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Shale gas in China – how much and when?

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A b s t r a c t. China is ranked as the world's largest resource-holder of unconventional gas (estimated at about 25–31 trillion cubic meters – tcm), and current production is 1.3 billion cubic meters (bcm). Also other unconventional resources(tight gas, CBM) are large in global standards. There are strong energy security reasons in China – a long run strategy for China is to reduce its dependency on imported gas resources, thus the growth of domestic output of unconventional gas production (coal bed methane, tight and in particular shale gas) has been recognized as very important both by the government, giving significant impetus to the development of shale gas extraction. However, significant uncertainties remain about the extent to which this resource will be developed as aspects of China's geology and the structure of the gas sector (in terms of pricing as well as access to water and pipelines) and population density, possess significant problems. A key role in Chinese unconventional hydrocarbons exploration is played by large Chinese national oil companies. The most productive shales are Lower Paleozoic marine strata in South China, in particular the organic-rich Lower Silurian Longmaxi Formation in the upper Yangtze region, characterized also by wide distribution, large thickness and generally fairly good other properties. Both subsurface geological and surface conditions of major shale gas plays in China are more complex than those in USA. Concerning geology, many shale gas plays in China are faulted and sometimes cross-cut by tectonically active zones – however, in some best productive zones tectonics improves conductivity of reservoirs. Number of Chinese shale plays (particularly those of lacustrine origin, representing a large share of Chinese resources) contain clay rich formations, which impairs effectiveness of hydraulic fracturing. Concerning environmental issues, China decided to go for a practice-oriented approach and no specific regulations for unconventional hydrocarbons currently exist in China, only some – pre-during and – post-operation recommendations are discussed. Interestingly, in many aspects unconventional hydrocarbon exploration in China show more similarities to the situation in Poland than to USA and bilateral cooperation may be fruitful for both sides.

Keywords: *shale gas, China, geology, resources, policy, cooperation with Poland*

China is ranked as the world's largest resource-holder of unconventional gas (Fig. 1). Resource estimates vary substantially (and will only become clearer once China develops a production history), but all the estimates point to enormous unconventional hydrocarbons resources. Shale gas resources are estimated at about 25–31 trillion cubic meters (tcm) with current production of 1.3 billion cubic meters (bcm). Other unconventional hydrocarbon resources include coal bed methane (CBM) – 10 tcm (current production: 12 bcm) and tight gas – about 10–12 tcm (although other estimates are lower, at several tcm); current production – 12 bcm. These figures are based on the Chinese Ministry of Land and Resources estimates and can change in time and depending on the source of information and methodology. Clearly, unconventional resources overwhelmingly exceeds the conventional ones (some 6 tcm). Currently, the worsening natural gas shortage in China and increasing dependence on foreign gas can be observed (Yuan et al., 2015).

Shale gas is important for China – Chinese government's policy support more gas in China's energy mix and energy sovereignty of the country:

– natural gas produced from shale gas reservoirs is becoming increasingly important in China as the country shifts from coal-based energy to cleaner energy sources – in particular, improving urban air quality is one of major challenges;

– in the last three years, the national consumption for natural gas has far exceeded domestic production (in 2013, national consumption consumption was 166 bcm, ~ 30% of it was filled by importing);

– there are strong energy security reasons in China – a long run strategy for China is to reduce its dependency on imported gas resources.

Therefore, growth of domestic output of unconventional gas production (coal bed methane, tight and in particular shale gas) has been recognized as very important both by the government and private sectors, thus giving significant impetus to the development of shale gas extraction.

However, significant uncertainties remain about the extent to which this resource will be developed. Although resources are the largest in the world and governmen'ts policy supports development of unconventional resources and planned output could reach total of 260 bcm by 2040, aspects of China's geology and the structure of the gas sector (in terms of pricing as well as access to water and pipelines) and population density, possess significant problems.

INVESTMENTS, EXPLORATION AND PRODUCTION

Till to the end of 2014, total investments in unconventional hydrocarbons in China has reached 23 billion RMB (~ 4 billion US dollars); 21818 km of 2D seismic and 2134 km^2 of 3D seismic have been carried out and 780 wells have been drilled. 54 blocks of shale gas mining

