Scientists Dig Deeper

Shale gas mining is mainly viewed as an industrial and economic issue. But we can also look at it from the scientific perspective. Why should we?

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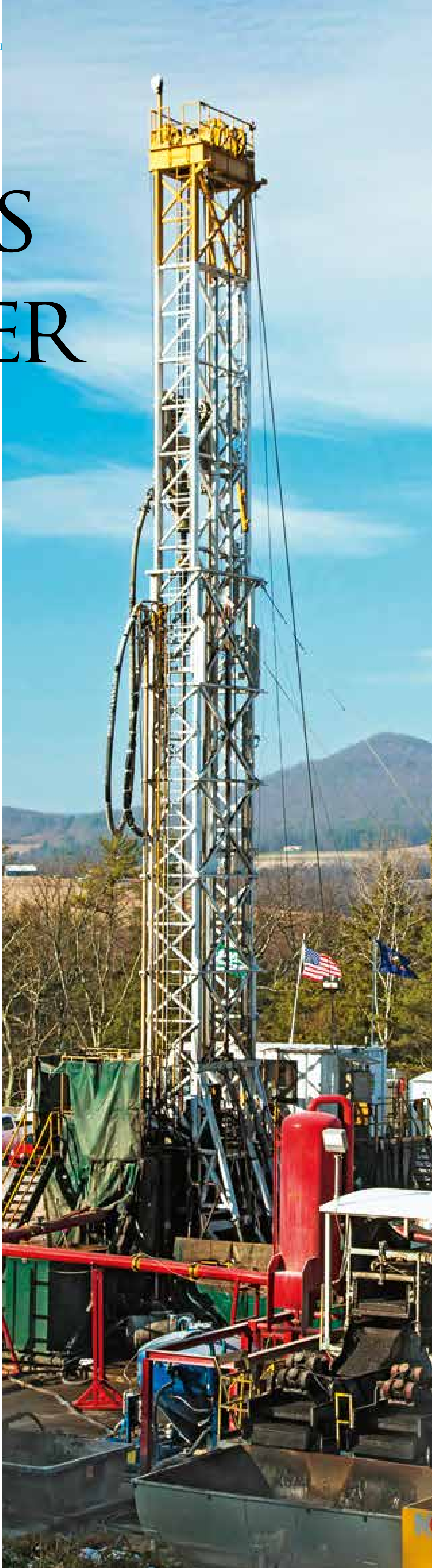
Over the past decade and a half, the harnessing of shale deposits has emerged as a vast new branch of the mining industry in the United States and Canada, with hundreds of billions of dollars having been invested in developing it. The result was an abrupt drop in the prices of natural gas and energy, which many economists see as having aided a revival in the lethargic US economy following the financial-sector crisis of 2008.

The notion of treating nearly impermeable shale deposits as a source rock ran counter to all the previous dogmas of petroleum geology. It is no surprise, therefore, that the leader in such experimentation was a property developer from Texas (though a geologist by education), George P. Mitchell. He became famous for the exceptional tenacity with which he kept funding, for a decade and a half, expensive experiments with hydraulic fracturing in deep boreholes, intended to break up the shale rocks and to force them to yield up the methane they contained. After many



A shale gas mining site in Pennsylvania

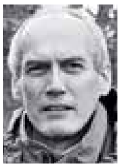
years of attempts with different fracturing fluids, the experiments were successful and starting in the early 21st century shale deposits began to yield natural gas in commercial quantities. From the scientific standpoint this was quite an extraordinary, as the success came not as a consequence of industrial implementation of advances made in modern science, but rather as the outcome of the fantasies of a "crazy" businessman. In Europe it would be unthinkable for anyone to pump dubious substances underground and fracture deep rock layers, with unpredictable environmental consequences.

Where's the boom?

Poland, which has large swathes of shale deposits quite similar to those being harnessed in the United States, was until recently anticipating its own shale-gas boom. The media devoted much attention to a report released by the US Energy Information Administration in 2011, forecasting that Poland's shale complexes contained 5.3 trillion cubic meters of natural gas – a quantity sufficient to meet Poland's demand for several hundred years, eliminating our dependence on Russian natural gas. For a long time these enthusiastic estimates, which were unsupported by analysis of geological data (which the report's authors did not have access to), did not just become fodder for the media, they also served as a source of inspiration for politicians eagerly planning how to divide up the spoils from future production. The first analysis based on real geological data, carried out by the Polish Geological Institute in 2012, downsized those forecasts by more than an order of magnitude. In the meantime, the companies that had acquired more than 100 different concessions for shale gas exploration in regions of Poland drilled some 70 exploratory wells several kilometers deep. Most of them were found to exhibit gas flow, albeit in quantities far below economically feasible levels. After several years of fruitless exploration, foreign corporations began to leave our country, additionally motivated to do so by the drop in world petroleum prices.

