Technology as the key driver to worldwide exploration succes : AAPG annual convention Pittsburgh may 2013 : selected highlights

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Technology as the key driver to worldwide exploration success. AAPG Annual Convention Pittsburgh May 2013 – Selected highlights

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1 General impressions and highlights

The convention: *The convention was held in Pittsburgh, Pennsylvania, the state currently at the centre of the Marcellus play, the biggest shale gas development in the US. The theme was «Go deep: making the play with Geotechnology». In fact, the main topic of the conference was the move from the purely «manufacturing» approach back to geosciences and technology, virtues that had been partly lost in the previous operational craze, especially in unconventionals. Environmental aspects of unconventional operations were also conspicuous topics.*

Asian presence remains strong, not only as visitors but increasingly in lecture contributions (an estimated 20% of the talks came from Asian authors). The accelerated acquisition of western oil and gas firms, especially by Chinese companies, is reflected in the lecture contributions which show that many of the large Asian corporations have become global players with important research and development.

US E&P Industry: *The move «back home» to the US onshore amongst US companies has been consolidated and a cautious re-opening towards the outside is taking place whereby American companies try to export their knowhow gained in domestic unconventional operations. This re-orientation is triggered by the high gas prices in Europe and especially in Asia. The revoking of unconventional exploration licences in Europe and short term changes in tax regimes and petroleum legislation during recent years have made US companies very cautious about investing in Europe. They regard several European countries to be falling into the category of «high country risk and low legal security». This may give European companies some protection from US and Canadian competition (though the legal insecurities unfortunately apply to all players).*

In May 2013, gas in the US was valued around 4$ / MMBtu, i.e. almost double the price in April 2012 but still very low by international standards (about $^1/_3$ of European and $^1/_5$ of Far East prices). The gas price is therefore still a headache for most gas producers and at present only those companies succeed financially, who can compensate the low gas income with significant amounts of associated liquids that fetch much higher prices. Many of the gas-only companies are being bought up by larger players, and by foreign companies who see this as a long-term and low-risk strategic investment. For European and especially for Asian companies N-America has become one of the main investment areas for E&P.

Gas and US economy: *The low energy prices have also a strong re-vitalizing effect on the*

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Comments and additions by the author in italics.

US economy. Energy intensive industries and industries with a large demand for gas as a raw material are increasingly relocating back to the US. The low energy prices make N-American companies more competitive and they are possibly the main factor, responsible for the conspicuous difference in development of industrial production between US and Europe (Fig. 1). Oil is definitely out for power generation: Oil costs 20$/MMBtu, Gas 4$/ MMBtu.

Gas and environment: *Higher Gas Production and low prices have a significant effect on the CO_2 balance. In the past five years, of all industrial nations, the US had the largest reduction in CO_2 emissions. This is almost exclusively due to the replacement of coal by gas in power generation. The reduction by about 10% – admittedly from a high level – amounts to a minus of 450 MM tons/a, i.e. about 12× the annual CO_2 production of Switzerland. During the same period, the CO_2 emissions have been rising in Asia and many European countries. It is expected that this trend to CO_2 reduction will increase in the coming years as more coal firing will be replaced by gas and as gas vehicles gain a foothold, especially in heavy transport. Efforts are being made by the US to provide incentives for conversion of transport vehicles, especially diesel trucks, to gas. By 2030 over 10 million vehicles in the US are expected to run on natural gas. Shell is the leading company in supplying gas to road transport.*

Reserve growth: *Both, gas and oil reserves of the US continue to grow. The reach of gas reserves expressed in R/P (reserves / present day production) grew from 10 years in 1990 to over 200 years in 2012. The amazing aspect for any explorer is that this happened in the country with probably the highest exploration maturity in the world, where until recently it was common wisdom that all significant hydrocarbon volumes had already been found. The consequences for the rest of the – much less explored – world, force us to completely revise the scenarios of worldwide energy supply: forecasts written prior to the year 2010 are today invalid.*

Peak Oil and Peak Gas: *The US example shows that the «peak oil theory», which is generally perfectly valid for a given area, a given price and a specified technology, tends to lose its predictive power as soon as major technological game changers are introduced. There will be no immediate peak in oil, as forecast, but a long drawn out plateau, while world gas production will continue to grow for many decades. The question is no longer whether there are enough geological hydrocarbon resources in the ground but whether we can afford to produce all of them on environmental, economical and political grounds. Gas as*

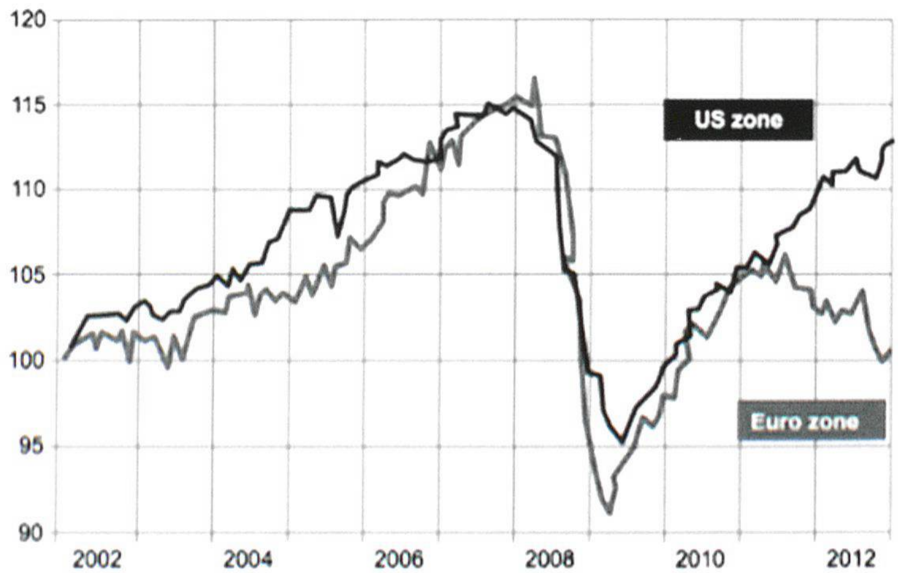

Fig. 1: Industrial Production Index US vs. Europe (Source: Les Echos-Economie, April 2013).