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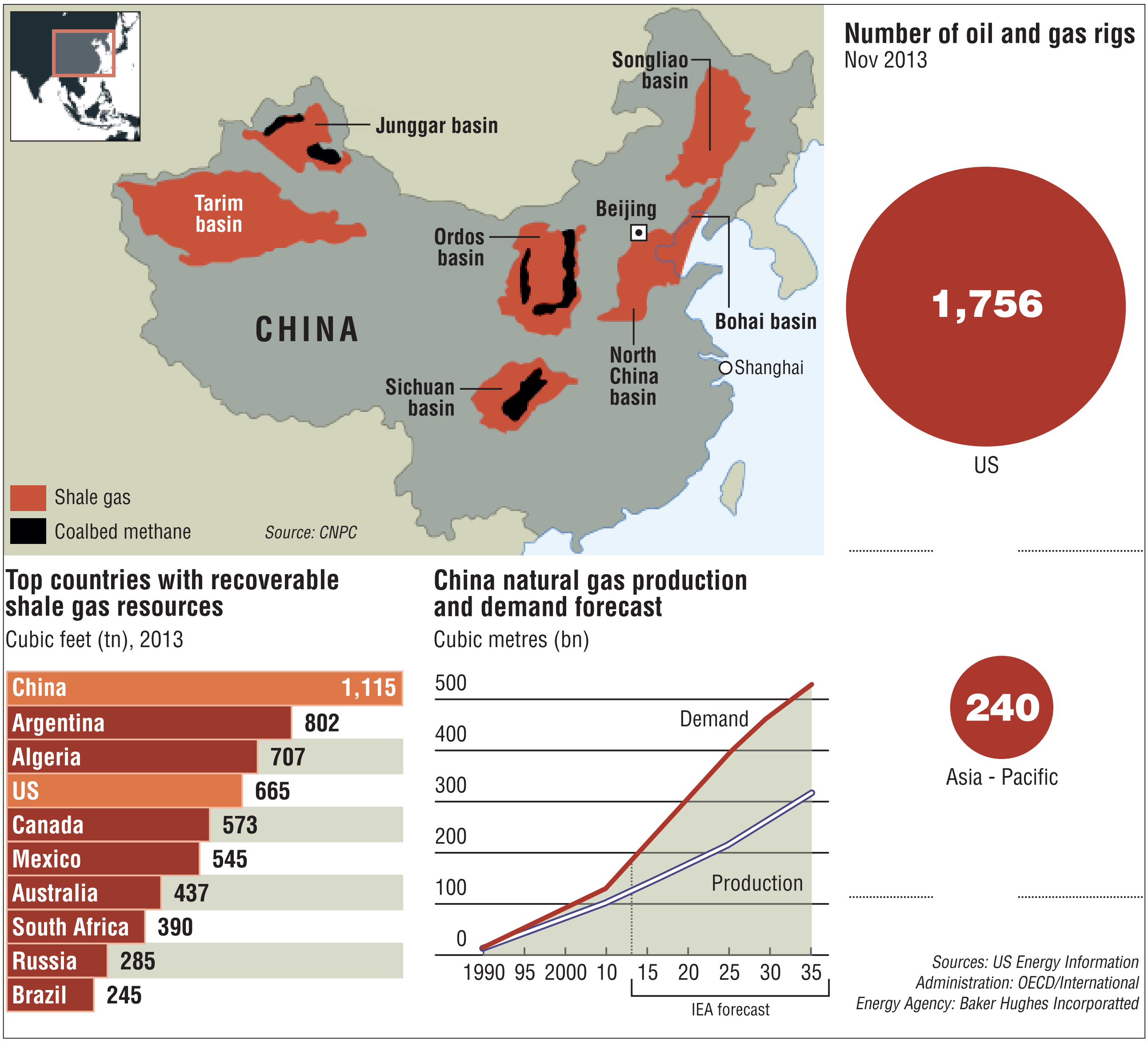

Fig. 1. China's shale gas resources (in cubic feet) on the global background, gas production and demand forecast (after IEA) and comparison of number of rigs (for November 2013). After: US Energy Information Administration: OECD/International Energy Agency. Baker Hughes Incorporated

Ryc. 1. Zasoby gazu łupkowego w Chinach na tle globalnym (w stopach sześciennych), produkcja gazu i prognozy zużycia (na podstawie IEA) oraz porównanie ilości urządzeń wiertniczych (stan na listopad 2013). Na podstawie: US Energy Information Administration: OECD/International Energy Agency. Baker Hughes Incorporated

rights with 170,000 square kilometers of exploration areas have been set up.

Since 2009, 0.66 billion RMB (c. 80 million US dollars) has been invested by the Ministry of Land and Resources in geological investigation and resource potential evaluation of shale gas, including 62 survey wells, 4 parameter wells, and 210 km of 2D seismic profiles. Besides, 1500 km other geophysical profilings (gravity-magnetic-polarization methods) have been performed. Only in 2014, China Geological Survey itself spent 280 million RMB (35 million US dollars) for geological investigation.

A key role in Chinese unconventional hydrocarbons exploration is played by large Chinese national oil companies. In total 21.88 billion RMB has been invested by CNPC, SINOPEC, CNOOC, Yanchang Petroleum, China CBM and others. More than 20,000 km of seismic 2D profiles, 2134 km^2 3D seismic mapping, 669 drilling wells (including 90 survey vertical wells, 234 vertical wells, and 345 horizontal wells have been done. Additionally, big Chinese companies built 235 km of pipelines (Fig. 2).

RESULTS OF GEOLOGICAL INVESTIGATION AND PROGRESS IN EXPLORATION AND PRODUCTION

The resource potential evaluation in 41 basins (or regions), in 87 evaluation units and in 57 intervals of gas-bearing shale formations has been done by the Ministry of Land and Resources in 2011 (Fig. 2). The recoverable resources are currently estimated (by the Ministry) at about 25 trillion cubic meters in marine, transition and continental facies. Confirmed geological resources reached

