PGS

THE AGE OF EASY OIL IS OVER//MAVERICKS ON A MISSION//EXORCIZING THE GHOST//

Erik Peterson:

Change the game

#1 2009

REFLECTIONS

CONTENT
REFLECTIONS #1

Editorial page 1 / **Photo Story: Exploring Extremes** page 6 / **Off the Bench** page 10 / **The Future and the Role of Clean Oil** page 14 / **Glossary** page 25 / **A New Urban Legend** page 34 / **Black Gold Green Focus** page 36

PGS innovation guru Rune Tenghamn on randomness, risk-taking and vision.

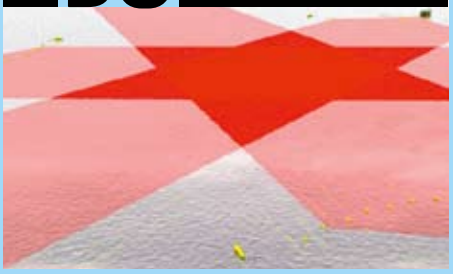
26

Meet Jon Erik Reinhardsen, the man guiding PGS through the swirling waters of the global oil services industry.

2

Sub-salt hydrocarbon seismic acquisition in the Gulf of Mexico, with a twist of lemon!

30



How GeoStreamer® exorcised seismic ghosting and is fast making PGS the industry ghostbuster.

20

From the Seven Revolutions future scenarios program to eco-sensitive seismic in the Peruvian rainforest and shark bites on conventional streamers, from the ghost busting potential of GeoStreamer to randomness and risk-taking as keys to innovation... Welcome to PGS Reflections # 1.

REFLECTING ON CHANGE

Welcome to the first issue of our magazine, Reflections. The title is a reference to our seismic operations, but also represents our ambition to engage our readers in a range of important developments affecting both our own business and the industry at large.

In this issue, we focus on change. Nobody has failed to notice the tumultuous changes taking place in the world economy over the past few months. Our CEO comments on this, and we interview a world-leading futurist on how he believes his predicted megatrends will affect the E&P business in the years ahead.

Change and innovation are intimately related. In this issue, we dissect the anatomy of innovation through the eyes of a proven innovator. We also visit recent technology developments which are potentially changing the face of our industry, or are set to do so in the near future. Finally, we take a short peek at how we are approaching the growing importance of environmental pressures in our daily work. This is a subject we will return to in future issues.

Enjoy the magazine and we are always happy to hear any comments and views you may have.

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CEO Jon Erik Reinhardsen:

GUIDING PGS THROUGH TROUBLED WATERS

AUTHOR: KEVIN REEDER **PHOTO:** LINDA CARTRIDGE

Reinhardsen brings a wealth of international experience with major Norwegian and international corporations to PGS, including six years in the United States, with Aker and in the upper management of aluminum giant Alcoa. Behind the industrial experience, however, are the deep roots of a research-based education in geophysics that still comes in useful today for PGS.

In position as CEO since April 2008, Reinhardsen says PGS can look ahead to exciting times despite the current global economic crisis. "I am very impressed by PGS' development the last years, as well as how the team continues to develop the company in an exciting direction. PGS is one of three leading geophysical companies globally. It has a very strong position, both with regards to markets and technology."

Informal, passionate, cooperative, curious

Reinhardsen combines many of the traits crucial in a successful leader. Determination, passion and a strong bias for action, are balanced with informality, curiosity and a good dose of charm. He believes in the power of teams and prefers a cooperative approach, and most of the time he leaves his tie in the desk drawer. Growing up as North Sea oil production transformed Norway into one of the world's richest

When oil prices go up again, any country with a coastline will be looking for oil or gas reserves. The whole world will be short of energy, that's the strategic future for our industry "

Nowhere is that "lean and agile" mantra more important than in the ability to balance the company's industrial thinking with the entrepreneurial expertise needed to develop new technology "

countries, he was the first in the family to join the oil rush. His father was a salesman and his great grandfather a harbor pilot near Kristiansand. Jon Erik headed for the city and took a Masters in Applied Math and Geophysics. In the 1980s, he worked at the Norwegian Seismic Array (NORSAR) research center outside Oslo. Ironically, PGS still uses some of the software he helped to develop 25 years ago and his thesis can still be found on employees' office shelves.

Apprenticeship at Aker and Alcoa

During his 22 years at Aker, Reinhardsen had the first of his two stints in the United States. Three years heading the company's non-European business and global equipment businesses were an ideal apprenticeship for the major position he took with Alcoa in New York in 2005, when he was headhunted to the position of head of primary aluminum growth. He travelled the world in search of new production sites, from Brazil to Iceland and Australia to Jamaica. The position also involved running the entire process of negotiations for government permits and energy supply and through the project phases. Reinhardsen describes Alcoa as a "star" in areas like management systems, corporate social responsibility, health, safety and environmental. The position gave him the opportunity to create growth opportunities around the world, building relationships with governments based on trust.

Both in New York with Alcoa and Houston with Aker, Reinhardsen was impressed by the American will to win. "I really liked the US business climate," he says.

Mentor and Coach, Not Boss

Asked about his leadership style, Reinhardsen sees himself as a mentor, guide or coach rather than a traditional executive. "I give people a lot of leeway, as long as they perform. I can help to map out a course, but I expect and trust my team to come up with the solutions." He also imposes a certain impatience around the task of getting results, to infuse dynamism into the PGS management process. "It's about having a goal to stretch toward and creating expectations of progress," he explains.

Throughout his career Reinhardsen has immersed himself in international life, as a young professional in 1991, by completing the International Executive Program from the Institute for Management Development at Lausanne, Switzerland and later in his roles within Aker and Alcoa. He has been part of key Norwegian oil and gas industry initiatives and involved in formulating the country's oil and gas industry strategy when it comes to R&D and exports. "I've always been keen to learn from differences and I'm naturally inquisitive. Curiosity is the main driver for me to grow as a person and as a leader," he says.

A Musical Interlude
But don't be fooled into thinking it's all work and no play for the 51-year-old. He didn't just bring back international business knowledge from his time in New York, he also brought back his American wife. He also keeps up his links with the Oslo male voice choir he has belonged to as a second tenor since the early 1980s. The Bislet Bad & Rundkjoring, named after a traffic intersection in central Oslo, is an ensemble of like-minded and lighthearted businessmen who occasionally perform informally at events abroad. Their repertoire ranges from sea shanties to Elvis. The choir has featured as far afield as Houston, London, Singapore and New York.

It will take more than sea shanties to pilot PGS through the choppy waters of the current market downturn but Reinhardsen is confident that PGS is strongly placed to sail safely through turbulent economic times. The company is financed long-term, through 2012. A decision to focus on long term orders rather than short term gain at the end of the up cycle, means, though rates are certainly lower, its 2009 order book is still strong compared to others in the sector. The third pillar of PGS's success is its assets. Its self-owned fleet brings costs down below those of competitors. "The best cash margin in a downturn situation, a solid asset base and financing, mean we will be 'last man standing" he says.

Reinhardsen brings his almost 30 years of industrial experience to PGS at a crucial time when the seismic industry is reaching a new stage in its lifecycle. The first stage was entrepreneurial, but the bigger players like PGS, WesternGeco and CCGVeritas have become more and more industrialized. "Our fleet of vessels is essentially not so different from a portfolio of smelters," underlines Reinhardsen, "so my Alcoa experience on cost-effectiveness and positioning comes in very useful now." PGS runs the most cost-effective fleet in the world.

Well Set to Weather the Storm
Reinhardsen says PGS is well prepared to face a challenging market through its ability to adjust its investment profile and to handle uncertainty through a lean and agile organization. Nowhere is that "lean and agile" mantra more important than in the ability to balance the company's industrial thinking with the entrepreneurial expertise needed to develop new technology. "They're two very different cultures, like combining a traditional shipping company with Google," says the CEO, who aims to strengthen the flow of ideas and new technology essential to maintaining PGS's position at the top.

The advanced seismic business – mapping complex geology and deeper reservoirs, with increasing clarity and accuracy, in more and more hostile environments – is PGS's core market. PGS's fleet and onshore crews, with their ultra-high channel counts are the most competitive in this segment. Its seismic processing solutions are among the best on the market. The new dual sensor GeoStreamer is a game changer when it comes to exploring deeper, through more complex geologies: a unique service with a clear technological edge. Reinhardsen says three of the company's strongest assets are its offering of high density products and technologies, its fleet's streamer capacity and its seismic data library – the largest in the world.

This will be a challenging year for the energy sector but long term the future is bright. When oil prices go up again, and Reinhardsen believes they will, any country with a coastline will be looking for oil or gas reserves, which will drive demand for PGS services. "The whole world will be short of energy and that's the strategic future for our industry, the shortage of oil and gas," he concludes.

JON ERIK REINHARDSEN

PGS President and CEO John Erik Reinhardsen is a Norwegian, born in 1956. He has an outstanding geoscience pedigree and an international industrial career track.

TAKING NO CHANCES

32°48'N 13°08'E

SAFETY FIRST

Vehicles are the No.1 risk onshore. As an industry we employ thousands of drivers worldwide. PGS is firmly committed to managing this hazard. We have redesigned our people carriers and constructed a fleet of new vehicles, installed GPS tracker units, and we monitor and reward good driving performance. Last year we retrained around 400 drivers worldwide. The results show a 25% decrease in vehicle related incidents and zero vehicle-related lost time injuries (LTIs) for 2008.

UNDER THE ICE

66° 34' 03" N

UNLOCKING THE ARCTIC

A 2008 study by USGS indicated that 22% of the world's undiscovered hydrocarbons may be found in the Arctic (roughly 412 Billion Boe), 84% is likely to be found offshore. GeoStreamer may be the key to unlocking the potential flood basalts in East and West Greenland, and the remote-operated marine vibrator could tip the balance in ice-bound exploration. PGS has few peers in this region, with offshore and onshore experience in Arctic regions from Norway and Greenland to the North Slope of Alaska and just south of the Arctic Circle, in the Russian Far East.

