ein dementsprechendes

über einen spezifischen Zeitraum maximal zu emittierendes Treibhausgas-Kontingent abgeleitet. Dieser Ansatz – das sogenannte Kohlenstoffbudget – ermöglicht deutlich präzisere Aussagen zu politischen und technologischen Optionen für zwei-Grad-kompatible globale Entwicklungspfade als blosse Reduktionsvorgaben mit Bezug auf ein Ausgangs- und Zieljahr (wie beispielsweise «80% weniger Treibhausgasemissionen bis 2050 gegenüber dem Jahr 1990»). Denn letztgenannte Vorgaben lassen letztlich offen, wie viele Tonnen Treibhausgase in der betreffenden Zeitspanne noch emittiert werden. Dabei ist die Menge der in die Atmosphäre emittierten Treibhausgase die entscheidende Einflussgröße für das zu erwartende durchschnittliche globale Temperaturniveau (IPCC 2013).

Das für eine gegebene Zeitspanne verfügbare, zwei-Grad-kompatible Kohlenstoffbudget bietet also wertvolle Informationen: Es lässt sich beispielsweise dem Kohlenstoffgehalt der zu einem bestimmten Zeitpunkt bekannten, wirtschaftlich förderbaren Reserven fossiler Energierohstoffe gegenüberstellen. Daraus wird ersichtlich, welcher Anteil dieser Reserven im betreffenden Zeitraum maximal gefördert und energetisch verwertet werden darf. Diese Gegenüberstellung haben bereits Meinshausen et al. (2009) durchgeführt. Ihr Ergebnis – vor dem Höhepunkt des Fracking-Booms in den USA: Weniger als die Hälfte der in den damals bekannten, wirtschaftlich und technisch förderbaren fossilen Energierohstoff-Reserven enthaltenen Treibhausgase dürfen bis zur Mitte des Jahrhunderts emittiert werden, wenn die Zwei-Grad-Grenze einzuhalten ist.

Neuere Studien haben diese Erkenntnis aktualisiert und präzisiert. Dabei ist zu beachten, dass keine objektiven Aussagen über ein definitives Kohlenstoffbudget für einen bestimmten Zeitraum möglich sind. Einflussvariablen auf die Größe des Budgets sind u. a. der vorgegebene maximale globale Temperaturanstieg, die Wahrscheinlichkeit, mit der dieser einzuhalten ist, der Einbezug von

nicht-energetischen Treibhausgasquellen und von nicht CO₂-Treibhausgasen (inkl. deren Umrechnung in CO₂) sowie Annahmen über Klimaschutzbeiträge der nicht-energetischen Treibhausgasquellen (Carbon Tracker Initiative 2014). Neuere Schätzungen beziffern das globale Kohlenstoffbudget – unter der Vorgabe, dass die globale Durchschnittstemperatur mit 80-prozentiger Wahrscheinlichkeit um nicht mehr als zwei Grad ansteigt – auf 900 Milliarden Tonnen Kohlenstoffdioxid (Gt CO₂) für den Zeitraum von 2013 bis 2049 und lediglich weitere 75 Gt CO₂ für den Zeitraum von 2050 bis 2100 (Carbon Tracker Initiative 2013).

Demgegenüber stehen 2'860 Gt CO₂, die emittiert würden, wenn die gesamten im Jahr 2012 bekannten fossilen Energierohstoffreserven gefördert und energetisch genutzt würden (IEA 2012a). Die damals bekannten – aber noch äusserst geringen – *unkonventionellen Öl- und Gas-Reserven* sind dabei berücksichtigt, die viel grösseren unkonventionellen *Ressourcen* dagegen nicht (IEA 2104).

Die Schlussfolgerung aus diesen beiden Daten – Kohlenstoffbudget und bekannte, förderbare Kohlenstoffreserven im Untergrund – liegt auf der Hand und wird auch von der Internationalen Energie Agentur expliziert: Zwei Drittel der bekannten Reserven fossiler Energierohstoffe dürfen nicht gefördert und verbrannt werden, wenn ein gefährlicher Klimawandel jenseits der Zwei-Grad-Grenze vermieden werden soll (IEA 2012a) – und zwar selbst über einen längerristigen Horizont bis Ende des Jahrhunderts. Damit ist klar: Für eine verantwortungsvolle Klimapolitik ist die weitgehende Förderung und Verbrennung der bekannten Öl-, Gas- und Kohlereserven tabu.

In den oben genannten 2'860 Gt CO₂ sind Energierohstoff-*Ressourcen* noch gar nicht berücksichtigt. Im Fall von Erdgas bedeutet dies: Den übereinstimmenden Statistiken der US-amerikanischen Energy Information Administration (EIA 2014) und des World Energy Council (2013) zufolge gelten derzeit

rund 200 Billionen Kubikmeter (tcm) Erdgas als technisch und wirtschaftlich förderbare *Reserven* – ein Grossteil davon vermutlich konventionelles Erdgas (IEA 2014). Gefördert und verbrannt entspräche dies rund 400 Gt CO₂, die in den 2'860 Gt der IEA (2012a) enthalten sind. Die technisch förderbaren Erdgas-*Ressourcen* sind jedoch deutlich grösser: 752 tcm – entsprechend rund 1'500 Gt CO₂ – wovon 331 tcm (rund 660 Gt CO₂) *unkonventionelle Erdgas-Ressourcen* sind (IEA 2012b). Es verbleiben also rund 1'100 Gt CO₂ in technisch förderbaren Erdgas-Ressourcen, von denen vermutlich mehr als die Hälfte unkonventionelle Ressourcen sind. Die Überführung von weiteren Erdgas-Ressourcen in die Gesamtheit der Reserven und ihre Förderung durch Fracking würde das oben skizzierte Problem also massiv verschärfen. Schliesslich werden alle Energie-Konzerne versuchen, einen möglichst grossen Teil bereits getätigter Explorationsinvestitionen durch Förderung der entsprechenden Reserven zu amortisieren.

Die fossilen Energierohstoffe Erdöl, Steinkohle, Braunkohle und Erdgas unterscheiden sich teilweise deutlich in ihrem jeweils spezifischen CO₂-Gehalt (siehe z. B. BAU 2014; inwiefern diese Werte auch für unkonventionell gefördertes Erdgas gültig sind, wird unten diskutiert). Es liessen sich also klimaverträglich mehr Energierohstoffe extrahieren, wenn es sich dabei um verhältnismässig CO₂-armes Erdgas handelt, als wenn beispielsweise CO₂-intensive Braunkohle gefördert wird. Aufgrund längst getätigter Investitionen in brennstoffspezifische Energie-Infrastrukturen (Kohlekraftwerke, Erdöl-Pipelines, Gasnetze, heizöl- oder erdgasbetriebene Wärmeerzeuger, Mineralöl-Tankstellen etc.) sind dem theoretisch denkbaren Optimieren des noch zu fördernden Energieträgermix in der Praxis allerdings kurzfristig deutliche Grenzen gesetzt. In Bezug auf das Kohlenstoffbudget bedeutet dies: Die weitgehende Begrenzung des klimaverträglich noch förderbaren Kontingents gilt für alle Energierohstoffe: Erdgas,

Erdöl, Kohle – sei es konventionell oder unkonventionell gefördert. Oder politisch ausgedrückt: Ohne eine global gültige, wirksame CO₂-Obergrenze bedeutet mehr (unkonventionelle) Gasförderung zwangsläufig global steigende CO₂-Emissionen (Broderick & Anderson 2012).

Ganz abgesehen davon stellt sich die Frage der fairen internationalen Verteilung eines gegebenen Kohlenstoffbudgets entlang des in UN-Verträgen anerkannten Prinzips von «equity» (United Nations 1992, p. 9). Derartige Überlegungen dürften dazu führen, dass wohlhabenden Industriestaaten wie der Schweiz ein deutlich kleinerer Anteil des verbleibenden Kohlenstoffbudgets zusteht, als dies nach ihrem aktuellen Bevölkerungsanteil zu erwarten wäre. Dies hätte entsprechende zusätzliche Restriktionen für die klimaverträglich förderbaren fossilen Energierohstoffe in diesen Ländern zur Folge.

2.2 Ausweg Carbon Capture and Storage?

Die Carbon Capture and Storage Technologie (CCS), mit der bei der Verbrennung fossiler Energierohstoffe entstehendes CO₂ abgeschieden und durch unterirdische Ablagerung von der Atmosphäre ferngehalten werden soll, wird das oben genannte Dilemma nicht entscheidend mildern. Selbst in dem bezüglich CCS äußerst optimistischen Szenario der IEA (2012a) würde ein umfassendes Roll-Out der Technologie das klimaverträglich förderbare Kohlenstoffbudget bis 2050 nur um 125 Gt CO₂ vergrößern. IEA (2013) zufolge würde CCS die klimaverträgliche Förderung von sogar nur maximal drei Prozent mehr Reserven – vor allem Kohle – erlauben. Die genannten Größenverhältnisse – höchstens ein Drittel der Energiereserven dürfen gefördert werden, zwei Drittel müssen im Boden bleiben – werden dadurch kaum berührt.

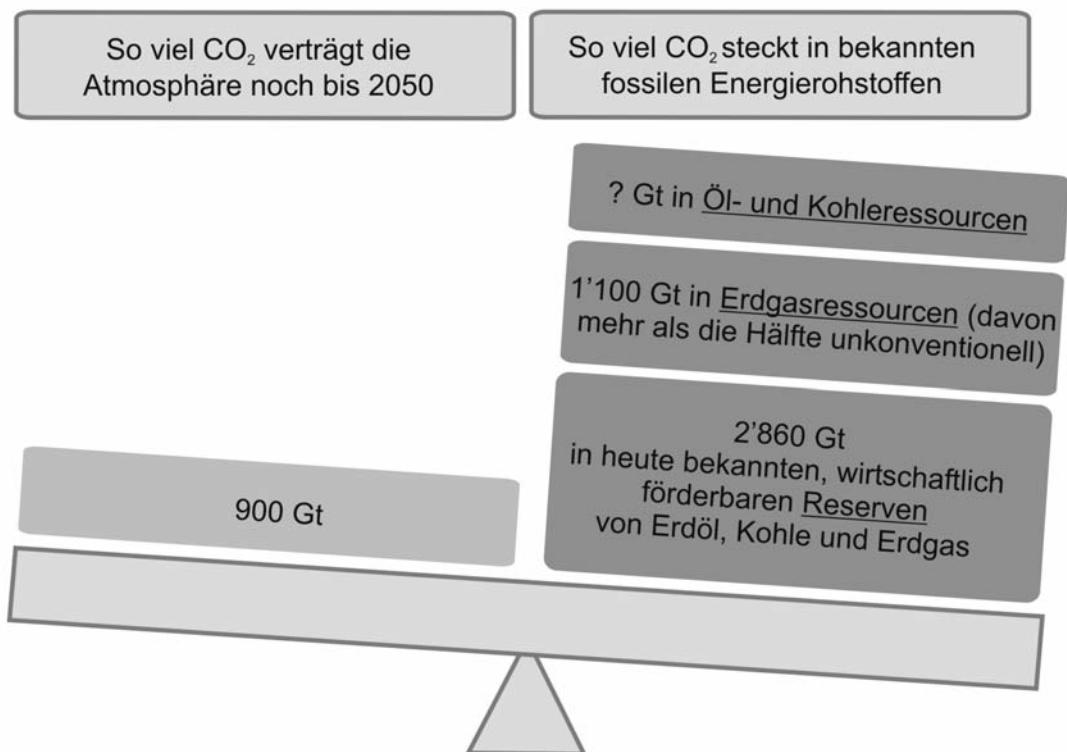


Fig. 1: Schematische Darstellung der Ressourcen und Reserven fossiler Energierohstoffe im Verhältnis zum klimaverträglichen Kohlenstoffbudget bis zur Mitte des Jahrhunderts [Datenquellen: IEA 2012a, IEA 2012b, IEA 2014, Carbon Tracker Initiative 2014].

Hinzu kommt, dass CCS aufgrund der hohen erforderlichen Investitionen zumindest auf absehbare Zeit eher für emissionsintensive Energieträger wie Braun- oder Steinkohle wirtschaftlich darstellbar scheint (ZEP 2011). Mit CCS ausgestattete Kraftwerke auf Basis des in dem vorliegenden Artikel im Fokus stehenden Energieträgers Erdgas hätten ein deutlich ungünstigeres Kosten-Nutzen-Verhältnis als beispielsweise Kohlekraftwerke, sodass CCS für die konventionelle und unkonventionelle Erdgasförderung sicher keine «Rettung» aus den Begrenzungen des Kohlenstoffbudgets bietet.

2.3 Lock-in durch Investitionen in fossile Energie-Infrastrukturen

Potenzielle CO₂-Emissionen sind nicht nur in den bekannten Reserven fossiler Energierohstoffe gespeichert, sondern implizit auch in der existierenden energierelevanten Infrastruktur (IEA 2012a). Damit setzen auch wirtschaftliche und infrastrukturpolitische Überlegungen klare Grenzen für die weitere Förderung von Energierohstoffen. So hat sogar die – nicht als ideologische Umweltschutzorganisation bekannte – Internationale Energie Agentur gefordert, dass aufgrund klimapolitischer Überlegungen nicht weiter wie bisher in fossile Energieversorgungsinfrastrukturen investiert werden darf (IEA 2012a). Andernfalls wäre bereits im Jahr 2017 durch die bis dahin geschaffene Energie-Infrastruktur und ihre über die Lebensdauer zu erwartende Nutzung der gesamte CO₂-Ausstoss festgelegt («locked-in», IEA 2012a, p. 25), der bis 2050 noch klimaverträglich emittiert werden darf. Investitionen in die (unkonventionelle) Förderung, Transport und Verbrennung von Erdgas ziehen zwingend hohe Fördermengen und/oder lange Nutzungsdauern der Infrastrukturen nach sich, um sich zu rentieren. Schwellenländer wie Indien oder China werden bei realistischer Betrachtung nicht von heute auf morgen sämtliche Investitionen in fossile Energieversorgung stoppen. Umso mehr verbie-

tet sich für wohlhabende Staaten wie die Schweiz erst recht jede Investition in neue Infrastrukturen zur Gasförderung, egal ob konventionell oder unkonventionell. Denn eine für die Amortisation der Investition ausreichende Nutzung der Infrastruktur verbietet sich aus klimapolitischen Gründen (siehe zur Lock-in-Gefahr in Bezug auf den Fracking-Boom in den USA auch Spencer et al. 2014).

2.4 Die Rolle von Fracking in der (internationalen) Energiewende

Fracking wird von seinen Befürwortern häufig eine wichtige Rolle im Übergang des heutigen Energieversorgungssystems in eine klimaverträgliche Zukunft zugeschrieben. Derartige Thesen beruhen teilweise auf Beobachtungen der Entwicklungen in den USA und sollen im Folgenden einzeln kurz betrachtet werden. Davon unberührt bleiben die zuvor genannten prinzipiellen Argumente gegen eine umfassende Förderung der fossilen Energierohstoffe.

Die erste These lautet kurz: «Shale Gas ersetzt Kohle». Demzufolge hat der Fracking-Boom in den USA dazu geführt, dass unkonventionell gefördertes Erdgas die – vermeintlich noch klimaschädlichere – Kohle in der Stromerzeugung verdrängt und somit einen positiven Netto-Effekt auf die globalen Treibhausgasemissionen hat. Während der – womöglich nur vorübergehende – Rückgang des Kohleverbrauchs in den USA zweifelsfrei festgestellt werden kann, ist der Netto-Effekt beim Blick über die amerikanischen Landesgrenzen weniger positiv. So zeigen Broderick & Anderson (2012), dass vermutlich mehr als die Hälfte der in den USA durch reduzierten Kohleverbrauch gesunkenen CO₂-Emissionen durch steigenden Kohle-Export (vor allem nach Europa) kompensiert wurden. Eine häufig vorgebrachte These attribuiert die in den vergangenen Jahren gesunkenen CO₂-Emissionen der USA auf den Fracking-Boom: «Shale Gas senkt die CO₂-Emissionen der USA». Afsah & Salcito (2012) belegen

jedoch, dass dieser Effekt offenbar nur marginal war. Die preisgetriebene Verdrängung von Kohle durch Shale Gas ist danach zumindest in den ersten Jahren des Fracking-Booms 2006 bis 2011 nur für 10% der US-amerikanischen CO₂-Reduktionen verantwortlich. Fast 90% des Emissionsrückgangs sind zurückzuführen auf den gesunkenen Mineralölverbrauch im Verkehrssektor und die Verdrängung von Kohle durch andere Faktoren wie erneuerbare Energien, behördliche Vorgaben und Kampagnen von Umweltorganisationen. Spencer et al. (2014) kommen zu ähnlichen Resultaten.

Aufbauend auf den beiden voran genannten – zumindest teilweise widerlegten – Thesen wird von einigen Fracking-Befürwortern postuliert: «Shale Gas ist eine notwendige Brücke zwischen Kohle und erneuerbaren Energien». In der Bildsprache bleibend könnte man darauf antworten: Die Gas-Brücke ist womöglich kurz und führt vor allem zu noch mehr Erdgas. Denn die durch Fracking bedingten vorübergehend günstigen Gaspreise in den USA haben zunächst vor allem zu einem deutlichen Anstieg des Gasverbrauchs geführt. Gleichzeitig wurden jedoch Investitionen in Energieeffizienz und erneuerbare Energien teilweise deutlich gesenkt (Martin 2013). Außerdem wurden zeitgleich mit dem Fracking-Boom in einigen US-Staaten die regulatorischen Rahmenbedingungen für erneuerbare Energien verschlechtert (Martin 2013). Offenbar sinkt durch die – vermeintlich – günstige und unerschöpfliche Energiequelle Shale Gas die Bereitschaft von Politik und Wirtschaft für förderliche Rahmenbedingungen und Investitionen zugunsten von Effizienz und erneuerbaren Energien. Auch Spencer et al. (2014) gehen davon aus, dass der Fracking-Boom nicht zu einer nachhaltigen Decarbonisierung der amerikanischen Energieversorgung führen wird. Aus globaler Perspektive scheint ein umfassender Ausbau der Gasförderung nur begrenzt kompatibel mit der Einhaltung der Zwei-Grad-Grenze (Levi 2013, Wigley 2011). Im Golden Age of Gas-Scenario der IEA (2011)

steigen die globalen Durchschnittstemperaturen zum Beispiel um 3.5 °C über vorindustrielle Werte – deutlich jenseits der Zwei-Grad-Grenze und damit auf dem Pfad zu einem gefährlichen Klimawandel. Dem neuesten Bericht des Intergovernmental Panel on Climate Change (IPCC) zufolge passt eine vorübergehend steigende Erdgasnutzung nur unter sehr restriktiven Bedingungen (geringer Methanschlupf, Nutzungsrückgang bis unter das heutige Niveau bereits vor 2050, etc.) zu Zwei-Grad-kompatiblen Szenarien (IPCC 2014).

2.5 Methan-Emissionen der unkonventionellen Gasförderung

Im vorangehenden Satz ist eine wesentliche Bedingung für die klimapolitische Diskussion von Fracking erwähnt, die bislang ausser Acht gelassen wurde: Das Ausmass der Methan-Emissionen und damit die Klimabilanz von unkonventionell gefördertem Erdgas im Vergleich zu konventionell gefördertem Erdgas und/oder Kohle. Verschiedenen Autoren zufolge kommt dieser Variable eine entscheidende Bedeutung zu, die die klimaverträgliche Nutzung von unkonventionellem Erdgas zusätzlich limitieren könnte (IPCC 2014, Wigley 2011, Broderick & Anderson 2012).