the cleanest fossil energy is likely to establish itself as the world's fuel of choice for power generation, heating and possibly transport. Together with increasing fuel efficiency in cars and buildings and environmental measures, gas is likely to contribute to a stagnation and then a decline of the world oil demand. The oil «peak» will therefore be most likely a demand peak and not a supply peak. Such a development will have dramatic political repercussions as it will weaken the large traditional oil producers, e.g. the Middle East, Russia and Venezuela. Big gas accumulations are geographically much wider spread than oil.

***Unconventional hydrocarbons** were the topic of about a third of the lectures. Compared to last year and in the light of continued low gas prices, the emphasis has further shifted to shale oil, wet gas production and the mitigation of environmental concerns.*

Regaining energy self-sufficiency for the US is a prominent topic. Only 5-6 years ago oil imports to the US were twice as large as its own production. Since 2013, domestic production again exceeds imports and continues to rise (Fig. 2). Given the strong decline in conventional fields it is difficult to see energy independence being re-established but the US dependence on imports of energy has been reduced to a degree where the US are theoretically no longer forced to import from politically unstable areas like the middle East or even N-Africa, e.g. a resource war in the Gulf would not make sense today.

The shale gas and shale oil plays are being further refined and advanced technology and geological thinking have replaced the «drill the hell out of it» principle that has reigned before. The result is fewer but smarter wells and considerably better life performance of producers. Even though wells producing from source rocks still show a rapid decline in production in the first year, they generally stabilize thereafter for many years of relatively low but commercial production. An economic life over 10 years has been achieved in some of the wells in the Barnett play.

***Environmental concerns about the fracturing technology** are still part of the US public discussion, especially in the State of New York, the only state where a development of the Marcellus play is still banned, although, interestingly, New York is the biggest consumer of this gas. In the meantime all studies by the US environmental agency and other independent think tanks have come to the conclusion that the risks in unconventional production can be controlled and that shale gas and shale oil operations should not be banned but properly regulated. As already stated in my 2012 AAPG Convention report there is still no case in North America where a contamination of groundwater, or the surface environment, by the process of hydraulic frac-*

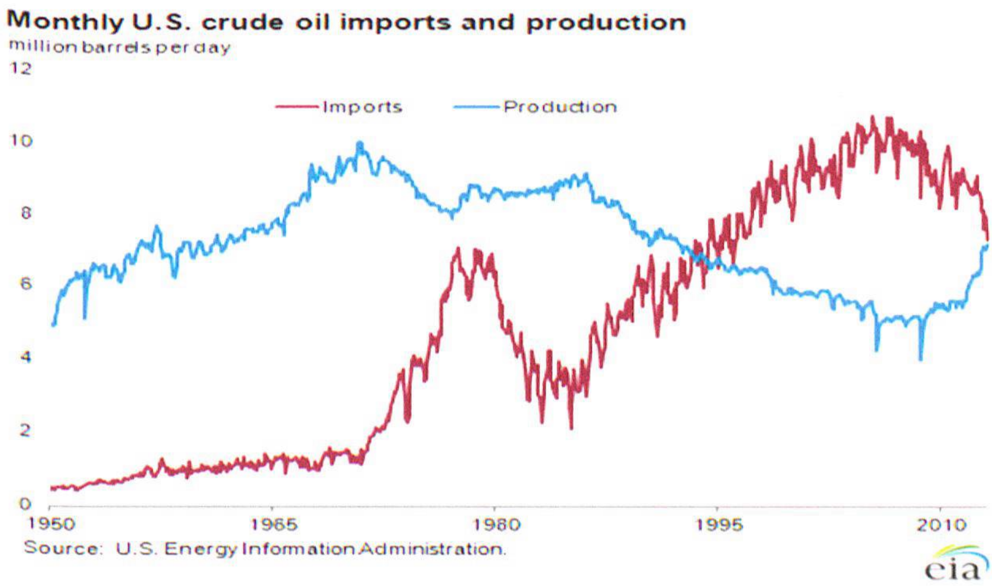

Fig. 2: US crude imports and domestic production. Domestic production has in 2013 reached the levels of the early 90s again and is exceeding imports.

turing itself has been proven. The ten thousands of wells drilled and hundred thousands of stimulations/fracs done every year are a very solid base for these statistics. Most contaminations were caused by poor well integrity (e.g. poor cement jobs) or by poor handling of completion fluids in the surface installations. In the meantime it has become common knowledge that the infamous burning water taps, shown in the film «Gas Land», have nothing to do with hydraulic fracturing or unconventional gas production. In some US states the film is banned.