RUMBLE IN THE JUNGLE

2°54'S 71°37'W

LIGHT FOOTPRINTS

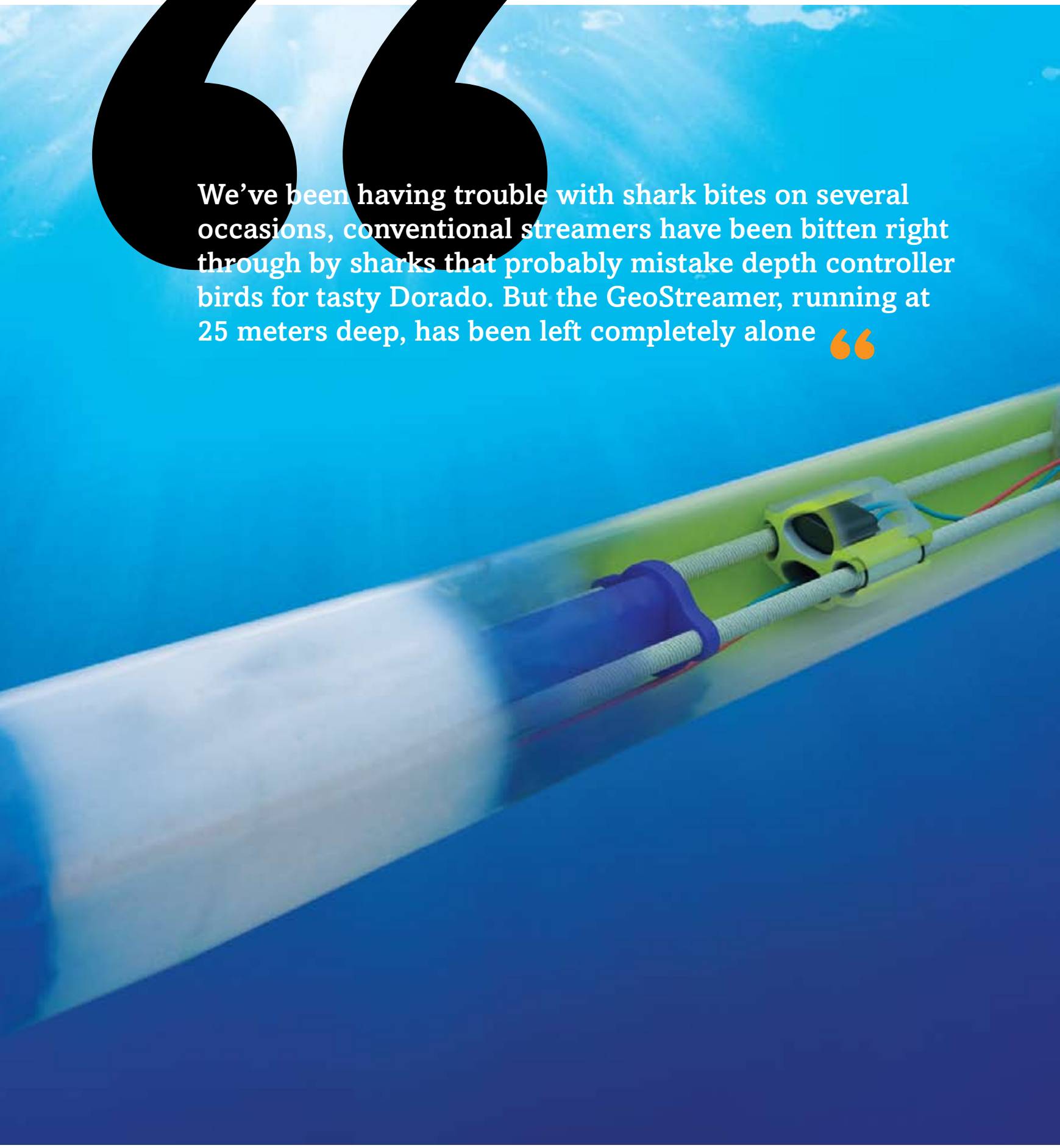
Flexible transport, heli-portable equipment and excellent logistics are essential for safe and efficient operation in dense and humid zones such as the Peruvian rainforest. Our HD3D® technology, with the ecological footprint of a mountain bike, is adapted to this challenging and sensitive environment. Specially trained local employees hand-cut tracks less than a meter wide. Data acquisition is possible even in the most inaccessible areas.

CRACKING THE WEATHER WINDOW

56°N 3°E

NON-STOP OPERATIONS

In many areas of the world, seasonal weather variations restrict the available time for marine seismic surveying to just a few months of the year. The European winter and the South Asian monsoon are both good examples of this. GeoStreamer cracks the problem by towing much deeper than conventional streamers, in a much quieter environment below the zone of wave action. This lengthens the operational season substantially, thereby offering cleaner data, lower downtime costs and avoids the risk of seismic interference from other conventional operations.

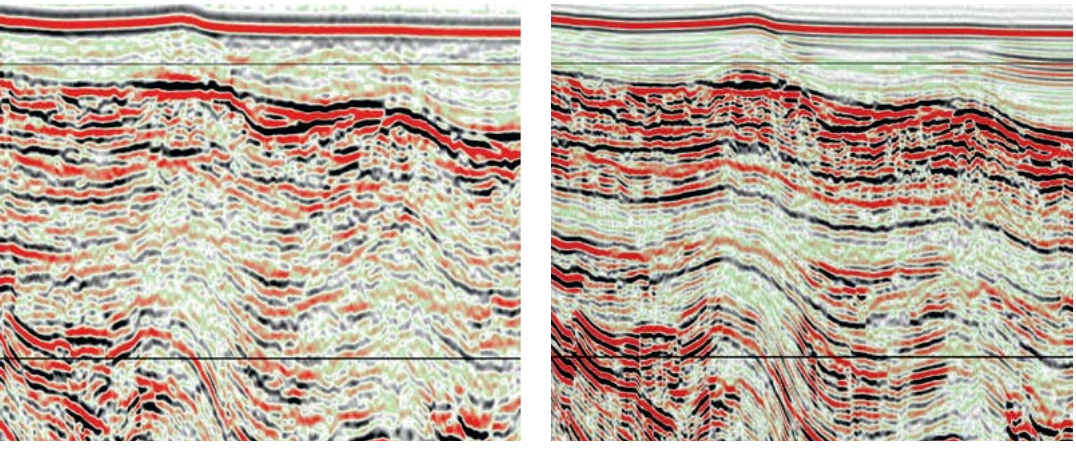


> We've been having trouble with shark bites on several occasions, conventional streamers have been bitten right through by sharks that probably mistake depth controller birds for tasty Dorado. But the GeoStreamer, running at 25 meters deep, has been left completely alone

OFF THE BENCH

New technology always works in the laboratory. It generally works on the test bench too. But the acid test comes when you put it into commercial operation. The GeoStreamer has been no exception.

AUTHOR: JOHN GREENWAY, OSLO **PHOTO:** PGS



These 2D data examples from offshore Cyprus clearly demonstrate the benefits of GeoStreamer. The broad bandwidth of the deghosted GeoStreamer data (right) gives much improved resolution as well as better penetration. Noise levels are also reduced.

The main concerns connected with the first full GeoStreamer deployment revolved around maintaining streamer depths much deeper than those usually towed, noise performance of the geo-sensors at towing speeds, and the reliability of the complex streamer electronics themselves. And so there were some surprises too – and we'll get to those shortly.

Maintaining a stable deep tow proved easier than expected during the first 2D projects. The success in rapidly establishing and maintaining a stable depth required nothing other than conventional streamer balancing and control, which was promising for the more challenging 3D operations to come.

Noise and Speed

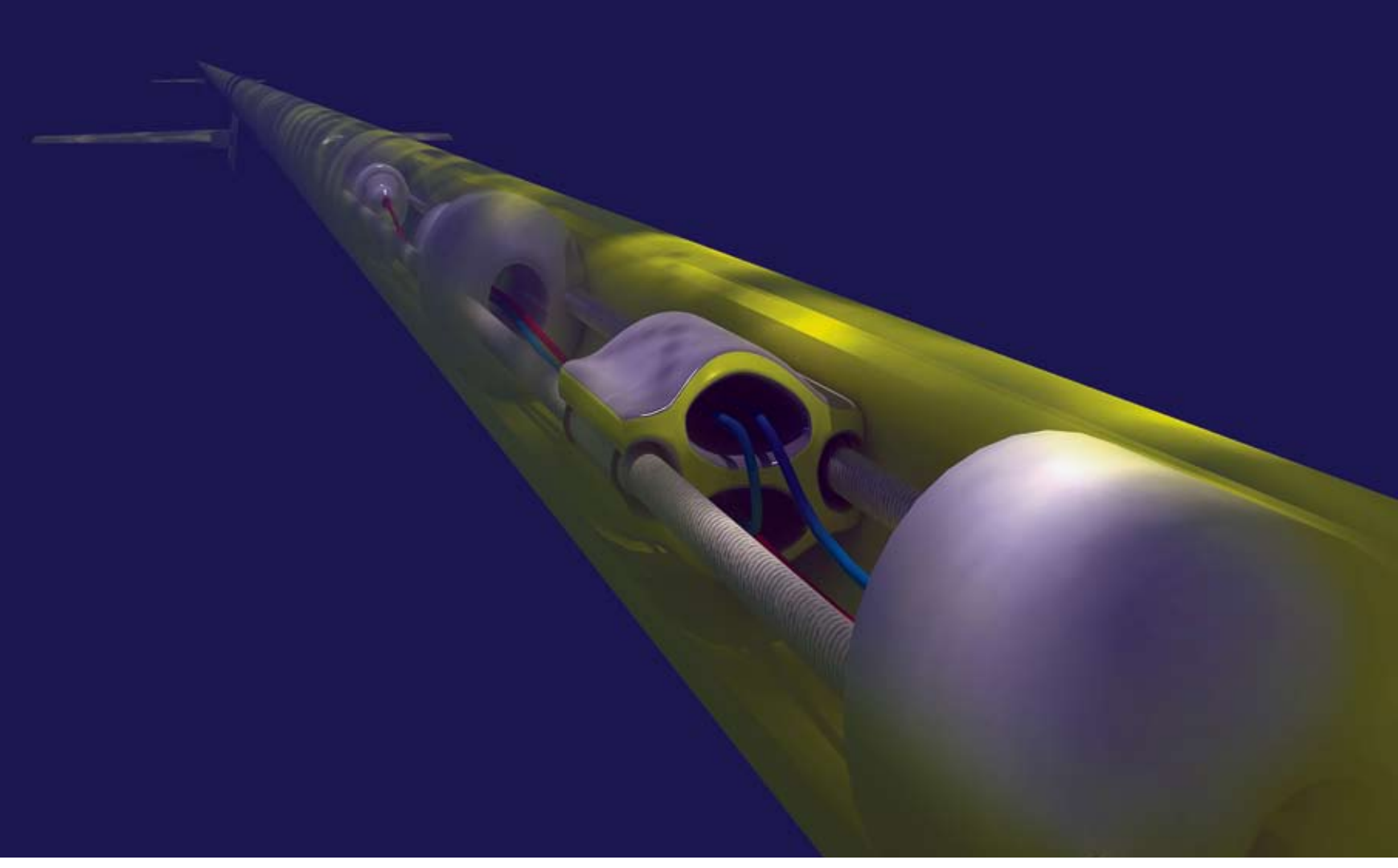
One of the main reasons why previous dual sensor streamer attempts have failed is the fact that the sensors are susceptible to low frequency mechanical towing noise, which naturally increases as towing speed increases. We carried out several initial tests to determine the effect of shooting speed on noise levels in the geo-sensor units. The first, carried out from 3.5 knots to 5 knots at half-knot intervals, were somewhat disappointing. They showed that noise seemed to increase quite rapidly with speed, limiting the pace of operations. However, internal engineering modifications to the prototype streamer sections were able to counteract the phenomenon, and the streamers can now operate at conventional towing speeds of 4.5 to 5 knots.

Staying On-Stream

As far as operational reliability is concerned, our experience so far is good. After a year's continual use, the first GeoStreamers deployed have demonstrated reliability at or above that of our conventional streamers of comparable age. Streamer downtime, in general, is a fairly modest proportion of total downtime and it looks as though GeoStreamer deployment is unlikely to change that.