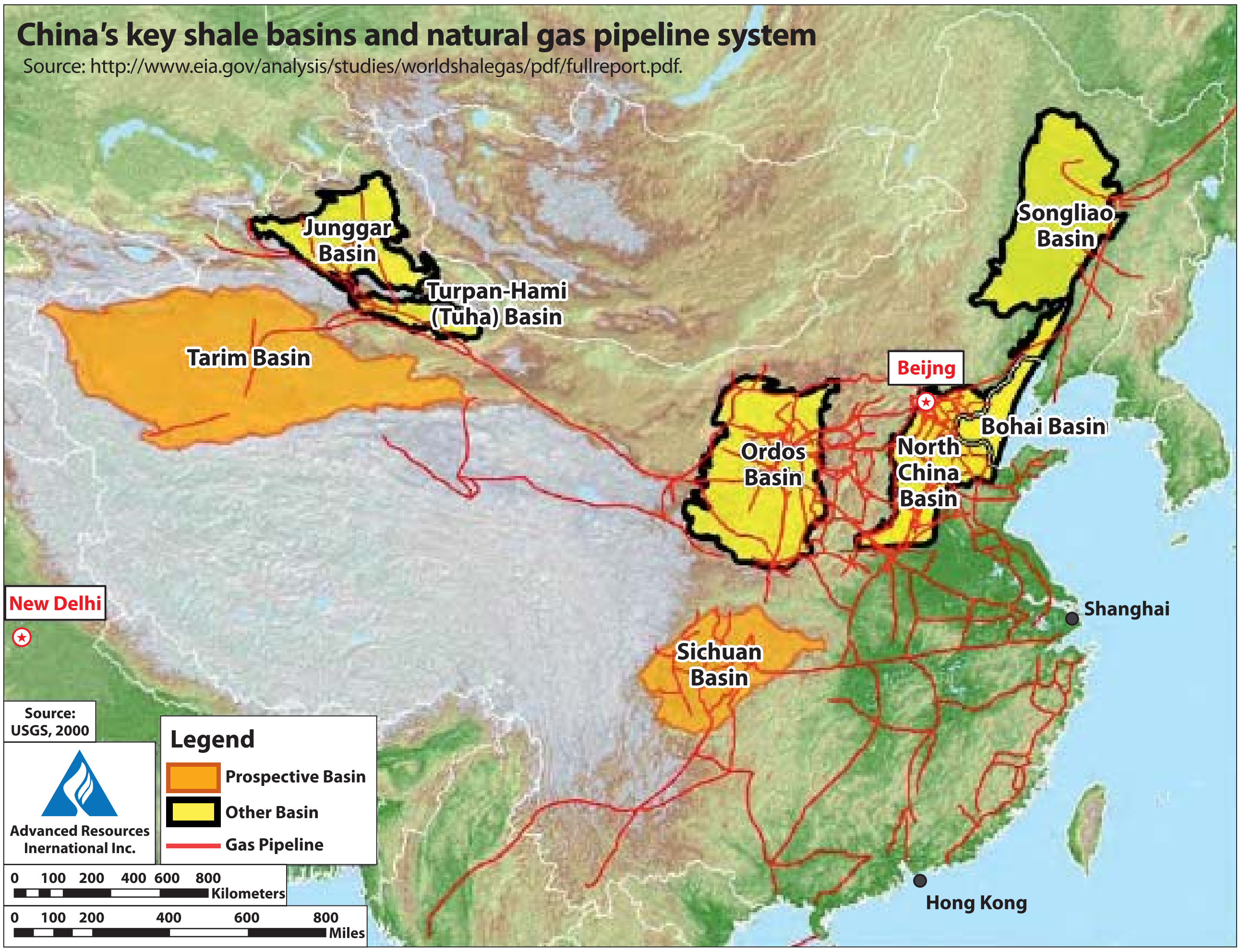

Fig. 2. China's key shale basins and natural gas pipeline system. Source: USGS and http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf

Ryc. 2. Główne baseny z formacjami łupków gazonośnych w Chinach. Prospective Basin = najbardziej perspektywiczne; Other Basin = inne baseny. Źródło: USGS and http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf

nearly 500 billion cubic meters, proven reserves currently amounts to 106.75 billion cubic meters. Hitherto, a major breakthrough in terms of economically viable production occurred in Changning – Weiyuan block and Fuling block in Sichuan province (Fig. 2, 3), although some economical estimation shows that even this most productive area us still slightly under threshold of economical viability in global terms (Yuan et al., 2015). Shale gas production in 2014 was 1.3 billion cubic meters. The Fuling shale gas pilot zone, located in the municipality of Chongqing in the Sichuan province, is the most active in China. To explore the prospects for shale gas development in China, the Fuling pilot zone is selected as the target area for the evaluation. Importantly, the Fuling block (Jiaoshiba shale gas field) yielded interesting geological data – SE part of the Sichuan basin is folded with SW–NE trending anticlines and synclines (Tonglou & Hanrong, 2014) and the most productive zones are connected with complex tectonic, folded

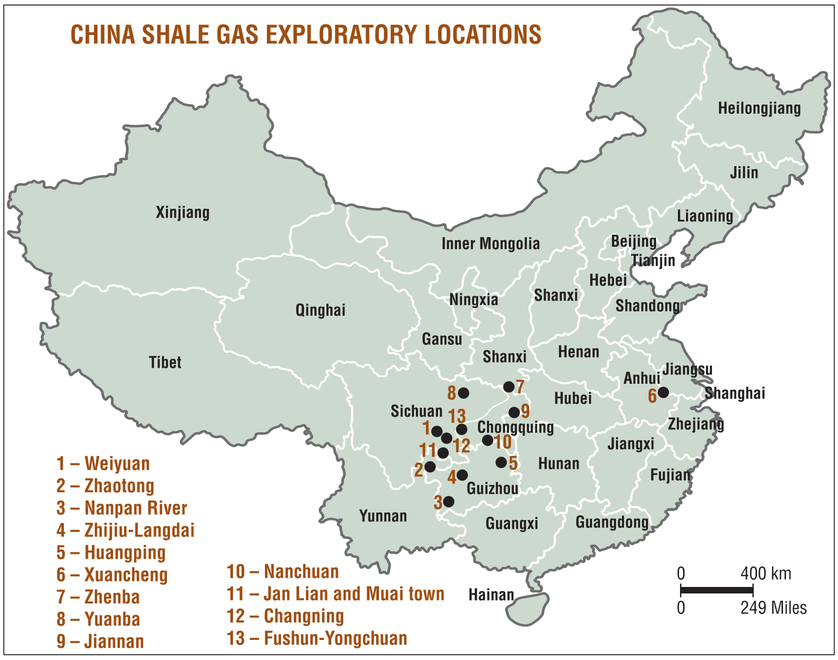

Fig. 3. Current shale gas exploration sites in China. Source: Shell/CNPC: http://www.naturalgasasia.com/shell-cnpc-sign-shale-gas-production-deal-4946

Ryc. 3. Obecnie prowadzone poszukiwania gazu łupkowego w Chinach. Źródło: Shell/CNPC: http://www.naturalgasasia.com/shell-cnpc-sign-shale-gas-production-deal-4946 areas (which due to conventional screening rules are usually avoided – for example in USA). Because the target gas-comprising Ordovician–Lower Silurian Longmaxi and Wufeng formations originated in a deep water marine environment shelf and the shale interval is stable in thickness, TOC and brittle mineral contents over the Sichuan basin, it is clear that shale gas accumulation in highly engaged tectonic zones resemble in a sense conventional gas accumulations in more porous and permeable zones (Tonglou & Hanrong, 2014). Most likely, the fractures formed at the crests of anticlines opened hydrocarbon pathway to wellbore, which resulted in enhancement of gas flow into the well. It also shows, that at least some systems of the fractures were not mineralized, which would worsen the shale play perspectives. In conclusion, priority exploration areas in Southern China within the widespread Longmaxi Formation will be those situated above the crests of anticlinal structures (Tonglou & Hanrong, 2014).