Many of the operators have realized that in order to retain their licence to operate they need to adapt some of the methods and become fully transparent to the authorities and the public. Interestingly, standards and clear regulations of operations have been developed and adopted faster by the industry itself than by the usually slow regulator. One of the main operators of the Marcellus area (the original pioneer, discovering the play), Range Resources, has been one of the first in setting new standards:

- *Disclosure of all additives that are used for drilling mud and fracturing fluid (Range welcomes controls on the rig site).*
- *Replacing all potentially problematic chemicals with «clean», non toxic household and food additives (e.g. Guar, an Indian bean).*
- *Almost 100% recycling of backflow fluids and re-use of the water in the next wells. Thus much lower water use and reduced trucking traffic.*
- *As a consequence of the recycling: no need for disposal wells (the only potential source for induced seismicity felt by humans).*
- *Cluster drilling to minimize surface impact (reduction by up to a factor 20–30).*
- *Immediate re-cultivation when drill sites are reduced to production sites.*

***Unconventional gas and oil exploration outside N-America** is still at a comparatively very low level. Coalbed Methane is established in Australia (where it will feed an LNG plant) and in China. China, Australia and possibly Argentina are also seen as the first areas to follow the US in major shale gas activities. It was generally felt that Europe will need much more time to sort out its political and public opinion problems, although the UK government has recently decided to lift the moratorium on hydraulic fracturing and is even encouraging shale gas exploration through tax incentives. The mid to long-term scenario is that Europe will most likely become increasingly dependent on energy imports and may have to cope with much larger energy costs than N-America and Asia.*

***Gas worldwide and LNG:** The world gas market continues to be bolstered by the rising imports in South Korea, China and the after effects of Fukushima; Japan has replaced nuclear power (26% of Japan's power mix) almost exclusively by gas and some coal. Today almost half of the global LNG import goes to Japan and Korea but this will change with the rising need in China. According to Hart Energy 1% of growth of primary energy In China could increase natural gas demand by up to 30 BCM (about 10 times the annual consumption of Switzerland).*

*Large new **conventional gas** volumes continue to be discovered in many parts of the world, e.g. in the Eastern Mediterranean Levante Basin, where the proven reserves offshore Israel have now reached 37 TCF (over 1000 BCM). The total potential of the Levante (incl. Lebanon and Cyprus) could eventually be well beyond 100 TCF (about 1 year present world gas consumption). Offshore East Africa, the big discoveries in Mozambique, with a potential of > 100 TCF, are being repeated in neighbouring Kenya and Tanzania where, after the recent large finds of Anadarko, BG and ENI, similar volumes may become available. By 2020 Mozambique is expected to become one of the world's largest LNG exporters after Australia and Qatar. LNG exports are now approved also for the US as from 2015, Canada will follow a few years later. Given the reluctance of the US authorities* *to allow large exports of energy, it is unlikely that the LNG Exports from N-America will have a significant worldwide impact. More significant is the fact that N-America may not require imports of gas for most of this century.*

CO_2*, *climate and sequestration: *CO_2 sequestration was only a few years ago promoted as THE solution to the CO_2 problem. In the meantime expectations have been considerably downsized. Existing pilot projects, mainly in Australia, suffer from high costs and (too) limited sequestration volumes. Australia manages at present to sequester less than 1% of its emissions in spite of several 100 MM $ investments. In Europe CO_2 sequestration (like almost any new activity underground) meets with increasing public resistance in the population. One of the best uses of CO_2 is still the application in enhanced oil recovery. Pumping CO_2 into depleted oil and gas fields will also meet less public resistance since the fields are proof that the system is sealing.*

A special note was brought into the CO_2 discussion by the German geologist and world-renowned authority in Geochemistry, Dieter Welte, who received the Sidney Powers Medal, the highest distinction awarded by the AAPG. In his acceptance *keynote address Welte stressed that he had still very major problems with the climatic models that were used for the prediction of global warming. His main points were: 1] Manmade CO_2 accounts for 6% of global CO_2 levels, the error margin of the current source – sink balance lies, however, above ± 10%. 2] In the Silurian and in the Carboniferous CO_2 levels were well above 1000 ppm (today 400 ppm) but there were major glaciations. 3] Present climate models restrict themselves to the biosphere and atmosphere of the Earth, the outer layers (stratosphere and beyond) are ignored, even though they have an important influence on the processes. 4] There has been no global warming in the past 18 years. 5] Glacial retreat is at present not higher than in the second half of the 19th century and roughly equal to the speed of retreats observed at the end of the last ice age. According to Welte, a contribution by man to global warming is absolutely possible but cannot be conclusively proven at present. Similar reservations were made by Peter Ziegler and other Scientists in the recent volume of Energy & Environment (see this bulletin).*

Own comment: If the outcome is uncertain and given the slow response of the system, it may still be prudent to take measures before conclusive proof of manmade contribution to warming is established. Substitution of oil and coal by gas will be a major contributor to CO_2 reduction. A replacement of coal and diesel by much cleaner gas, has major benefits to the environment far beyond CO_2 and global warming.

Renewables: *The US E&P industry is at present so focused on the technical and financial challenge of the unconventional revolution that renewables have barely been a theme at the conference. This vindicates to a certain degree the criticism that the boom in unconventional gas is delaying necessary investments and research in renewables. The much higher profitability in hydrocarbons has led to a drain of financial resources in geothermal, wind and – to a lesser degree solar. Windpower has suffered a setback since industrial tycoon T. Boone Pickens, who invested 2 billion $ in 2008 to construct thousands of windmills between the Gulf of Mexico and the Canadian border, has pulled out of the project on the grounds of failing economics. Development of solar energy depends mainly on state initiatives; in California solar energy is strongly subsidized and power providers have a compulsory target to supply 30% of their electricity with renewables (including hydropower) by 2020.*

Geothermal *use of hot well fluids in oil and gas fields is continuing to get attention and this may trigger investments in more efficient heat extraction technologies from which also geothermal plants would benefit. Deep geo-*

thermal activities are still concentrated in volcanic areas with little investment or research going into enhanced geothermal systems (EGS), designed to artificially create deep heat exchangers. Given the large areas with shallow volcanic heat, deep geothermal EGS systems are not a prime target and the progress in the development of EGS is therefore slower than in Europe. For the first time in several years the AAPG convention did not have a special geothermal session.