Eine kürzlich erschienene empirische Analyse der Methan-Emissionen in den USA legt nahe, dass der Methanschlupf bei der Gasförderung deutlich höher ist als bislang angenommen (Miller et al. 2013). Danach entweichen circa drei Prozent des geförderten Methans direkt in die Atmosphäre (Romm 2013). Brandt et al. (2014) schätzen die Methan-Emissionen von unkonventioneller Gasförderung noch höher ein – bis zu sieben Prozent des geförderten Gases. Das genaue Ausmass der Methan-Emissionen ist offenbar umstritten und hängt u. a. stark von den eingesetzten Technologien und dem Bohrstandort ab. Unstrittig ist jedoch, dass der Methanschlupf deutlich höher ist, als häufig in öffentlichen Statistiken oder Angaben von

Bohrloch-Betreibern beziffert (Miller et al 2013, Brandt et al 2014). Entscheidend ist, ab welcher Schwelle die energetische Nutzung von unkonventionell gefördertem Gas eine schlechtere oder nur unwesentlich bessere Klimabilanz als die von Kohle hat. Wigley (2011) zufolge ist dies bereits bei zwei Prozent Methanschlupf der Fall. Das bedeutet: Im ungünstigen Fall heizt unkonventionell gefördertes Erdgas den Klimawandel sogar noch mehr an als Steinkohle.

3 Schlussfolgerungen

Die genannten Argumente zeigen, dass aus klimapolitischer Perspektive Fracking in den allermeisten Fällen nicht Teil der Lösung, sondern Teil des Problems ist. Allein die Tatsache, dass zwei Drittel aller heute schon bekannten fossilen Energiereserven im Untergrund verbleiben müssen, verbietet es, politische, technologische und finanzielle Ressourcen in Praktiken zur Erschliessung der bekannten und künftigen Reserven zu investieren. Dies gilt umso mehr, als die investierten Mittel meist de facto in Konkurrenz zu einem verstärkten Engagement für Energieeffizienz und erneuerbare Energien stehen. Und kapitalintensive Fracking-Infrastruktur führt in ein Kohlenstoff-Lock-in: Um Investitionsruinen zu vermeiden, müsste in grossem Ausmass und über ausreichende Zeit unkonventionell gefördertes Erdgas energetisch genutzt werden. Das wiederum heizt den Klimawandel an bzw. schränkt den Spielraum für Klimaschutzmassnahmen weiter ein. Diese Argumentation gilt umso mehr, wenn sich die wachsende Evidenz bestätigt, dass Fracking deutlich höhere Methanemissionen mit sich bringt als bislang vermutet bzw. als aus der konventionellen Erdgasförderung bekannt.

Ausser dem letztgenannten Aspekt sprechen alle in diesem Artikel genannten Argumente auch gegen die konventionelle Erdgasförderung. Aus diesem Grund ist es aus klimapolitischer Perspektive nur konsequent, wenn

jede Förderung von Kohlenwasserstoffen eingeschränkt wird. Für die Schweiz – derzeit ohne Anlagen zur kommerziellen Förderung von Kohle, Erdöl oder Erdgas – bedeutet dies sinnvollerweise ein umfassendes Verbot jeglicher Förderung von Kohlenwasserstoffen. Entsprechende Vorgaben können die Kantone problemlos in ihren jeweiligen Landesgesetzen verankern.

Auf der Basis einer solchen konsequenten Position lässt sich auch einfacher eine differenzierte positive Bewertung der tiefen Geothermie begründen. Denn Projekte zur Gewinnung von Erdwärme unterscheiden sich von Fracking aus klimapolitischer Perspektive grundsätzlich durch das Förderziel und die Treibhausgasemissionen – auch dort, wo sich die eingesetzten Verfahren ähneln: Hier soll weitgehend erneuerbare Wärme aus dem Erdinnern gewonnen werden, um nahezu CO₂-frei Strom und Wärme zu erzeugen und ausserdem womöglich fossil betriebene Heizungen zu ersetzen. Eine konsistente Energie- und Klimapolitik in der Schweiz würde demnach die Nutzung der tiefen Geothermie – unter Beachtung der spezifischen lokalen Chancen und Risiken – fördern und zugleich die konventionelle wie unkonventionelle Erdgasförderung ausschliessen.

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Voraussetzungen zur Nutzung von unkonventionellen Kohlenwasserstoffen mit Hilfe von Fracking in der Schweiz

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Stichworte: Unkonventionelle Kohlenwasserstoffe, Schiefergas, Fracking, Schweiz, Bergregal

Abstract

Five conditions must be met in order to consider non conventional hydrocarbon production in Switzerland using fracking: 1. Clear and specific legal regime, 2. Sufficient scientific and technological expertise, 3. Effective and competent supervision and control, 4. Sustainability, 5. Limited potential for conflicts and risks; political and social acceptance.

The analysis comes to the conclusion that the conditions for unconventional hydrocarbon production and the massive use of fracking are not given so far in Switzerland, and suggests possible improvements in the case the project should continue.

Résumé

Cinq conditions de base devraient être remplies pour envisager l'exploitation d'hydrocarbures non conventionnels à l'aide du fracking en Suisse: 1. Une législation spécifique et claire, 2. Des connaissances scientifiques adéquates et la maîtrise de la technologie, 3. Une surveillance et un contrôle effectifs et efficaces, 4. La durabilité du projet, 5. Potentiel de conflits et risques limités; acceptance politique et sociale. L'analyse arrive à la conclusion que les conditions pour l'exploitation d'hydrocarbures non conventionnels à l'aide du fracking ne sont de loin pas remplies en Suisse. Elle propose enfin des pistes pour des actions à engager si le projet devait être poursuivi.

Zusammenfassung

Fünf Bedingungen müssten erfüllt sein, um die Produktion unkonventioneller Kohlenwasserstoffe mit Hilfe von Fracking in der Schweiz zu erwägen: 1. Klare und spezifische rechtliche Regelung, 2. Hinreichende wissenschaftliche und technologische Beherrschung, 3. Effektive und kompetente Überwachung und Kontrolle, 4. Nachhaltigkeit, 5. Begrenztes Konfliktpotential und Risiko; politische und soziale Akzeptanz. Die Analyse kommt zur Schlussfolgerung, dass die Bedingungen für die Produktion unkonventioneller Kohlenwasserstoffe mit Hilfe von Fracking in der Schweiz bei Weitem nicht gegeben sind und schlägt mögliche Pisten vor, wie weiter vorgegangen werden könnte, falls das Projekt weiter verfolgt werden sollte.

Einführung

Seit einigen Jahren entwickeln sich die Prospektion und Förderung von unkonventionellen Kohlenwasserstoffen in rasanter Weise. Aufgrund dieser Entwicklung werden selbst die Vereinigten Staaten von Amerika, bis jetzt ein grosses Importland, zu einem Exportland. Das Ganze gleicht einem neuen «Goldrausch», diesmal für Schwarzes Gold. Europa zieht bei dieser Entwicklung nicht voll mit. Starke Widerstände haben sich namentlich in Frankreich, in etwas geringerem Masse auch in andern Ländern entwickelt. Dabei stehen sowohl die generelle Ablehnung eines neuen Gas- und Petrolbooms, die Frage des nachhaltigen Grund- und Trinkwasserschutzes und des Schutzes der Atmosphäre vor Gaslecks (v.a. Methan), sowie die in Europa höheren Förderpreise als in den USA im Vordergrund (siehe z.B.

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Schnyder 2013, Titz 2013 und andere Presseberichte). Kritisiert wird oft auch die zur Förderung verwendete Technik des Frackings in abgelenkten Bohrungen, bei welcher Erdbeben auftreten.

Die Schweiz verfügt, aus geologischer Sicht, über ein reelles, wenngleich nicht ausgesprochen attraktives Potential für unkonventionelle, und in geringerem Mass auch für konventionelle Kohlenwasserstoffvorkommen (Brink et al. 1992, Burri et al. 2011, Leu 2008, 2014). Deshalb laufen Anstrengungen verschiedener Akteure, um Konzessionen zur Prospektion zu erlangen. Allerdings kam es bisher zu keinen neuen Prospektions- oder Förderbohrungen. Es bleibt also ein gewisser Raum, um darüber nachzudenken, ob die Rahmenbedingungen für die Prospektion und eventuelle Ausbeutung unkonventioneller Kohlenwasserstoffe unter Verwendung von Fracking überhaupt gegeben sind.

Grundvoraussetzungen zur Prospektion und Förderung von unkonventionellen Kohlenwasserstoffen in der Schweiz

Folgende Grundvoraussetzungen müssten heute zur Bewilligung der Prospektion und eventuellen Förderung von unkonventionellen Kohlenwasserstoffen mit Hilfe von Fracking erfüllt sein:

1. Klare und spezifische rechtliche Regelung.
2. Hinreichende wissenschaftliche und technologische Beherrschung.
3. Effektive und kompetente Überwachung und Kontrolle.
4. Nachhaltigkeit, im Sinne der Umweltverträglichkeit, sowie der sozialen und wirtschaftlichen Verträglichkeit.
5. Begrenztes Konfliktpotential und Risiko, politische und soziale Akzeptanz.

1 Klare und spezifische rechtliche Regelung

Heitzmann (2007) gibt einen Überblick über die rechtlichen Grundlagen der Nutzung mineralischer Rohstoffe in der Schweiz. Gemäss Bundesverfassung und Zivilgesetzbuch haben die Kantone bezüglich der Nutzung von Bodenschätzen über ihre Bergregale weitgehend freie Hand. Gewisse Einschränkungen und begleitende Massnahmen erwachsen aus anderen Gesetzgebungen, wie etwa dem Umweltschutz, dem Gewässerschutz und dem Kernenergiegesetz. Dementsprechend gelten bezüglich Prospektion und «Schürfung» mineralischer Rohstoffe, inklusive fossiler Kohlenwasserstoffe, ebenso viele unterschiedliche Bergregale wie die Schweiz Kantone zählt. Einige Kantone vereinigten sich im Hinblick auf die Erdölprospektion in einem Konkordat, was aber aufgrund der schwachen Tätigkeit in diesem Sektor in den vergangenen Jahren zu keiner weiteren Entwicklung führte.

Generell kann festgehalten werden, dass die Schweiz und ihre Kantone über keine klaren gesetzlichen Regelungen zur Erteilung von Konzessionen für die Prospektion und Ausbeutung von unkonventionellen Kohlenwasserstoffen und für die Überwachung und Kontrolle verfügen. Angesichts der Erwartungen der Öffentlichkeit an die Sicherheit und Nachhaltigkeit der Nutzung derartiger Bodenschätze, müsste das Bergrecht entsprechend ergänzt und interkantonal und national koordiniert werden. Dabei wären namentlich folgende wichtigen Themen zu berücksichtigen:

- Vollständigkeit der Gesuchsunterlagen und ihr öffentlicher Charakter.
- Rahmenbedingungen und Grundregeln beim Einsatz von Fracking, wie z.B. Regeln zur Verwendung von chemischen Substanzen zur Mobilisierung der Kohlenwasserstoffe.
- National geregelte Umweltverträglichkeitsprüfung, von der Prospektion bis hin zum Verschluss der Bohrungen. Nachweis

- der Nachhaltigkeit des Vorhabens. Der Umfang der Prüfung ist heute gemäss Verordnung über die Umweltverträglichkeitsprüfung (UVPV) den Kantonen überlassen.
- Risikoanalysen, inklusive langfristige Trinkwassersicherheit, Seismizität, Bodensenkung, etc.
 - Überwachung und Kontrolle durch die Behörden.

Übergeordnete Anliegen müssten auf nationaler Ebene geregelt werden. Dazu zählen insbesondere landesplanerische Aspekte der Nutzung des Untergrundes und die Definition von Prioritäten zwischen unterschiedlichen Nutzungen.

2 Hinreichende wissenschaftliche und technologische Beherrschung

Die nachhaltige Entwicklung eines neuen technologischen und industriellen Wirtschaftszweigs, behaftet mit Schwierigkeiten und Risiken für Mensch und Umwelt, verlangt eine wissenschaftliche und technologische Beherrschung auf hohem Niveau.

In der Schweiz wird zurzeit unseres Wissens keine Grundlagenforschung zu Themen betrieben, welche das Fracking und andere Fragen der Kohlenwasserstoffprospektion oder -förderung direkt betreffen. Damit werden auch auf dem Hochschulniveau keine Fachleute auf diesem Gebiet ausgebildet (etwa auf dem Niveau Master oder Doktorat). Die Thematik wird allenfalls in Vorlesungen und Masterkursen gestreift. Exponenten, welche in Fachzeitschriften und Vorträgen zur Diskussion beitragen, tun dies meist auf Grund von Erfahrungen aus einem industriellen Kontext in Weltregionen mit geringerer Bevölkerungsdichte und weniger entwickelten Infrastrukturen, d. h. mit kleineren Risiken für Mensch und Umwelt.

Eine ähnliche Entwicklung einer neuen Industrie, ohne nachhaltige wissenschaftliche und industrielle Verankerung, erlebte die Schweiz im Bereich der zu Ende gehenden

Nutzung der Kernenergie. Sie kontrastiert mit der Geschichte der Maschinen-, der Uhren- und der chemischen Industrie, welche seit weit mehr als einem Jahrhundert mit robustem Hintergrund in Forschung, Entwicklung und Ausbildung prosperieren. Eine derartige Entwicklung im Bereich der fossilen Energieträger würde entsprechende mittel- und langfristige, öffentliche und private Anstrengungen verlangen, sowohl in der Nachwuchsförderung, als auch in der Forschung und Entwicklung, etwa so, wie dies heute auf dem Gebiet der Geothermie geschieht.

3 Effektive und kompetente Überwachung und Kontrolle

In den meisten gesellschaftlich relevanten Bereichen erlassen in der Schweiz Parlament und Regierung auf nationaler Ebene Gesetze und Verordnungen, deren Umsetzung den Kantonen obliegt. Die Landesregierung bzw. die Zentralverwaltung überwachen die Umsetzung. Dagegen ist der Bund z.B. in den Bereichen des Eisenbahnwesens, der Sicherheit der Gas- und Ölpipelines und der nuklearen Sicherheit gleichzeitig als regulierende, ausführende und kontrollierende Instanz tätig. Bei der Umsetzung der Minenregale sind die Kantone alleinige Meister an Bord, solange keine anderen, dem Bund unterstellte Bereiche betroffen sind. Zu Fragen der Kohlenwasserstoffprospektion und der Produktion verfügen die Kantone allerdings in der Regel weder über qualifiziertes, kompetentes Personal, noch über entsprechende technische und wissenschaftliche Ausrüstung. Auch wenn sie gewisse Überwachungs- und Kontrolltätigkeiten an externe öffentliche oder private Institutionen delegieren würden, wären sie weder imstande, die Pflichtenhefte zu redigieren, noch die Resultate zu prüfen.

Damit ist die Frage der Überwachung und Kontrolle offen. Lösungen könnten entweder durch eine Zusammenarbeit zwischen den

Kantonen, oder durch die Schaffung einer nationalen Fachstelle gefunden werden.

4 Nachhaltigkeit, im Sinne der Umweltverträglichkeit, sowie der sozialen und wirtschaftlichen Verträglichkeit

Akzeptiert man den Begriff der Nachhaltigen Entwicklung in seiner ursprünglichen Definition (United Nations 1987), so bedeutet er namentlich Gerechtigkeit zwischen den heute und den zukünftig lebenden Menschen, und dass auch künftige Generationen knappe Ressourcen nutzen können.

So betrachtet, kann die Nutzung einer beschränkten Kohlenwasserstoffressource, welche durch die heutige Generation ausbeutet und nachher verlassen würde, nicht als nachhaltig betrachtet werden. Allenfalls könnte die Ressource z.B. als Notreserve bereitgestellt und im Falle einer Krisensituation zu einer teilweisen Nutzung freigegeben werden.

Weitere wichtige Aspekte, welche die Nachhaltigkeit der Nutzung einschränken können, betreffen eventuelle Ressourcenkonflikte, namentlich mit der Nutzung von Geothermie, der Nutzung als Wirtsgestein oder als Caprock für die Untertagslagerung (radioaktive Abfälle, Kohlendioxyd, flüssige Kohlenwasserstoffe und Gas), oder für die Anlage von Transportinfrastrukturen.

Die Ausbeutung von fossilen Kohlenwasserstoffen im geologischen Untergrund steht damit bezüglich der Nachhaltigkeit in krassem Gegensatz zur Nutzung der erneuerbaren Geothermie und der Nutzung von Tiefengrundwasser im Allgemeinen. Bei einer Abwägung zwischen den verschiedenen möglichen nutzungen des Untergrundes schneidet die Ausbeutung dieser fossilen Energieträger schlecht ab.

5 Begrenztes Konfliktpotential und Risiko, politische und soziale Akzeptanz

Fracking zur Gewinnung von fossilen Kohlenwasserstoffen beinhaltet verschiedene Risiken. Diese können sich während der Prospektion, der Produktion, oder gar nach dem Verschluss der Bohrungen realisieren:

- *Erhöhte Seismizität:* Kleinere Erdbeben können sich während dem Bohrvorgang bzw. dem Frackingprozess, aber auch während der Nutzung einer Ressource ereignen. Wichtigere Ereignisse können vermutlich einzig in eigentlichen Erdbebengebieten ausgelöst werden.
- *Bodensetzung:* Mit Subsidenz ist während und bis einige Jahre oder Jahrzehnte nach der Ausbeutung einer Lagerstätte zu rechnen. Sie kann Bauten und Infrastrukturen beschädigen. Subsidenz ist in Bergbaugebieten und Gasfeldern eine übliche Erscheinung (Ketelaar 2009).
- *Gasaustritte in die Atmosphäre:* Diese können bei Undichtigkeit direkt aus der Bohrung austreten und damit das Klima beeinflussen. Das Risiko ist etwa mit jenem von Lecks an Gasleitungen zu vergleichen. Es verschwindet mit dem sauberen Verschluss der Bohrung.
- *Grundwasserverschmutzung:* Grundwasser kann durch die chemischen Zusatzmittel zur Mobilisierung der Kohlenwasserstoffe, aber auch durch die Kohlenwasserstoffe selbst erfolgen. Meist ist oberflächennahes Grundwasser betroffen, da es sich vor allem um Verschmutzungen verursacht durch unvorsichtigen Umgang mit Bohrflüssigkeit und Wasser aus der Förderung handelt. Grundwasserverschmutzung kann aber, beispielsweise etwa bei mangelhaftem Bohrlochverschluss, noch weit über die Nutzungsperiode hinaus ein Thema sein.
- *Veränderung der tiefen Wasserzirkulation:* Fracking lockert die betroffene Gesteinsformation auf. Diese kann dadurch ihre Eigenschaft als Aquitard verlieren. Damit

kann die Tiefenzirkulation stark verändert werden. A priori geht die Veränderung in Richtung einer verstärkten Wasserzirkulation. Dies kann bei Tiefenlagerprojekten, Geothermieprojekten, bei der Gewinnung von tiefer gelegenem Trinkwasser oder bei Projekten für Transportinfrastrukturen zu Beeinträchtigungen und Konflikten führen (siehe Punkt 4, oben).

Eine teilweise weitergehende Analyse der Risikofrage, inklusive ökonomischen und sozialen Risiken, wurde durch IRGC (2013) für die Entwicklung unkonventioneller Gasressourcen präsentiert.

In der öffentlichen Diskussion überwiegen in Europa die Themen der erhöhten Seismizität und der Grundwasserverschmutzung. Dabei vertreten die Befürworter der Projekte zur Prospektion und Produktion von unkonventionellen Kohlenwasserstoffen meist private Akteure. Die Risiken erscheinen als Risiken zu Lasten der Bevölkerung. Entsprechend ist die Akzeptanz von Projekten zur Erschließung von unkonventionellen Kohlenwasserstoffen sehr schlecht. Der Widerstand kann regional bezüglich seiner Intensität mit jenem gegen Kernkraft verglichen werden. Vor diesem Hintergrund scheint die Schaffung öffentlicher Kompetenzzentren und kompetenter öffentlicher Kontroll- und Überwachungsbehörden als einziger Ausweg, um die Vertretung öffentlicher Interessen kompetent zu vertreten.

