Welcome to the third SHEER newsletter. The aim of this Horizon 2020 project is to develop best practices aimed at assessing the impacts and mitigating the environmental footprint of shale gas extraction and exploration.

**In memory of Prof Paolo Gasparini**

Paolo Gasparini, Professor Emeritus of Terrestrial Physics at "Federico II" University of Naples, eminent volcanologist and seismologist, and our dear friend, died on 28th July 2016.

Paolo started his career at the Institute of Earth Physics, University of Naples. As Professor and Director of the Institute of Earth Physics and Director of the Vesuvius Observatory, and under his auspices, the Neapolitan Geophysics and Volcanology group grew into a global force. During his fifty-year career, he held the Presidency of the International Association of Volcanology and Chemistry of the Earth’s Interior, and the Directorship of the National Volcanology Group.

SHEER and EPOS colleagues will know him best for leading successful European Grants but I first met him 40 years ago while working on the geodynamic evolution of the East African Rift/Red Sea. His work with Italian and French colleagues on the enigmatic and still incompletely understood Afar Depression in Ethiopia, unpicked the complex history of this young rift zone from the voluminous and heterogeneous basalts erupted there.

His visionary projects, such as tomographic imaging of Vesuvius and Campi Flegrei, identified the main magmatic reservoirs of Neapolitan volcanoes which led to the development of seismic alert systems providing real-time mitigation of Volcanic and Seismic hazard.

Paolo Gasparini was preeminent in European Geoscience; a scientific personality of the highest level inspiring generations of researchers while combining his commitment to his academic role with research of the highest quality. The many students who trained under his guidance, will fondly remember Paolo’s passion for teaching and his devotion to his science.

Mostly though, we will remember him as the kindliest of men, with a perpetual twinkle in his eye and we will miss him greatly.

Professor Emeritus Peter Styles

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**Latest Project Developments**

- Hydraulic fracturing for shale gas was conducted at Wysin from 7-19 June 2016
- Environmental monitoring continued during the fracking and is still in place, after fracking
Shale Gas Exploration and Exploitation Induced Risks

SHEER first annual meeting, 6-9 June 2016, Naples, Italy
By Rachel Westwood (Keele University)

The first SHEER Annual meeting was held at the Palazzo Esedra Hotel in Naples from 6-9 June 2016. There were three days of excellent presentations and discussions about the current status and future steps of the project.

Day 1 kicked off with an interesting invited talk by Grzegorz Pieńkowski from the Polish Geological Institute in which he discussed the Polish experience of Unconventional hydrocarbons. This was followed by Prof Gasparini summarising the state of the project after the first year.

The sessions over the following days were focused on each of the work packages, starting off with details of the monitoring of the Wysin site and the news that this will be extended for the full three years of the project.

WP2 talks detailed the unique data sets that are currently, and due to be, implemented into the SHEER database, which will be linked to the EPOS IP project Anthropogenic Hazard platform (available at http://tcsah-epos.eu). Data sets will be available from shale gas sites, incl Wysin in Poland and Preese Hall in the UK, conventional hydrocarbon extraction, incl Groeningen Field in the Netherlands and geothermal energy incl. Gross Schoenebeck in Germany.

Some very interesting modelling work related to induced seismicity was presented by Keele University, GFZ, IGF-PAS, and the University of Napoli Federico II in the WP4 session. This was followed by the great work conducted by RSKW and the University of Glasgow on the groundwater chemistry for WP5 and the air pollution measurements conducted by IGF-PAS.

As a brief interlude Franco Terlizzese, from the Italian Ministry of Economic Development, gave an invited talk on the regulations on monitoring of on-land and off-shore hydrocarbon activities in Italy. Three talks on multi-hazard risk and socio-economic impacts from AMRA, followed by lively discussion closed the second day.

The final session of the meeting involved valuable discussion around best practices and dissemination, with useful feedback on ways to engage stakeholders and interested parties. This session concluded with talks from two of the other successful projects (M4Shale and Fracrisk) under the same Horizon 2020 call.

Overall, a very successful meeting was had and it was obvious that a lot of good progress has been made during the first year. Here’s to the second and third years with more excellent work to come!

Presentations from the meeting are available to download from the SHEER website: http://www.sheerproject.eu/events/first-annual-meeting.html.
Statistical description of the induced seismic processes and assessment of the relationship with the technological/operational parameters

By Konstantinos Leptokapopoulos (IGF PAS)

A high quality dataset from The Geysers Geothermal field, (California, USA) has been analysed using a range of methods. It contains both high accuracy seismic data and production data and was selected because the mechanism of inducing seismicity in this enhanced geothermal field is similar to the one associated with hydraulic fracturing. It has been generally accepted that the seismicity is a result of the combined influence of poroelastic phenomena, heat transfer, conductive temperature changes and chemical reactions. Amongst these mechanisms, poroelastic effects by fluid injection cause the most prominent impact on seismic occurrence, evolution and source characteristics.