2 Global E&P industry

World oil supply in transition (Kelley, W. and Bishop R.S. RSK (UK) Ltd., Houston, Oil & Gas Reserves Evaluation and Advisory Services)

- The combination of technology and increased oil price have spurred exploration activities and have added large volumes to the reserve base, but much of these additions are «high cost» oil. At the same time, excess/spare production capacity has shrunk from 15 million BOPD in the 90's to around 4 to 6 million BOPD today. The cost to add new production ranges from approximately 25 billion $ per million BOPD production capacity to over 50 billion $ per million BOPD.
  The result is a «two tiered» market of low cost oil (e.g. giant onshore fields) and a 10 to 20 times more expensive high cost oil (e.g. deep water fields, unconventional oil). But a largely single world price for oil remains (Brent and WTI differed in Quarter 2/2013 by less than 10 $/BBL). This creates a very unequal profitability base. Many of the National Oil companies who have taken over old fields from foreign companies have extremely wide profit margins while international oil companies and especially the Majors produce the new, expensive oil with low profit margins.
- Giant fields (> 1 Billion BBL recoverable) have produced about 60% of world oil since 1975 and are about 50% depleted. By 2040 most of the giant fields, i.e. the low cost oil, will be depleted. OPEC has estimated the cost to add new production at around 50 billion $ per million BOEPD.
- Costs to add 1 BOEPD of new production:
  Middle East onshore → 8,000 $
  Middle East offshore → 16,000 $
  Iraq → 25,000 $
  Deepwater → 35,000-45,000 $
  Shale Oil → 35,000-45,000 $
  Venezuela Heavy Oil → 40,000-55,000 $
- Estimates of new oil supply (volume, costs/BOE):
  Discovered reserve growth → 665 BBO, 25 $
  Discovered / undeveloped → 388 BBO, 25-50 $
  Exploration conventional → 435 BBO, 20-30 $
  Exploration deepwater → 130 BBO, 35-50 $
  Arctic → 66 BBO, 35-50 $
- Global annual decline rate is about 3 MMBOPD. Annual additions are 3-4 MMBOPD.
- The most visible effect of this change of balance between high cost and low cost oil is the tightening of supply and its vulnerability to interruption. This tightening is not likely to ease due to both limitations of low-cost production (decline of giant fields) and the high cost of adding supply. Furthermore, even though reserve volumes have grown, the time and cost to add production has increased significantly. Supply is evolving from one with flexibility to «just in time» since companies will not want to invest large amounts without the assurance that these fields can be produced early and at preferably maximum rates. The volatility of price, driven by demand instead of low cost supply, will be amplified as excess supply shrinks and low cost production cannot be expanded.
- In the short to mid term the low cost producers will benefit from the high world oil price and will continue to reap windfall profits. The EIA estimates that over 500 billion $ per year is flowing into the Gulf Region, a

dimension that can impact the global financial system. Oil is the second largest industry in the world and oil price significantly impacts on the global economy.

This will also have an effect on the further level of oil production. CERA is predicting a plateau of oil production until about 2050–2060. The plateau could well be shorter, given the likely substitution of oil by gas and by renewables, as well as the tighter market and continued high prices, caused by the eroding production spare capacity and «just-in-time» development of new fields (lack of supply cushions).

3 Technical presentations

3.1 Geophysical

Lightning data, a new geophysical data type (Nelson, H. R. et al., Dynamic Measurements LLC)

- Lightning patterns have for the first time been tested for their potential use in the detection of geological features and hydrocarbons. Lightning strikes in clusters. Telluric currents – which are modified by faults, mineralization, anisotropy, fluids, and geology – control lightning strike locations and not topography, vegetation, infrastructure. These lightning strike clusters show some consistency over time i.e. lightning tends to strike in the same places again (Fig. 3).
- Data mining of lightning databases provides a new geophysical data type. This data type is unique in that it is already collected, ready for licensing and evaluation, and is evergreen, in that new data are constantly being added to the database.
- Exploiting lightning data bases has enabled the mapping of faults and anisotropy, has shown a relationship to sediment thickness and possibly predicting seeps.
- Up to now geophysicists have missed out on the fact that there are databases with the location of billions of lightning strikes, available to data mine and to integrate with other exploration data.

The method is exotic and still has a long way to go but has certainly a scientific charm and merits further attention. The author came over as a very professional scientist not as a «prophet». The project is funded by an insurance company.

3.2 Source rocks, geochemistry

Mapping the Extent and Distribution of Oil Formation in the Upper Bakken Formation, Williston Basin (Lewan, M. et al., Energy Resources Program, U.S. Geological Survey, Denver)

- Vitrinite Reflectance (VR) is not a reliable tool for maturity. The problem is that oils generate from kerogen not vitrinite. In most good oil source rocks VR is scarce or absent or its reflectance is suppressed. VR indicates therefore often a too low maturity, especially in Palaeozoic rocks. E.g. true maturity values in the Bakken shale are VR 1.4 vs. 0.8 measured.
- Source rocks containing sulfur (mainly type II) are reaching maturity earlier at VR 0.5–1.0, the low sulfur New Albany source rock reaches maturity between VR 0.9 and possibly as high as 2.0. The Bakken is still generating oil now even at a VR far over 2.5.
- A direct relationship exists between atomic H/C ratios and Transformation Ratio (TR) for transformation of expelled oil. The TR-contour maps provide a means of calibrating thermal-history models with respect to oil formation when vitrinite is scarce or its reflectance is suppressed.

4 Unconventionals

4.1 Unconventional oil

The surplus in gas in the US and the ensuing very low gas prices have led companies to place more attention on unconventional oil, especially shale oil, where their experience in unconventional gas production can be deployed profitably. The understanding of unconventional oil plays is improving dramatically and delivers large new reserves, to the extent that some companies are talking about a new oil independence of the US. Some old plays, like the Permian, are experiencing a dramatic revival through unconventional oil.