Diskussion

Wie die obigen Ausführungen aufzuzeigen versuchen, sind in der Schweiz heute die Voraussetzungen für die Produktion unkonventioneller Kohlenwasserstoffe mit Hilfe von Fracking nicht gegeben. Fakten, wie ungenügende rechtliche Regelung, fehlende wissenschaftlich-technologische Beherrschung aufgrund mangelnder Nachwuchs-

förderung und fehlender Grundlagenforschung, ungenügende Überwachung und Kontrolle, ungenügende Nachhaltigkeit der Projekte und mangelhaftes Risikomanagement können nicht mit Aussagen wie den Folgenden aus dem Wege geräumt werden (Burri & Häring 2014): «Wissenschaftliche Fakten sind zunehmend mit unzureichender Information von Bevölkerung und Behörden konfrontiert. Der leichte Zugang zu Informationen über Internet führt zu einem starken Anstieg des Pseudo-Wissens. [...] Die Kritik basiert mehr auf Glauben, denn auf Fakten und es ist deshalb schwierig, ihr mit rationalen Argumenten zu begegnen.»

Sollen die Projekte zur Prospektion und Produktion von konventionellen Kohlenwasserstoffen in der Schweiz mit Aussicht auf Erfolg weiter verfolgt werden, so müssen diese Mängel sicher korrigiert werden. Dabei ist der wichtigste Punkt jener, dass das Land weder über eine Vision noch über eine Strategie der Nutzung seines geologischen Untergrundes verfügt. Sodann fehlen die zur Umsetzung notwendigen rechtlichen Grundlagen sowie die Instrumente, um diese Nutzung im Sinne der nachhaltigen Entwicklung zu steuern und zu begleiten.

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The Global Impact of Unconventional Hydrocarbons (Hydraulic Fracturing on the way to a clean and safe technology). AAPG Annual Convention Houston, April 2014 – Selected highlights

Peter Burri¹

Comments and additions by the author in italics.

Key words: AAPG, natural gas, unconventional gas, unconventional oil, hydraulic fracturing, fracking, global energy, climate, CO₂, coal, US energy, gas reserves, peak oil, peak gas

1 General impressions and highlights

The convention: The convention was held in Houston, the centre of the US oil and gas industry and drew, with over 8.000 attendees almost twice the crowd of the Pittsburgh meeting last year.

The focus of the talks has been very much on domestic business: never in the past years have there been so few contributions by US companies on plays outside America. There were many very specialized technical talks (many by Chinese scientists) but disappointingly few overviews of large new international plays. Especially the independents are retreating to domestic activities. The other general observation is the still increasing importance of unconventional exploration and development, a topic that had an absolutely dominant role at this year's conference.

US E&P Industry: Amongst US companies the move «back home» to the US onshore is still on-going. This may also be a matter of funding: unconventional domestic activities have attracted a very large part of the worldwide E&P investment and fewer companies can afford to dance on too many shows. In addition, banks and private capital are still

reluctant to invest in exploration activities outside N-America. An additional reason may be the disappointment of many US companies with the progress of unconventional activities outside America, especially in Europe, even though high gas prices in Europe, and especially in Asia, are most attractive. US companies see Europe increasingly as a high-risk area with low legal security. This mood has been triggered by the moratoria on shale gas and the revoking of valid exploration licences (also in Switzerland) as well as short term changes in tax regimes and very slow and unpredictable approval processes.

Gas in the US was in April 2014 valued around 4.0–4.5 \$/MCF, i.e. about half the prices in Europe and 3–4 times lower than in the Far East. Prices of 4–5 \$/MCF do allow breakeven production in most of the plays but the main profits are presently made on associated liquids. European Majors who had invested heavily in unconventional gas acreage in the US (e.g. BP, Shell, Statoil) have grown more cautious. Most of these companies have been late-comers to the game, have overpaid corporate acquisitions and acreage and often only managed to get second grade blocks. The most successful companies in the US unconventional business remain the smaller independents.

The low energy prices continue to have a strong positive effect on the US economy. Energy inten-

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sive industries and/or industries with a large demand for gas as a raw material are relocating back to the US. The US draws a major competitive advantage from the gas boom and the recovery of the US economy over the past years is at least partly driven by energy costs.

The Obama administration has called unconventional gas «America's answer to Fukushima». The switch to gas, mainly the substitution of coal in power generation, has led to a further decrease in CO₂ emissions in 2013 in strong contrast to Germany where CO₂ emissions are rising (Figs. 1, 2). Gas will also impact the transport sector: by 2030 over 10 million vehicles in the US, especially diesel trucks are expected to run on natural gas. This will have a major positive impact on the environment. In spite of not having signed the Kyoto Protocol the US may eventually be one of the few countries achieving the Kyoto target reductions (reducing greenhouse gases emissions until 2020 to 18% below 1990 levels).

Reserve and Production growth: Gas reserves and oil reserves of the US continue to grow. The country added over 35 TCF in 2013 (production 24 TCF). Proven gas reserves are therefore about double of those 20 years ago. Oil reserves and production grew even stronger. The country is approaching about 9 Mio BBL/D in total liquids production (includ-

ing NGL) compared to 6.8 Mio BOPD in 2006 (Fig. 3).

Energy self-sufficiency for the US is still a prominent topic. Though it is very questionable whether the US will reach self-sufficiency in oil, imports are steeply decreasing and the US do in principle not need any imports from the Middle East or N-Africa. The US will become a net exporter of gas in 2020 (Fig. 5).

Unconventional hydrocarbons

Unconventional oil in US: Unconventional oil exploration is today in the US as important as unconventional gas – and more profitable. Contrary to gas where the biggest plays have probably been identified, unconventional oil plays continue to emerge. The production of the Bakken oil shale in Montana has already changed the US energy landscape and has led to a situation where the domestic oil production now exceeds imports for the first time in 20 years (Fig. 3).

Unconventionals US: There is a conspicuous move away from the «drilling the hell out of it» approach to a sweet spot exploration. The brainier part of the Industry has realized that 80% of the production came from only 20% of the wells and that many wells (possibly up to 50%) were not or only marginally commercial. The new approach gives much more weight to

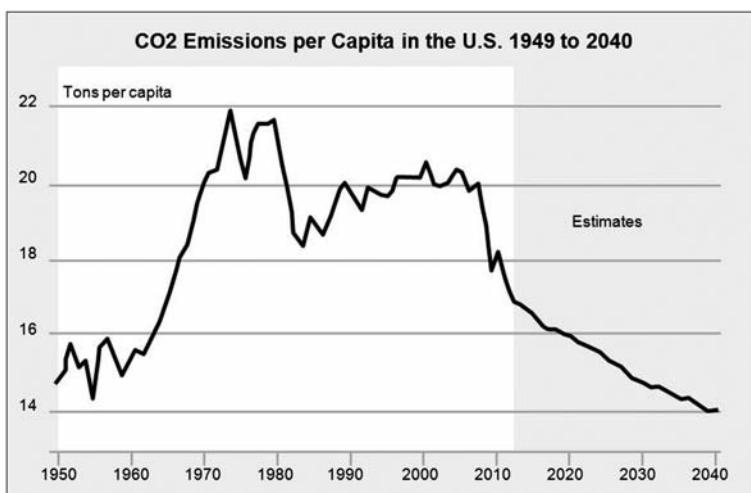


Fig. 1: CO₂ emissions in US per capita are at present back to levels of 1960s (contrary to Europe).

geological thinking, reservoir analysis, geochemistry and rock mechanics. Parallel to this, the drilling performance and well completion/stimulation technology are continuously improved. Thanks to these improvements one year drilling delivers today in the Marcellus 10 × more production than 6 years ago. Oil production in the Eagle Ford has risen 20 × in 5 years (see Fig. 4). The often heard statement that in general unconventional production per well is low, not sustainable and thus not commercial, is clearly incorrect. Production does drop steeply in the first year in most wells but it stabilizes thereafter and economic production can reach far over 10 years.

Unconventionals worldwide: There is no doubt that the success of unconventional will be repeated in many other parts of the world. There is, however, at present more caution in the forecasts as to how fast this will happen. Nowhere else are unconventional hydrocarbons tackled in the determined approach of the US and nowhere else will there be the same huge resources in money and technology dedicated to such exploration. In addition action by regulators in almost all countries and especially in Europe is slow and unpredictable. Unconventional gas and oil will be developed worldwide but it will most likely take decades rather than years.

There are also some technical/geological concerns: e.g. China, seen after Argentina as probably the next major development area for unconventional gas, has geological settings that are very different from N-America. Most basins have a lacustrine source rock. Lacustrine shales are often rich source rocks but may provide lower quality shale gas plays since proximal intracratonic settings produce much more variable lithology and a more mineralogically immature clastic input. Lacustrine source rocks are also generally more shaly than marine ones and may thus be less brittle and less suited for hydraulic fracturing.

Environmental concerns with hydraulic fracturing are still part of the public discussion, especially in the State of New York, the only state where a development of the Marcellus play is still banned, though interestingly New York is the biggest gas consumer of unconventional gas. In depth studies by the US Department of Environment show conclusively that the very large majority of water contamination by drilling fluids and gas is not related to hydraulic fracturing. Extensive water analyses in Pennsylvania identify methane as a very common constituent of drinking water from water wells (some 36% of wells in W Pennsylvania contain natural methane). Most methane stems from coal

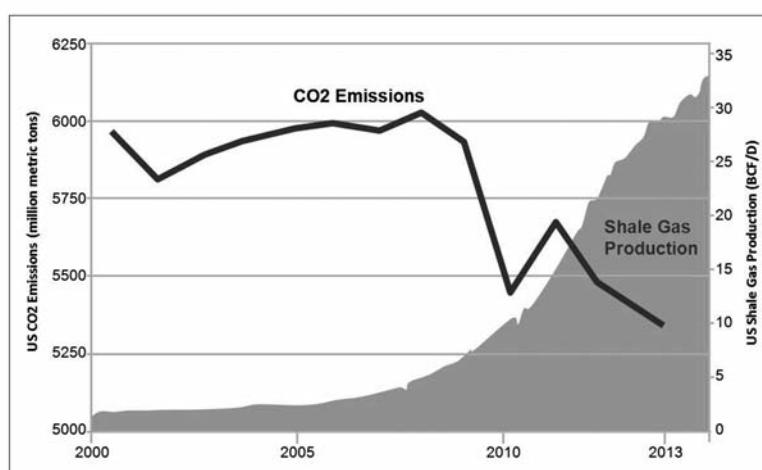


Fig. 2: US CO₂ emissions and shale gas production. Shale gas allows emission reductions that are not achieved in any other industrialized country. (Source US DOE).

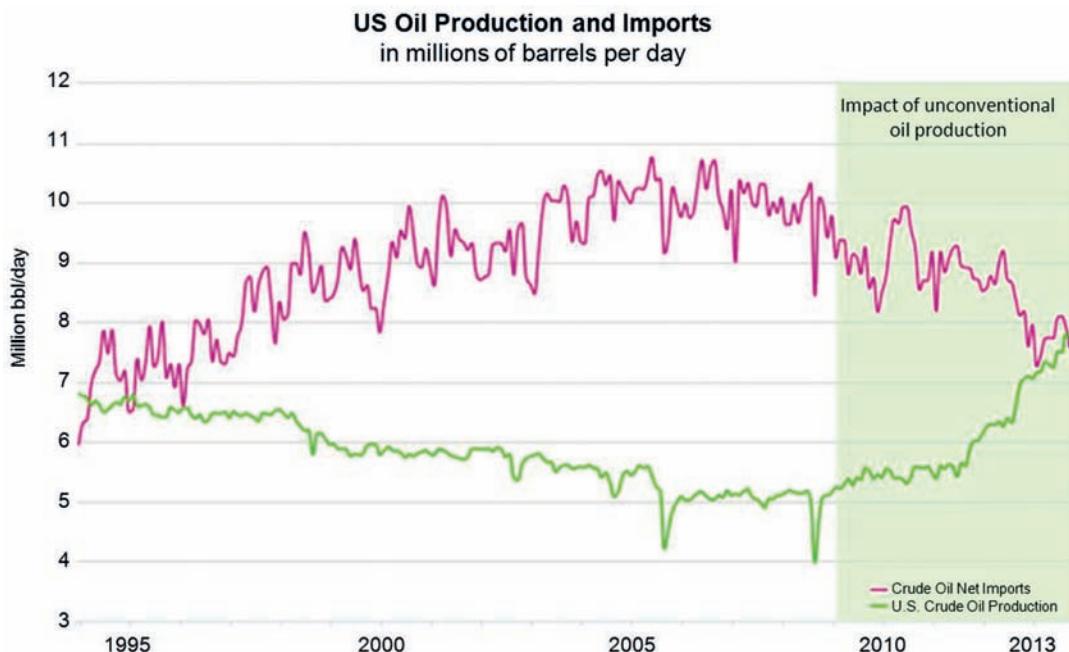


Fig. 3: US oil imports vs. exports 1994 to 2013 (source US DOE).

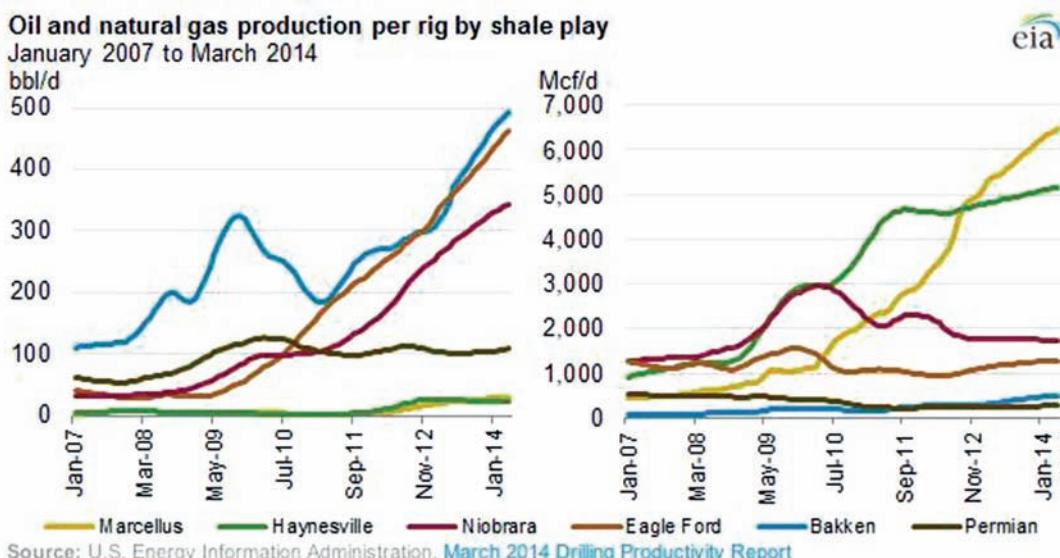


Fig. 4: Dramatically improved production per drilling rig (liquids left, gas right). The graph gives daily production added per rig active in the play. The growth reflects reduced drilling times as well as higher production per well as a result of sweet spot location and better completion/stimulation (Source US EIA).

seams, some rise naturally from deep thermally mature Marcellus Shale. There is still no case in North America where a direct contamination of groundwater, or the surface environment, by the actual fracturing has been proven, this in spite of several hundred thousand stimulations/fracks every year. Proven contaminations were caused by poor well integrity (e.g. poor cement jobs) or by poor handling of completion fluids in the surface installations. Contaminations can also stem from old historical wells that were not properly abandoned. Best practice operations are being developed by several operators in the Marcellus Shale; they allow operations without excessive water use (thanks to total recycling) and without the use of toxic additives. Cluster drilling has reduced the land use by a factor 20–30.

Large water use is always mentioned as a main criticism for hydraulic fracturing. In this context it is important to know that burning gas produces CO₂ and water, an average Marcellus well produces therefore over its lifetime 15 × more water than all the water needed for drilling and fracturing of this well. Biofuels, praised as renewables, use one order of magnitude more water than HC production.

The only major environmental problem remaining is the flaring or venting of gas in unconventional oil production. Very large volumes of gas are being flared in the Bakken Shale of North Dakota or in the Eagle Ford in Texas since gas-gathering nets are lacking and flaring is more cost effective. This is an enormous waste of energy (about 10 BCM/y) and has a negative environmental impact. Flaring and venting have been largely eliminated in most oil fields worldwide and there is no technical reason to flare in unconventional production. This harmful practice can only be stopped with clear guidelines and laws by the regulator.

Application of unconventional technologies to mature conventional plays: Through the unconventional boom the previous advanced technologies, like horizontal

drilling, multilaterals and multifrac have become very affordable routine tools. These technologies are increasingly applied to mature areas that were previously deemed to be in tail-end production. Prime example is the highly mature Permian Basin where oil production from old fields has been rising by over 30% since 2007 and is expected to double to about 1.3 MMBOPD by 2018. Plenty of other similar revivals of old conventional plays exist in the US and the added volumes may even exceed those of the new unconventional liquids production.

Worldwide Gas Market and LNG: The world gas market continues to be bolstered by the rising imports in South Korea, China and the after-effects of Fukushima. Though almost half of the global LNG production goes still to Japan and Korea, China is soon likely to become the main importer and Europe may follow in a desire to diversify its energy sources.

LNG exports will start from the US in 2015 and from Canada in 2016; considering also the still ongoing imports from Canada this will lead to the US becoming a net gas exporter before 2020. At present four LNG export projects have been approved by the DOE, others will follow. The American Petroleum Institute (API) has published an export forecast for the period 2015–2035, giving a cumulative total of 41 TCF or 1.15 BCM (Fig. 5). This amount is relatively small compared to the US domestic gas production (some 7%) but is significant for the world LNG market. On average the US LNG exports will add almost 60 BCM/y to the present LNG world market (18% of the 2012 global volume). Larger volumes would be possible but are unlikely in view of the strong political opposition against export of domestic energy. Similar LNG export volumes can be expected from Canada; in total N-America is thus likely to add some 120 BCM LNG per year to the world market (over 1/3 of the 2012 world LNG market). At present the world LNG market is still characterized by very large regional price differences, ranging from 3.15 to 16.40

USD/MMBTU. The new LNG volumes for N-America will, however, greatly add to the global availability and will have a moderating and equalizing effect on gas prices. With increasing global gas to gas competition the link of gas to oil prices will further weaken.

Conventional gas has in many parts of the world been neglected in exploration, especially where pipeline transport was not possible and where volumes were assumed to be too marginal for LNG. It is therefore not surprising that very large amounts of conventional gas continue to be found. The important new gas volumes discovered in the last 5-6 years in many parts of the world are being confirmed and keep growing, e.g. in the Eastern Mediterranean Levante Basin, where the proven reserves offshore Israel have now exceed 40 TCF (over 1.100 BCM). Israel is likely to export up to 23 BCM/year. The total potential of the Levante (incl. Lebanon and Cyprus) is estimated at > 100 TCF (about 1 year present world gas consumption). Additional upside will soon be tested offshore Cyprus. Offshore

East Africa, the big discoveries in Mozambique, with reserves of > 100 TCF, are being repeated in neighbouring Kenya and Tanzania with similar volumes. By 2020 Mozambique is expected to become one of the world's largest LNG exporters after Australia and Qatar. The reserves offshore Mozambique could cover the demand of Switzerland for some 1.000 years.