So what about the surprises we have had, and the new learning? We know that conventional streamer operations shut down in bad weather when noise contamination exceeds specified levels. This usually happens when significant wave heights reach around 2.5 meters. We also know that noise contamination reduces as you go deeper, but how much and how deep has never been tested before over extended periods. A recent winter project in the North Sea has started to give some answers.

The Beaufort Explorer recently acquired over 3000 line kilometers of data in the North Sea in mid winter. This was achieved in the space of about four weeks, towing at a depth of 25 meters with swells reaching up to 4 meters. Noise levels and data quality remained well within specifications throughout the project period. Clearly, in such conditions other issues arise related to maintaining high HSE standards, positioning stability and so on, but it seems that noise is not one of them. This opens up



The secrets within – the theory behind the dual sensor recording method has been widely understood for quite a while. The uniqueness of the GeoStreamer is the engineering solution which allows it to work in a towed streamer combined with specially developed data processing methodologies.

appealing possibilities for year-round operations in seasonal environments such as the European winter and the Asian monsoon.

Surprise, Surprise…

And the final surprise? This comes from Project Manager Jon Midgeley. PGS has recently been running two operations in close proximity in the Eastern Mediterranean – one a conventional survey and the other using GeoStreamer.

We've been having trouble with shark bites", says Jon, "on several occasions, conventional streamers have been bitten right through by sharks that probably mistake depth controller birds for tasty Dorado. But the GeoStreamer, running at 25 meters deep, has been left completely alone.

At a depth of 25 meters there is a lot less light, much less heat, and far fewer life forms than at a depth of eight meters. All in all, it's a much better depth for towing seismic gear – and perhaps an example of geophysics and biology in perfect harmony.

At time of publication, more than 45,000 km of 2D data have been acquired and processed using Geostreamer. These surveys have been carried out in many different regions of the world including Australia, the Eastern Mediterranean, the Red Sea, Norwegian and UK North Sea, several locations in Latin America and the Gulf of Mexico. Imminent surveys are planned in Greenland, Brazil, India and several locations in West Africa.

PGS operates a fleet of three fully equipped 2D Geostreamer vessels.

Two 3D vessels are equipped with the system, with surveys carried out in the Gulf of Mexico and the UK North Sea.

The plan is to equip the whole 3D fleet with Geostreamer systems as fast as manufacturing capacity and investment capacity will allow.

Portrait interview

By Stein Arne Nistad

ERIK PETERSON

I first met Peterson almost a year ago. The world was different then with Bush at the helm. The big chill of the financial crisis was still months away and the main media focus was global warming. Arriving in the US and Washington DC after Obama's inauguration is like visiting another country. The USA has been imbued with new energy fuelled by the promise of change. Already at the airport, Obama has almost blanket coverage on merchandise and magazine covers. It's as if a major rock star has monopolized the world arena. In Washington, politics is power and energy, a fact manifested on our way from the airport when we had to pull over for a passing motorcade. Three limousines were flanked on all sides by dozens of police cars and motorcycles. "It's the vice-president", explains our taxi driver. "I know his and Obama's limousines".

Change

Obama's campaign promise was "change". Things are certainly different. You notice it everywhere: houses for sale, stores with sales campaigns and malls like abandoned shopping deserts. Crises and bail-outs occupy the news, not only here but worldwide. The world's biggest economy, the locomotive of the global economy, is a nation deep in debt. The current paranoia resembles the shock waves after 9/11. The financial crisis struck like lightning out of a clear sky, creating an erratic world that can shift in a few hours or weeks. Oil and stock prices are rising and falling like a cork in a stormy sea. Up and down – unpredictably and with a dizzying rapidity. Is it at all possible to think long-term and strategically in a world where stability and predictability seem more like utopia than achievable reality?

Remember 1990?

Peterson is an unusually jovial and open person. His nordic ancestry is clear in his face and demeanor and may contribute to his ability to communicate clearly and

THE FUTURE AND THE ROLE OF CLEAN OIL

Mr. Erik R. Peterson of the Center for Strategic and International Studies (CSIS) in Washington DC, is in charge of the Seven Revolutions program for fact-based future scenarios until 2025-30. He says neither financial crises nor the election of Obama can change that fact that global warming and the world's growing energy needs are our greatest challenges in the medium term.

The growth of alternative sources of energy will not be able to meet the world's exponential growth in energy demand. Oil and gas demand will increase, putting further pressure on energy resources

precisely. And I am not alone in hoping that Peterson has some answers. He is in great demand. Reflections managed to squeeze in a meeting in the late afternoon, after Peterson had given a lecture in Miami and before he went to Washington DC, to convene with members of the Obama administration. He shared the bill with Clinton's minister of health, Donna Shalala. Mr Peterson is not just another soothsayer. He forecasts future scenarios going forward to 2020-30. That may seem far off, but it roughly corresponds to the period from 1990 until today. To put it in perspective: in 1990 the Berlin wall had just come down and Germany was about to become one nation. The Internet as we know it was not yet born.

Energy

Peterson starts off by outlining the energy challenges, starting with USA's vast fleet of motor vehicles, largely manufactured by a critically injured American auto industry. The US alone has 200 million automobiles. If the current trend in China and India continues, China, which had 12 million automobiles in 2004, will have 500 million in 2050. India will in the same period increase its fleet from 5 million to 600 million vehicles. Mr. Peterson says that after the recession has peaked, this surge will come, just as strong, though later than previously presumed. The growth of alternative sources of energy, like wind, water, solar and nuclear, will not be able to meet the world's exponential growth in demand for energy. Of the financial crisis and recent dramatic drop in oil prices, he says this is a temporary and relatively short-lived situation. The fact remains that demand for oil and gas will increase, putting further pressure on energy resources.

Time to Clean Up

The effect of global warming can now be documented, says Peterson, and despite the temporary slowdown, we know that the world's energy requirement will probably increase by 50% before 2030. It is impossible to meet this demand with today's resources and infrastructure. Using fossil fuels to fill the gap would be inconsistent with the call to cut CO_2 emissions. In other words, this scenario will be an incentive to find new energy sources – but perhaps even more so to develop new solutions that produce less greenhouse gases.

There's also a lot to be gained through better and more efficient engines, better-insulated buildings, improvements in the power grid, better and cleaner power plants. Peterson nevertheless sees the energy situation as a major challenge – especially because it will inevitably lead to higher prices for oil and gas. On the other hand, higher prices will naturally lead to an increased focus on alternatives, which is both desirable and necessary. The Obama administration has this perspective in its energy policy, something which will most certainly influence developments in both the US and in other parts of the world. In other words, the challenge for global industry and the world community will be: how to clean up fossil fuel.

Old Infrastructure

Peterson describes a dire need to modernize the entire gas and oil infrastructure, from extraction to the end user. He says this is necessary in order to meet the growing demand. Estimates from the International Energy Agency indicate that such modernization will cost an unfathomable USD 22 trillion – USD 3,000 for every person on earth. Although the need exists, the question remains how to finance it, if at all possible.

Peak Oil is not the Threat

Peterson believes a peak oil scenario is several decades away – although it's as inevitable as death itself. There is a finite amount of fossil fuel and it will eventually be

depleted. In the short term, however, we see there are fewer geographical areas – the Persian Gulf, Africa and the Caspian Sea – supplying more and more of the world's energy requirement. Accordingly, hydrocarbons will increasingly follow a sort of geopolitical logic by which oil and gas resources are used as bargaining pieces. He reminds us of Europe's vulnerability, where a conflict between Russian and the Ukraine earlier this year resulted in a shut-down of the gas pipelines.

Energy Crossroads

Peterson also observes that the main energy transport route, which goes through four or five key junctures including Panama, Suez and Gibraltar, creates a vulnerable situation with many potential ramifications, both political and practical. Piracy off the coast of Somalia, instability in the Middle East, local cultural divergences, conflicts and regimes can all easily spread, creating a global dilemma. The vulnerability lies in the fact that there aren't many alternative transport routes.

Asymmetrical Growth

According to Peterson, population explosion is one of the factors impacting the world the most, the financial crisis notwithstanding. Firstly, we are growing in number: by 2025 there will be an estimated 8.0 billion people in the world, compared to 6.5 billion in 2005; by 2050 there will be 9.2 billion. Secondly, the growth is asymmetrical: a handful of countries will experience significant population growth, while Europe, North America and China will have an aging and declining population, because of a low birth rate and increased life expectancy. Through their sheer numbers and purchasing power, the elderly will influence both the economic and the political agenda. This development can create conflicts of interests between the younger and the older generations.

Labor

If Peterson is right, there will be a labor shortage in some parts of the world. Other countries, overpopulated with

ERIK PETERSON

Dr. Erik R. Peterson is Senior Vice President at the Center for Strategic and International Studies (CSIS). He is director of the CSIS Global Strategy Institute, a research program for long-term strategic studies. As part of this program, Peterson heads the "Seven Revolutions" program, which presents future scenarios within seven main areas up until 2025.

young people, will have the opposite problem: unemployment and lack of resources. The result of this trend is that the world will enter a new era of significant migration pressures driven by the need to find work.

Mega Cities
Urbanization will increase; by 2025, as much as 60% of the world population – nearly 3.9 billion people – will live in cities. Peterson refers to it as "hyper-urbanization." The number of could rise to a staggering five billion by the year 2030. Many of these people will live in so-called mega cities. These are often located near the coast and in low-lying, vulnerable areas. This creates both a resource problem and scenarios for natural disasters such as tsunamis, earthquakes, floods and typhoons/hurricanes.

Food and Water
Peterson points out that water already is, and will increasingly be, a scarcity factor. Restricted access to clean water poses a considerable health problem, resulting in epidemics, dysentery and a high child mortality rate. The earth is about to reach its maximum capacity for food production, and without continued gains in productivity it will be progressively harder to feed the expanding population. Insufficient access to food and clean water will increasingly staunch economic development and create conflicts among countries and population groups.

Maths, Anyone?
Peterson says the greatest innovations will not be in IT technology, although computers will become ever faster and we will see processors with enormous computing power. Nevertheless, the greatest revolutionary developments are expected to be in genotechnology and nanotechnology, he claims. One can hardly overestimate the potential that genetics and biotechnology

2025: THE SEVEN REVOLUTIONS

Population: There will be more of us. Of the earth's 8.0 billion people, 60% will live in cities and mega cities – many in coastal areas vulnerable to major natural disasters. Many countries in Western Europe will experience a shrinking and increasingly elderly population, while developing countries will continue their population growth.

Resources: Water will become increasingly scarcer with respect to food production and health. Energy consumption will increase dramatically because of economic development in developing countries, and the need for resources (particularly oil, coal and gas) will outgrow the availability of new sources of energy.

Technology: Computers will become ever more powerful, while nano-, geno- and biotechnology will usher in new possibilities and ethical issues – and a longer life span. Children born today will with great likelihood live into the next century.

Information: We will get a global, information-driven economy with free-flowing labor. Continuous education will be necessary for workers, who will probably change career tracks five or six times during their working lives. Free flow of information will challenge established power structures both politically and economically.