1st commercial production occurred on 28.11.2012 from the Ordovician–Lower Silurian Longmaxi Fm in Sichuan.

In short, hitherto obtained results of geological investigation are as follows:

The most productive shales are Lower Paleozoic marine strata in South China, in particular the organic-rich Lower Silurian Longmaxi Formation in the upper Yangtze region, characterized also by wide distribution, large thickness and generally fairly good properties concerning thickness (35–45 meters thick high-quality lower part of the shale), organic matter (Ro more than 2.2%, TOC > 2%) and brittleness (Tonglou & Hanrong, 2014). The Longmaxi Formation shows a good potential in Sichuan (around Chengdu – Fig. 4, and Chongqing) and to some extent also in Hebei, Hunan and Guizhou provinces. It is estimated that the Longmaxi Formation accounts for 20% of the total shale gas resources in China. In the Sichuan basin proven geological reserves reach 10 tcm (of which recoverable reserves are estimated at 3 tcm). The Fuling gas field in Sichuan with relative favourable geology, operated by Sinopec, accounted for vast majority of current shale gas production in China and has targeted an annual output of 10 bcm/year by 2017. However, other prospects in the Sichuan Basin are proving harder to commercialise because of complicated tectonics and bigger depths.

Both subsurface geological and surface conditions of major shale gas plays in China are more complex than those in USA. Concerning geology, many shale gas plays in China are faulted and sometimes cross-cut by tectonically active zones. This not only provides a challenge for the placement of the wellbores, but heavy faulting may also have allowed the trapped gas to escape over time, resulting in lower gas-in-place and thus lower ultimate recoverable volumes per well. Moreover, many gas-bearing shale formations are deeply (4000–5000 m) seated, which require higher pressure during hydraulic fracturing and push up costs. Also the total organic carbon content is lower in many of the Chinese shale basins than in many of the main North American plays. Number of Chinese shale plays (i.e. Junggar and Songliao basins) contain clay rich formations, which impairs effectiveness of hydraulic fracturing (because of lower brittleness), and hence will challenge existing hydraulic fracturing techniques.

Significant part of shale gas resources in China is of lacustrine (continental), non-marine origin – which is atypical in terms of majority of world's resources (Xiangzeng et al., 2014). Continental shales in China reveal huge volume of organic-rich shales (with 2–4 wt.% TOC, type-II kerogen,

Fig. 4. Multi-well pad W202H2, Weiyuan block, Sichuan, operated by the CNPC Company. The picture shows the 6-well pad. Photo by G. Pieńkowski

Ryc. 4. Wielootworowa platforma eksploracyjno-wydobywcza W202H2, blok koncesyjny Weiyuan, Syczuan: operator – CNPC. Schemat pokazuje 6-otworową platformę. Fot. G. Pieńkowski

0.5 to 1.5% *Ro*) in the deep lacustrine, but are generally characterised by low thermal maturity and high clay content – significantly different from those of marine shales documented in the USA and elsewhere (Jiang et al., 2014). Continental shales might have huge shale hydrocarbon resources. However, the clay content of the continental shales, ranging from 40 to 60% of the bulk mineral content, are much higher than for gas produced in marine shales, which might lead to significant challenges for successful development (Jiang et al., 2014). Massive fracturing (Fig. 5) is considered as a remedy, but it pushes up the costs. Vertical drills in the lacustrine shales in the Triassic Yanchang Formation produced in average only two to five tons of oil and 1000–3000 m^3 of gas per day, but it is just an initial stage of exploitation.

Since both marine and lacustrine basins in China experienced complex tectonic/structural activities, which could cause the leak of ancient shale gas and shale oil reservoirs, exploration should be focused in relative tectonic stable regions (Jiang et al., 2014).

The following wells brought significant outputs (Fig. 3):

1. Changning-Weiyuan block (Fig. 4) –
   well Wei-204's initial production: 165,000 m^3/d;
   well Ning-201's test production: 150,000 m^3/d;
2. Zhaotong (only 7 wells and only 2 hydraulically fractured ones) –
   well YS-108H1's gas production: 200,000 m^3/d;
3. Fushun-Yongchuan (only 3 hydraulically fractured) –
   well Yang-101's gas production: 60,000 m^3/d;
   well Lai-101's gas production: 100,000 m^3/d;
   well Tan-101H's gas production: 40,000 m^3/d.

It was reported, that one well in the Jiaoshiba field, Fuling shale gas pilot zone, reached record output of 340,000 m^3/d (Wojtczak, 2014).

The other productive formations are deep shelf shale facies of the Lower Cambrian age – Niutitang formation and Qiongzhusi Formation in Weiyuan – well Jinye-1HF's delivered gas production of 80,000 m^3/day).

It should be noted, that there is a number of much less productive wells (between a few to 10–20 thousands m^3/day), and even those with output of just 3000 m^3/day are exploited.

Currently, three major national Chinese oil/gas companies undertaking the major task of unconventional hydrocarbons exploration and exploitation:

Sinopec – 131 horizontal drilled wells , 112 wells completed, 82 wells hydraulicly fractured, 75 wells produced gas, 2.5 bcm/year production capacity in Chongqing – Fuling area has been confirmed.

CNPC – 96 drilled wells, 41 wells completed, 0,7 bcm/year production capacity in Weiyuan, Changning and Zhaotong area has been confirmed (Fig. 4).