CO₂ Sequestration and Climate (see also Figs. 1, 2): CO₂ sequestration was only a few years ago a prominent topic at the AAPG and was seen by many as the final solution to the CO₂ emission problem. Few talks were dedicated to this theme now. Not only in the US but worldwide the hope pinned on sequestration appears to be waning. This is partly due to the very high unit costs of sequestration: they would kill the economics of any coal power-plant (which might actually be a positive thing). Reasons for skepticism come also from the very modest volumes handled so far in pilot plants and the fact that public opposition and NIMBY («not in my backyard») attitude

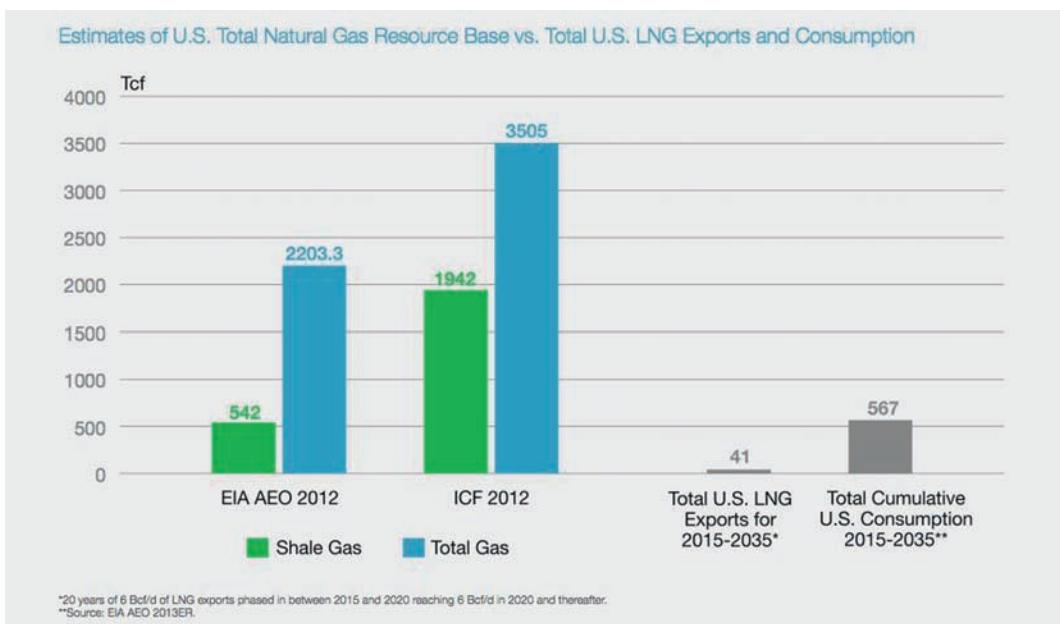


Fig. 5: US natural gas resources (left side) and domestic consumption and LNG Exports 2015–2035 (right side). All in TCF (1 TCF = 28 BCM). Total US LNG exports 2015–2035: 1.15 BCM [Source EIA].

are increasingly affecting the support for new projects. Energy projects of any kind, also renewables are in today's society more and more difficult to realize. This is unlikely to change as long as people have access to ample and cheap energy supply.

One of the best ways to sequester CO₂ is still in the enhanced oil recovery. With aging fields this is a growing opportunity, especially in the US where CO₂ pipelines from e.g. coal powerplants to oil fields already exist. Pumping CO₂ into depleted oil and gas fields will also meet with less public resistance since the existence of the old fields is proof that the system is sealing. Leakage of CO₂ back into the atmosphere is one of the main concerns in the public.

Renewables: As last year, the US E&P industry is so focused on the technical and financial challenge of the unconventional revolution that renewables were not really a theme at the conference. The much higher profitability in hydrocarbons has led to a drain of financial and technical resources away from geothermal, wind and – to a lesser degree solar.

Geothermal use of well fluids in oil and gas fields is still being pursued. New technologies that would allow a much more efficient heat extraction, especially at lower temperatures, would give a much needed boost to these efforts. Deep geothermal activities are concentrated in volcanic areas with little investment or research going into true enhanced geothermal systems (EGS), designed to artificially create deep heat exchangers. Given the large areas with shallow volcanic heat in the US, the more complex and less proven artificial stimulation methods are not a prime target and development is much slower than in Europe.

A philosophical thought by the director of the Smithsonian's National Museum of Natural History: The 21st century is unique in the 200.000 years of humans on earth. In the last 200 years the population of our planet has increased 700% to 7.1 Billion. Since the birth of our grandfathers the increase has been 3–4 ×. This explosive growth is the effect of the industrial revolution,

which, in turn, has been triggered by the availability of abundant cheap fossil energy. Oil and gas people have shaped the last 100 years of the earth's development, they have a responsibility for the next 100 years.

2 Presentations of special interest for the topic hydraulic fracturing and unconventional production

2.1 Unconventional gas and oil, general aspects

The Future of US Shale (Scott Tinker, Bureau of Economic Geology, Texas University)

- The energy need grows with people: world population will grow by 1 Billion every 13 years.
- Over 50% of world population live in China, India, SE Asia. 85% of their energy needs are covered by fossil fuel.
- Wrong perceptions distort public discussion:
 - High water use: Hydraulic fracturing and unconventional drilling consume < 1% of Texas water needs.
 - Fracs contaminate drinking water: fracs are 5–6 Eiffel Towers below ground water. Heavy frac waters do not rise (gravity!).
 - Land use: 15.000 wells of Barnett shale would be only 800 locations if clustered. The productivity of wells is rising every year (fewer and fewer wells are needed).
 - Unconventionals are not economic: Most presently produced plays are economic or break even at 4\$/MCF.
 - The recovery factor is negligible: Average RF is 10% but some areas achieve 50%, the RF is rising in all plays.
- Global aspects:
 - Peak Oil and Peak Gas: Oil peak estimate 2060, coal 2070, gas next century?
 - Unconventional gas could eventually reach 4 × the conventional volume (Fig. 6).
 - Shale gas will require 2.000 Billion \$ investment globally until 2040.
 - The world will produce 40–50 TCF/y of

shale gas by 2050 (equivalent to 33–42% of present world production).

- Worldwide do-ability of unconventional gas developments:
 - Russia and Middle East: negative (not yet, too much cheaper gas).
 - Europe: mixed to negative.
 - Rest of world: positive.

Assessment of Technically Recoverable Resources (John Browning, Bureau of Economic Geology [BEG], Texas University)

- The statement that unconventional gas production levels are not sustainable is incorrect. There is generally a rapid decline of production in the first year but production stabilizes thereafter in most wells with low further decline rates. Most Barnett Shale wells produce over 5 years, Haynesville wells produce 5–10 years and for Fayetteville up to 20 years appears to be possible.
- The Barnett shale will require some additional 90.000 wells for complete drainage.
- Reserve estimates and remaining Ultimate Recovery in TCF (GIIP / Recoverable):
 - Barnett → 440 / 86
 - Fayetteville → 80 / 38
 - Haynesville → 487 / 138Recoverable volumes have kept increasing, driven by technological and geological (e.g. sweet spot) improvements; recovery factors are likely to increase further.

Shale Gas sparks Innovation (Vikram Rao, Research Triangle Energy Consortium)

- Almost anything that can be produced by oil can be produced by gas.
- 5 TCF/y are flared worldwide, a tremendous waste and pollution that must stop. All venting and flaring should be abandoned. Flexible, temporary pipelines will help to do this. The co-produced gas can be processed/used in the field.
- Mini LNG plants (producing about 200 m³ LNG/day) exist and could be deployed in fields.
- Diesel must be eliminated from operations:

field installations can all be driven by gas.

- Fresh water should no longer be used. There is plenty of saline, brackish water available, including oilfield waters.

Panel on shale gas

- US lessons for overcoming resistance in other countries:
 - Education and communication. Demonstration of positive economic impact.
 - Positive involvement of government representatives.
 - Local people must benefit.
 - Industry must realize that regulations are positive.
 - Show best practice cases and especially that land use has been dramatically reduced.
 - Show consequences of saying NO: Saying NO to gas is saying YES to something else: e.g. more coal and more CO₂.
- Transport can be the main bottleneck: trains should be used for LNG or CNG (trains are more flexible than pipelines).
- One well in the Marcellus produces over its lifetime out of the gas 15 × more water than what it uses for drilling and fracturing (burning gas produces water and CO₂).
- Decline rates: The Marcellus production can keep building capacity for another 10–20 years.
- The drilling effort decreases since wells deliver continuously higher flow rates and ultimate recoveries (The Industry has been too successful, resulting in a gas bubble and low prices). But unconventional production uses still in average 10 × more wells than conventional production for equivalent ultimate volumes.
- Economy: Cheap gas due to unconventional production has so far triggered > 100 Billion USD investments in new industry plants. Repatriation of industry back to the US is continuing. Without shale gas the gas price in the US would be at 10–12 USD/MCF (actual is 4–5 USD/MCF). Shale gas has given stability to gas prices.

2.2 Expulsion efficiencies in source rocks

Determining Oil-Expulsion Efficiencies of Source Rocks by Hydrous Pyrolysis (Lewan, Michael, US Geological Survey, Denver)

- Expulsion processes have in the past probably not adequately been understood and expulsion efficiency was therefore generally overestimated. RockEval can e.g. not handle a mixed system of oil and gas. For the determination of expulsion efficiency RockEval should therefore be replaced by a process called hydrous pyrolysis.
- The initial porosity of a source rock and to a lesser degree clay mineralogy have the biggest effect on expulsion efficiencies. Higher TOC values (greater than 4 wt%) have no clear effect on expulsion efficiencies. High clay-mineral content can reduce expulsion efficiencies by 88%.
- Oil expulsion needs a continuous bitumen network in the SR. A 1–2% TOC SR never expels.
- Increasing porosity in the SR decreases (*sic*) the expulsion efficiency (organic porosity soaks up the oil)! The effect of porosity is best observed in carbonate-rich source rocks where chalky marlstones with porosities of > 30% can reduce expulsion efficiencies by 35%.
- Expulsion Efficiency increases with overburden. Without overburden a SR would grow 33% in volume during maturation due to creation of porosity in Kerogen during maturation.

The talk of Lewan confirmed again that the expulsion efficiency of most SR has in the past been grossly overestimated. The higher percentage of non-expelled HC creates the large opportunity of unconventional oil and gas.

2.3 Water use and potential groundwater contamination

The Prevalence of Methane and Solutes in Shallow Ground Water (Siegel, Donald et al., Syracuse University, NY.; Groundwater & Environmental Services, Altoona, PA).

- A geochemical synthesis of ~20.000 samples of shallow ground water from northeastern and western parts of the Appalachian Basin were collected 3–6 months prior to drilling for Marcellus Shale gas. In addition detailed temporal studies on the variability of methane and other parameters in ground water of 11 water wells in different hydrogeological settings was carried out in northeastern Pennsylvania.
- Mineral content: The results of the study show that the natural mineral content of drinking water is generally much higher than previously assumed. The spatial and temporal variability in concentrations of constituents (e.g. Na, CH₄, Fe, Mn, Sr, and Ba) span factors of an order of magnitude or more. Concentrations of these elements commonly exceed regulatory maximum levels because of natural geochemical processes.
- Methane: Tap water contained methane in 24% of analyzed samples in N-Pennsylvania and in 36% of samples in W-Pennsylvania. Traces of heavy metal are very common.
- In the absence of clear baselines, an observation of higher solute and gas concentrations in domestic well water after gas drilling cannot be considered as compelling evidence for contamination by shale gas development. Additional independent isotopic data and other forensic geochemical tools are needed.
- Best practice:
 - Sample 3–6 months prior to drilling.
 - Have analysis done by State certified labs.
 - Measure not only chemical composition but also temperature, turbidity, pH.

- Collect water samples in houses after flushing lines and taps (naturally occurring high mineral content turbidity and methane accumulations occurs when water wells are not used continuously).
- Take unfiltered samples.

The study confirms previous findings by the Department of Environment that water from domestic wells in many cases do not correspond to official standards for drinking water quality. Only in very rare exceptions a possible link to gas drilling can be established. Cases with clear proof of contamination by unconventional gas wells are still lacking.

2.4 Economics of unconventional plays

Scott Tinker Bureau for Economic Geology (Texas University)

- On a global scale unconventional gas resources (tight gas, shale gas, coalbed methane) have a volume potential that could be $4 \times$ the volume of all so far produced and remaining conventional resources (Fig. 6).
- Unconventional gas is becoming more competitive with technical progress and experience. Production costs for uncon-

ventional gas will in future be less than double the average production costs of conventional gas. Unit production costs have been steadily decreasing.

- Between 1/3 and 1/2 of the known unconventional gas plays can today be produced at prices of 6 USD/MCF or lower. At least 25% can be produced below 5 USD/MCF. These figures are for dry gas, wet gas improves commerciality substantially (Fig. 7).

Economic Evaluation of Unconventional Plays (Clarke, Robert, Wood Mackenzie, Houston)

- It is unlikely that there are big unconventional gas plays in the US that have not yet been identified. The remaining plays are mainly for niche players but can still be very attractive.
- In the US the economics for unconventional gas are still marginal. The profits achieved in unconventional gas are only about 1/10th of profits in conventional gas plays. Better well placement and better stimulation may improve this. The main profit comes from associated liquids.
- Internationally the development of unconventional resources is a very slow progress. The road to unconventional suc-

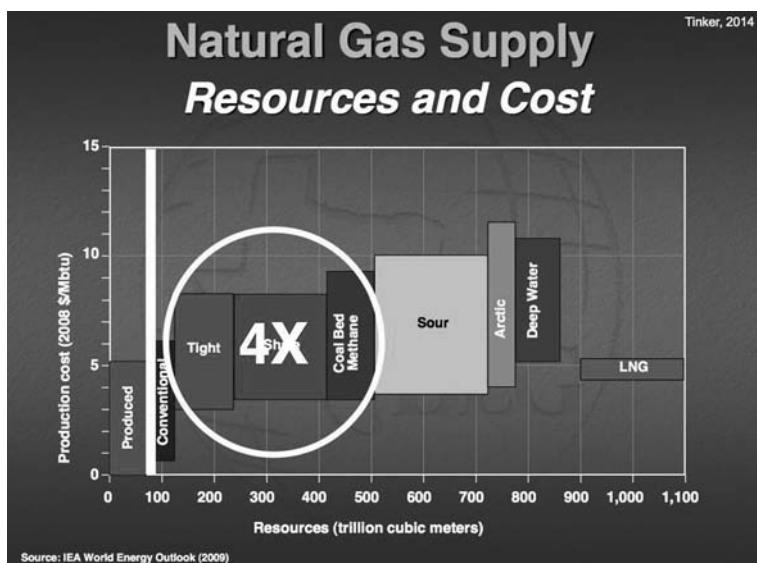


Fig. 6: Estimated production costs and resource volumes of unconventional and conventional gas supplies. Unconventional gas resources may be $4x$ larger than the produced and remaining conventional reserves. (Source IEA and Scott Tinker 2014).

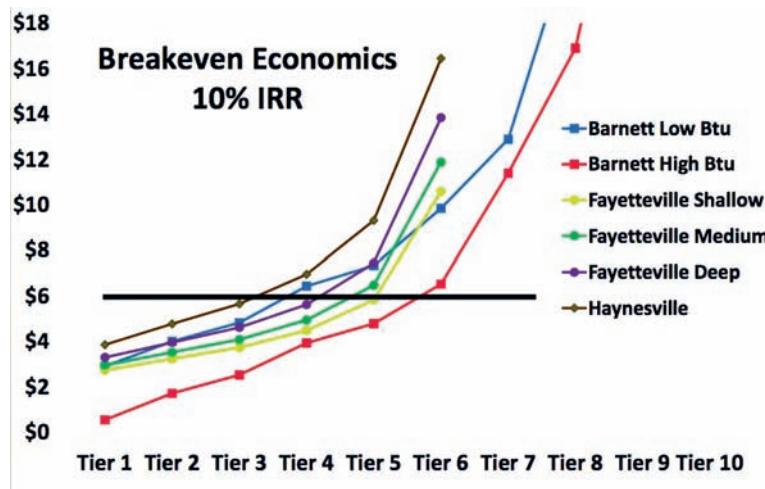


Fig. 7: Breakeven economics for different US shale gas plays. Reading example: some 2/3 of the wet gas (high BTU) Barnett Play can be produced at prices below 6 USD/MCF, at least half can be produced at gas prices \leftarrow 5 USD/MCF. [Source: Bureau of Economic Geology, Texas University].

cess will be much longer, more risky and more expensive by up to a factor 2 than in the US. Regulators do often not understand the business and the progress of regulation is very slow, especially in Europe.

- Number of shale gas or shale oil exploration wells drilled outside US by end 2013:
 - Europe 25
 - Russia 20
 - Australia 25
 - Asia (mainly China) 165
 - Argentina 250

Argentina is likely to be the first country outside the US to have a substantial unconventional oil and gas production, followed by China.

- Role of Majors: Majors will be the dominant players in international unconventional activities. This contrasts with the US where the Majors came late, were often overpaying for the acquisition of acreage or companies and frequently ended up with second-rate acreage. Plays like the Vaca Muerta of Argentina, the Bazhanov source rock of Siberia or the Cooper Basin are too big to be tackled by independents. Majors are already well placed in e.g. the UK or China.

Acronyms and terms

B: Billion (10⁹); BBO: Billion Barrels Oil; BOE: Barrel Oil Equivalent; BOPD: Barrel Oil per day; BBL: Barrel; BCF: Billion Cubic Feet (10⁹); BCFD: Billion Cubic Feet per Day; BCM: Billion Cubic Metres; BTU: British Thermal Units (mostly as Million Btu - MMBtu); CBM: Coal Bed Methane; CF: Cubic Foot; CNG: Compressed Natural Gas; DHI: Direct Hydrocarbon Indications (from seismic); DOE: Department of Energy (US); E&P: Exploration and Production; EIA: Energy Information Administration (US); GIIP: Gas initially in place; IEA: International Energy Agency; Industry: here always meant as the Oil and Gas Industry; M: Thousand; MCF: Thousand cubic feet; MM: Million; Majors: the category of the largest multinational private oil and gas companies; mD: Millidarcy (permeability measure); Nm: Nano metre; RF: Recovery Factor; SR: source rocks; TCF: Trillion Cubic Feet (10¹²); TCM: Trillion Cubic Metres (10¹²); TOC: Total Organic Carbon; USD: US Dollar; USGS: US Geological Survey; 3D: three dimensional seismic.

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Energie aus dem Untergrund – who cares?

Ueli Seemann¹

Am 7. Oktober 2014 fand ein Symposium unter obigem kryptischem Titel im neu erstellten Konferenzpavillon auf Berns Hausberg, dem Gurten statt. Das Symposium war der erste Anlass, welcher in diesem wunderbaren Pavillon mit einer faszinierenden Aussicht auf die helvetische Hauptstadt abgehalten wurde. Eine andere Schweizerische Premiere war auch der Themenkreis, welcher während eines vollen Tages integral abgehandelt wurde. Vereinfacht zusammengefasst handelte es sich dabei um eine technische und operationelle «state of the art review» bezüglich Untergrundgeologie und Energie in der Schweiz mit «Hydraulic Fracturing» als aktuellem Trigger und Buzzword. Das Symposium wurde von der Eidgenössischen Geologischen Kommission EGK initiiert. Dieses Gremium berät den Bundesrat in Fragen der Geologie und des Untergrundes. Die Kommission hat den Auftrag, dem Bundesrat bis zum Frühling 2015 eine Empfehlung zur Methode des Hydraulic Fracturing in der Kohlenwasserstoffexploration und der Geothermie zu unterbreiten. Das Gurten-Symposium sollte dazu eine breite Basis von Fakten und Meinungen liefern. Das Symposium stand unter dem Patronat von CHGEOL, SASEG, swisstopo und sc | nat. Dabei trug die SASEG in entscheidendem Masse bei der Zusammenstellung des Programms und vor allem bei der Rekrutierung von hochkarätigen Referenten aus der Industrie bei. Angesichts der Tatsache, dass es sich bei diesem Anlass um den ersten seiner Art handelte, war die Anzahl von über 150 Teilneh-

menden erfreulich hoch. Die hohe Anzahl von SASEG- und SFIG-Mitgliedern war ebenso bemerkenswert. Andererseits war die Präsenz der Politik (nicht?) überraschend niedrig. Immerhin hatten zwei prominente Politiker den Weg auf den Gurten gefunden: der Präsident der nationalrätslichen Umwelt-Raumplanung und Energiekommission (UREK) und der Präsident der kantonal-bernerischen Grünen Partei.