Global integration: Some developing countries will develop just as fast in 30 years as the industrialized countries did in 100 years. The growth in developing countries will continue to define new centers of power. In 2025 the economies of Brazil, Russia, India and China (BRIC) will probably constitute 50% of the G6 countries' production. The difference between rich and poor will nevertheless continue posing a major global challenge (currently 2.8 billion people live on less than 2 dollars per day).

Conflicts: September 11th showed how a small group can challenge a dominant military power – so-called asymmetrical warfare. This development will continue, and there is a possibility for asymmetrical, super-violent strikes by small ideological or political groups acquiring weapons of mass destruction – and using them. This trend will necessitate the military to change its structure and use of weapons, in order to adapt to an amorphous, swift and lethal enemy.

Management: Major organizations will become bigger, incurring greater social and global responsibility. A new type of manager will be required, one with the ability to see the big picture, think long-term and responsibly – beyond short-term profit.

More information about 2025: Seven Revolutions at **www.7revs.csis.org**

will provide for new methods of medical treatment, new forms of therapy and the use of stem cells.

Nanotechnology will eventually permeate and change many disciplines. Microelectric machines smaller than a dust particle have already been constructed. Microscopic sensors, switchers and electronic circuits will revolutionize many fields within medicine, genetics and biotechnology.

Harmonized Rules for Flow of Capital
Eric Peterson has worked with the "Seven Revolutions" for many years. It's a dynamic model. Global warming is occurring faster than assumed, affecting the paradigm. So is the financial crisis, which few, if any, saw coming, and which has an enormous impact, says Peterson. The challenge now is to stabilize things first before administering the right medicine. In his opinion the financial crisis has knocked down many basic assumptions we used to have. Because we have a global economy, the ripple effects of such a crisis are enormous. The absence of globally harmonized regulations makes it hard to agree on unified measures to prevent major players from exploiting the situation. Peterson says this is indeed where the major challenges lie. As it stands, regulations in Europe, America and Japan, etc., are different. Capital will therefore flow in the path of least regulatory resistance.

High Definition Managers
Peterson also stresses that large organizations are becoming even bigger. Wal-Mart is now the world's 22nd largest economy – and on a par with Indonesia and Switzerland. Such huge, global organizations incur social, political and environmental responsibility, he says.

Most organizations will be challenged on the management side. Corporations will need leaders who are far better able to figure out the details as well as focusing on the big picture

One of Erik Peterson's main messages is that most organizations will be challenged on the management side. He believes corporations will need leaders who are far better able to figure out the details as well as focusing on the big picture. He calls it a High Definition (HD) approach. HD-Leaders must think long-term, not only regarding economic gain, but also with respect to social, political and environmental consequences of their operations. Peterson is crystal clear in his view that the only way to achieve change on a global scale is to focus on steering the major economic powers in the world.

Optimism
Peterson is a developmental optimist. He believes the financial crisis is transient, though serious. In his opinion, fossil energy will be the most important source of energy in the foreseeable future. The paramount challenge is thus to clean it up. Peterson's perspective is that people have an exceptional ability to solve challenges, once they become threatening and obvious. He believes, therefore, that most of the challenges facing mankind are solvable, if our incentive to solve them is great enough. This includes environmental, energy and resource issues. However, we must think more in the long term and the major organizations must think long-term and develop HD-managers.

CSIS

The Center for Strategic and International Studies (CSIS) was founded in 1962 with the aim of providing strategic insight and decision-making knowledge to the public and private sectors. CSIS conducts more than 25 research programs within three main areas: defense and security, global challenges and regional studies.

CSIS is a non-profit organization located in Washington DC and employing 220 people.
www.csis.org

EXORCIZING THE GHOST

Seismic ghosting has plagued offshore seismic acquisition for decades. Andrew Long describes why the GeoStreamer is fast becoming the de facto ghostbuster the industry has waited for.

AUTHOR: ANDREW LONG, PERTH

GeoStreamer is the long-awaited solution to the seismic "ghosts" that degrade images of reservoir geology. Ghosting is a common problem in all seismic data acquired in offshore locations. The worst "ghosts" appear as false or misleading seismic "events", hiding or obscuring the real geology, or even creating false geology.

Seismic ghosting can be clearly seen in computer simulations. In Figure 1, the seismic image on the right is the "ideal" image we want to see. Each linear feature or "event" represents an acoustic reflection from the interface between rocks with contrasting physical properties. These contrasts exist because the rock matrices in each layer have different mineral compositions, were deposited in different physical environments, or have been subjected to different geological processes during the process of burial and compaction over millions of years.

GeoStreamer Magic

The image on the left in Figure 1 represents the typical seismic result when a pressure

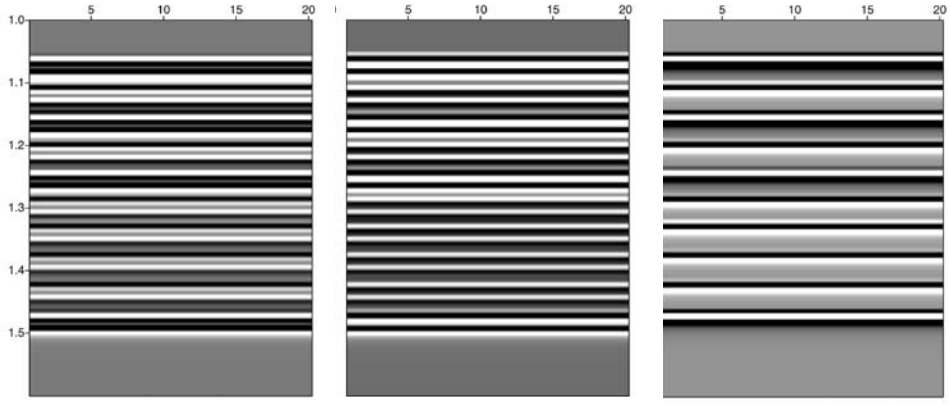


Figure 1. Computer simulation (or "synthetic") example of a seismic image from a stack of thin geological layers. The two images on the left are simulated for a conventional pressure sensor (left) and a particle velocity sensor (middle). The image on the right is the ideal result, clear of the confusing mixture of real and "ghost" seismic events. Only GeoStreamer can yield the image improvement shown here.

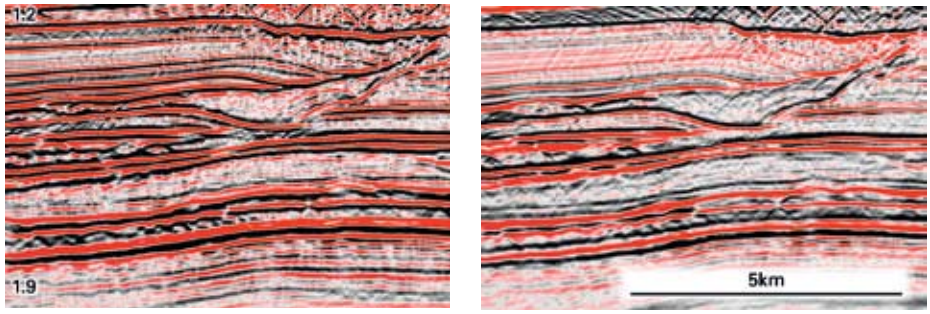


Figure 2. In these seismic data each red-black "event" represents the interface between rocks with contrasting acoustic properties. The data on the left is from a conventional streamer. Here, ghost reflections from the sea surface interfere with true reflections from the reservoir.

The data on the right is from a GeoStreamer. The image gives a truer representation of the reservoir geology. Each event is sharp and clean. It is possible to determine very thin sands and geological formations. Furthermore, the contrasts between small-scale and large-scale geological features are clearly differentiated. The GeoStreamer image meets all the criteria of "ideal" seismic data. The horizontal axes are distance, and the geological depth on the vertical axes is increasing towards the lower part of each image.

sensor or "hydrophone" is used in a conventional streamer. The real reflections are lost within a jumbled and confusing set of events – some are real and some "ghosts". The image in the middle of Figure 1 represents the equivalent seismic result when a "particle velocity sensor" is used. Again, the overall seismic result is confusing and ambiguous.

If both types of sensor are simultaneously deployed in a towed seismic streamer, however, something magical occurs. A simple summation of the two images on the left side of Figure 1 yields the perfect result on the right side of Figure 1. This is the principle behind the PGS GeoStreamer.

The Offshore Restaurant Effect

Why do these "ghost" events affect all offshore seismic data? Imagine a conversation in one of those modern, minimalist restaurants where shiny, hard surfaces reflect even the slightest sound. The result is cacophony of reverberating sounds that drown out and muffle your partner's conversation.

The surface of the ocean is even worse. Acting as a perfect "seismic mirror", it reflects seismic energy we are recording back down to the streamers being towed in the water. It also adds a time lag, so that our seismic information is muffled and distorted. The "ghost" events are in fact unwanted echoes from the interface between the ocean and the air above. Figure 1 shows that every seismic event on the left-hand image is elongated by the reverberating ghost that trails every reflection event from geological interfaces. Unfortunately, each ghost event obscures the reflection of events from deeper depths.

The only solution in the restaurant is to try and shout above the din, to the annoyance of the other guests, who also start shouting, and nothing is improved. Ideally, the restaurant could replace the hard surfaces with soft furnishings, which reduce, but not solve, the noise problem. In the seismic case, there was nothing we could do about the surface of the ocean – until dual-sensor seismic recording came along.

Busting the Ghosts

Conventional seismic streamers use arrays of pressure sensors known as hydrophones (typically 12.5 m in length, and separated into groups 12.5 m apart). A hydrophone can record pressure fluctuations in the water column with equal sensitivity in all directions. Hence, ghost events reflected down from the sea-surface "mirror" are recorded with equivalent strength to the reflection events from the target geology, and everything is indistinguishable.

In contrast, two types of sensor are collocated everywhere along a dual-sensor seismic streamer: a hydrophone that measures pressure, and a velocity sensor that measures particle velocity. Mathematically, the two measurements are related. But, the key issue is that the two measurements have opposite polarity in respect of the ghost events, and equal polarity in respect of the target reflection events on the velocity sensor. Thus, it is possible to "break apart" the recorded information, and then throw away all the events we do not want — the ghost events that degrade what we want to see in the reservoir. This can be seen in Figure 2, a real data example from the North Sea.