Yanchang – demonstrated production capacity of continental-lacustrine shales (Fig. 5) on the area of 250 square kilometers in the Ordos basin (mostly of Triassic age), with estimated geological resources of 3.88 tcm; current production is 20 million m^3/year (Xiangzeng et al., 2014).

Implementation and development of technology in China is also in progress:

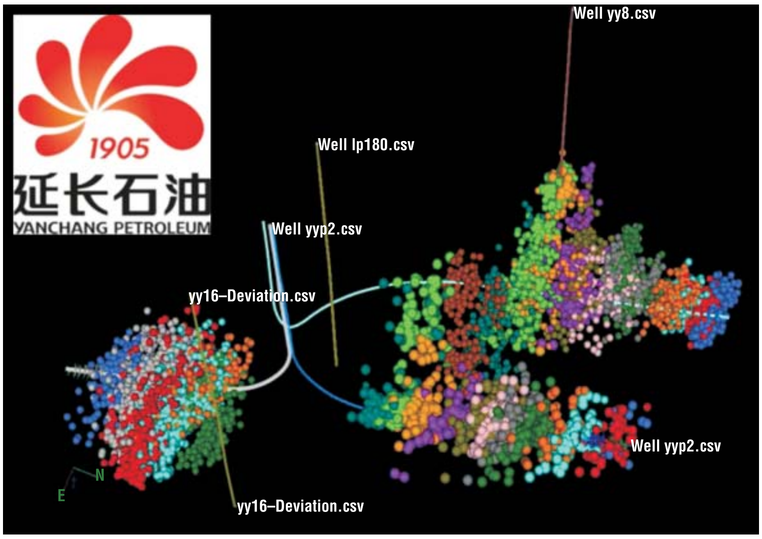

Fig. 5. Picture showing mass, high-pressure fracturing applied by Yanchang Petroleum in Ordos Basin, Central China in recalcitrant Triassic clay-rich shales of lacustrine origin. Source: Gao Ruimin, Yanchang Petroleum

Ryc. 5. Schemat ukazujący intensywne, wysokociśnieniowe szczelinowanie zastosowane przez Yanchang Petroleum w basenie Ordos, centralne Chiny, w opornych na szczelinowanie, ilastych łupkach triasowych pochodzenia jeziornego. Źródło: Gao Ruimin, Yanchang Petroleum

– China adopted and mastered to the local conditions the geophysics, drilling, completion, fracturing and testing gas technology (Fig. 4, 5);

– up to 3500 meters horizontal sections can be drilled;

– up to 22 fracturing stages, reaching total length of 2130 meters, can be implemented;

– own research allowed development of portable drilling rigs and other equipment – performance of drillable bridge plug (made of composites) reached a very advanced level; for the first time cross fracturing was performed, shortening the completion period by 40% and reducing the number of fracturing vehicles by 35%;

– horizontal well drilling and completion period was reduced from 150 to 70 days and the single well cost (although still significantly higher than in USA) was reduced from 100 million RMB (c. 12.5 million USD) to 50–70 million RMB (6.25–8.75 million USD);

– currently, more market-oriented approach has been applied: subsidy 0.4 RMB/m^3 has been cut to 0.3 RMB between 2016 and 2018 and then further cut to 0.2 will follow after 2018. The whole business will be based on domestic operators – Sinopec and CNPC;

– China has held two auctions to kick-start the shale gas extraction development (first one – June 2011). By the end of 2014. 52 exploration rights have been issued, covering 164.000 square kilometers. Fast development should be noticed – only in 2010 the first vertical well was drilled, and in 2012 – first horizontal one.

SUPPORT OF THE CENTRAL AND LOCAL GOVERNMENTS

The Ministry of Land and Resources, together with other central Chinese authorities, such as the National Development and Reform Commission, the Ministry of Finance and the National Energy Bureau of China introduced a number of policies to encourage and support the shale gas development plan. It is planned that shale gas production will reach more than 30 bcm till 2020. In particular, the Ministry of Land and Resources of China implemented the following steps:

1. Shale gas has been listed as an independent minerals. The Ministry of Land and Resources listed shale gas as the No. 172 independent natural resource in China;

2. Exploration, production and administration of shale gas resources is strengthen and promoted;

3. Opening of the market of shale gas production. More companies will get free way into shale gas production through open tenders of shale gas mining rights;

4. Fostering establishment of demonstration and production fields. MLR set up the demonstration area of shale gas production in Chongqing/Fuling and exploration test area in Northern Guizhou;

5. Research and evaluation of shale gas resources will be strengthen. In order to evaluate the shale gas resources, more than 680 million RMB (85 million USD) will be invested in 2015;

6. Support of the supervision and technical service, including expert support. The data-sharing platform will be built;

7. Standards for calculation and evaluation of shale gas resources and reserves will be prepared.

Shale gas exploration is also supported by the local (regional) governments. Local (provincial) governments invested 460 million RMB (28 million US dollars), which resulted in completing of 45 survey wells and 740 km of 2D seismic profiles.

Chongqing local government invested 240 million RMB (performing 740 km 2D seismic and 14 survey wells), Guizhou province invested 150 million RMB and did 26 survey wells. Jiangxi province invested 36 million RMB and Shanxi province 30 million RMB. Hunan, Hubei, Inner Mongolia, Anhui provinces also invested in unconventional hydrocarbons exploration. It resulted in selection of most promising geological targets. Development plan for shale gas in Chongqing (2015–2020) embraces setting up the demonstration area of shale gas development in China, supporting the shale gas production by investments in logistics – i.e. land, water and local connections and setting up the shale gas industrial bases in order to attract capital from domestic and international sources. Production and consumption of shale gas will be also supported by the regional government of the Jiangxi province – the project started in 2011 and will last till 2020.

SHALE GAS IN CHINA – HOW TO MAKE IT COMPETITIVE IN CHINA AND IN GLOBAL TERMS?