Die Themen, welche während des Symposiums behandelt wurden waren breit abgedeckt und ausgewogen:

Nach einer kurzen Einleitung durch die Symposiumsleiterin Marianne Niggli ergriff Olivier Lateltin – Leiter der Landesgeologie bei swisstopo – das Wort. Er präsentierte ein feuriges Plädoyer für die strukturierte Weiterforschung «seiner» (schweizerischen) Untergrundgeologie und für eine prominentere Rolle, welche Geologen in energiepolitischen und technischen Angelegenheiten spielen sollten.

Prof. Kurt Reinicke (Technische Universität Clausthal) beeindruckte mit seiner Keynote Lecture: «Hydraulic Fracturing – Technologie, Herausforderungen und Chancen in Gas-Exploration und Geothermie». Martin Bachmann (Leiter E & P Wintershall Holding GmbH) referierte in der Folge zum Thema Schiefergas, Fracking und zu «Best Practices». Bei beiden Referenten war deutlich spürbar, dass sie Personen aus der operationellen Praxis repräsentierten. Sie relativierten die oft zitierten und übertrieben dargestellten Risiken im Zusammenhang mit Schiefergas-exploration und Fracking (Seismik, Grundwasserverschmutzung etc.) in einer wohltuend bestimmten und auf Fakten basierenden Art und Weise.

¹ Vorstandsmitglied SASEG

Prof. Peter Huggenberger, Beauftragter der Universität Basel für Kantonsgeologie, plädierte in seinem Vortrag für mehr «Ordnung» im Untergrund, will heissen: mittelfristig sollte die Möglichkeit geschaffen werden, landesweit alle Untergrundressourcen (beispielsweise Geothermie, Schiefergas) systematisch und konsistent zu erforschen und zu priorisieren.

Prof. Walter Wildi, em. Prof. Institut F. A. Forel Université de Genève befasste sich in seiner Präsentation mit Umweltaspekten im Zusammenhang mit der Erforschung der Untergrundgeologie, speziell mit denjenigen der Exploration nach Schiefergasvorkommen. Auf Grund eines ausführlichen Katalogs von umweltrelevanten Beurteilungskriterien kommt Wildi zum Schluss, dass laut dem bestehenden Regelwerk und dem Fehlen von entsprechenden Experten die Bedingungen zur Exploration nach Schiefergas in der Schweiz nicht gegeben seien.

Nga Le (CFO ver.de München) wagte sich in das problematische Gebiet der Versicherbarkeit – oder Nicht-Versicherbarkeit – von Untergrundprojekten. Die in diesem Zusammenhang relevanten Umweltrechte wurden erst in den letzten Jahren entwickelt. Nga Le kommt zum Schluss, dass Umweltrechte noch nicht genügend ausgereift sind, um ein komplexes Haftungsgebiet wie dasjenige des Untergrundumweltrechts adäquat abzudecken.

Die Präsentationen von Fredy Brunner, Stadtrat St. Gallen und Dr. Michel Meyer, Services Industriels de Genève SIG, befassten sich beide mit aktuellen Geothermieprojekten. Es war interessant festzustellen, dass bezüglich dem Approach zu Geothermieprojekten, insbesondere der damit verbundenen Fracking-Methode, kein «Röschtigraben» zwischen dem St. Gallischen und dem Genferprojekt zu bestehen scheint, trotz der in diesem Zusammenhang verfänglichen Bedeutung des englischen Ausdrucks «Frack» (= Bruch, Riss, [«Röschi»]-Graben). Hervorzuheben ist auch die Präsentation des St. Gallerprojektes, welches einige High-

lights zu verzeichnen hatte: absolute Akzeptanz durch die Bevölkerung und exzellentes Bohrmanagement, um nur zwei zu erwähnen.

Das Symposium wurde durch zwei Podiumsgespräche bereichert, welche durch Karin Frei vom Schweizer Fernsehen souverän moderiert wurden. Die Diskussionen und Frage-Antwortrunden konzentrierten sich erwartungsgemäss auf geologisch-technische Themen. Bemerkenswert war allerdings, dass trotz der technischen Fokusse weiteren Themenkreisen wie Umwelt, gesellschaftspolitischen und anderen Aspekten ebenfalls genügend Raum und Zeit gegeben wurden. Das Symposium wurde dadurch in einem gesunden «bipolaren» Klima abgehalten – ungleich anderen Veranstaltungen zu denselben Themenkreisen, welche öfters zu Polarisierungen tendieren. Die lange Podiumsdiskussion zeigte aber auch einen fundamentalen Unterschied in den Erwartungen zum weiteren Vorgehen. Während die Vertreter der Industrie, aber auch von swisstopo oder SASEG dafür plädierten, dass nur gut kontrollierte Pilotprojekte eine sachliche Evaluation und Weiterentwicklung der Technologie ermöglichen würden, verlangten die Vertreter der Universitäten ausgedehnte, theoretische Grundlagenforschung als Voraussetzung für weitere Schritte.

Dr. Franz Schenker, Präsident der Eidgenössischen Geologischen Kommission, bedankte sich mit einer launigen Ansprache bei allen Anwesenden und Referenten für das Erscheinen an diesem doch denkwürdigen Symposium. Was der Schreibende den präsidenzialen Worten noch beifügen möchte wäre der Wunsch, dass dieses erfolgreiche Symposium absolut eine Fortsetzung verdient.

Hydraulic Fracturing – Postscriptum. A geologist's attempt to summarize what we know and where we go Peter Burri¹

P. Burri is Co-author of the 2014 Study of the German National Academy of Science and Engineering [Deutsche Akademie der Technikwissenschaften, acatec] on Hydraulic Fracturing and is a member of the Expert Group on Hydraulic Fracturing of EASAC (European Academies Science Advisory Council) that has in September 2014 formulated a recommendation on this technology for the EU Member States.

Key words: hydraulic fracturing, natural gas, unconventional gas, global energy, global climate, methane, CO₂, coal, greenhouse gas

1 Introduction

During my professional life as a geologist there has never been a geoscience topic so hotly and emotionally debated as is the case with the concept and application of hydraulic fracturing, the only likely exception being the geological concepts surrounding nuclear waste disposal. There has also rarely been a topic in geology and subsurface-engineering that has led to such violent opposition and attacks. Many geoscientists – grown up in the belief that science was largely a matter of logical debate where rational arguments, empirical facts and observations prevailed – were caught off-guard by this wave of rejection and had difficulties adapting to a new world in which the knowledge of scientific facts and arguments was not good enough anymore. Scientists discovered that there was a need to explain their lines of thought to a large, often sceptical – if not hostile – public. They also discovered that the trust of the public in scientific judgment and wisdom had been seriously impaired; a loss of credibility caused to a large extent by the scientific community itself which did not deem necessary to «sell» its arguments outside its own circles. The scientific community has now become

aware that talking to the media, the politicians and the greater public has become a must in order to be heard beyond the «ivory tower». This applies not only to hydraulic fracturing but also equally to other geoscientific activities that are in the public focus (e.g. waste disposal, mining, large engineering works, exploration for fossil fuels). In Europe the time of innocence of the geoscience community appears to be definitely gone and it will take a long, tedious effort at all levels to re-establish a new base of confidence.

A second aspect of the discussion on hydraulic fracturing is the speed with which opposition to the technology has spread. During over 60 years hydraulic fracturing was practiced in Europe with many thousand frac jobs carried out in Germany, NL, UK, Denmark and Norway. This occurred without any known accidents or any impairment to the environment and was accepted by the authorities as a routine process, necessary for increasing flow rates from poor reservoirs, be it oil, gas or water. As recently as five years ago, hydraulic fracturing was a process unknown to anybody outside the technical world and the mining authorities. This changed after 2010 when the film «Gasland» stirred up opposition against hydraulic fracturing and unconventional gas

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in some parts of the US. The pictures in the feature play in an emotionally very suggestive way to the fears of the broad public. Unease exists in the greater public with anything that impacts the ground under our feet or the quality of our drinking water as the lifeline of humans. The approach of the film is best characterized by the cover picture, showing the author playing banjo in front of a drilling rig with a gas mask on his face. Although in the meantime most of the accusations of the film have proven to be wrong – not by industry but by the environmental authorities in the US – the pictures of burning water taps, gas seeps in scenic streams and murky water samples have long started to lead their own life. Within a year the pictures had spread to Europe and – true to the rule: only bad news is good news – there is today no television debate without a diligent replay of the alleged horror pictures. Many unfounded ideas prevail even though in the meantime a second film by an Irish Journalist («Fracknation») has tried to confront «Gasland» with the real facts. It is possible that without the film «Gasland», hydraulic fracturing would still be a technical term, known to few technical insiders only and we could devote ourselves to the more urgent environmental problems of this planet.

Having said this, it is fully understandable that the public is concerned by the many accusations and doubts raised about the technology. The scientific community has, therefore, the duty to provide insight and contribute as much as possible to factual arguments. Getting back to a rational discussion is also essential since a potential ban on hydraulic fracturing would also severely endanger deep geothermal projects that have to rely on creating artificial heat exchangers, requiring extensive fracturing of the reservoir rock.

2 Hydraulic Fracturing: Criticism vs. Facts

The process of hydraulic fracturing is confronted with the following main points of criticism:

- Artificially created fractures can reach the surface or intersect aquifers of drinking water, thus creating pathways for possible pollutants.
- Additives to fracturing or drilling fluids are toxic and a hazard to drinking water as well as to the water in the fractured reservoirs.
- Hydraulic Fracturing uses large quantities of freshwater.
- Hydraulic Fracturing causes earthquakes.
- Unconventional gas production leads to excessive land use.
- In the course of the hydraulic fracturing and the later gas production large quantities of methane leak into groundwater, the soil and into the atmosphere.
- Hydraulic fracturing leads to heavy traffic during the operations.
- Wells stimulated by hydraulic fracturing have high decline rates, dropping to negligible levels within months. Shale gas production requires continuous high levels of drilling and unconventional gas is, therefore, not sustainable and largely uneconomic.

Some of the above issues have indeed been areas of concern during the earlier «gold rush» boom time of unconventional gas exploration in the US. Most of the problems have in the meantime been resolved (partly due to more severe regulations, partly through self-control of industry in an effort to keep the licence to operate). It has to be noted that the majority of the critical points have never been issues in Europe, given the fact that European legislations have already introduced a much stricter control and regulation of deep-well-drilling, well integrity and hydraulic stimulations.

At the risk of duplicating the statements in

some of the other papers in this special volume of the Bulletin, I like to sum up briefly the present state of knowledge, relating to the above criticism. The factual arguments for the statements below can be found in the following publications: Emmermann (editor) 2014, EASAC 2014, Reinicke 2014, Reichetseder 2014, Burri & Leu 2012, Burri & Häring 2014 and Burri 2014.

Hydraulic fractures reach the surface and create pollution pathways to the drinking water aquifers

- Microseismic measurements allow a very precise mapping of the extension of artificial hydraulic fractures.
- Fracture volume cannot exceed the volume of fluid injected. With the limited injected volumes and pressures, a creation of vertical fractures over 1.000 and more metres is physically not possible.
- In the very rare cases where leaks into aquifers have been observed, they have been caused by poor well integrity, defect casings or poor cement jobs.

Conclusion: There is no proven case where hydraulic fracturing has created a vertical fissure as a pathway extending from depths of > 1.000 m to surface.

Toxic additives in fracking and drilling fluids

- Potentially harmful substances have indeed been used in some of the US operations. Recent developments in Europe have, however, led to a reduction to only two additives, both non-toxic and biodegradable (recent publication Exxon Germany).
- Additives used in Germany in the past are classified by the authorities at the lowest water-hazard level (in concentrated form); liquid agricultural manure belongs to the same category. In contrast to manure (spread at a few 10 m above groundwater) the frac additives are, however, diluted by a factor of about 1:100 and are injected in reservoirs at a depth of several 1.000 m.
- Disclosure of additives is today common

practice in Europe and many parts of the US and should become compulsory standard practice worldwide.

Conclusion: Hydraulic fracturing can today be carried out without any harmful additives.

Large water use

- Hydraulic fracturing requires indeed large quantities of water: several 100 m³ per frac in gas wells, 10.000–20.000 m³ in geothermal wells (smaller volumes in future multi-fracs).
- A large part of these fluids is recovered in backflow and production.
- Burning of gas produces CO₂ and water. The gas from an average Marcellus shale well produces over its lifetime some 15 times the water needed originally for drilling and the frac job (AAPG convention 2014, panel on shale gas).
- Companies in the US with best practice operations recycle up to 100% of the backflow.
- Hydraulic fracturing does not need freshwater. It can equally use saltwater, brackish water or even wastewater.

Conclusions: Hydraulic fracturing still uses relatively large quantities of water but does not require freshwater. Water use is being significantly reduced through recycling. Water availability is a potential problem only in very arid climate with no access to brackish water.

Induced seismicity, earthquakes

- Any artificial fracturing of rock causes microseismicity. Seismic magnitudes correlate directly with injected volumes and fracture size.
- In shale gas and other sedimentary fracs the induced seismicity lies generally below M 1 (Magnitude), i.e. far below the threshold noticed by human beings. The highest magnitude known and related to shale gas fracturing has reached M 2.5 (Quadrilla UK). In geothermal wells, injecting into basement or close to basement, seismicity

- of up to M 3.5 has been observed, largely caused by shear movements, releasing tensions in pre-existing tectonic stress fields.
- Induced seismicity has in several areas been observed in wells where large fluid volumes were being injected.

Conclusions: In spite of some 3 Million frac jobs that have been carried out globally for oil and gas production from sedimentary rocks, there has been no recorded case of a damage quake. Seismicity in injection wells can be eliminated by avoiding disposal of fluids through recycling. In deep geothermal stimulation the risk of higher magnitude seismicity can be mitigated by replacing very large volume single fracs by much smaller volume multifrac jobs.

Land use

- Land used has been intensive in the early stages of shale gas developments when exclusively vertical wells were drilled.
- The use of horizontal drilling and the development of cluster drilling with up to 30 wells from one drilling location have led to a drastic reduction in land use. Up to 10 km² or more of reservoirs in the subsurface can be drained from one location. Drilling sites can now be spaced at several km intervals.

Conclusions: Land use is no longer an issue in modern cluster shale gas development. Geothermal projects have the lowest footprint of any renewable energy.

Methane leaks (see also «Methane as a climate gas» below)

- In large gas generating basins mature source rocks and mature coal seams produce trillions of m³ of methane of which a significant part migrates to surface and leaks out into the atmosphere. In prolific basins, e.g. in the Marcellus Shale of Pennsylvania thousands of natural gas seeps occur and studies by environmental authorities reveal that, depending on the area, between 24% and 36% of all drinking water wells contained significant amounts of methane.

- Except for very few and yet unproven cases with damaged wells, where gas could leak into neighbouring sediments, there is no leakage from shale gas wells into groundwater and the sediments. All alleged methane contaminations in the film «Gasland» have been proven to be of natural origin.

Conclusion: Where high drilling standards and good maintenance of the surface equipment are observed there is no risk of contamination of groundwater or sediments with methane. High standards of regulations for well design and operations in Europe have led to a situation where methane leaks are not an issue.

Heavy traffic during hydraulic fracturing operations

- This has been a serious issue in areas of intense drilling and stimulation efforts that often have led to thousands of truck-loads within a few months of operations.
- Trucking can be reduced significantly where recycling of backflow (with recovery of water and chemicals) is applied. Several US companies have a 100% recycling target. Also the reduction of additives leads to a lower transport intensity.
- Using local groundwater of non-drinking quality can further reduce traffic.
- Temporary water pipelines are increasingly used to replace trucking.

Conclusion: Trucking remains an issue with local communities during the drilling and fracturing phase. It is not an issue during production. Traffic intensity needs close attention and further improvement. Recycling and temporary pipelines go a long way to mitigate the impact.

High decline rates of fractured wells requires continuous drilling

- In most hydro-fractured wells production is highest in the weeks after the stimulation and shows then a steep decline within the first year.
- After the initial decline phase the wells enter a phase with very slow further

decline and most wells continue production over many years. Production lifetimes of 10 years and more are known even in old, not optimally treated wells.

- Focus on geological sweet spots and better completion has led to lower decline rates, considerably longer production life and an up to tenfold increase of ultimate recovery per well. Drilling time per unit gas produced has decreased by a factor 10 between 2008 and 2014 (US EIA Drilling Productivity Report, March 2014). Over the same period the number of rigs drilling for gas has fallen by 80% while total unconventional gas production kept growing.
- 25% of all the Marcellus shale gas reserves can be produced at gas prices below 5 USD/1.000 cubic feet. For the more valuable wet gas the percentage is much higher.

Conclusion: Fractured wells do show high initial decline rates but stabilize later for many years at still commercial levels. Recent technological progress has multiplied ultimate recovery per well. Drilling time per unit gas produced has in the Marcellus operations been reduced to as little as 10% of the time required 6 years ago. Unconventional gas production has therefore become increasingly sustainable and commercially robust.

3 Methane as a climate gas

Methane is a potent greenhouse gas (over a time frame of 100 years it is $28 \times$ more effective than CO₂) and should therefore not enter the atmosphere. There is no doubt that in the past methane leaks from the oil and gas industry have significantly contributed to the amount of greenhouse gases. Source of the emissions are mostly leaks during testing and from poorly maintained production installations as well as pipeline systems and venting. Again, these emissions are still a concern in parts of the US and in some other oil and gas producing countries but methane leaks are today insignificant in

Europe, where tight regulations for production operations and maintenance prevent gas to escape into the atmosphere. In Germany 53% of the total methane originates from agriculture, 3% from the energy industry and only 0.1% from gas production. Since 1990 the methane emissions in Germany have been decreasing by 55%, mainly through closing coal mines (Umweltbundesamt 2014).

It is scientifically incorrect to use individual US worst case examples and extrapolate them to a global scale. Such an extrapolation has recently been presented by Howarth 2014. His assumptions for methane emissions from unconventional gas production range from 3.6% to 7% of total gas production. Emissions at such high levels would imply leakage of millions of m³ of gas from one location. Leaks at such levels would cause a very high level of explosion risk that would be incompatible with even low safety standards. Gas concentrations at production locations are routinely monitored and emissions in the several % range would automatically lead to a shut down of the plant. What is certainly not tolerable in today's world is the widespread flaring and partly venting of associated gas in oil fields and particularly in unconventional oil production where the initial lack of infrastructure makes a gathering of the associated gas economically not attractive. US flaring and venting has reached the highest level since the early 70's with almost 7.5 Billion m³/y (over 2 \times annual gas consumption of Switzerland). Flaring and venting is banned in Europe except for production tests. Such wastage of gas needs to be eliminated through stringent regulations. Flaring, as occurring in some parts of the US is, however, not a valid argument to ban gas production – we do not ban cars because they cause accidents, we regulate the traffic and carry out technical inspections.

The level of methane emissions in European gas fields lies well below 1% and is thus an order of magnitude below the Howard esti-

mates. The European experience demonstrates that methane emissions can be successfully eliminated. In well run and well maintained gas fields the risk of methane leakage is minimal.

4 Gas production and CO₂ emissions

Doubts are regularly surfacing on whether the new availability of much larger gas resources can have an impact on climate change at all. Proof of this is relatively simple: from 2008 to 2013 the US were able to reduce CO₂ emissions by 600–700 million t, i.e. by over 12% or 15 × the annual CO₂ emissions of Switzerland. The lion share of this reduction was achieved through replacement of coal by gas in power plants. With this, the US have achieved the largest CO₂ reduction of any industrial country and have almost reached the 1990 emission levels, target of the Kyoto Protocol (not signed by the US). During the same time CO₂ emissions in Germany have been rising against a backdrop of a politically strangled gas production and its replacement by coal.