Technological Developments for Enhancing Extra Heavy Oil Productivity in Fields of the «Faja Petrolifera del Orinoco» (FPO), Venezuela (T. Villarroel, R. Hernández, PDVSA)

- The Orinoco heavy oil belt covers an area of 55,000 km^2 and currently has a recoverable oil estimate of 257 billion BBLS, production totaling 1.1 million BOPD and upgrading facilities that convert the 8.5° API crude into oils of 16° to 32° API.
- Wells are drilled with 3,000 to 5,000' horizontal sections, allowing a cold recovery factor of 8–12%. Through polymer flooding, steam injection and downhole heating (electrical cable) the recovery factor could be raised to at least 20–25%, thus doubling the estimated UR to 500 billion bbls. For comparison: world oil production is at present 31 Billion BBLS/y).

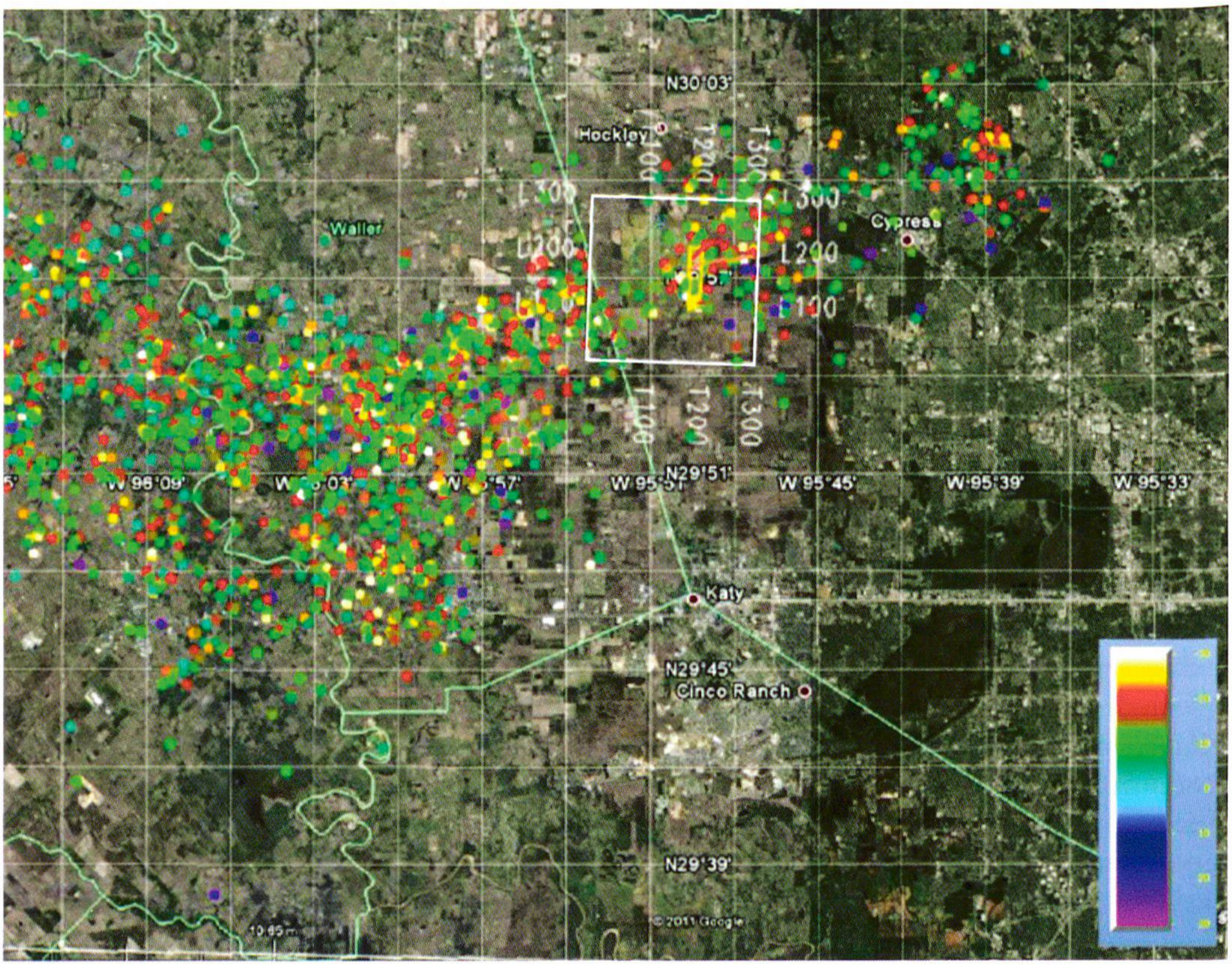

Fig. 3: Lightning strikes pattern, colours indicate peak current in kilo-amps (yellow – red is high). The Hockley Salt Dome oil field is in the centre of the white box at top centre.

- Partners of PDVSA are Chevron, Elf, Petronas, Petrovietnam, Lukoil.

4.2 Unconventional gas

The move from purely operations-driven exploration (drilling as many wells as possible) to a more selective geology and technology-focused approach continues. Unconventional plays are no longer seen as blanket targets but as more complex plays with sweetspots and «dry» areas. This is accelerated by the need to concentrate on liquid rich targets to balance the economics in the present low gas price environment.