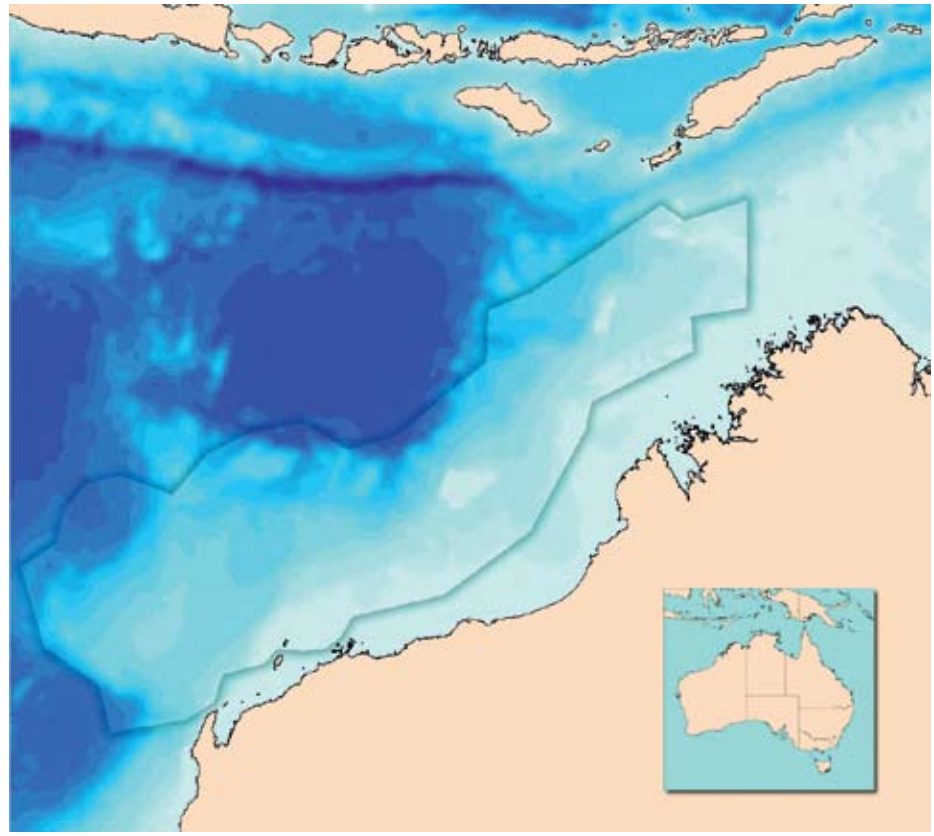


Figure 3. Location map for PGS' first commercial deployment of GeoStreamer on the North West Shelf of Australia. The survey area is about 1000 kilometers long, and included the acquisition of more than 10,000 line kilometers of new data. About 10% of the proven gas reserves in the world are located on the North West Shelf.

The Concept Comes to Life

Dual-sensor seismic recording began in the early 1990s, using seafloor cables that were stationary, and unaffected by weather and operational noise. A decade of towed dual-sensor streamer failures by various vendors followed. These efforts failed because the turbulence noise from being towed through the water, coupled with noise from operations, weather and other sea-state effects, all combined to create a confusing cacophony. However, after years of engineering development PGS overcame these problems, and introduced GeoStreamer in 2007. Towed dual-sensor streamer recording had come of age.

PGS began commercial deployment of the GeoStreamer in early 2008, in one of the most challenging areas for seismic exploration in the world: the North West Shelf of Australia (seen in Figure 3). Of particular relevance in the northern parts of the survey area is the almost complete absence on conventional streamer data of coherent seismic events at target depths. PGS acquired a line in the southern Browse Basin three times to give an apples-for-

Imagine a conversation in one of those modern, minimalist restaurants where shiny, hard surfaces reflect even the slightest sound “

apples comparison of conventional versus GeoStreamer seismic data quality. The results are shown in Figure 4.

Super Ghosts

Figure 4 shows that seismic data in the target depth range are now both coherent and strongly represented at most locations along the line when the GeoStreamer is used. The processing of seismic data on the North West Shelf is infamously difficult, compounded by severe reverberating energy known as “multiples” from extensive carbonate layers throughout the region. These carbonates occur in the shallow geological overburden, thus reducing the penetration of seismic signals to the deeper target geology, and creating severe multiples.

The multiples act as “super ghosts”, obliterating and masking target seismic events over depths of up to several kilometers below the surface. In principle, various techniques exist to remove multiples in seismic processing. However, they depend on deducing the speed of seismic energy in each subsurface formation, and being able to visually distinguish which events are true target events.

These tasks are now proven to be considerably easier on GeoStreamer data, due to the low noise and rich low frequency content. Figure 4 demonstrates a combination of improved seismic energy penetration through the shallow carbonates and the effect of removing ghost events from all depths in the image.

Zero Degradation

Conventional seismic streamers are typically towed at a depth of between four and nine meters. Towing at shallow depths improves reservoir resolution, but with a severe noise penalty from everything going on at the surface of the ocean – sea swell, weather noise, operational noise from the vessels and all other sea-state effects. Towing at greater depths reduces these noise levels, but the interference from the ghost reflections becomes increasingly severe, degrading mid and high frequency information from the reservoir. Thus, conventional streamer acquisition is in a no-win situation.

In contrast, the GeoStreamer is typically towed at a depth of between fifteen

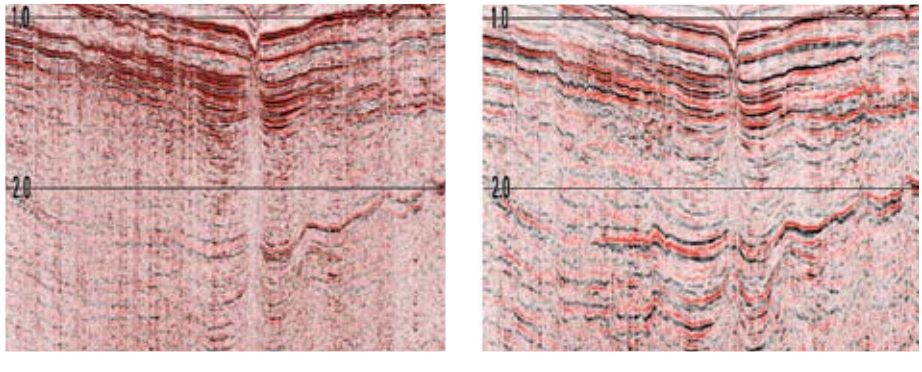


Figure 4. Comparison of (new) conventional streamer seismic data on the left with GeoStreamer seismic data on the right. The seismic line location is the northern part of Figure 2, and is about 100 kilometers in length. The target geology is in the lower half of each image.

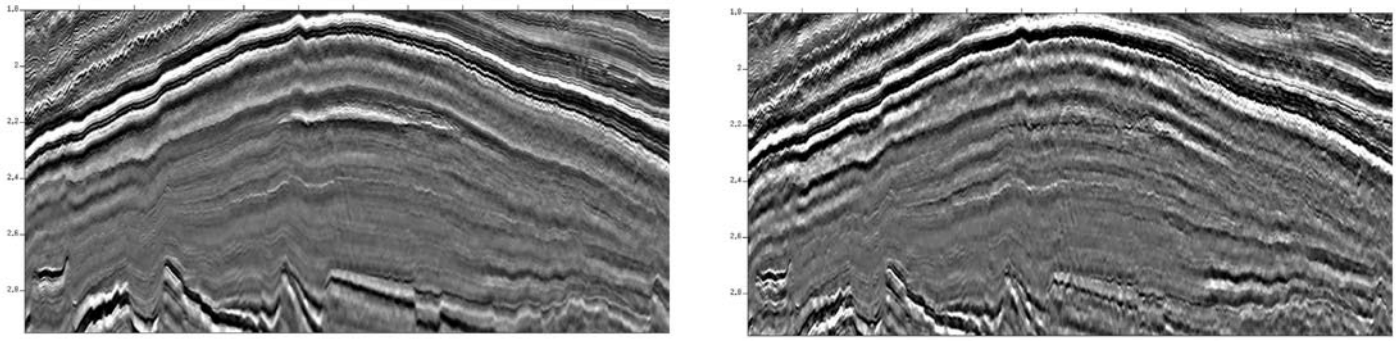


Figure 5. Seismic inversion across a 100 km line known to intersect a large (6–8 trillion cubic feet) gas field. The left image clearly highlights the gas in the middle of the image at a depth of about two kilometers. The gas-water contact is also apparent as a clear "flat spot". This image shows the "relative impedance" for compressional seismic waves traveling through the earth. The right image shows the equivalent relative impedance result for shear seismic waves traveling through the earth. Compressional waves have particle motion in the direction of wave propagation, and should be sensitive to gas in the reservoir pore spaces – as shown. Shear waves have particle motion perpendicular to the direction of wave propagation, and should be insensitive to the presence of gas in the reservoir pore spaces – again as shown. The character and resolution of these two images validate GeoStreamer as the optimum platform for seismic inversion and reservoir analysis.

and twenty five meters. The noise levels are so low that operational flexibility and performance are demonstrably improved. Because the ghost events can be completely removed, there is now zero degradation of any frequency information. Thus, GeoStreamer acquisition is a win-win situation.

Improved Imaging – Improved Performance

During a period of almost four months of operations the GeoStreamer survey in Australia had zero days of downtime due to weather and sea-state issues. Similar performance has been observed in all other global arenas of operation through 2008 and 2009, reducing PGS' downtime and improving its efficiency.

Quantitative analysis of GeoStreamer data acquired in a spatially-coincident manner with conventional streamer data demonstrates a four to five-fold boost in the low frequency signal content, about three times the high frequency signal content, and a higher signal-to-noise content for all frequencies and for all depths. Reservoir resolution is a function of the range of frequencies being available, and the highest noise-free signal achievable. In addition to tripling the high frequency signal content for the Australian example in Figure 4, the frequency range of signal is boosted by 55–65% through the main target interval.

The ultimate application of seismic data is to build detailed geological models of the earth, which allow reservoir engineers to study the elastic rock and fluid properties. The link between seismic data and reservoir models is a process called "seismic inversion". Robust seismic inversion requires seismic data with high signal-to-noise content and strong low frequencies. The low frequencies necessary for inversion are typically missing from conventional seismic data, due to the combination of ghost events, towing the streamer too shallow, and the effect of the recording filters. Thus, the low frequency information required for accurate inversion must in practice be derived from wireline logging in wells. This is impossible if well data are unavailable.

Whilst not entirely providing all the low frequency information desired, GeoStreamer data reduce the traditional low frequency gap in seismic data used for seismic inversion. The example in Figure 5 clearly identifies a large gas reservoir, set against a background rich in low and high frequency information.

Overall, the GeoStreamer is delivering on all its promises. The examples described here are all 2D applications with a single GeoStreamer. PGS is now acquiring 3D GeoStreamer surveys in the Gulf of Mexico, and will have comparable operations in all global areas by the end of 2009.

GLOSSARY

Accelerated weight drop – a form of seismic source used in land seismic. A weight is forced downwards to strike a plate on the ground creating the seismic impulse. Low environmental impact, in contrast to dynamite

Barnacle – filter-feeding crustaceans that live attached to hard surfaces. Goose barnacles often attach themselves to seismic streamers, growing very quickly and causing extra drag on the equipment as well as noise on the seismic recordings as a result of increased water turbulence

Bin size – the many millions of discrete seismic reflections recorded during a seismic survey are sorted into a grid at a very early stage of processing. The bin size refers to the physical size of the grid cells.