5 Gas, fossil fuels and the world energy supply

The likely link between manmade greenhouse gases and the burning of fossil fuels suggests that it is wise to reduce our dependence on non-renewable energy, no matter where we stand in the discussion on global warming. Requests for reduction range from «no investment into fossil energy after 2017» to a reduction of CO₂ by 40–70% until 2050 and zero fossil fuels by 2100 (Press release IPPC, 2 November 2014). Reaching these targets will require transformations at an extremely high speed that is not in line with the statistical experience of the last decade. In spite of a very impressive growth of over 300% in the last 10 years, renewables w. o. hydro provide today only 2.4% of the global energy supply while the share of fossil fuels has decreased since 2004 only very marginally from 87% to 86% (Reinicke 2014). Only 7% of the energy growth in the same 10 years period could be covered by the large rise in the new energies. This implies that, while we make most impressive progress in developing renewables, we are still decades away from even covering the growth in energy, let alone replace fossil fuels. In addition the supply may have to cover an approximate doubling of world energy demand within 50 years (assuming the present growth can be halved).

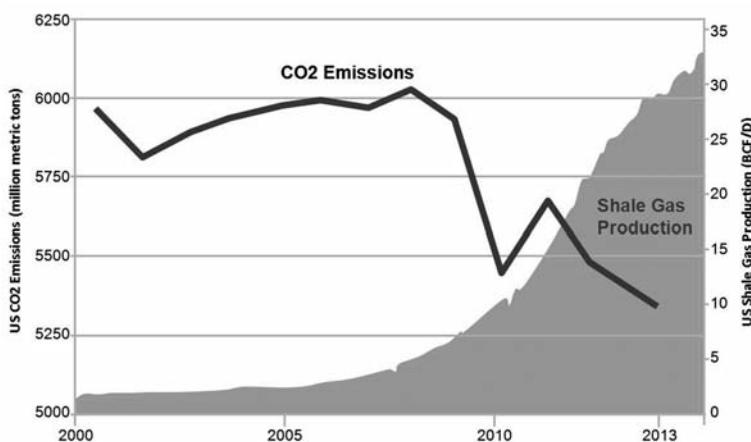


Fig. 1: US CO₂ emissions and shale gas production. The availability of shale gas allows emission reductions that are not achieved in any other industrialized country. The 1990 CO₂ emissions of the US were 5.100 million t [Kyoto Protokoll target]. Source US DOE.

It will be important to structure the transition to a renewable energy world in a way that protects economic development and does not put the burden on a few countries alone. We should not forget that only prosperous countries can afford a high level of environmental protection. Where countries and people are in survival mode there is little concern about the state of the world that we may leave to future generations.

In the absence of a major technological breakthrough that would revolutionize the global energy supply (like nuclear fusion) the world has two options:

The «pure renewables scenario»: political barriers will be used to block the development of unconventional gas in many parts of the world. Growth of renewable energies will cover an increasingly larger share of the market but – given the likelihood of rising NIMBY public opposition to windfarms, hydro dams, geothermal powerplants and solar farms – renewables may take well into the next century to cover the global needs. The remaining energy will predominantly be supplied by coal, the cheapest and most abundant fossil energy. Oil will gradually make place to renewables, especially in transport and heating. The consequence will be a very slow improvement of the global CO₂ balance (see developments in present day Germany) and a severe deterioration of air quality in most of the Asian, African and Latin American megacities with millions of fatalities caused by respiratory diseases.

The «mixed gas – renewables scenario»: The present abundance of gas resources (reach 250–300 years at present day demand) is being deliberately used for a rapid replacement of coal power stations and of diesel-driven heavy vehicles by gas. This could within two decades lead to a very drastic reduction in global CO₂ emissions (several 10%) and would improve the air quality in most megacities of the developing countries. Political steering of the energy use

would be required, probably in the form of a CO₂ tax, which ideally should be complemented with an additional pollution tax for coal.

6 Scientific advice and decision makers

A proper assessment of chances and risks of new technological applications requires in-depth knowledge and profound experience in the sciences involved. In the case of hydraulic fracturing and unconventional gas production this calls for geologists and geophysicists with expert knowhow of the processes in deep sedimentary basins and for engineers, specialized in drilling and in the very sophisticated subsurface engineering technologies. Unfortunately decision makers have often ignored the need for competent specialists, with very unfortunate results: most of the bans declared on the technology have not been introduced on the grounds of technical expertise but were largely emotionally and politically motivated.

Today we have a very peculiar situation where there is not a single scientific organization or institution worldwide (with competence in these technologies), that advocates a ban on hydraulic fracturing, neither in gas nor in geothermal applications. All these institutions, private as well as state controlled, recommend that the technology be properly regulated and that adequate standards and controls be introduced. In Europe they also stress the need for pilot projects without which there will be no learning and no scientific progress.

The worrying aspect is that the advice of all these highly competent scientific bodies has, so far, been almost totally ignored by decision makers. France has banned the technology at the very moment when the Academie des Sciences de France and the Bureau des Recherches Geologiques et

Minières advised to the contrary; Germany and several other countries show similar behaviour patterns. It is time that geoscientists regain their voice and make themselves heard. Important decisions, like the future of our energy supply and the quality of our environment, should not be left to politicians, pressure groups and sensation-hungry media alone.

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High Pressure (HP) and Ultrahigh Pressure (UHP) metamorphism in continental crust and oceanic lithosphere («subduction metamorphism») Roberto Compagnoni¹

Abstract of the talk given on June 21, 2014, in Aosta, Hotel Europa, at the 81st SASEG Convention.

Subduction and eclogite-facies metamorphism

According to Plate Tectonics, the unifying Earth's Science theory, the lithospheric plates may be subjected to three main relative movements:

1. At passive boundaries, the plates slide horizontally past each other (see Fig. 1 left), such as the San Andreas fault in California;
2. At divergent boundaries, plates move apart and create new lithosphere (see Fig. 1 center), such as in the mid-ocean ridges;
3. At convergent boundaries, plates collide and one is pulled down (subducted) into the mantle and recycled (see Fig. 1 right). Three different types of subductions may be distinguished:
 - a. oceanic plate sinking below oceanic plate,
 - b. oceanic plate sinking below continental plate (Fig. 1 right), or
 - c. continental plate colliding against another continental plate (Fig. 2).

This last type of collision produces the so-called «collisional orogens», such as the Himalayan-Alpine mountain belt. It is important to point out that, before collision, the two continental plates (in the case of the Western Alps the European plate to the north

and the African (or Adria) plate to the south) were separated by an ocean (the Mesozoic Tethys) which favoured the subduction of oceanic lithosphere below continental lithosphere. With advance of subduction, the ocean basin progressively disappears until the two continental blocks (plates) collide (Fig. 2). However, remnants of the former oceanic basin – squeezed between the two blocks – are preserved and allow to recognize the «oceanic suture», i.e. the original location of the disappeared ocean. These oceanic remnants are known as «ophiolites». In the Alps, the *Piemonte zone of Calcschists with meta-ophiolites* (Fig. 5) is the remnant of the former Mesozoic Tethys oceanic basin. During subduction, within the subducting plate the isotherms are deflected downwards, because the rock thermal re-equilibration is slower than the velocity of the sinking lithospheric plate (see Figs. 1, right, and 2). As a consequence, in the subducting plates the geothermal gradients (i.e. the rate of increasing temperature with respect to increasing depth in the Earth's interior), which are normally ~ 25 °C/km, may decrease down to ~ 5 °C/km, depending on the speed of the subducting plate.

Most minerals or mineral assemblages, stable at «normal» gradients (i.e. within the fields of greenschist, amphibolite and granulite facies, Fig. 3), become unstable and transform into new minerals as a consequence of the pressure increase.

¹ Department of Earth Sciences, the University of Torino (Italy)

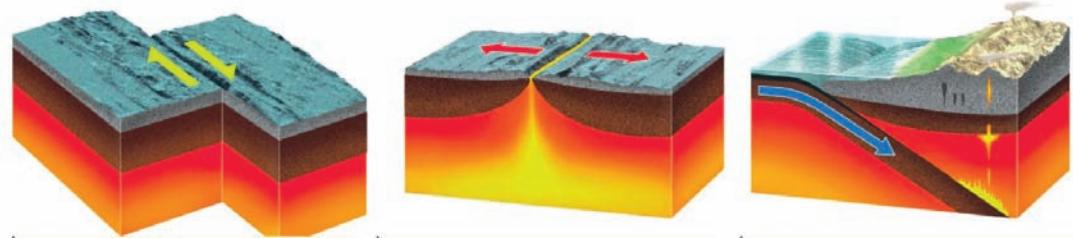


Fig. 1: The three main relative plate movements expected by the Plate Tectonics Theory. Left: passive plate boundaries; center: Divergent plate boundaries, where new ocean floor is generated by uprising basaltic magma; right: convergent plate boundaries, where lithospheric plates sink (subduct) into the mantle and andesitic magma (in yellow) is generated. Grey: oceanic (thinner) and continental (thicker) crust; brown: rigid lithospheric mantle, forming the prevailing part of the lithospheric «plates»; red to yellow: ductile upper (asthenospheric) mantle. T is progressively increasing with depth (from red to yellow) [from Press et al. 2003].

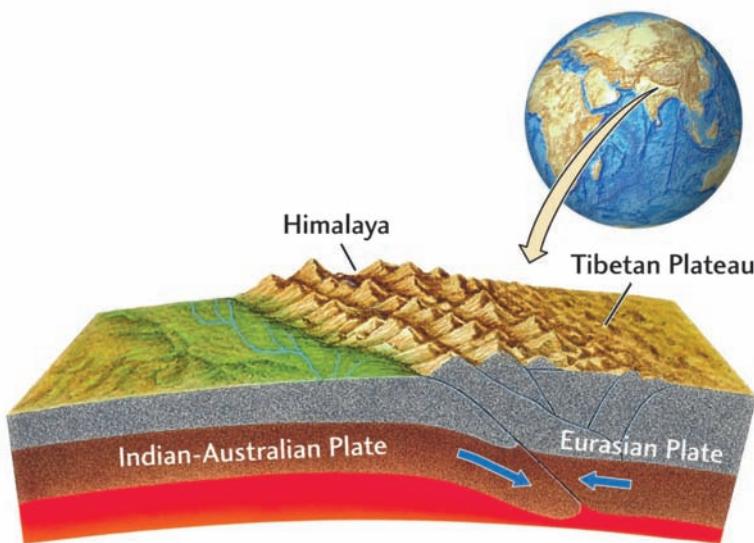


Fig. 2: The best example of a collisional orogen is the Himalaya chain, formed by the collision of the Indian-Australian Plate against the Eurasian Plate. In grey the continental crust of the two plates, in brown the lithospheric mantle, and in red the asthenospheric mantle [from Press et al. 2003].

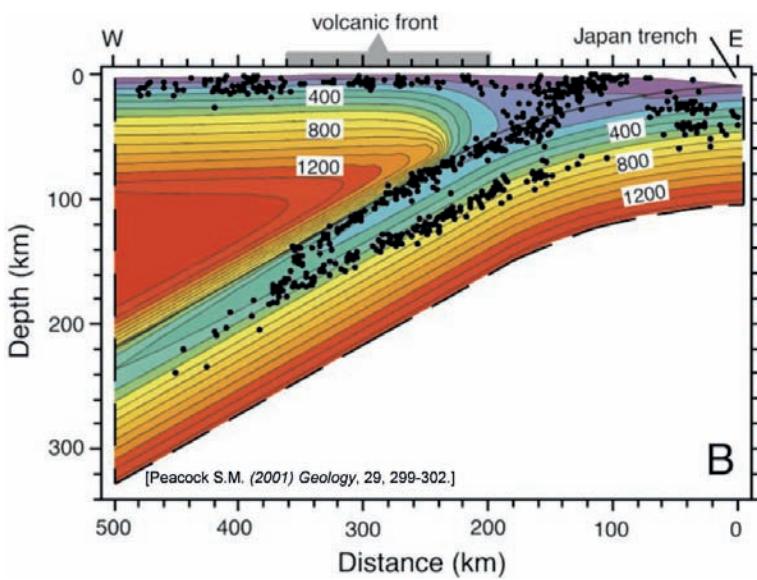


Fig. 3: The downward deflection of the isotherms in a subducting slab is well exemplified by the Japan Islands subduction zone. The T distribution is highlighted by different colours, at constant intervals of 400 °C. The black dots show locations of the earthquake foci.

The subduction metamorphism corresponds to P - T conditions of the blueschist facies and of the eclogite facies (green in Fig. 4), which is named after eclogite, the most typical rock type. The eclogite facies has been further subdivided into the quartz-eclogite subfacies, where quartz is the stable silica phase, and coesite-eclogite subfacies, where coesite – its higher- P polymorph

– is the stable silica phase (Fig. 4). Rocks recrystallized under the quartz-eclogite subfacies are said to belong to the High Pressure (HP) metamorphism (darker green in Fig. 4), whereas those recrystallized under the coesite-eclogite subfacies to the Ultra High Pressure (UHP) metamorphism (lighter green in Fig. 4).

The basalt to eclogite transformation

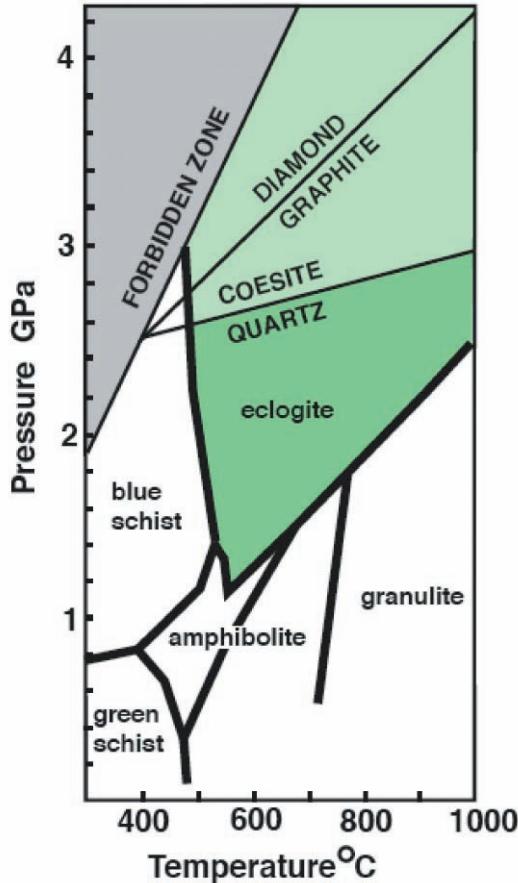


Fig. 4: P - T diagram which shows in green the eclogite-facies field, characterized by low- ($10\text{--}20\text{ }^{\circ}\text{C}/\text{km}$) to very low (down to $\sim 5\text{ }^{\circ}\text{C}/\text{km}$) geothermal gradients. In darker green the quartz-eclogite subfacies [i.e. the field of High-Pressure (HP) metamorphism], and in lighter green the coesite-eclogite subfacies [i.e. the field of Ultra-High-Pressure (UHP) metamorphism] where diamond may be present at the higher-pressure portion. In grey the «forbidden zone», bounded by the $5\text{ }^{\circ}\text{C}/\text{km}$ geotherm line, which corresponds to extremely low geothermal gradients so far never observed in nature (drawn by Jane Gilotti).

Because the eclogite is the most typical HP rock, mineral reactions leading to its formation are useful to understand the process of the subduction metamorphism.

The eclogite is a mafic rock with the bulk chemical composition of a basalt (or a gabbro, its equivalent plutonic rock). The most significant reactions, leading to the conversion of basalt (or gabbro) to eclogite, are triggered by the P increase and accompanied by a density increase from 3.0 (basalt) to 3.5 (eclogite).

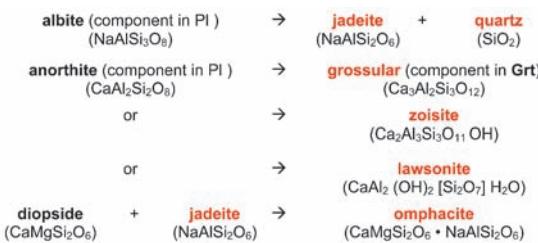
Basalt (or *gabbro*) consists of two igneous minerals: *plagioclase* (anorthite-rich) and *clinopyroxene*, and *eclogite* of two main metamorphic minerals, *garnet* and *omphacite* (a Na-clinopyroxene). However, each phase is a complex solid solution of two or more pure end-members.

Plagioclase is a solid solution of albite ($\text{NaAlSi}_3\text{O}_8$) and anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$), the *clinopyroxene* of diopside ($\text{CaMgSi}_2\text{O}_6$) and hedenbergite ($\text{CaFeSi}_2\text{O}_6$). *Garnet* is a solid solution of three main end-members, almandine ($\text{Fe}_3\text{Al}_2\text{Si}_3\text{O}_12$), pyrope ($\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_12$), and grossular ($\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_12$), and *omphacite* is a solid solution of jadeite ($\text{NaAlSi}_2\text{O}_6$), diopside ($\text{CaMgSi}_2\text{O}_6$) and minor aegirine ($\text{NaFe}^{3+}\text{Si}_2\text{O}_6$).

The eclogite usually includes, in addition to the anhydrous minerals garnet and omphacite, accessory rutile (TiO_2), quartz or coesite. However, locally other hydrated mineral phases may be present, which are useful to infer the peak eclogite-facies conditions: they are amphiboles (mainly glaucophane, ~ 2 wt % water), zoisite (0.5–2 wt %),

lawsonite (12–13 wt %), white micas (phenogite and/or paragonite, ~ 4 wt %), etc. The hydrated minerals are also very important for the transfer to depth and later release of water during subduction, which favours the andesitic magma generation of the volcanic arc (cf. Fig. 1 right).

The basalt to eclogite transformation, therefore, may be summarized by the following simplified mineral reactions (in black the igneous and in red the metamorphic minerals):



An interesting consequence of the albite breakdown is the release of free silica (lacking in the original basalt), which may crystallise as either quartz (at lower P) or coesite (at higher P) (see Fig. 4).

The geologic cross section of the lower Val d'Aosta

This short introduction to the subduction metamorphism is essential to the understanding of the outcrops visited in the first day of the 2014 SASEG field excursion along the lower Val d'Aosta cross section.

During mountain building, deformation processes – folding, thrusting and faulting – are accompanied by metamorphism and magmatism. In the western Alps, magmatism is limited to the small Oligocene intrusions of Brosso-Traversella (Fig. 5) and of Valle del Cervo with related andesitic dykes and flows. On the contrary, two main types of orogenic metamorphism are observed: an earlier high- P metamorphism, which generates during subduction and collision, and a

low- P metamorphism, which develops during the subsequent rock exhumation. Usually, in most orogenies this second event pervasively obliterates, especially in continental crust, the minerals formed during the HP event. However, in the western Alps, the Eclogitic Micaschist Complex of the Sesia Zone shows extraordinary fresh HP mineral assemblages, well preserved most likely because a very fast exhumation prevented retrogression. Between Ivrea and Châtillon (Fig. 5) both the continental crust of the «Eclogitic Micaschist Complex» (EMC) of the Sesia zone (Fig. 5, Stops 1 to 4) and the ocean-derived Piemonte zone of «Calcschists with meta-ophiolites» (Fig. 5, Stop 5) are extensively exposed on fresh surfaces polished by the Val d'Aosta Quaternary glacier.

For the stops description we refer to the Field Excursion Guide-book.