General and regional papers

The Marcellus (Jeff Ventura, Range Resources, presented in the Halbouty key note lecture which always addresses a topic of high profile)

- In 2003 Range Resources were a small E&P company in conventional gas plays, struggling with decreasing exploration success factors of at best 20% and decreasing discovery volumes.
- Decision in 2004 to explore as first company the Marcellus play, based on similarities with the Barnett Play. First vertical well in 2004, first horizontal wells with multifracs drilled in 2005-06.
- Production of shale gas went from zero in 2007 to 9 BCFD (0.25 BCM/D) in 2013, expected to go to 12 BCFD in 2015 (i.e. production in 10 days equals about the annual gas consumption of Switzerland).
- Realizing a threat to its license to operate, Range Resources paid special attention to the environmental and social concerns as from 2009, e.g.:
  - First company to disclose all drilling and fracturing additives.
  - Reduction of amount of additives, now 99.9% water and sand. Elimination of potentially toxic additives.
  - 100% recycling of backflow. Therefore no disposal wells.
  - Methane baseline studies of groundwater.

  Range Resources could prove that environmentally clean and safe hydraulic fracturing and gas production are possible and economical.
- Ultimate recovery per well has improved: average 3 BCF/well in Barnett, 9 BCF/well in Marcellus. The frequently used statement that most shale gas wells have a short life and economically marginal production is not supported by the facts.
- The Marcellus Play has at present an ultimate potential of 490 TCF (about 14,000 BCM). World consumption is at present about 4300 BCM/y,
- Range went from a market capitalization of 400 MM$ in 2003 to 12 Billion $ in 2013, though only 6% of the acreage have been drilled.
- The gas boom has a major impact on the US economy:
  - The US covers now 84% of its energy needs and the share grows annually.
  - Oil imports are now 40% of consumption (were 66%).
  - Gas is replacing coal: 2003 → Gas 13%, Coal 51%; 2013 → Gas 30%, Coal 37% of total energy. As a consequence toxic air emissions have decreased by 14% in the same period.
  - Energy savings for the economy amount to 113 Billion $/year.

Note: After the conference I had the possibility to visit a large number of operation sites (exploration, stimulation-fracturing, producing). The visits provided convincing evidence that clean shale gas is not only technically possible, but is now daily routine (Fig. 4).

Source rocks, shale reservoirs and geochemistry

Shale Gas Geochemistry Mythbusting (Dembicki, Harry, Anadarko Petroleum Corporation)

- Myth 1: «TOC, organic matter and kerogen is all the same stuff».
  - TOC is defined as the weight-% of organic matter in the rock.
  - The organic matter in the rock evolves with temperature from immature organic matter to generated bitumen to reactive kerogen to inert kerogen.
  - The more Hydrogen associated with Carbon, the more productive is the generation in the oil window.
- Myth 2: «There is no real difference between oil prone and gas prone source rocks, they both produce gas in the end».
  - Gas source rocks (type III) are over all much leaner and have a much lower capacity to produce hydrocarbons.
  - Oil prone type I and II source rocks have a much higher hydrocarbon generating capacity than type III source rocks. Oil source rocks are therefore the main gas producers, not the type III «gas source rocks».
- Myth 3: «Vitrinite reflectance is the only maturity measurement needed».
  - Vitrinite reflectance increases not only with temperature but also with time.
  - Vitrinite reflectance gives trends not absolute values.
  - Good oil source rocks have little or no Vitrinite.
  - Vitrinite is very error prone in well samples: cavings give too low values; reworked material gives too high values.
- Maturity data are very crucial information in the evaluation of unconventional source rock plays. Vitrinite data are unreliable maturity indicators. Other maturity measurements should be used whenever available.

Hydraulic fracturing and seismicity

Using Microseismicity to Understand Subsurface Fracture Systems and Increase the Effectiveness of Completions: Eagle Ford Shale, TX (John P. Detring and Sherilyn Williams-Stroud, Analysis, MicroSeismic Inc., Denver)

- Microseismic monitoring provides very precise and reliable monitoring data.
- Successive fracs have increasingly higher seismicity. Note. Seismic risk of fracturing is increasing with repeated frac jobs.
- Fracs in sediments were generally thought to be extensional but strike-slip and shear

Fig. 4: Shale gas multi well production site Range Resources (Pennsylvania). Dark green area around production site indicates the surface previously used during drilling and stimulation.

motions are much more common than previously assumed.

- Reactivation of existing faults is common. Microseismic monitoring in combination with regional tectonic and stress patterns studies allows detection of reactivated faults.
- Projection onto seismic allows better understanding of actual processes and patterns in the subsurface (Fig. 5).
- Hydraulic fracture stimulations do induce new fracturing. However the fracturing is controlled by pre-existing joints.
- Excellent signal strength and high amplitude microseismicity yields great assurance in the location of events and therefore great assurance of the locations of the fracture trends observed in the microseismicity. Microseismic data of this quality can be utilized to create accurate subsurface fracture maps.
- High seismic activity is directly linked to higher transmissivity/permeability. This allows the plotting of permeability maps from microseismic.
- Seismic events in shale fracs in the Barnett generate Magnitudes of -1 at most. All events > 2.5 are linked to reactivated faults. Typical amplitude for Barnett fracs is max. 2.5. No seismic events, noticeable by humans at surface, have occurred in over 100,000 fracs in the Barnett.
- In general, seismically-active zones are expected to be hydraulically transmissive because the most active features are the ones under the highest resolved shear stress. Resolved shear stress correlates positively with fracture transmissivity.

The paper shows that microseismic monitoring has evolved into a high precision tool to not only image fracture patterns but even map areas of high permeability. This implies that in combination with 3D seismic the placement of future wells can be done with high accuracy. Also the overall productivity of individual wells is improved.