Boe – Barrel of oil equivalent

Crossline offset – term describing the distance of a point, perpendicular to the trajectory of the survey vessel, typically between the source location and a point of reference in the receiver spread

Fold – the number of discrete seismic reflections emanating from the same point in the subsurface. High fold results in generally improved signal-to-noise ratio in the seismic image, and is therefore a good thing

Full-azimuth tomography – seismic tomography is a method of deducing certain properties of the earth, by analysis of the seismic waves passing through them. Primarily used for deducing the propagation velocity of sound waves in the various geological formations in the survey area. Knowledge of these velocities is vital to creating accurate images of subsurface structure. Full azimuth tomography makes use of the broader range of data available from WAZ surveys

Geek – a term, often used in a derogatory sense, to describe someone smarter than the person using the term

Geophone – a type of sensor which records particle motion rather than pressure variations. It is conventionally used in land seismic and in ocean floor recording systems where the sensors are in contact with the earth. They are used together with hydrophones in the GeoStreamer system

GeoStreamer – a unique seismic streamer system which uses particle motion sensors as well as conventional pressure sensors (hydrophones) to yield a vastly superior seismic image

Ghost – disturbances to seismic signals caused by the reflected sound waves bouncing off the sea/air interface and overlaying the desired signals with a similar signal arriving around 10 milliseconds or so later. Causes a loss of low and high frequency content in the seismic image. Solved by the GeoStreamer technology

Hydrophone – a type of sensor used in conventional streamer systems. It detects sound propagating in fluids by measuring pressure variations in the fluid as the sound passes by. It works in much the same way as the human ear registers sound in air

iPOD – a fashion accessory which also plays music

LTI – Lost Time Injuries

Multi-azimuth (MAZ) – term describing a survey design where a seismic vessel records several times over the same survey area, but in a different direction (azimuth) each time. A combination of narrow-azimuth surveys

Multiples – multiply-reflected seismic energy. Any event in seismic data that has incurred more than one reflection in its travel path. These arrive later than the primary signal from the reflector in question, and are often highly problematic, as they can mask desired signals from deeper targets arriving at the same time

Narrow-azimuth (NAZ) – term describing conventional survey design, where both source and receivers are towed by the same vessel. Seismic reflections are recorded from below the receiver spread only

Offset – term to describe the horizontal distance between the source and a reference point in a seismic receiver spread

Source line – the surface trajectory followed (or planned to be followed) by a seismic source during a survey

Tile – in wide-azimuth surveying, it is common to use more than one pass of the survey vessels over the survey area to acquire the full range of crossline offsets. In the first pass, the source vessels is quite close to the streamer spread, while in subsequent passes source vessels are further out to the side of the spread. The area covered in each pass is called a tile

True-azimuth SRME – Surface-related multiple elimination (SRME) uses the recorded seismic data to predict and iteratively subtract multiplesThe key advantage of SRME is that it needs no subsurface information whatsoever. The multiples are completely and automatically predicted from the data. True-azimuth SRME is a new method developed by PGS for WAZ data, overcoming the restrictions imposed by sparse source sampling (read more on this in PGS Techlink, Vol. 8, No. 11)

Vibroseis – a method used to propagate energy signals into the earth over a period of many seconds, as opposed to the nearly instantaneous energy provided by impulsive sources such as dynamite charges. The data recorded in this way must be mathematically correlated to convert the extended source signal into an impulse

Wave equation depth migration – Migration is a step in seismic processing in which reflections in seismic data are moved to their correct locations in space, so that the seismic image is a true geometrical representation of the subsurface geological structure. Depth migration is a particularly advanced and highly compute-intensive form of migration, much used in areas of complex geology. Migration is almost a science in itself, and there are several mathematical methods in use for carrying out the procedure – wave equation migration is the most sophisticated and accurate of these. Particularly important for WAZ surveys

Wide-azimuth (WAZ) – term describing a survey design where separate source vessels are used to record seismic reflections from areas out to the side of the recording spread

MAVERICK WITH A MISSION

The story of how PGS innovation guru Rune Tenghamn made one of the seismic industry's impossible dreams come true pays homage to randomness, risk-taking, and a vision of ghost-busting and beyond.

AUTHOR: KEVIN REEDER PHOTO: MIEKO MAHI

RUNE TENGHAMN

PGS' VP Innovation & Business Development holds 35 patents and heads the company's innovation capture team. But he is best known as the "father of GeoStreamer".

With the launch of its GeoStreamer® in 2007, PGS cracked a problem that had defeated the seismic industry's best brains and deepest pockets for decades: the ghosting connected with towed seismic. This success was the result of a relentless R&D drive that began at a technology conference in 2001, survived the turmoil of Chapter 11 restructuring, and was piloted by a man who considers innovation to be "a fundamentally random process".

Ironically enough, this advocate of chance is today responsible for systematizing innovation at PGS. Mild-mannered and distinguished looking, Rune Tenghamn is widely known as the 'father of GeoStreamer', though his business card says 'VP Innovation & Business Development'. His personal makeover reflects a decade-long process that has not only introduced a game-changing product, but also positioned PGS as the new technology kid on the seismic block.

Chaos Theory

Following the GeoStreamer development track is an exercise in joining the dots of what Rune Tenghamn modestly describes as "mostly random events". At an underwater defense technology conference in Hamburg in 2001, he wondered why the velocity sensors used for military purposes hadn't been successfully adopted in seismic streamers. Shell had tried towing combined dual sensors in the 1980s without success. However, Rune had a hunch: a near-field hydrophone close to a source… summing the data from hydrophone and geophone sensors… reproducing the near-field signature… a principle starts to emerge.

Back at the PGS Cable & Acoustics group facility in Houston he conducted lab tests using hydrophones and velocity sensors with a small source suspended below. They were not a great success, but his faith was unshaken. Together with colleagues Andre Stenzel and Claes Boressen, Rune ran a

GeoStreamer represents the most significant advance in towed marine streamer technology since its original invention 61 years ago. There have been many attempts to implement a viable dual-sensor streamer and all of them have failed, with the notable exception of this latest one by PGS.

Fred J. Barr, recipient of the 1995 SEG Virgil Kauffman Gold Medal Award for his groundbreaking work in dual-sensor ocean bottom cables

field trial in Galveston Bay in December 2001. The results from a small streamer section with many different sensors initially seemed unremarkable, but closer inspection of the data in 2002 revealed a breakthrough. The 'ghostbusting' had begun.

Never Say Die!

Rune, who admits to "never having a problem getting people to buy into my ideas", quickly got a green light from group management to gear up the project and produce a prototype. His team was faced with a triple challenge: design a solid streamer as a platform for the sensors; invent new streamer electronics; design and construct the GeoStreamer itself.

The result was three R&D projects running in parallel but slightly out of phase, and a never-say-die spirit that saw the solid buoyant void filler (BVF) platform introduced in 2004, new mini-electronics in 2006, and a 12,000-meter GeoStreamer with a sensor group every 12.5 meters launched at the EAGE in London in 2007. Rune describes the launch – done without having any data from a commercial streamer to demonstrate, because there were rumors of a competing technology – as one of his proudest moments.

"We held a presentation at our stand and 200 hundred people swamped the whole area. I had never seen anything like it. Oil companies praised us, and even competitors said 'well done!'"

Fast-Track Commercialization

PGS' success with fast-tracking GeoStreamer from potential game changer into commercial product has had numerous payoffs. The oil and gas industry recognizes PGS as a real technology company, in addition to being a leader in operational efficiency. The PGS board's decision to pump funding into R&D, even when the company was involved in a restructuring process, has also been vindicated. Overall, PGS has gained a renewed confidence in its ability to act as a performance benchmarker to partner exploration companies in exploiting 'hard oil' as the industry moves toward the peak era.

For Rune Tenghamn, the GeoStreamer process has certainly reinforced his belief in the essential randomness of the innovation process. It has also given him insights that he is busily mining, together with his 'innovation capture' team, in order to optimize PGS' innovation process. Rune considers this a twin endeavor.

"On the one hand, you have to create a transparent process for identifying and generating new ideas, and not least for identifying and encouraging the few individuals who may become future innovators; on the other, you have to identify and nurture the people who can turn the great ideas into commercial products. You rarely find the two skills-sets in one person."

Rune, who himself holds around 35 patents, readily admits that most companies have more inventors than people who can see how to utilize good ideas to create commercial products. As he says, Edison didn't invent the light bulb, but he got the credit because he was first to commercialize and make money from it.

Chaos Theory

According to Rune, a project like GeoStreamer – a perfect fit with PGS core business and with obvious commercial potential – happens maybe once in a lifetime. Even then, its realization depends on several 'non-givens'. Having access to great people is one. Rune's chaos theory is another.

"My visit to the underwater defense technology conference; having the company contacts needed to jump-start the project; becoming VP of Marine Technology which allowed me to push progress at a critical stage; Restructuring giving us a new board that was committed to positioning PGS as a technology company. Without all these random elements, there would be no GeoStreamer."

Generating ideas that can be developed into commercial applications is still the great challenge for Rune. And whereas GeoStreamer was an easy sell – everyone saw the potential of a seismic technology step change that Rune likens to going from a transistor radio to quadraphonic sound surround – his experience with another groundbreaking PGS product has been quite different.

"I spent 10 years developing the marine vibrator, and by the early 1990s we thought it would spawn a multi-billion-dollar market. But 20 years on, the market has still not developed."

Ghost-Busting and Beyond

PGS put the project on hold in 2001, but later restarted it. Why? Another fortuitous factor – timing. Environmental concerns now favor the vibrator, which can be used in eco-sensitive areas where other technologies may disturb sea life and fish stocks. PGS will release the marine vibrator in the near future, mainly for use in 'transition' zones just off the coast.

When PGS presented the prototype at the US geophysical conference, SEG in Houston in 2005, the response was immediate and overwhelming. Early exposure was a calculated risk, of course, and prompted some R&D efforts by competitors. But it succeeded in capturing first-mover advantage and today the marine vibrator is firmly identified with PGS.

"By releasing a batch of highly innovative technologies in the space of a few years, PGS has reinforced its status as a technology innovator," concludes Rune Tenghamn – PGS' man with a vision of ghost busting and beyond.