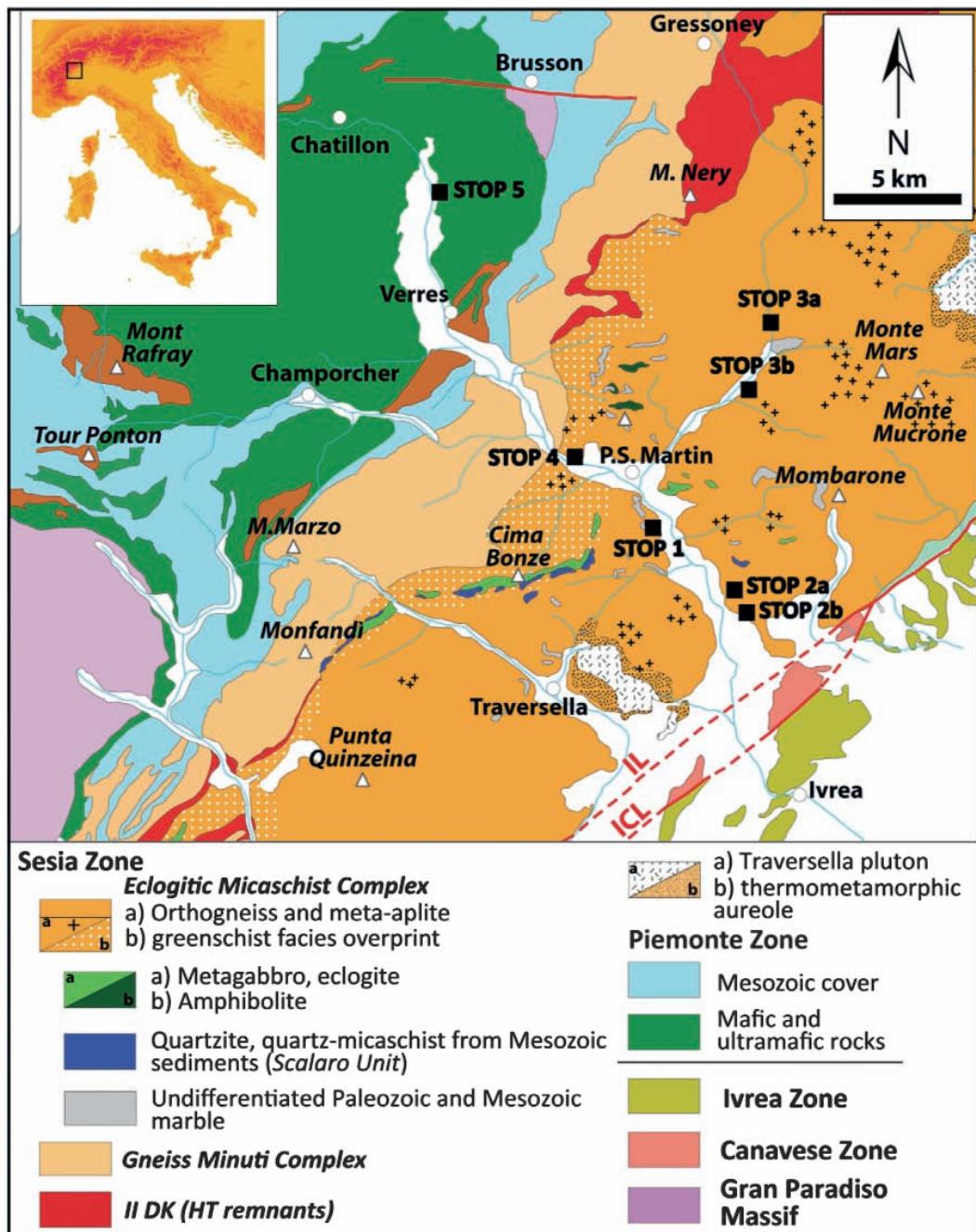


Fig. 5: Geotectonic map of the lower Val d'Aosta with location of the stops visited during the 2014 SASEG excursion. Stops 1 to 4 are within the eclogite-facies continental crust of the Eclogitic Micaschist Complex of the Sesia Zone, Stop 5 within the eclogite-facies Piemonte zone of Calcschists with meta-ophiolites [from Compagnoni et al. 2014].

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Bericht der 81. Jahresversammlung der SASEG vom 21. bis 23. Juni 2014 in Aosta (Italien) Heinz M. Bürgisser¹

Teilnehmer (91): Baumgartner, Walter; Béguelin, Karim (StN); Belgrano, Thomas (StN); Bolliger, Werner & Renate; Bollinger, Daniel; Boulicault, Lise (St); Brumbaugh, William & Michele; Burckhardt, Jenny; Bürgisser, Heinz & Trudy; Burri, Peter; Carmalt, Sam; Christe, Fabien (StN); Compagnoni, Roberto (E, R); De Loriol, Jean-Pierre & Mary; Do Couto, Damien (StN); Fankhauser, Kerstin (StN); Fischer, Andreas & Eva; Fomin, Ilya (StN) & Kozhina, Ekaterina; Franks, Sibylle; Frei, Walter; Glaus, Martin; Grossen, Viktor & Friederike; Guggiari, Orlando (StN); Gunzenhauser, Bernhard & Censier, Kathrin; Hansen, Wolfgang; Häring, Markus; Häusler, Mauro (St); Heckendorn, Werner; Heitzmann, Peter & Anni; Hemsted, Tim; Hynes, Pierre (StN); Kalbskopf, Reinhard (N); Kaufmann, Manuela (StN); Keller, Franz; Knup, Peter; Leu, Werner; Massaras, Dimitri & Schurtenberger, Heidi; Matter, Albert; Meier-Senn, Beat; Mermoud, Cédric (StN); Meylan, Benjamin; Minnig, Christian; Moscariello, Andrea & Mondino, Fiametta, with Camilla; Pittet, Céline; Pümpin, Volkmar & Anne; Scherer, Frank; Schmid, Stefan (E, R) & Jacobs, Inge; Schmidt, Thomas & Martina (Sp); Schwendener, Brigitte; Schwendener, Heinrich; Seemann, Ulrich; Siddiqi, Gunter (R); Stäuble, Albert & Tilda; Stäuble, Martin (R); Stenger, Bruno & Roux, Pauline, with Louis, Paul and François Stenger; Stumm, Fred & Margrit; Suana, Michael; Tangtuengtin, Pakorn (StN); Teumer, Peter & Renate; Trümpty, Daniel; Vimpere, Lucas (StN); Walter, Patric (St); Wicki, Antonia (StN); Wyss, Roland & Wyss-Bönni, Kristina; Zanoni, Giovanni (StN); Ziegler, Martin; Zürcher, Benjamin (StN); Zwaan, Frank (StN).
 (E) Exkursionsleiter 22. und 23.6.; (R) Referent 21.6.; (St) Studentenmitglied; (StN) Neues Studentenmitglied; (N) Nichtmitglied (Gast); (Sp) Vertreter des Sponsors des Apéros

Samstag 21. Juni: Administrative und wissenschaftliche Sitzungen (Biblioteca Regionale), Partnerausflug, Apéro und Nachessen (Restaurant Bataclan)

I Generalversammlung

(Protokollentwurf, zu genehmigen am 20. Juni 2015 an der GV in Baden)

Um 13:50 Uhr begrüßt Präsident Peter Burri die anwesenden Mitglieder im gut besetzten Konferenzsaal des Bibliothekgebäudes, einer ehemaligen Kirche, die nun jedoch komfortable Sitze aufweist. Er erklärt auf englisch, dass traditionsgetreu die Geschäfte der Vereinigung auf deutsch durchgenommen würden; da nun aber zahlreiche Neumitglieder nicht gut deutsch verstanden, werde er seinen Jahresbericht auf englisch vortragen.

P. Burri preist kurz das Buch «*Swiss Gang – Pioniere der Erdölexploration*» an, das die Ver-

einigung in der Pause und am Ende des Nachmittags zum Verkauf anbieten wird.

1 Genehmigung des Protokolls der GV vom 22. Juni 2013 in Chamonix

Der Protokollentwurf der letztjährigen Versammlung, publiziert im Swiss Bulletin für angewandte Geologie (18/2, 2013, 95–99) wird diskussionslos genehmigt.

2 President's Report, June 2013 – June 2014

P. Burri started his report by showing the excellent development on membership:

Membership as of June 22, 2013	319
Personal members joining	+ 29
Resignations	- 12
Expulsions	- 5
Deaths	- 4
Membership as of June 21, 2014	327

¹ Vorstandsmitglied SASEG

The increase by 8 members contrasts with the decreases in the two previous years (-7, -8); main contributor is the higher joining rate (+ 80%, caused especially by more students joining), though there were also fewer resignations.

During a period of silence the assembly's thoughts went to the four members who died during the past 12 months:

- Carl Eduard Burckhardt (member for 60 years, died at age 99)
- Peter Lehner (member for 43 years)
- Heino Lübben (member for 17 years)
- Helmut Niko (member for 9 years)

The merits of Peter Lehner, VSP president preceding Peter Burri, get specially mentioned, as well as those of Heino Lübben, former CEO of BEB, and also of Charles Mercanton, who left the association shortly before his death.

Five members are honoured for their long membership: Fritz Burri and Edouard Lanterno for 65 years, Mrs. Greti Büchi (together with her deceased husband U. P. Büchi) and Peter Diebold for 60 years, and Martin Ziegler for 50 years. Martin Ziegler receives his commemorative membership certificate, signed by the President, personally from Peter Burri, whereas the others will receive it by mail, together with a personal cover letter.

Then P. Burri reviews the past year. SASEG experienced many positive developments: The Association has managed to be placed on the distribution list of all consultations of Switzerland's Federal Department of the Environment, Transport, Energy and Communications; SASEG was invited to give significant input to a positioning paper by the German Academy of Science on hydraulic fracturing for both hydrocarbons and geothermal energy and will also be the copatron of a one-day symposium in Bern this October on the same topic, together with Swisstopo and the Swiss Academy of Science. SASEG has received 2-3 requests per

month for lectures, papers and panel discussions, which causes the Committee to consider an increase in Committee members. There was much positive feedback on the symposium organised by SASEG and the University of Berne to honour Peter Lehner. Also the themed Bulletin issue (on climate change) received praise, both from supporters and critics. The only negative observation was that the AAPG Distinguished Lectures that SASEG organised in Geneva were attended only by people from the Geneva region, not from other parts of Switzerland.

P. Burri reiterates that SASEG has no political agenda; as per by-laws discussions are conducted on the basis of facts, not political beliefs. The Annual Convention will remain important, and although the Association is changing face, Convention attendance has been good, with more than 90 participants at the rather remote Aosta. P. Burri urges members to talk to earth scientists with an interest in energy issues to become members of the Association.

Finally, P. Burri reads the names of all 29 members that joined SASEG in the past 12 months, whereby each member present rises from his/her seat, to be seen by all members of the assembly.

There are no questions from members regarding the President's Report.

3 Bericht des Kassiers

Kassier W. Heckendorf charakterisiert die Finanzen der SASEG als gesund, was durch die mit einem Überschuss von Fr. 4'342 abgeschlossene Gewinn- und Verlustrechnung für 2013 demonstriert wird (Tab. 1):

Vermögen per 31.12.2012	94'730.05
Überschuss 2013	4'341.56
Vermögen per 01.01.2014	99'071.61

Der Überschuss erklärt sich vor allem aus viel tieferen Ausgaben für die Website gegenüber 2012 (als die Transformation von der

VSP zur SASEG durchgeführt wurde) und aus einem kleinen Überschuss der Tagung Chamonix (gegenüber einem Verlust der Tagung Luzern 2012). Das Konto zum Sponsoren von Studenten enthielt zu Beginn von 2014 beinahe Fr. 6'000, wonach noch Honorare für Referate, die P. Burri im Namen der SASEG hielt, diesem Konto gutgeschrieben wurden. Mit Applaus wird W. Heckendorf's Arbeit verdankt.

4 Bericht des Redaktors

Bulletin-Redaktor D. Bollinger erinnert die Mitglieder an den Höhepunkt der letzten 12 Monate, das Erscheinen des 164-seitigen Themenheftes «Klimawandel», das ein exklusives Gespräch mit Prof. Thomas Stocker, Co-Vorsitzender der IPCC Working Group I des 5. Sachstandberichts, enthielt. Er informiert, dass Heft 19/2 ebenfalls ein Hauptthema haben werde, nämlich Fracking.

Im Weiteren zeigt D. Bollinger, dass der Mix der Bulletin-Artikel nur wenig gegenüber dem Vorjahr änderte (je ungefähr 25% über Energie & Klimawandel, geologisch-wissenschaftliche Artikel und über Naturgefahren, und 18% zu Ingenieurgeologie). Von der Anzahl Seiten der wissenschaftlichen Artikel in den letzten zwei Heften des Bulletins waren 49% durch die Autoren aus eigenem Antrieb eingereicht und 51% auf Anfrage des Vorstandes; dies ist ähnlich des vorhergegangenen Jahres.

5 Bericht der Revisoren

Revisor W. Frei liest den auch von Revisorin D. Decrouez unterzeichneten Bericht vor, der beantragt, dem Kassier Décharge zu erteilen. Mit Handmehr und Applaus wird die Décharge erteilt und damit die Rechnung 2013 genehmigt sowie Kassier W. Heckendorf entlastet.

6 Décharge des Vorstandes

Durch Handmehr erteilen die Mitglieder dem Vorstand Décharge und sprechen ihm damit ihr Vertrauen aus. Es standen keine Vorstandswahlen an.

7 Tagung 2015

Der Tagungsschwerpunkt Geologie der nuklearen Endlagerung bleibt unverändert, jedoch beschloss der Vorstand an der Sitzung am Morgen der GV, auf der Montag-Exkursion das Mont-Terri Felslabor bei St. Ursanne zu besuchen. Vize-Präsident B. Gunzenhauser erläutert dazu, dass deswegen der Tagungsort von Baden nach Westen verlegt werden wird (nach Aarau oder Solothurn). Die Exkursion am Sonntag, der Geologie des Jura im Querschnitt Brugg – Rhein gewidmet, bleibt unverändert.

8 Tagung 2016

Der Vorstand hat sich für eine Tagung im nördlichen Oberrheingraben entschieden (Tagungsort entweder Heidelberg oder eine kleinere Stadt in der Umgebung). Das vorliegende Konzept umfasst eine geologische Exkursion zum Kohlenwasserstoff-System des nördlichen Oberrheingrabens und eine Exkursion mit Besuchen von Energie-Produktionsstätten (mehrere Möglichkeiten sowohl für Öl/Gas als auch für Geothermie).

9 Varia

P. Burri erwähnt, dass die Firma Stump Foratec AG die Cocktails am Abend sponsert und auch ein gutes Honorar für P. Burris Referat beim Rotary Club in Zürich bezahlt hatte, das dem Studenten-Sponsoring zugute kam. Vize-Präsident B. Gunzenhauser ergreift das Wort, um der Versammlung mitzuteilen, dass an der AAPG Annual Convention im



Swiss Association of Energy Geoscientists
Schweizerische Vereinigung von Energie-Geowissenschaftern
Association suisse des géoscientifiques de l'énergie
Associazione svizzera geoscienziati dell'energia

Bilanz per 31. Dezember 2013

Aktiven	1000	Kasse	27.50
	1010	Postscheckkonto	16'899.27
	1022	ZKB Firmenkonto	16'341.22
	1025	ZKB Depotkonto	70'000.00
	1030	Eurokonto CHF (BRD)	1'207.60
	1035	Verrechnungssteuer	211.07
Passiven	2000	Vorausbezahlte Beiträge	100.00
	2020	Kreditoren	480.00
	2030	Vorausz. Jahrestagung 2013	-900.70
	2040	Sponsoring Studenten	5'935.75
	2300	Vermögen	94'730.05
		Gewinn 2013	4'341.56
		Total	104'686.66
			104'686.66

Gewinn- und Verlustrechnung

Aufwand	3000	Bulletin	15'460.00
	3010	Büromaterial	243.60
	3020	Porti & Spesen	1'638.80
	3030	Webseite SASEG	2'435.00
	3040	Vorträge Spesen	3'319.30
	3050	Steuern 2012	270.40
		Gewinn 2013	4'341.56
Ertrag	6000	Mitgliederbeiträge	26'595.15
	6040	Jahrestagung Chamonix	287.51
	6110	Wertberichtigung EURO	66.15
	6200	Zinsen	624.85
	6300	Spenden	135.00
		Total	27'708.66
			27'708.66

Vermögen per 31. Dezember 2012	94'730.05
Gewinn 2013	4'341.56
Vermögen per 1. Januar 2014	99'071.61

Tab. 1: Bilanz SASEG per 31. Dezember 2013; Gewinn- und Verlustrechnung.

April P. Burri den Distinguished Service Award der AAPG erhalten habe. Grosser Applaus folgte auf diese Mitteilung.

V. Grossen fragt den Vorstand, wie die Verbindung der SASEG zu den eidgenössischen Räten sei. Er erwarte keine plötzliche Veränderung, aber würde die Vereinigung «politische Leute» aufnehmen? Wie kritisch sind wir bei der Aufnahme von neuen Mitgliedern? P. Burri repliziert, dass nur Geowissenschaftler und Fachleute im Energiebereich aufgenommen werden. Da ein Einzelmitglied nicht für die SASEG spricht, ergäben sich Probleme höchstens bei den Vorstandsmitgliedern. Im Weiteren lehne die Redaktionskommission des Bulletins tendenziöse (z. B. polemische, mit politischen Zielen) und nicht wissenschaftlich fundierte Artikel ab. V. Grossen zeigt sich von den Antworten befriedigt, warnt jedoch in seinem Schlusswort vor Gruppierungen, die wissenschaftliche Vereinigungen desavouieren wollen.

Daraufhin wird die Generalversammlung um 14:40 Uhr geschlossen.

II Technical and Scientific Meeting

The Technical and Scientific Meeting that followed the General Assembly straight away were conducted in English. The presentations were the following:

- Prof. Dr. Roberto Compagnoni (Torino University): *High Pressure (HP) and Ultrahigh Pressure (UHP) metamorphism in continental crust and oceanic lithosphere («subduction metamorphism»).*

The first part of this talk was to the many non-metamorphic geologists in the audience a welcome introduction / refresher to subduction and metamorphism at plate boundaries, whereby R. Compagnoni also showed the progress in the past 20 years in extending the petrology phase diagrams to greater pressures

and temperatures. Then he zoomed in on minerals found in the Western Alps and the excursion area, which indicate specific fields of the phase diagrams (see p. 153 of this Bulletin for the extended abstract of this presentation).

- Prof. Dr. Stefan Schmid (Prof. em. Basel University and SASEG committee member): *Geodynamic aspects of high-pressure metamorphism; how do subducted rocks reach the earth's surface again?*

Also this presentation was related to the excursions of our Annual Convention. S. Schmid presented, energetically and enthusiastically, different models published within the last 30 years on how exactly the formerly deeply subducted continental crust near the Africa-Europe plate boundary could have reached the surface again. Experts don't agree on the validity of a series of dynamic models (e.g. extension, extrusion and slab extraction), all of which have shortcomings or contradict actual observations also to be made in the wider excursion area.

- Dr. Gunter Siddiqi (Swiss Federal Office of Energy): *The role of Geo-Energies in Switzerland's Energy Strategy 2050.*

G. Siddiqi described the Energy Strategy 2050, based on a scenario characterized by a major decrease in demand despite continued population and economic growth. The strategy rests largely on a massive improvement in energy efficiency, a much bigger share of renewable energy, imports and more research and development to enable the implementation of the strategy. He then focussed on the stimulation of the search for geothermal energy in Switzerland: the feed-in tariffs, the geothermal guarantee scheme, more funds for pilot and demonstration projects and more coordinated geothermal research and development. The discussion showed that some members are concerned about the envisaged decrease of energy demand in Switzerland driven by efficiency targets and more regulation.