BE&W

It was in this industrial context that the Blue Gas research program was launched in Poland in 2013, devoted to the study of gas-bearing shale complexes and funded by Poland's National Center for Research and Development. Each of the projects carried out under the program is led by an industrial leader, providing data from its exploration concessions. The value of such data is best illustrated by citing the cost of drilling a single exploratory well (including horizontal fracturing), which is significantly higher in Poland than in the United States, reaching 100 million PLN. Information from the drilled wells is supplemented with seismic images showing the deep spatial structure of the sedimentary basin, a natural laboratory of research for geologists. Because the individual projects each analyze several drilled wells, it is easy to calculate that the cost of obtaining the data is actually tens of times greater than the funding for data analysis itself. This is a specific aspect of research into geological resources, which is usually not possible without an industrial partner. On the other hand, the value of such data for the industrial partner is only as great as the quantity and quality of the information that can be extracted from the data. Herein lies the potential for synergy between the scientific and industrial partners of the consortiums involved in the program. The Polish state, investing hundreds of millions of zlotys in budgetary funding into such research, does so in anticipation of obtaining future budgetary revenue from mining activity, or at least a reliable verification of divergent resource forecasts. Having realistic forecasts in this respect is important for planning the state strategy for developing the energy sector. To what extent these hopes will come to fruition will become clearer a year and a half from now – after the completion of



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the Blue Gas program. In this article, I would like to share a few thoughts concerning the implementation of two large-scale R&D projects that I lead, ShaleMech and ShaleSeq, funded under the Blue Gas program and the Norwegian Financial Mechanism.

The boom's here – but in research

In the case of the ShaleMech project, the industrial leader is the company PGNiG (Polish Oil & Gas Co.), whereas the scientific leader is our team from the Polish Geological Institute. This research is focused on analyzing the *in situ* mechanical properties and tectonic loads of prospective shale formations. Here, geomechanical knowledge is used in analyzing the optimal course of hydraulic fracturing, and also to forecast the stability of borehole walls, failures of which can cause millions in losses to concession operators. The final results of the ShaleMech project are intended to help PGNiG make rational, knowledge-based decision on whether to continue or discontinue further shale gas exploration efforts in the concessions it holds. To process the large quantity of diverse datasets from the concessions, a broad consortium of research participants had to be pulled together, which apart from us (the lead team) also included teams from the Faculty of Geology (University of Warsaw), the Institute of Geophysics (Polish Academy of Sciences), and – from outside the consortium – also the Polish Oil and Gas Institute (National Research Institute) and the University of Wrocław. The project has reached its midpoint, and the cost of carrying out all of the research is estimated at 10 million PLN.

The value of data for an industrial partner is only as great as the quantity and quality of the information that can be extracted from it. Herein lies the **potential for synergy between scientific and industrial partners**.

Given the unwavering interest in shale deposits in the world, we managed to secure funding from the Norwegian Financial Mechanism for a second project, ShaleSeq, the well data for which is also being supplied by PGNiG. Here we are studying the possibility of using hydrocarbon shale reservoirs to store away CO_2, excess emissions of which are responsible for rapid climate warming and all the attendant negative phenomena. CO_2 has properties that are particularly conducive to becoming entrapped in the pores of shale matrix (adsorption), especially in the organic matter therein, and it also exhibits a certain ability to displace hydrocarbons out of shale. This property is being utilized in practice to boost production of natural gas or oil from conventional reservoirs, thereby compensating for the high costs of CO_2 sequestration. In shale reservoirs, however, this technology has not yet been applied in practice. As such, the study is of a theoretical nature, in many aspects involving fundamental research pertaining to universal physical and chemical reactions occurring under the influence of CO_2. The aspects we are studying include the mechanisms by which gasses penetrate through the tight pore space of shale (diffusion), the microflows within fractures supported by a grainy substance, and microflows accompanying the chemical reactions involved in the acidification of the rock matrix by CO_2. We strive to ensure that our theoretical models are rooted in a real geological context and to this aim we study the mineral composition and structure of the pore space within gas-bearing shale. In connection with this we are trying to verify whether the capacity of shale deposits may be significant in terms of reducing excessive CO_2 emissions. For technological and economic reasons, a necessary condition for CO_2 storage in nearly impermeable shale is the prior extraction of natural gas and the related presence of hydraulic fractures in the reservoir. This means that CO_2 storage in shale deposits in Poland is currently a distant prospect and at present the technology cannot compete with the option of sequestration in natural, porous geological reservoirs filled with salt water. However, that does not detract from the attractiveness of the Paleozoic shales of Poland's Pomerania region as a natural research laboratory. The ShaleSeq project, with a budget of nearly 2 million euro, is being carried out jointly with Norwegian partners from the University of Oslo, physicists and geologists from the Universities of Warsaw and Wrocław, and engineers from the Silesian University of Technology. All told, there are some 30 participants from 6 European countries.