A More Complete Catalog of the 2011 Youngstown, Ohio Earthquake Sequence from Template Matching Reveals a Strong Correlation to Pumping at a Wastewater Injection Well (Holtkamp, Stephen et al. Miami University)

- From March to December 2011, the Ohio Seismic Network recorded 11 earthquakes in Youngstown OH (magnitude 2.1 – 4.0). Although small earthquakes are not

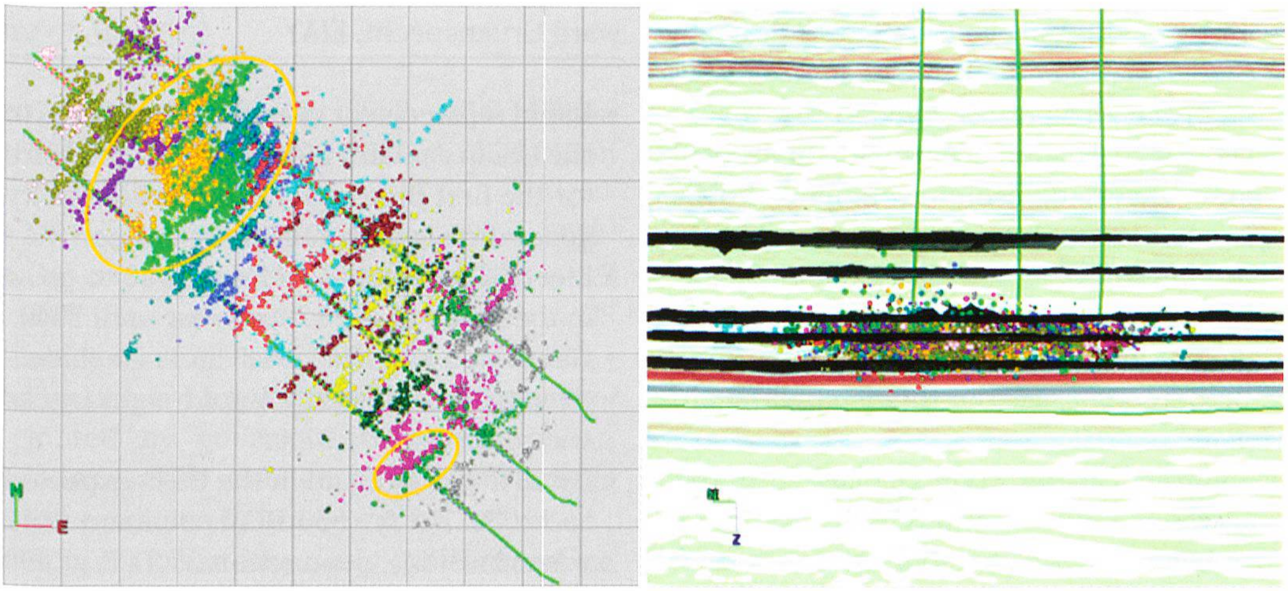

Fig. 5: Microseismic records showing hydraulic fracture pattern between three horizontal wells and projection of microseismic fracture information on 3D seismic of the reservoir section. Distance between wells is about 200 m. Note: frac extension is very limited.

uncommon to intraplate regions, the persistence of events led to speculation that the earthquakes were being caused by a nearby wastewater injection well.

- Injections lasted over 2 years, magnitudes of seismicity increased over time. The 4000' well injected wastewater into the basement, triggering fault shear over time.
- There is a direct relationship between the volume of injected wastewater and the number and magnitude of earthquakes.

Note: the example proves again that noticeable induced seismicity has nothing to do with hydraulic fracturing but is linked to fluid injection.

Unconventional gas and groundwater

Several presentations on gas in groundwater in the Marcellus play of Pennsylvania (C. Whisman et al., L. Molofsky et al., A. Iannacchione et al. Pennsylvania National Energy Technology Lab.)

- Extensive baseline studies have shown that natural methane in groundwater is much more common than previously thought. Long-term measurements are important: natural methane levels can vary up to a factor 10 within one year (highest levels are in spring and summer). Baseline studies may therefore not be representative unless taken over a long period (1 year).
- Natural petroleum degradation in the shallow subsurface produces plumes of CO_2, N_2, Fe, HS and CH_4 that may enter the groundwater.
- In the majority of the over one million water wells in Pennsylvania Methane can be detected, most of this is shallow biogenic or coal gas.
- Different water types have different methane concentrations. Saltwater tends to have higher concentrations.
- Shallow groundwater levels tend to have lower methane concentrations than deeper ones.

Evolving Water Management Practices in Shale Gas Development (Soeder, Daniel, Rodriguez, Rebecca S., National Energy Technology Lab, U.S. Dept of Energy)

- Significant progress is being made in reducing water use and additives for fracturing.
- Freshwater is increasingly replaced by water of lower quality: saltwater, mine water, waste water.
- Some 2,000 fracs have so far been carried out without water (propane or liquid CO_2).
- Total water use for fracs has been reduced by 45% largely due to recycling (in Pennsylvania 90% of flowback is recycled). Recycling saves 200,000 – 400,000 $ per well (no disposal), even more if no injection well is needed. Recycling also eliminates the risk of induced seismicity through water injection.
- Non-toxic additives (e.g. Guar) replace chemicals.

5 Worldwide Gas

Forum: The demand side of gas

Projection US Gas demand from the US Energy Information Administration (Howard Gruenspecht, EIA)

- Rapid replacement of coal by gas occurs in the US. In January 2012 coal and gas were for the first time equal in price. Electricity generation is very sensitive to price.
- Electricity demand will continue to grow in the US by about 1% per year until 2040.
- Gas in cars and trucks will increase (incentives by government), $^2/_3$ of freight trucks will run on gas by 2040.
- By 2040 gas demand in the US is expected to be 30 TCF/y (850 BCM, demand 2012 was 680 BCM), production 35 TCF/y (990 BCM).