It is generally agreed that, the break-even output for a horizontal shale gas well in China should be around 100,000 cm of gas per day – most horizontal shale gas wells in China produce several thousand, or several tens of thousands cubic meters of shale gas, although the best wells in Sichuan (well YS-108H1) reached 200,000 m^3/day. Despite that, governmental policy is to continue exploration and production, supported by subsidies. The NDRC (National Development and Reform Commission), the top planning organization in China, sets the prices of oil and gas, electricity and supervises the development of the Five Year Plans, including shale gas. As the state owns all mineral resources, international players must deal with the designated state-own entities; the oil and gas SOEs (CNPC, Sinopec, Yanchang) have direct reporting lines to the State Council. However, as a part of its overall policy to promote competition in unconventional gas, Ministry of Land and Resources has changed the classification of shale gas from a “natural resource” to an “independent mining resource”, which removed the big 3 SOE exclusivity over shale gas. Opening of the market of shale gas production is crucial in terms of future competitiveness. More companies will get free way into shale gas production through open tenders, although they will have to seek commercial success without subsidies.

A company engaged in shale gas development will make investment decisions based on the expected returns to the capital invested in the project. However, under current technical and economic conditions, shale gas development in China is marginal in terms of global challenges, indicating that current incentive policies should be probably more aggressive to support economically viable shale gas production (Yuan et al., 2015). At the early stages of shale gas development, strong policy support is needed to incentivize shale gas production. At later stages, because of technological advances, shale gas development may not need such strong preferential policies to achieve economic feasibility or to remain profitable. Furthermore, when the shale gas industry reaches maturity, policy support may not be required at all (Yuan et al., 2015).

ENVIRONMENTAL PROTECTION

Recommendations for Regulation of Shale Gas Environmental Impacts in China was presented by Fuqiang Yang (2015) at the IEA Forum, April 10, 2015 Chengdu.

– Release of Interim Shale Gas Development Environmental Regulations is planned – based on choosing a shale gas pilot area, performing comprehensive studies, and implement interim environmental regulation, draft standard and environmental technologies in pilot area.

– Indicating safety setbacks of drilling procedures, performing baseline research and following environmental testing during and after operation.

– Establishment of concrete environmental protection rules for well casing and cementing, including testing and measuring of well integrity to avoid polluting underground water.

– For fracking water, avoid competition with industrial, agricultural and residential water use, encourage re-use of backflow water.

– Support safe underground injection of shale gas wastewater, introduction of injection management rules and supervision.

– Promote green completions and other environmental technologies.

– Establish management requirements for well plugging, temporary and permanement well abandonment.

– Disclose information on fracking fluid chemical composition, to support environmental remediation if accidents occur.

– Establish emergency plans for possible accidents, establish accident reporting system and environmental damage compensation system.

Currently, environmental regulations are based on best practices learned from conventional hydrocarbons operations. Concerning the land use, multi-pad drilling significantly reduces the land use (Fig. 4). Water is delivered mostly from rivers, while local needs/household water supply will be safely guaranteed. Shallow caverns or underground water flows are avoided and clean water is used when drilling in shallow aquifer layers. Recycling of backlow water is a demand. Concerning the soil protection, the operators adhere to "zero discharge" principle and environmentally harmless treatment of all drill cuttings.

Interestingly, NO SPECIFIC REGULATIONS for unconventional hydrocarbons currently exist in China, some – pre-, during and – post-operation recommendations are discussed between the five central authorities concerning protected areas and public participation. China decided to go for a practice-oriented approach.

CONCLUSIONS

Although China needs to get more experience in many technological aspects of shale gas exploration (geology, technology – i.e. 3-D seismic, policy, infrastructure etc.) and the costs of shale gas exploration and exploitation are twice as much as in USA (due to a more complicated geology, deeper settings >2400 m, heavily populated areas, rugged terrains and less developed infrastructure), this country records a fast progress (partly, thanks to purchase of technologies). Premium need is a well-factory workflow – and it has been to a large extent achieved. China with its rich shale gas resources and competitive labour costs can become a major player on the unconventional hydrocarbon market in 10–20 years, although there are still many uncertainties, such as cost competitiveness, largely caused by a more complicated geology and less developed infrastructure and services. China could replicate USA's success in terms of shale gas (and UH) development, question how long it will take and how much it will cost. The cost itself won't be so important because of general political priorities and financial resources (although it can also change in future). The key factors of success are not even the volume of resource reserves, but the appropriate regulations, well-established and clear market rules, adequate pipeline infrastructures, the availability of water resources (particularly in Tarim and Junggar basins).

Ministry of Land and Resources indicated the following problems and priorities for the years to come:

1. Rich resources, but only parts of most promising formations yielded satisfactory production and localities of sweet spots and recoverable resources are not sufficiently recognized.

Answer: geological survey needs to be intensified and more research on microseismic monitoring is needed – setting the national science and technology research projects of shale gas, begin the measure research of accumulation and evaluation, promotion of the scientific research and demonstration projects (such as shale gas production demonstration areas in Fuling – Southern Sichuan and Northern Guizhou. Ministry of Land and Resources will begin the system of identification and prediction of "sweet spots", transformed in the future into own technical system. It should allow confirming of the reserves and speed up the production, which is planned to reach 30 billion m^3 in 2020.

2. Supervision system.

More effective supervision (including geology, probing etc.) – 21 shale gas blocks has been set for tender in two rounds with bids of 1 petroleum enterprise, 14 non-petroleum state-owned enterprise, 2 private enterprise. More advanced system of supervision, including information sharing platform, should be developed.

3. Equipments adjusted to domestic conditions.

China will develop own studies (based on existing standards) on the rotating geo-steering, sliding sleeve-staged fracturing, micro-nano-structure and element analysis.