The most distinct characteristic of the seismogenic process is its dependency on time and production parameters. The analysis being carried out aims to reveal such connections and is twofold; firstly, multi-dimensional clustering is attempted after transforming selected catalogue parameters (e.g., hypocentral coordinates, distance of events from the injection point, stress drop) into equivalent dimensions. Then clusters, as hierarchically connected neighbours in multi-dimensional space, are identified. In addition, the correlation between spatio-temporal seismicity evolution and variation of the injection/production data will be performed and quantified by analysis of the time-series using a set of statistical tools (cross-correlation, z-statistic evaluation, binomial test to investigate significant rate changes and b-value variation).

Preliminary results will be presented at the 35th General Assembly of the European Seismological Commission, 4-10 September 2016, Trieste, Italy.
High-Level Conceptual Models for Determination of Potential Impacts on Groundwater Resources
By Dr Catherine Isherwood (RSKW), Dr Nelly Montcoudiol (University of Glasgow), Andrew Gunning (RSKW)

A high-level review has been undertaken of gas shale basins in the EU in order to provide a basis for considering the potential influence of shale gas developments on groundwater as a public water supply resource. The review considered publicly available information concerning the shale oil and gas prospectivity and the geological setting of the basins, together with the political, social and economic situation in each country current at the time of writing. Some EU member states do not have gas shale basins within their boundary, whereas others have several.

The review was undertaken on a basin-by-basin basis, for the 25 basins identified within the EU member states. A number of these are cross-border, located within two or more countries, and are, therefore, affected by different political and regulatory regimes. For these cross-border basins, information was included for each individual country to ensure that the study’s findings were as comprehensive as possible within the constraints.

Following the data collection and review process, a determination was made regarding the requirement for a Hydrogeological Risk Assessment (HRA). This was based on the potential for future development work in the shale oil or gas industry within the next five years, and the existing political, social and economic situation within the countries of interest. For example, where significant political opposition is present, there is unlikely to be development work undertaken in the near future.

Of the 25 basins reviewed, 19 were taken forward for HRA. This included assessment of the level of reliance on groundwater for public water supply, and of the groundwater resource in terms of quantity of available water and the quality of this water for drinking water purposes. The HRA findings were combined to provide a hydrogeological resource classification for each basin.

These 19 basins were grouped together on the basis of similar characteristics to form ‘generic settings’. Eight groups were defined, and a conceptual model for each group was drawn up on the basis of the key characteristics identified as being most important within the context of potential influence on groundwater.

The key factors identified are as follows:

- Depth to target shale and depth to water, combined to give the separation between target shale and groundwater resource.
- Tectonic setting of the basin, for its influence on contaminant transport pathways.
- Past and current human activity within the basin, particularly with respect to oil and gas development, mining activities and geothermal energy exploitation was studied for their influence on preferential flow pathways and connections between previously distinct catchments.
- Value and sensitivity of the groundwater resource.

Following development of conceptual models for each setting, these factors were combined for each basin on an individual basis to form a screening matrix in order to identify the areas where further investigation is required to understand the specific basin setting. The screening matrix also included an
indication of the level of confidence in the supporting data, as some countries and basins have very limited information available whereas for others the data availability and quality are very high.

The conceptual modelling and screening exercise provide a useful analysis tool designed to be used in complex systems that require a level of simplification in order to develop a broad understanding of the key issues. The results allow a general overview of the important factors in groundwater assessment but do not seek to give basin-specific or location-specific detail. In addition, the screening process has been designed to be easily applied to future basin studies, as required by the potential for shale oil and gas development in basins not considered within this study.

The initial screening exercise will help to identify areas with sparse or poorly constrained data, as well as areas with significant internal variation or complexity, and will provide an initial dataset to feed into a more detailed basin- or location-specific study. This process will be tested and refined through the more detailed investigation into the Baltic Basin as part of the ongoing SHEER project, leading to the development of wider recommendations for best practice to inform future development work.
**Stress drop distribution for seismic hazard assessment**

By Monika Staszek (IGF PAS)

One of the most important aspects of research concerning human-induced seismicity, including hydraulic fracturing, is seismic hazard assessment. Various parameters of induced seismic events are used to estimate seismic hazard and indicate the areas of enhanced seismic risk. Static stress drop of induced earthquakes is a parameter which reflects the influence of induced seismicity on the stress field in reservoir rock. On the other hand, events occurrence time and location depends on the previous stress distribution in the rock mass. Therefore, we decided to use static a stress drop to assign areas of relatively higher probability of future event occurrence with respect to the entire area of seismic activity.