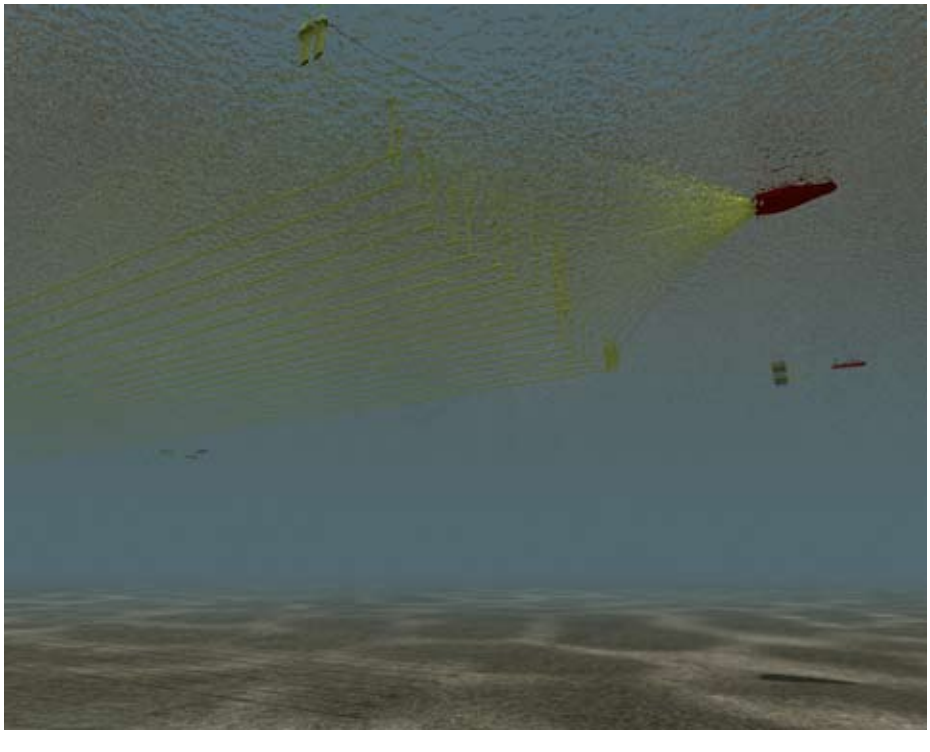
TOP TIPS FOR INNOVATORS

- Good ideas are not enough; you also need good timing.
- Bring good ideas to the stage where they are ready for commercialization – even if the market is not ready – before moving on to something else.
- Don't get so involved with projects that you cannot step back and let 'your baby' go.
- Plan to launch a commercial product as early as possible, to avoid 'techno-myopia' and increase focus on implementation.
- Don't credit others' failures more than your hunches.
- Don't trumpet good ideas too loudly – they attract attention that can be detrimental to progress

WATS IT ALL ABOUT?

The great investor Warren Buffet warns us to beware geeks bearing formulae. Whilst this may be good advice for Wall Street, geeks have served us well in sub-salt hydrocarbon seismic acquisition in the Gulf of Mexico.

//////////////////// **AUTHORS:** EIVIND FROMYR, HOUSTON, JOHN GREENWAY, OSLO **PHOTO:** PGS



The exploration history of the Gulf is long and rich in terms of technology and discoveries, right from the early days of careful steps from onshore into the shallow waters of the shelf. As exploration moved further offshore it became clear that large areas of the Gulf subsurface were characterized by huge and complex salt structures. For many years, geologists postulated the presence of hydrocarbon riches below these vast bodies, but lacked the means to map them adequately.

As well as being highly reflective and therefore allowing little seismic energy to penetrate through, the salt bodies also distort the ray paths of acoustic waves, confusing the receivers – it's like a form of prehistoric stealth technology. Nonetheless, during the early nineties the first sub-salt discoveries were made. The advent of commercially available massively parallel computing, skillfully applied by the subjects of Warren Buffet's complaints, made it possible to unravel many of the complexities of the imaging process, and it was 'game on' for sub-salt.

Reading Through G&T

Sub-salt imaging has been likened to trying to read a letter through a large glass of Gin and Tonic on the rocks. You can certainly see something, but it resembles an SMS message from a 15-year-old schoolchild – pretty much indecipherable. However, if you know the physical properties of the ice cubes and liquid, their shape and orienta-

Ramform Viking and 2 simultaneously controlled source vessels acquire the PGS Crystal WATS survey, Gulf of Mexico 2008.

tion, then the right formulae will unravel the text for you. Sub-salt imaging has additional complexities of course – you don't exactly know the shape and orientation of the ice cubes, and you don't even always know if they're actually made of ice either. It also has the disadvantage that you can't drink the experiment after you've finished sweating over the calculations. Nevertheless, great strides have been made and the Gulf has become the nursery for a booming depth-imaging industry.

In the early days of sub-salt imaging, very little occurred on the data acquisition front, other than streamer lengths becoming successively longer, from around 6 km during the early nineties to 10 km and beyond by the end of the decade. Multi-vessel operations were often introduced to create even longer offsets, in an effort to catch as many seismic reflections as possible from the deep targets. Developments in depth imaging – and the formulae that we call migration algorithms – continued apace with ever increasing refinement. But they all had a common and decisive drawback. However advanced the imaging algorithm, it is only as good as the image data it is fed with. If the data acquisition method does not deliver good data, the migration falls short. This was the case as wide-azimuth data acquisition entered the scene.

A Shot in the Dark

Imagine a Game Show. The rules are very simple. There is a darkened room with a closed door. Inside the room is a mystery item. You put up a stake of one million dollars and try to guess what it is. If you guess right, a huge prize is yours. If you guess wrong, you lose your million. (You wouldn't get many takers for this, though there may still be a few left on Wall Street, assuming it's someone else's million of course). Alternatively, you can choose to go on to step two. Here, for a million more, you are given a flashlight and allowed to enter the room to illuminate the object. However, you are not allowed to move around, just to stand still at one end of the room. Again you have the opportunity to guess what it is. If it's a simple familiar object, like an oil barrel for instance, you may be confident enough to guess what it is. Guess right, and you win. However, if the object is unfamiliar you may choose to go on, and for a further million you get to walk around the object on all sides with your flashlight. Now you are able see what it is, win the prize, and have the opportunity to make your investment advisor ridiculously wealthy.

Standing still in the room with the flashlight is analogous to conventional seismic acquisition, often called NATS – Narrow Azimuth Towed Seismic. Walking around the room illuminating the object from all sides is analogous to WATS acquisition. WATS = Wide Azimuth Towed Streamer. The trick is to make sure that we generate seismic reflections which return from all sides of the object (the salt bodies) rather than just a narrow strip above.

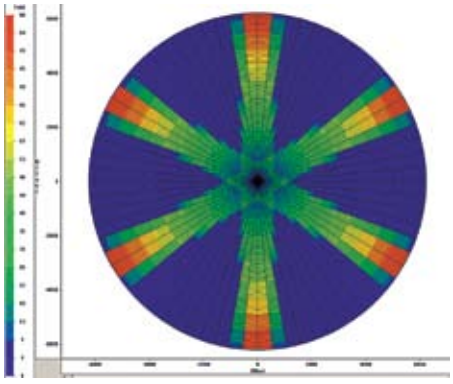
Undershooting on a Grand Scale
This is done by using a streamer boat capable of towing a large number of cables in a very wide tow, typically 2.5-3 km wide. The Ramform vessels are very well suited for these kinds of surveys, in which separate source vessels are deployed on each side of the streamer spread. The operation is split into two passes, one with the source vessels close to the spread and one with the source vessels further away from the cables. One source vessel is positioned ahead of the spread, the other symmetrically at the tail end of the spread. In such a way we cover a large range of cross line offsets and azimuth ranges.

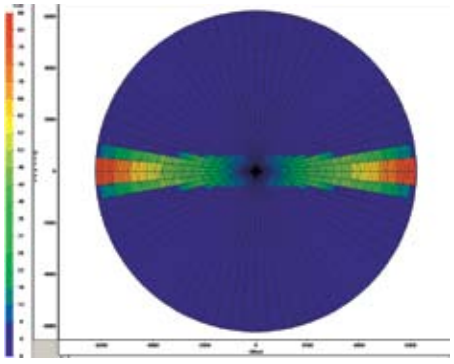
Wide azimuth surveys, which resemble undershooting on a grand scale, are usually more complex and expensive than conventional narrow azimuth surveys (NATS). This is due to having to shoot the survey more than once, in addition to the number of vessels deployed, the coordination between them and the associated mechanics and logistics of line turns. However, the benefits of wide azimuth acquisition, a product of the greater diversity in surface coverage, extend beyond the pure illumination benefits to include improved noise reduction, and higher fold.

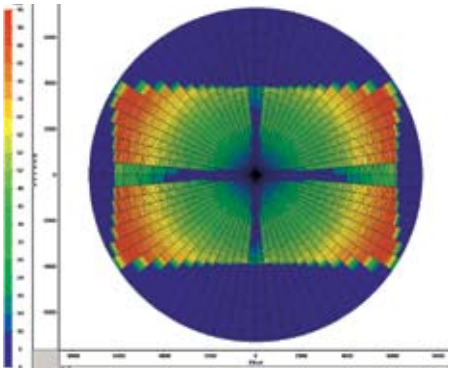
A good example of the technique is the Crystal dataset data acquired by PGS completed during 2008. It involved a three-vessel configuration: Ramform Viking towing ten 8.1 km streamers at 120-metres separation, and two simultaneously controlled source vessels. Each source line was sailed twice; once with streamers positioned close to the source line, the second time with them shifted one spread width further away. These two passes are referred to as 'tiles'. The 600-metre-long source lines result in an impressive trace density of 565,333 traces per km^2.

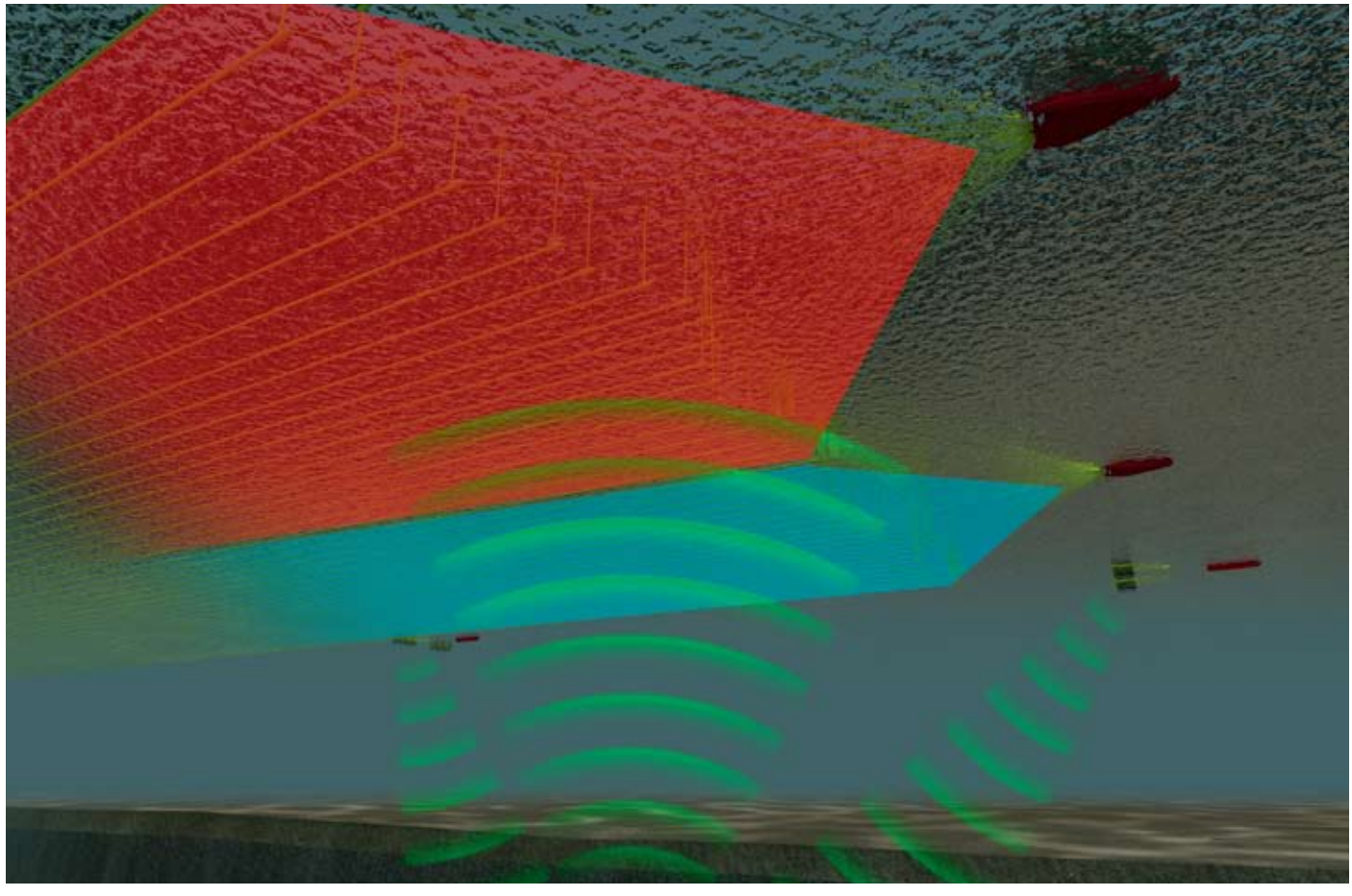
Step Change in Imaging
Wide azimuth surveys offer a step change in imaging quality in sub-salt exploration and appraisal. The results obtained have confirmed the supporting principles of the field design: the WATS images are superior to those obtained from NATS acquisition. WATS survey geometry requires the most advanced processing technology, and the optimal final image is only available when the entire range of acquired traces are used, honoring the full 3 dimensional character of the acquisition. In addition to more conventional steps, WATS processing includes Full Azimuth Tomography, and True Azimuth 3D SRME followed by Wave Equation Depth Migration.