CHINESE-POLISH COOPERATION

Interestingly, in many aspects unconventional hydrocarbon exploration in China show more similarities to the situation in Poland than to USA. Chinese-Polish similarities regard more difficult geological conditions than in USA (deep-seated, clay-rich shales, more intense tectonics, lower brittleness). This will need application of new technologies and cooperation in this field can be fruitful for both sides. Also, the supervision system in China could be to some extent inspired by currently updated Polish geological and mining law and model of hydrocarbon legal system (including controlling role of the National Geological Survey, i.e. the Polish Geological Institute). Of great interest for China are currently completed 7 detailed environmental reports ("The environment and shale gas exploration..." and "Environment and exploration of shale gas – The results of seismic monitoring"), based on seven wells in Poland. These reports can shorten establishment of Chinese environmental protection standards. If the shale gas operations in Poland will continue to slow down, export of services to the "hungry" Chinese service market can be also an attractive option for both sides. Chinese policy shows, that pursuing shale gas and other unconventional hydrocarbon exploration can be accepted as a long-term policy, despite intermittent economical seatbacks.

Current political contacts (Wojtczak, 2014; Brochwicz-Lewiński & Rudnicki, 2015) indicated extensive areas of possible Chinese-Polish cooperation in the field of unconventional hydrocarbon exploration. It regards many similarities in geology (i.e. problems of a high clay content, role of tectonics in improvement of conductivity of reservoirs), as well as in other complementary fields, such as environmental and technological issues.

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STRESZCZENIE

Chińskie zasoby gazu z łupków są obecnie szacowane, w zależności od różnych źródeł, na około 25–31 bln m^3 (25–31 tcm), co czyni je największymi na świecie (ryc. 1). Do tego dochodzą również ogromne zasoby metanu w złożach węgla (10 bln m^3) i gazu zamkniętego (10–12 bln m^3). Są to dane z chińskiego Ministerstwa Terytorium i Zasobów (Ministry of Land and Resources), które zarządza także służbą geologiczną w Chinach. Zasoby te wielokrotne przekraczają zasoby gazu konwencjonalnego (ok. 6 bln m^3). Zasoby niekonwencjonale, zwłaszcza gazu z łupków, może zweryfikować jedynie wydobycie, które w chwili obecnej jest jeszcze w skali tego kraju skromne: 1,3 mld m^3 rocznie gazu z łupków oraz około ok. 12 mld m^3 metanu z pokładów węgla i około 10–12 mld m^3 gazu zamkniętego (często trudnego do odróżnienia od gazu konwencjonalnego z mniej wydajnych złóż). Tymczasem Chiny coraz bardziej uzależniają się od importu gazu ziemnego (Yuan i in., 2015).

W chińskiej polityce energetycznej dotyczącej węglowodorów i struktury energetycznej są dwa silne wektory: więcej gazu w strukturze energetycznej i jednocześnie stopniowe uniezależnianie się od importu (suwerenność energetyczna). Z tego wynikają założenia dotyczące rozwoju wydobycia gazu z łupków i innych węglowodorów niekonwencjonalnych, stanowiących dominującą część chińskich zasobów. Gaz z łupków ma odgrywać więc coraz ważniejszą rolę, gdyż kraj ten chce także stopniowo odchodzić od węgla, którego jest największym konsumentem. Jedną z kluczowych przesłanek do takiej polityki jest pilna potrzeba poprawy jakości powietrza, zwłaszcza w wielkich aglomeracjach. W 2013 r. zużycie gazu ziemnego w Chinach (pochodzącego głównie ze złóż konwencjonalnych) sięgnęło 166 mld m^3, z czego ok 30% pokrywano importem – przede wszystkim z Turkmenistanu.

Scenariusz ten jest obciążony jednak sporym marginesem niepewności (niepewności, która notabene będzie silnie oddziaływać także na światowy rynek energii). Chociaż zasoby gazu z łupków są największe na świecie i Chiny planują do 2040 r. osiągnąć wydobycie na poziomie 260 miliardów m^3, to warunki geologiczne mogą stanąć na przeszkodzie do osiągnięcia tak ambitnie nakreślonego celu. Do tego dochodzą inne problemy – ograniczona dostępność wody w basenach węglowodorowych na północnym zachodzie kraju, struktura rynku gazu, infrastruktura rurociągowa oraz gęstość zaludnienia (np. w Syczuanie).

Niemniej rząd Chin energicznie wspiera projekty poszukiwawcze. Do końca 2014 r. całkowite inwestycje w eksplorację osiągnęły 23 mld juanów (RMB), czyli około 4 mld USD. Wykonano 21 818 km przekrojów sejsmicznych 2D i 2134 km^2 zdjęć sejsmicznych 3D, odwiercono 780 otworów. Ministerstwo udzieliło koncesji na 54 bloki koncesyjne o łącznej powierzchni 170 000 km^2. Z portfela samego Ministerstwa Terytorium i Zasobów wydatkowano od 2009 r. 0,66 mld RMB (ok. 80 mln USD) na prace geologiczne, w tym na 62 otwory badawcze, 4 parametryczne, 210 km przekrojów sejsmicznych 2D i 1500 km innych profilowań geofizycznych (grawimetrycznych, magnetycznych itd.). Sama Chińska Służba Geologiczna wydatkowała na geologiczne badania zasobów węglowodorów niekonwencjonalnych 280 mln RMB, czyli 35 mln USD.

Kluczową rolę w działalności poszukiwawczej odgrywają chińskie narodowe koncerny naftowe (CNPC, SINOPEC, CNOOC, Yanchang Petroleum, China CBM), które na poszukiwania węglowodorów niekonwencjonalnych wydatkowały 21,88 mld RMB. Badania te objęły wykonanie ponad 20 000 km profili sejsmicznych 2D, 2134 km^2 zdjęć 3D, 669 otworów badawczych (w tym: 90 otworów pionowych rdzeniowanych w dużym zakresie, 234 innych pionowych otworów eksploracyjnych, z czego ogółem 345 otworów było krzywionych. Dodatkowo, chińskie koncerny naftowe zbudowały 235 km rurociągów (ryc. 2, 3).