A challenging research environment

One fascinating aspect of both projects is the vast range of scales involved in the research, stretching across 13 orders of magnitude: from angstroms, a unit equal to 10^{-10} m (in the case of analyzing sorption bonds and gas diffusion within tight pore space), up to thousands of kilometers (for instance in the case of modeling how ice sheet transgression and regression during times of glaciation deformed the shale complexes). Between these two extremes lie the various spatial scales on which shale analyses are carried out, which require parameters to be scaled depending on the processes being considered. The selection of the right scale of analysis in an anisotropic and non-homogeneous medium is perhaps the most difficult challenge we face. Our research is of unprecedented scale in Poland both in the industrial practice of our companies and at the universities involved. Such a risky broadening of the scope of collaboration was inspired by the multitude of questions that we still do not know how to answer. For this reason we decided to initially test a broad range of factors potentially influencing performance of shale reservoir, so as to conclusively sift out those that are of key importance for gas production or CO_2 storage. That demanded that we bring geologists, physicists, mathematicians, and computer specialists from different institutions onboard to contribute to interdisciplinary work. Among such a diverse team of personnel, it is a challenge to find a common language and to create a common synthesis of the research, which can only be achieved after individual researchers abandon the safe niches of their existing specializations. In view of the complexity of the processes taking place inside a shale reservoir, analytical results are usually synthesized using numerical methods, the code for which is being written by project participants. The common language is therefore starting to be mathematics (a language geologists are unfortunately sometimes illiterate in).

Scientific researchers in the field of petroleum geology face strong rivals in the form of service-providing companies that drill wells, carry out geophysical studies, and interpret the results of the measurements on behalf of the oil companies. The R&D budgets of the largest of them exceed $1 billion (!) per year in good times. Their degree of experience, derived from drilling thousands of boreholes in prospective shale deposits, is incomparable to what we research institutes have to offer, especially the inexperienced Polish institutes. And so what kind of added value can we actually offer in our projects, aside from being centers of learning, potentially preparing modernly-educated personnel for future employment in industry? This question is as brutal as it is well-founded.

Frankly speaking

Well, to put things frankly, it does not seem that the Blue Gas projects will have led to the discovery of any new technology able to alter the course of history for shale gas in Poland. But at the same time, in our projects we find many details of industrial analyses, including those carried out by service companies, which in our opinion could be improved, better configured, or interpreted more closely. Service companies operate quickly and standardly. Maintaining a standard is highly valued in the oil sector, but the answers should be clear-cut and not leave room for additional interpretations. The software that these service companies use can very quickly integrate as much data as possible, and so for ordinary well operations, where decisions need to be made quickly, they are unbeatable. But from the standpoint of the precision of the models created, we see do space for better honing the calculation parameters.

Our analyses are therefore in a sense the very antitheses of the work done by the big competitors: they are non-standard, time-consuming, frequently ineffective – we sometimes lapse into dead-end analyses that do not yield any practical results, or end up discovering long-known, though concealed algorithms. In other words, we fumble around in the zone where true science springs forth… There are no shortcuts, science and knowledge can only be built up through small but consistent steps, and there is no way to leap from inexperience straight to innovation. Flashes of great discovery occur only very rarely. The Achilles heel of Polish science (particularly geology) is an inability to create and maintain interdisciplinary teams, irrespective of the caliber of science they represent. That is the case for our project as well: after three years of painstaking team-building, just as our teams are attaining the capacity for mature research – we will nonetheless have to dissolve them and go back to our respective niches. Several years from now, when the leaders win another project, we will start building again from scratch.

A kind of consolation prize?

Irrespective of whether Poland's shale gas deposits are ultimately harnessed for commercial production, the results of our research may prove useful in other fields: in modern mining of conventional hydrocarbon deposits, in the sequestration of wastes and storage of liquid fuels in deep geological structures, and in improving innovative fracturing technologies which are still a focus of interest in many regions of the world. In terms of research techniques, the interdisciplinary approach will impose a more practical framework on the analysis work done by physicists, equip geologists with more advanced mathematical and computational tools, and in general open up a broader window to Earth science in Poland. With a favorable stance on the part of the oil companies, the potential disappointment in the once-anticipated natural gas Eldorado might be at least partially recompensed by the quiet successes enjoyed by scientists like us, building modern research teams in part funded with the money of foreign taxpayers.

Marek Jarosiński

Further reading:

Economides M.J. & Nolte K.G. (2000). *Reservoir Stimulation*. John Wiley & Sons.

Zoback M.D. (2007). *Reservoir Geomechanics*. Cambridge University Press.

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