The plots below show the range of azimuths recorded by three common acquisition methods, where the ring represents the whole 360 degree range of possible azimuths. To the left is a result from a Multi-Azimuth survey using three passes of a conventional configuration, in three different shooting directions over the same area. The middle diagram shows the result from a conventional narrow azimuth survey. This gives a very small range of azimuths, restricted to a narrow band close to the direction of shooting. The right hand diagram illustrates the azimuth range resulting from a typical Wide-Azimuth survey. Here, we see a very rich distribution of recorded azimuths covering pretty much the whole range from 0 to 360 degrees.



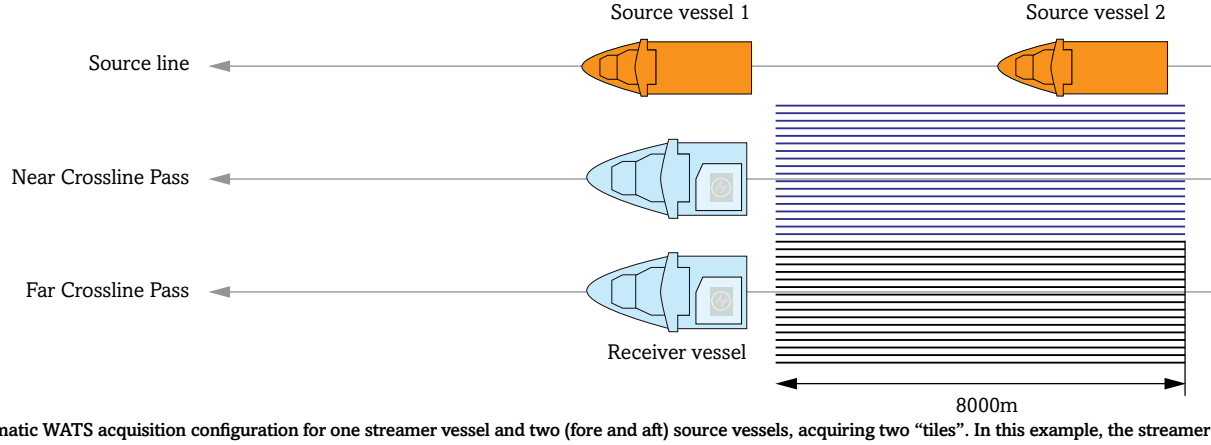






Artists impression of Crystal WATS acquisition from beneath the waterline.

So what does the future hold? An intriguing opportunity is the combination of WATS with GeoStreamer, described elsewhere in this issue. Current WATS programs are generally performed using relatively deep towed streamers (at least for conventional streamer systems) in order to recover as many deep reflections as possible. This is at the expense of higher frequency shallow data. It's a bit like listening to a pop song, but just hearing the bass line. (Rather unsatisfactory, though it doesn't seem to bother our 15 year old "iPOD therefore I am" generation). Imagine a full-blown WATS operation using GeoStreamer. WATS + Geeks + GeoStreamer. Now that would be a game change.



Schematic WATS acquisition configuration for one streamer vessel and two (fore and aft) source vessels, acquiring two "tiles". In this example, the streamer length is 8000 m.

onSeis – A NEW URBAN LEGEND

A new 3D source called PGS onSeis offers a high quality, low impact solution for difficult areas onshore.

AUTHOR: BILL PRAMIK, HOUSTON PHOTO: MACDUFF EVERTON/GETTY IMAGES

Let's face it, if you woke up one morning to see a group of people busily planting dynamite charges outside your home, you'd be a little worried. You'd be less nervous, but perhaps equally surprised, to see a line of monstrous heavy trucks battering away at the ground along your street. Not to mention the surprises you might get in the days to follow as you find that your water pipes and power lines have suffered serious damage. This is the challenge facing land seismic contractors acquiring data in urban or industrial areas. The restrictions on the use of conventional seismic sources mean that contractors have to look for alternatives.

The conventional solution has been seismic signal generators like the accelerated weight drop (AWD), which have less environmental impact, but at the same time, unfortunately, are less suited for acquiring high quality data. Now there is a better solution – the PGS onSeis, or Synchronized Electrical Impulsive Source.

Close to Home

PGS onSeis is more suited for operating in industrial and urban areas than explosives and Vibroseis sources, which generate substantial surface vibrations. These can damage buildings, pipelines, or other types of infrastructure. To avoid this damage, these sources have to be kept at minimum distances from infrastructure. This results in having to relocate source points or even skip them altogether. The surface vibrations from a PGS onSeis unit are significantly less, allowing for source points closer to buildings, resulting in fewer relocated shots and more consistent acquisition geometry.

Small SEIS

Compared to a Vibroseis truck or a buggy-mounted drilling rig, PGS onSeis units are small and can be mounted on a variety of vehicles. This bestows additional advantages. It makes PGS onSeis easier to use in areas with difficult terrain or dense vegetation. This suits them for use in all types of jungle,

not just the urban variety. It also creates benefits in environmentally sensitive areas. Whereas Vibroseis often requires bulldozers to clear trails, a PGS onSeis unit can operate on a hand-cut, two-meter-wide track.

Speed, Efficiency… and Data Quality

We've already mentioned that Accelerated Weight Drop sources are often used in built-up areas. They share the logistical and environmental benefits of PGS onSeis units, but in one particular area, they cannot compete. Their key disadvantage is that AWDs cannot be synchronized. This means that multiple AWDs cannot work together simultaneously to increase the total source energy.

The fact that PGS onSeis can synchronize has a direct impact on both the quality of the seismic data collected, and the speed at which data can be gathered. Here's why. The answer lies in the difference in how signal-to-noise ratio is improved in seismic data. If a single "shot" from an Accelerated Weight Drop source is not sufficient to obtain the desired signal-to-noise level in the data, you have to record multiple shots and combine their results. Each time a shot is added, the signal-to-noise ratio improves by the square root of the number of shots summed together. In other words, to get double the signal-to-noise ratio of a single shot, you need to take four shots and combine their results.

If multiple sources can be synchronized – as is the case with PGS onSeis – the addition of more sources increases the signal-to-noise ratio linearly. One shot from two synchronized PGS onSeis units will therefore have double the signal-to-noise ratio of a shot from a single unit. This simple mathematical trick means that fleets of synchronized PGS onSeis sources can significantly improve the efficiency and speed of data acquisition, without sacrificing data quality.

OnSeis Fits All?

Will PGS onSeis replace explosives and Vibroseis as the source of choice in all areas? Probably not. But wherever the location of a seismic project proves too difficult or expensive for traditional sources, this is an alternative that may move the goalposts enough to keep the project onside.

SEIS IN ACTION

PGS has tested onSeis in numerous locations in North, Central and South America, in various terrains and environments. Commercial operations have begun in both Mexico and Colombia. Many clients are showing strong interest in the source for applications covering the entire Western hemisphere

BLACK GOLD GREEN FOCUS

There is increasing recognition that the days of easy oil and gas exploration may have passed. Perhaps the days of easy answers to our global environmental challenges have also passed.

AUTHOR: DAVID HEDGELAND, LONDON

For many years the environmental focus in the oil and gas industry has been on addressing the issues of material waste and emissions, factors that are relatively easy to measure. While we continue to improve performance in these areas, the potential implications of larger scale environmental issues such as climate change, sustainable development and habitat conservation are rapidly presenting new challenges. These are less easily measured and monitored.

The challenge now facing the exploration and production (E&P) industry is to develop a globally coordinated and consistent approach to the environment. It must address a variety of commercial, operational and technology implications related to E&P activities offshore and onshore.

Eco-focus & Key Business Drivers
Investors, clients and suppliers continue to focus on 'green' issues. Climate change and sustainable development are being scrutinized through supply chain management mechanisms and independent reporting initiatives. This in turn is leading to an increasing demand for companies to develop environmental monitoring, reporting and reduction strategies for global activities.

Governments and regulatory authorities are striving to balance national needs to develop new energy resources with the social and economic needs of local industries, such as fishing, and the well being of the general population and environment. For example, a number of core exploration areas, including the UK, US GoM, US Alaska, Canada, Australia, Brazil and Ireland have now implemented specific regulations and guidelines related to seismic survey activities offshore. Their aim is to reduce the risk of acoustic disturbance to marine animals, particularly marine mammals, turtles and fish.

Eco-focus & Operational Challenges
All PGS businesses are experiencing increased demand for technical and operational environment-related support. This ranges from environmental assessments for permit applications, to survey planning activities and mitigation activities in the field.

E&P companies increasingly ask the geophysical industry to provide technical and operational solutions for acquiring seismic surveys that mitigate the environmental effects those surveys may create. These measures are required for compliance with regulatory frameworks or companies internal best practice requirements.

An Environmental Benchmark
PGS is determined to set performance benchmarks in the seismic industry. One of our current focuses is to improve our Environment Management System, based on international standards, such as ISO 14001. This will enable our marine business units to make informed decisions based on up-to-date information on the risk associated with operating in environmentally sensitive areas, from planning and contracting through acquisition of surveys in the field.

By focusing on key environmental areas, such as carbon reporting, waste management and the ecological impact of field operations, we aim to become not only more environmentally aware but also an environmentally proactive geophysical company.

PGS ECO-FRAMEWORK

The new PGS environmental framework incorporates:
- Environmental stewardship
- Identifying environmental aspects of primary activities and defining achievable environmental objectives and targets
- Engaging all levels of the PGS organisation
- Periodic review mechanism to ensure continual improvement
- Evaluation of potential future environmental touch points (energy use, sound)

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