Osiągnięta wiedza geologiczna pozwala na stwierdzenie, że najbardziej produktywne są dolnopaleozoiczne morskie łupki formacji Longmaxi w południowych Chinach (głównie w prowincji Syczuan). Charakteryzuje je znaczny zasięg lateralny, duża miąższość i inne korzystne parametry – zawartość TOC, czy w określonych miejscach dobra podatność na szczelinowanie, co jest dokonywane poprzez koncentrację w optymalnych strefach wielootworowych platform wydobywczych (ryc. 4). Ocenia się, że w formacji Longmaxi zawarte jest nawet 20% całkowitych zasobów gazu z łupków w Chinach. Sam basen Syczuanu (ryc. 1–4) może zawierać do 10 bilionów m^3 gazu, z czego 3 bln m^3 są zasobami wydobywalnymi. Rolę „demonstracyjnego" pola wydobywczego odgrywa pole Fuling koło Chongquing, gdzie osiągnięto wyjątkowo duże przypływy do jednego z otworów (340 000 m^3/d), a z innych w granicach 100 000–200 000 m^3/d, co wynika z naturalnego spękania łupków w strefie osiowej antykliny.

Nie da się jednak ukryć, że warunki geologiczne głównych basenów Chin są znacznie słabsze, niż te znane z basenów amerykańskich. Przypływy z bardzo wielu otworów osiągają zaledwie kilka–kilkanaście tysięcy m^3/d, a należy podkreślić, że nawet te o wydajności 3000 m^3/d są eksploatowane. Wiele stref basenów węglowodorowych ma skomplikowaną budowę geologiczną (co lokalnie – jak w Fuling – może prowadzić do wyjątkowych sukcesów wydobywczych), gdzie indziej jednak komplikuje i podraża eksplorację. Uskoki i spękania (jeśli nie są zmineralizowane) mogą lokalnie korzystnie podnosić przepuszczalność łupków, ale mogły też w przeszłości geologicznej stanowić drogi ucieczki węglowodorów z warstw łupków, co wydaje się w wielu miejscach znajdować potwierdzenie. Innym problemem jest znaczna głębokość położenia formacji docelowych (4000–5000 m), co wymaga stosowania znacznie wyższych ciśnień szczelinowania. Także zawartość TOC na ogół jest niższa od tej znanej z basenów amerykańskich. Wiele chińskich basenów (np. Junggar czy Songliao) zawiera formacje łupków bogatych w iły (kosztem komponentu węglanowego czy krzemionkowego), co czyni je zbyt plastycznymi dla efektywnego szczelinowania. Należy przy tym zauważyć, że unikatową cechą chińskich basenów węglowodorowych jest bardzo znaczny udział formacji pochodzenia jeziornego. Właśnie te formacje są często mocno zailone, choć miąższości i zawartości TOC bywają wysokie. W przypadku tak bogatych w ił formacji proponuje się zastosowanie intensywnego, gęstego szczelinowania pod bardzo dużymi ciśnieniami (ryc. 5).

Jeśli chodzi o kwestie środowiskowe, w Chinach nie obowiązują regulacje szczególnie dedykowane eksploracji i eksploatacji węglowodorów niekonwencjonalnych. Zastosowanie mają istniejące przepisy dotyczące prowadzenia robót wiertniczych. Rząd Chin przyjął pragmatyczne podejście, że ewentualne regulacje będą wprowadzane, jeśli w praktyce zaistnieje taka potrzeba, i że ich kształt będzie zależny od nabytych doświadczeń, a nie założeń wynikających np. z analiz ryzyka.

Podsumowując, można stwierdzić, że z bogatymi (choć trudniej dostępnymi niż amerykańskie) zasobami i tańszą siłą roboczą Chiny mogą się w ciągu 10–20 lat stać jednym z kilku głównych potentatów na rynku węglowodorów niekonwencjonalnych. Zależy to jednak w dużym stopniu od zbudowania konkurencyjnego rynku i inwestycji w infrastrukturę przesyłową. Przy założeniu, że priorytety chińskiej polityki będą nadal zakładały silne wspieranie eksploracji i eksploatacji węglowodorów niekonwencjonalnych, nie tyle kwestie wyższych kosztów wynikłych z geologicznych i innych warunków naturalnych, a właśnie kwestie regulacji i stworzenia jasnych reguł rynkowych przesądzą o przyszłej pozycji Chin na tym polu.

Chiny i Polska mogą nawiązać owocną współpracę – wydaje się, że problemy geologiczne znacznie bardziej zbliżają sytuację w Polsce do tej w Chinach, niż do tej (wyjątkowo korzystnej) w USA, do której próbowaliśmy naszą geologię porównywać. Z tego wynika możliwość wymiany podobnych doświadczeń, co może mieć wpływ na postęp poszukiwań w obu państwach. Np. stwierdzenie bardzo dobrych przypływów w niektórych bardziej zaangażowanych strefach tektonicznych w Chinach może być pewną przesłanką, w którym kierunku mamy zmierzać z naszymi poszukiwaniami. Z kolei polskie doświadczenia i osiągnięcia związane z oceną oddziaływania szczelinowania hydraulicznego na środowisko, opartą na analizie realnego wpływu na środowisko, a nie analizie ryzyka, już budzą bardzo duże zainteresowanie strony chińskiej – chodzi tutaj zwłaszcza o ostatnie raporty środowiskowe wykonane w Polsce w 7 otworach: *Environment and exploration of shale gas – The results of seismic monitoring* i *The Environment and shale gas exploration – Results of studies on the soil-water environment, ambient air, acoustic, climate, process fluids and wastes*. Jeśli intensywność poszukiwań w Polsce spadnie (co ma miejsce obecnie i co jest prawdopodobne w przyszłości), eksport usług geologicznych i serwisowych do Chin może być realną opcją, gdyż w tym kraju wszystko wskazuje na duży wzrost intensywności działań poszukiwawczych.