Expectations for future US gas and LNG exports (Ch. Smith, US Department of Energy)

- US would be in recession without unconventional gas.
- Gas reserves will last at least 200 years.
- Rapid replacement of coal by gas occurs in the US.
- Gas markets worldwide will be affected by the new situation. There will be a complete decoupling of the worldwide gas and oil prices.
- Export of LNG from the US has been approved in May 2013 (9 MMt/y). 16 other LNG export schemes are waiting for approval.
- The new decentralized energy supply plan for the US will rely on renewables and gas.
- 60 GW installed coal powergen capacity has been replaced by gas in recent years. Oil is definitely out for power generation. Brent costs 20$/MMBTU, Gas 4$/MMBTU.
- Gas in shipping: a large container ship uses 25-30 Million Gallons (95-114 Mio l) diesel per year. Gas is much cheaper and ships easy to convert.
- Conclusion: Gas will within 20 years show a high growth not only in power generation, but also in transport.

Potential growth of natural gas demand for vehicles (Lloyd Sanford, VP Gas Travel Centre of America)

- Gas vehicles globally: 2003 → 2.8 Million, 2012 → 17.2 Million, 2020 → 65 Million (estimate).
- US heavy trucks: 2017 → 8%, 2050 → 50%
- Gas use for vehicles today globally → 5.2 TCF; Gas use forecast for vehicles in US alone by 2030 → 3.5 TCF.
- Gas use in cars and trucks is actively promoted by government through cheap loans for gas vehicles. $^2/_3$ of freight trucks are predicted to run on gas by 2040.
- Conversion is easy. Only gas can replace diesel in heavy duty vehicles. Electricity has too little power or needs too big/heavy batteries.
- CO_2 emission advantage of natural gas: -22% against diesel, -29% against gasoline.
- Added costs for conversion: ca. 10,000 $ for family car, ca. 100,000 $ for heavy truck. Costs are easily recovered through cheaper fuel (heavy trucks run up to 1 Million miles per lifetime. Taxis run up to 100,000 miles per year). Benefits are 80-100,000 $ over average lifetime of a normal car (8 years).
- The main problem is still the low filling station density. Shell is in the lead in US with over 100 LNG stations.
- Additional challenge: energy density is lower in gas: 1.7 gallons LNG are needed to give the energy of one gallon diesel. Large trucks need a 2 ton gas tank.

Potential growth in natural gas demand for chemicals (James Cooper, VP Petrochemicals, American Fuel and Petrochemical Manufactures)

- The focus of the petrochemical industry today is Ethane and Ethylene (for Polyethylene, plastic), both need a lot of energy and hydrocarbons as raw material. Two main feedstocks are being used by the chemical industry: Naphta (from oil) and Ethane (from gas).
- The abundance of cheap gas brings a lot of competitive advantage to the US against Japan, China and Europe. Manufacturing is therefore moving back to the US. Since these are new factories, the related and interdependent industries can settle in gas producing areas (this clustering makes environmental sense as it provides very short transport distances and local energy synergies).
- 30% of associated gas in US is still flared. This should be used by industry.

Note: a significant part of the energy savings in Europe over the last decade are actually «fake savings», since energy intensive (and «dirty») industries were relocated to emerging countries, mainly in Asia, from where products are imported back to Europe.

5 Climate, CO_2 sequestration

Earth's Deep Time insight into our Climate System (Isabel Montanez, Prof. Geology and Geochemistry at the University of California and member of the National Research Council where she chairs the «Committee on the Importance of Deep-Time Geologic Records for Understanding Climate Change Impacts»)

- By the end of this century atmospheric CO_2 is projected to increase to levels that the Earth has not experienced for more than 30 million years.
- Throughout its long geological history, the Earth has had two fundamentally different climate states – a cool «icehouse» state, characterized by the waxing and waning of continent-based ice sheets at high latitudes, and a «greenhouse» state characterized by much warmer temperatures globally and only small – or no – ice sheets. The Earth has been in an icehouse state throughout the time that humans evolved and for the previous 30 million years, but this is not typical since the Earth has been in the warmer greenhouse state for most of the past 600 million years of geological time.
- Answers to how the earth reacts to a greenhouse scenario should be derived from the past warm periods, prior to the Miocene, but this meets with many problems, not the least since the biosphere was very different in earlier geological times (e.g. CO_2 reaches today 400 ppm but levels of 450 to 850 ppm, possibly even > 1000 ppm, are assumed for the Palaeozoic glaciations. Also the response of the ecosystems in oceans is very different from land. The past is therefore not an exact analogue but it is the only record of such warm time processes that we have.
- Rapid climate changes have also been common in the past and the speed of the present changes is probably not an exception.

  Note: On the recent SASEG excursion to the Mont Blanc Massif dedicated to the effect of warming on the glaciation we learned that the present retreat of glaciers is not faster than in the second half of the 19th century or after the Würm glaciation.
- Present day climate models are still very rudimentary estimates with many question marks, they need to be refined with the knowledge from the geological past. Geologists and Geochemists must be key people in the climate debate.

Acronyms and terms

B: Billion (10^9); BBO: Billion Barrels Oil; BOE: Barrel Oil Equivalent; BOPD: Barrel Oil per day; BBL: Barrel; BCF: Billion Cubic Feet (10^9); BCFD: Billion Cubic Feet per Day; BCM: Billion Cubic Metres; BTU: British Thermal Units (mostly as Million Btu – MMBtu); CF: Cubic Foot; DHI: Direct Hydrocarbon Indications (from seismic); E&P: Exploration and Production; Industry: here always meant as the Oil and Gas Industry; M: Thousand; MM: Million; Majors: the category of the largest multinational private oil and gas companies; mD: Millidarcy (permeability measure); Nm: Nano metre; TCF: Trillion Cubic Feet (10^{12}); TCM: Trillion Cubic Metres; TOC: Total Organic Carbon; USD: US Dollar; 3D: three dimensional seismic.