- Dr. Martin Stäuble (MD Shell China und Vice President Shell China EP): *China Unconventionals*.

The pursuit of unconventionals is driven by China's huge predicted increase of energy demand. M. Stäuble characterized China's numerous basins as having (1) generally complex geological histories and therefore complicated structures, (2) lacustrine shales as the source for unconventional oil and gas, and (3) a regulatory framework for exploration based on a very supportive government. He then presented the many issues during the initial years of Shell's operations in the densely populated Sichuan Basin (see p. 69-74 of this Bulletin for the extended abstract of this presentation). Also here the discussion time was fully used.

- Dr. Bernhard Gunzenhauser (SASEG Vice-President): Logistic details of the further convention programme.

The meeting closed at 6 p.m., leaving sufficient time to get ready for the cocktail reception and dinner.

III Partners' Programme: Guided tour of Aosta

Whilst members convened for the General Assembly, nineteen partners of members explored on foot, with a German- and an English-speaking guide, the many architectural jewels of Aosta's more than 2.000 years of history: the Town Hall (Hôtel de Ville) in neoclassical style, completed in 1841; the collegiate church of Saint Orso and its Romanesque cloister; the eastern entrance to the town during Roman times, the Porta Praetoria; the Roman theatre with its back wall rising to the impressive height of 22 m; and the cryptoporticus, part of the market of the Romans, situated today partly underneath the town's cathedral. Many of the city centre's streets through which the SASEG partners walked on their guided tour go

back to the initial layout of the town by the Romans.

IV Evening

Convention participants gathered under the arcade of Bataclan restaurant, near the Arch of Augustus, the perfect location for established and new SASEG members and their partners to meet and to enjoy the cocktails sponsored by Stump Foratec AG (Fig. 1/1). President Peter Burri welcomed all in the traditional short address (Fig. 1/2), in which he first warmly welcomed partners; through their presence the SASEG Annual Convention distinguishes itself from conventions of other Swiss earth science associations. He then talked passionately about the distortion of scientific facts in the present European campaign against shale gas and hydraulic fracturing, pointing out that no scientific organisation in Europe supports a ban of fracturing. He pleaded to members to be, as scientists, ambassadors (not lobbyists) for a scientifically correct discussion of our energy options. Finally P. Burri touched on the history of the Aosta valley and on its inhabitants who have kept the French language and their autonomy much alive; he compared their single-minded character to those of geologists.

The subsequent dinner was served in the open air in the back garden of the restaurant, whereby participants not only enjoyed excellent food, but also the views of the mountains surrounding the venue (see Fig. 1/2), with the sun slowly setting.

Excursions

Both Sunday and Monday excursions belonged to the same theme and were led by Prof. Dr. R. Compagnoni and Prof. (em.) Dr. S. Schmid (SASEG board member). An excellent 17-page excursion handout with numerous colour illustrations of maps, cross-sec-

tions, outcrops and thin-sections was printed free of charge for each participant by Proseis AG. This handout has been the source for most of the descriptions and interpretations below.

Sunday 22nd June: Sesia Zone and internal part of the Piemonte-Liguria Zone (Lower Valle d'Aosta, northwest of Ivrea)

At 8 a.m. 87 participants climbed in Aosta into three coaches. In a beautiful morning light we made our way downvalley towards Ivrea, on the motorway.

Quincinetto: We reached the «outcrops», which were large fallen blocks, by an easy yet invigorating morning walk along a minor road on the valley floor. Here Roberto Compagnoni introduced the Sesia Zone, its tectonic setting and its metamorphism (Figs. 1/3, 1/4) before explaining the actual rocks seen at this spot of the Eclogitic Micaschist Complex of the Sesia Zone: continental-crust sediments of a large block that rifted off the Adria plate in Jurassic times and became subducted underneath the Southern Alps in late Cretaceous time. Minerals indicate P-T conditions of 15–20 kbar at 550–600 °C (eclogite metamorphic facies, high pressure/relatively low temperature), suggesting subduction of this continental crust to 50–70 km depth. As co-leader Stefan Schmid emphasized, the rocks themselves were not eclogites; we observed phengite micaschists with garnets and other metasediments in eclogite facies.

Montestrutto: About 50 participants hiked 150 m up to a glacially polished terrace above the village (Fig. 1/5), whilst the others walked to a rock-climbing park at the foot of the cliffs where similar lithologies were visible. Also these rocks belong to the Eclogitic Micaschist Complex of the Sesia Zone; parascists dominate the outcrop, with a few layers of leucocratic orthogneiss containing roundish jadeite megablasts several cm

across (Fig. 1/6). Jadeite, a rare mineral ($\text{NaAlSi}_2\text{O}_6$) of the pyroxene family, forms when albite ($\text{NaAlSi}_3\text{O}_8$) of a granitoid rock breaks down to form jadeite + quartz at high pressures and relatively low temperatures.

Donnas: This outcrop contains a spectacular feature of the Roman era: A 221 m long exposure of the Roman consular road from Ivrea to Aosta and the Gallic provinces (modern-day France), with furrows and an impressive arch (Fig. 1/7). The road was cut into rocks typical of the northernmost (most external) part of the Eclogitic Micaschist Complex of the Sesia Zone. These rocks have Early Tertiary pervasive greenschist-facies metamorphism that overprints the earlier eclogite facies mineral assemblages. Visible evidence of this overprint are garnet relics preserved at the core of iron-rich chlorite masses, the outline of which indicated they were pseudomorphs after garnet porphyroblasts. Soon afterwards we enjoyed, on three long tables, a five-course lunch with local flavour at La Kiuva restaurant in Arnad (Fig. 1/8).

Hillock west of the Clapey house: In the shade near the isolated house, Roberto Compagnoni introduced the setting of the Piemonte-Liguria Zone, representing the spreading ocean north of the Sesia Zone (Penninic Domain). Then we scrambled to the top of the hillock (Fig. 2/9), a «roche moutonnée» shaped in the Quaternary by the Valle d'Aosta glacier. Glacial evidence included striations and an erratic boulder of a porphyritic granite from the Mont Blanc massif, resting on the polished surface and aligned in the direction of the former ice flow. A lot of observations could be made on the well-exposed bedrock itself, a foliated antigorite-bearing serpentinite, i.e. a high-pressure metamorphic ultramafic rock. Perhaps most spectacular were veins of rodingite, which were folded and boudinaged, with the yellowish rodingite being preserved only in the central parts of the largest boudins. Rodingite is the product of metasomatism altering an original basaltic dyke, which intruded a peridotite and formed during the

serpentization at the ocean floor. This outcrop led to a discussion initiated by Stefan Schmid (Fig. 2/10) on the initial definition of ophiolites by the Penrose Conference, which was guided by outcrops on Cyprus, where sheeted dyke complexes are common. However, the latter are missing in Alpine ophiolites.

At 5:30 p.m. the coaches brought us back to Aosta, where the participants had time to further explore the town and enjoy in small groups dinner in one of the many restaurants.

Monday 23rd June: Geotraverse across the major tectonic units exposed in the upper Valle d'Aosta (between Aosta and Courmayeur)

At 8 a.m. 59 participants left Aosta in three small coaches and five private cars. The six stops, of which the first four were on the north-eastern slope of the upper Valle d'Aosta, were spaced out at relatively short distances.

St. Pierre castle: This beautiful outcrop was just underneath the castle, along the track to the church. It comprised calcareous schistes lustrées with a layer of the white hornblende, tremolite. The outcrop belongs to the Combin Zone of the Piemonte-Liguria Zone, which is the part of the Piemonte-Liguria Zone that did not reach the eclogite metamorphic facies, in contrast to yesterday's last outcrop which represented the internal part of the Piemonte-Liguria Zone that did reach eclogite metamorphic facies.

Outcrop near the road to S. Nicolas: This small outcrop, also in the Combin Zone, comprised a fine-grained meta-basaltic rock with the greenschist facies mineral assemblage actinolite-chlorite-epidote-albite (prasinite), overprinting earlier blueschist facies parageneses. Excursion leader Stefan Schmid explained that these were intercalated within the schistes lustrées metasediments and discussed a mafic dyke vs. basaltic pillow lava origin of these rocks.

Viewing terrace in front of St. Nicolas church: At this panorama stop we overlooked the entire southern flank of the upper Valle d'Aosta, including the Gran Paradiso Massif. First Stefan Schmid demonstrated the 1937 Carta geologica Alpi Nord-Occidentale by F. W. Hermann, the most beautiful geological map of the area (Figs. 2/11, 2/12). Then he embarked on explaining the paradox of the schistosity dipping to the foreland, which Stefan Bucher, a student of Stefan Schmid, found to have been caused by re-folding of nappes at a large scale during the Oligocene. This re-folding was preceded by subduction (to blueschist metamorphism) at 50–43 Ma and by subsequent exhumation. Blown-ups of the guidebook illustrations helped explaining the complex geological history of the area.

Roadside outcrop SE of village of Cérellaz (Figs. 2/13, 2/14): Crenulation and tight folding in the gneisses of the Nappe du Ruitor. This gneiss belongs palaeogeographically to the Briançonnais basement and tectonically is part of the Grand S. Bernard nappe system.

Cascata di Lenteney: We parked off the main road at the valley bottom and walked up a trail to a bridge just below the spectacular Lenteney cascades, produced by a stream from a hanging valley. The geological interest in this stop was a small outcrop of Zone Houillère rocks: metamorphosed pebbly sandstones in which elongated quartz pebbles manifest the intense deformation. The Zone Houillère represents the fill of Permo-Carboniferous troughs within the Briançonnais basement; (Alpine) metamorphism is lowermost greenschist facies.

Morgex, outcrops within vineyards off rue des Condemeines (Fig. 2/15): These impure carbonates belong to yet another palaeogeographic unit, the Valais trough. Stefan Schmid explained the development of this palaeogeographic element that straddles the northern parts of the Western Alps in Valais and Savoy. The small outcrops featured sandy limestones and dolomites of the Couches de

l'Aroley, deposited above an unconformity interpreted as the break-up unconformity, formed after rifting of the passive continental margin of the Briançonnais facing the Valais Ocean. The Couches de l'Aroley represent therefore the earliest part of the post-rift phase (Barremian-Aptian) of the Valaisan Unit.

We continued driving towards Courmayeur, where we took the steep and winding road up to the Val Vény. Along the road we observed strongly deformed schistose limestones that are part of the root zone of the Helvetic nappes and the Chaînes Subalpines. Later we had good views onto a lateral moraine with large erratic blocks. Shortly before 1 p.m. we reached Restaurant Petit Mont-blanc, at an elevation of 1.500 m a.s.l. (Fig. 2/16). Before the five-course lunch was served, P. Burri thanked organizers and excursion leaders for a very successful Convention, and the participants for the good attendance. Before 3 p.m. we hurried back into the coaches in order to reach Aosta in time, to allow some participants to catch the last postal coach to Martigny in Switzerland.

Acknowledgments

Sincere thanks to P. Burri for contributions to the report and S. Schmid, G. Siddiqi and M. Stäuble for suggestions to improve an earlier draft.



Fig. 1: Selected photographs of the 2014 SASEG Convention in Aosta. [1-2] 21st June, Restaurant Bataclan, Aosta. 1] SASEG treasurer Werner Heckendorf (centre) and Prof. Dr. Andrea Moscariello of the University of Geneva (right) with six of his students, all of them new members sponsored by SASEG for the Convention, raise the glass at the cocktail reception (Photo: H. M. Bürgisser); 2] President Peter Burri welcomes all in the traditional short address (Photo: B. Gunzenhauser); [3-8] 22nd June, excursion Sesia Zone. 3] Prof. Dr. Roberto Compagnoni introduces the Sesia Zone geology ... (Photo: I. Fomin); 4] ... to an attentive audience (Photo: H. M. Bürgisser); 5] Stop 2, high above the vineyards of the village of Montestrutto; ... 6] ... featured jadeite in an orthogneiss dyke within the paraschists (both photos: H. M. Bürgisser); 7] Roman consular road with furrows and an impressive arch (Photo: I. Fomin); 8] Lunch at La Kiuva restaurant (Photo: W. Heckendorf).



Fig. 2: Selected photographs of the 2014 SASEG Convention in Aosta. [9-10] 22nd June, afternoon: Hillock near Clapey house, Piemonte-Liguria Zone. 9] Roche moutonnée outcrop; Montjovet Castle in background (Photo: H. M. Bürgisser); 10] Prof. Dr. Stefan Schmid explains the complex history of this Zone (Photo: W. Heckendorf). [11-16] 23rd June, excursion Geotraverse Upper Valle d'Aosta. 11] On the terrace of the church of S. Nicolas, S. Schmid presents the 1937 map of the area ... (Photo: F. Stumm); 12] ... which everyone admires (Photo: B. Gunzenhauser); 13/14] Participants align at the roadside near Cérellaz to listen to S. Schmid's explanation of the Ruitor gneiss (Photos: B. Gunzenhauser); 15] A walk through vineyards was required to reach the Couches de l'Aroley outcrop outside Morgex (Photo: H. M. Bürgisser); 16] Lively discussions at lunch at restaurant Petit Mont Blanc in Val Vény (1.500 m a.s.l.), where the convention ended (Photo: B. Gunzenhauser).

Heini Schwendener

1952 – 2014

Ich habe Heini Schwendener relativ spät kennengelernt, auf einer VSP-Tagung im Unterengadin vor etwa 15 Jahren, wo der Dauerregen uns zwang, statt der geologischen Exkursion bei einem Glas Wein lange Diskussionen zu führen. Als ich nach 35 Jahren im Ausland 2005 in die Schweiz zurückkehrte, war Heini Schwendener derjenige, der mich in das Tiefengeothermie-Projekt Basel holte. Daraus wurden 9 Jahre enge Zusammenarbeit in der Energieszene der Schweiz und ein Kontakt, der weit über das Professionelle hinausging.

Es ist nicht leicht, ein Leben zusammenzufassen, das trotz seiner viel zu kurzen Dauer so vielschichtig und reich war wie dasjenige von Heini Schwendener. Er hat viele von uns gerade mit seiner Lebensintensität fasziniert; mit seiner Leichtigkeit und anscheinend unerschöpflichen Energie, sich allem widmen zu können: seiner Familie, seinem Beruf, seinen vielen Interessen und daneben noch immer da zu sein für seine Kollegen und Freunde, wann immer man Heini brauchte. Vielleicht war das auch für Heini zu viel, aber er hat in kurzer Zeit mehr bewegt und mehr Spuren hinterlassen, als manche andere in einem viel längeren Leben.

Das Bedürfnis, sich breit für die Welt um ihn herum zu interessieren und zu engagieren, prägte schon seine Schulzeit, wo er einerseits ein begabter Schüler war und anderseits doch nur gerade so viel machte wie es brauchte, um zur Matur zu kommen, was ihm aber genügend Reserven gab, um sich für die vielen anderen Dinge einzusetzen, die ihn faszinierten. Das Studium der Geophysik mit Schwerpunkt Gravimetrie war mit Feldarbeiten und Reisen auf die Vielseitigkeit



von Heini zugeschnitten und liess noch Zeit für Segelfliegen und die Reisen auf Fischkuttern in der Nordsee. Und in diesen Projekten war er auch der Perfektionist, der erst zufrieden war, wenn alles hundert Prozent in Ordnung war. Die Leidenschaft für das Segelfliegen und auch das Hochseesegeln sollten ihn das ganze Leben begleiten, und als Bündner behielt er auch eine spezielle Liebe zum Hochgebirge.

Heini konnte seine Kenntnisse nach dem Doktorat bald in die Praxis umsetzen. Er nahm 1984 eine Stelle als Geophysiker an bei der Exxon/Shell-Tochter BEB in Hannover, dem grössten Gasproduzenten Deutschlands. Er kam im richtigen Moment in die Gas-Industrie. Es war die Zeit, in welcher die 3D-Seismik in der Exploration für eine Revolution sorgte, was die Qualität der Abbildung des Untergrundes betraf und in der die Geophysiker ins Zentrum der Geo-Aktivitäten rückten. Der neue Job führte ihn auch zu seiner Frau, Brigitte, die ebenfalls als Geophysikerin in der Exploration von BEB arbeitete.

Frisch verheiratet kehrte er 1988 in die Schweiz zurück, um beim Stanford Research Institute für internationale Energie- und Chemie-Firmen als Unternehmensberater zu arbeiten, vor allem im Bereich von Technologie-Management und Strategie. In dieser Zeit kamen die zwei Söhne Martin und Dario zur Welt, und die wachsende Familie zog auf einen Bauernhof hoch über dem Zürichsee, wo sie sich äusserst wohl fühlten.

1996 kam Heini Schwendener nach Basel zu IWB, den industriellen Werken der Stadt Basel als stellvertretender CEO und verantwortlich u.a. für die Bereiche Beschaffung, Marketing und Verkauf. Hier liess sich Heini für die Deep Heat Mining Idee von Markus Häring begeistern und – mit IWB als Hauptaktionär der Geopower Basel – war er der eigentliche Förderer des Projektes. Ohne Heini Schwendener wäre die Bohrung möglicherweise nie realisiert worden. Als das Projekt wegen der verursachten Seismizität eingestellt werden musste, realisierte Heini, klarer als viele andere, den grossen Wert der generierten Daten und die Notwendigkeit, die Anstrengungen für die Entwicklung der Tiefengeothermie in der Schweiz, trotz Rückschlägen, weiterzuführen. Er war denn auch wesentlich beteiligt an der Gründung der neuen, schweizweiten Firma Geo-Energie Suisse und gehörte bis zuletzt dem wissenschaftlichen Beirat dieses Unternehmens an, mit ein Grund, weshalb wir intensiv miteinander zu tun hatten. Heini war überzeugt, dass die unerschöpflichen Wärmeressourcen der Erde gerade in der Schweiz genutzt werden konnten und mussten und er setzte sich mit dem für ihn typischen Enthusiasmus bis zuletzt dafür ein. Genau so engagiert wehrte er sich in den vergangenen Jahren gegen die für ihn unwissenschaftliche Verfehlung von unkonventionellem Gas.

2010 gab Heini Schwendener das tägliche Pendeln nach Basel auf und wurde stellvertretender CEO und Mitglied der Geschäftsführung von Swissgas. In dieser Firma war er wenigstens teilweise wieder näher bei seiner

alten Profession, der Erdgasexploration, da er die Beteiligungen der Swissgas in Norwegen, in Dänemark und in der Schweiz betreute. Daneben ging es um Erdgasspeicher und um neue Herausforderungen, wie Power to Gas. Heini war nicht mehr an eine Stadt gebunden, sein Tätigkeitsfeld war nun wieder die ganze Schweiz und Europa und er lebte in dieser neuen Weite sichtlich auf.

Heini Schwendener war über seine Frau Brigitte seit 1991 mit dem damaligen VSP und der heutigen SASEG verbunden und wurde 2009 zusätzlich separates Mitglied. Wir freuten uns an seiner treuen Teilnahme an fast allen Tagungen und an den meisten SASEG Vorträgen.

Heini Schwendener hat uns alle viel zu früh und zu plötzlich verlassen. Die Energie-Industrie der Schweiz hat kaum mehr jemanden, der so sehr auf «zwei Beinen» steht wie er das konnte, da er sowohl auf der technischen Seite der Energiegewinnung, wie auch auf der wirtschaftlichen Seite bestens zuhause war. Sowohl die Wissenschaftler wie die kommerziellen Kollegen werden seinen Rat vermissen. Und vor allem wird uns eines fehlen: Heini hatte ein enormes Geschick, in schwierigen Situationen Brücken zu bauen und mit Imagination Lösungen zu finden. Er tat dies mit grosser Liebenswürdigkeit und Diplomatie, aber auch mit zäher Hartnäckigkeit, und er hatte damit fast immer Erfolg. Viele von uns aber verlieren einen fröhlichen, stimulierenden und vor allem sehr lieben und herzlichen Freund.

Peter Burri