For the analyses, we used a dataset from NW part of The Geysers geothermal site. We analyzed distributions of interpolated stress drops, determined on the basis of events from constant moving time window using a bi-harmonic spline interpolation method, for chosen groups and sequences of events.

Some of the distributions reveal that events tend to occur in the areas of specific ranges of interpolated stress drop values indicating potential for future use of static stress drop in seismic hazard assessment.

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**New Publications**


Geomechanical modelling of hydraulic fracturing

By Rachel Westwood (Keele University)

A model of hydraulic fracturing using a “generic” horizontal well with a single injection point has been created to investigate fracture propagation under shale gas production conditions. A discrete fracture network was created in Fracman using geology and pumping parameters based on the Preese Hall-1 hydrofrac well in Blackpool, Lancashire, UK.

The images below show the development of the new tensile hydrofracture and inflated natural fractures (left), and the corresponding microseismic events (right). The colours indicate the elapsed time into the pumping stage that the fracture opens or seismicity occurs. The model is based on the parameters described by Westwood et al. (2016, in review) and has a pumping duration of two hours (500 time steps) at a rate of 0.117 m³/s.

Parametric studies have been carried out to investigate a) the effect that the differential pressure at injection (the pressure difference between the pore pressure and the normal pressure on the fractures), b) the flow rate and c) the pumping time, have on, i) the flow distance, ii) the total area of the induced and opened natural fractures and iii) the lateral respect distance (the lateral distance that fracking should occur from a fault in order not to reactivate it and cause felt seismicity).

The analyses were conducted using a Monte Carlo approach involving 50 simulated discrete fracture networks. Three weighted source mechanisms, involving a combination of inflation, strike-slip and reverse have also been investigated for each parameter. The lateral respect distance results are observed using failure stress threshold values from the literature of 0.5MPa, 0.3 MPa, 0.1 MPa and 0.001 MPa.

Initial results indicate that pumping time has the greatest impact on the outputs and that flow rate has the least impact.

The results of this are currently being written up for a paper, which it is hoped will be published later this year.
**SHEER Participation in meetings and events**

Dr. Jose Angel Lopez Comino, GFZ Potsdam, presented a poster entitled *Assessing the monitoring performance using a synthetic microseismic catalogue for hydraulic fracturing* at the EGU general assembly held in Vienna, Austria from 17 to 22 April 2016.

Professor Paul Younger (left), University of Glasgow, presented a talk, *Fuelling the Future: The UK’s unconventional oil and gas revolution* at the UK Onshore Oil and Gas Planning & Environment Summit in Manchester, UK on 6th July 2016. This event was also attended by Keele University. Paul has also given a talk as part of the Geol Soc of London’s prestigious ‘London Lectures’ series. It is available to view at www.youtube.com/watch?v=PpX1eyDgomA.

Three abstracts, relating to SHEER work, have been accepted for presentation at the 35th General Assembly of the European Seismological Commission to be held in Trieste, Italy from 4 to 11 September, 2016:


Dr Catherine Isherwood (left), RSKW, is due to present findings from WP 3 at the GeolSoc Groundwater - Our Hidden asset conference in Birmingham on the 13-14 September 2016. Following this, she will be joined by Prof Paul Younger and Dr Nelly Montcoudiol to present to the Central Scotland Regional Group of the Geological Society on 21 September 2016.

Grzegorz Lizurek (right), IGF PAS, attended the 7th International Geosciences Students Conference in Katowice, Poland from 8-10 July where he talked to the students attending the event about SHEER. Listen again to him talking about SHEER on Radio TOK - http://goo.gl/0I0yzA or read his recent article in Nauka Online at http://www.naukaonline.pl/nasze-teksty/nauki-o-ziemi/item/2817-wzburzenie-skal

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**SHEER Key Facts**

*Project acronym:* SHEER

*Project full title:* Shale Gas Exploration and Exploitation Induced Risks

*Project duration:* 01.05.2015 – 30.04.2018

*Funding Scheme:* EU Horizon 2020

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**Project Partners:**

- 8 partners from 6 countries
- AMRA (Italy), IGF PAS (Poland), Keele University (UK), GFZ Potsdam (Germany), KNMI (Netherlands), RSKW Ltd (UK), University of Glasgow (UK), University of Wyoming (USA)

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**Communication and Dissemination**

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