PGS

A VIEW FROM THE TOP // WHY BROADBAND ROCKS // RISKY BUSINESS // DOWN TO EARTH

The Art of Managing Risk

#1 2010

REFLECTIONS

PGS MAGAZINE

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REFLECTIONS #1

Can lessons be learned from other fields of extreme exploration, like space?

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New fiber-optics developments might be the game changer for permanent seismic monitoring.

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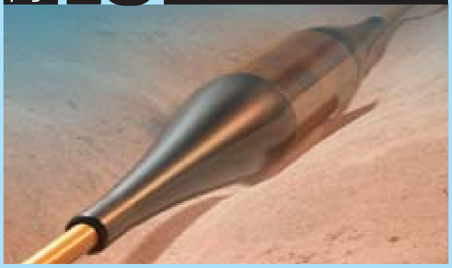

"There are basically just two aspects of seismic we can improve on," says Chief Geophysicist Eivind Fromyr at PGS.

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The scale and nature of environmental risk is changing. Once identified, we have a duty to assess the probability of an undesirable event happening.

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Welcome to the second issue of Reflections. This time we take a look at an area that is close to the heart of our industry: risk. It impacts at all levels from investors to exploration and asset managers, from regulators to roustabouts.

SOME REFLECTIONS ON RISK

Recent events in the Gulf of Mexico amply illustrate that the risks are real and while not all of them can be contained, that is what society expects. Exploring extremes will never be risk free. In this issue we interview a NASA strategist and an astronaut on how the space industry works to overcome its many challenges to build a path to the stars.

Is managing risk an art? The dictionary defines art as a skill acquired by study, experience and observation. Reservoir characterization certainly requires all of that with a dash of imagination. Our technical feature explains how inversion of broadband seismic can reduce risk in new exploration areas.

Risk and uncertainty are closely related and accurate information is our arsenal to combat the unknown. Permanent reservoir monitoring is the closest we get to information on tap, but how long is permanent? Can fiber optics make life of field data last a lifetime? Finally, we sound out the risks of our environmental behavior? Can we do better?

We hope you enjoy the magazine and look forward to your comments and feedback, as usual.

Tore Langballe
SVP Group Communications
tore.langballe@pgs.com

“We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win….”

AUTHOR: STEIN ARNE NISTAD **PHOTO:** NASA

Those born in the fifties are the space generation, whether they like it or not. The sixties was a decade of change and development: the Cold War, global TV and the breakthrough of pop culture fused the world together through conflict, flower power, communication and development. Arguably though, the space race epitomized all of this.

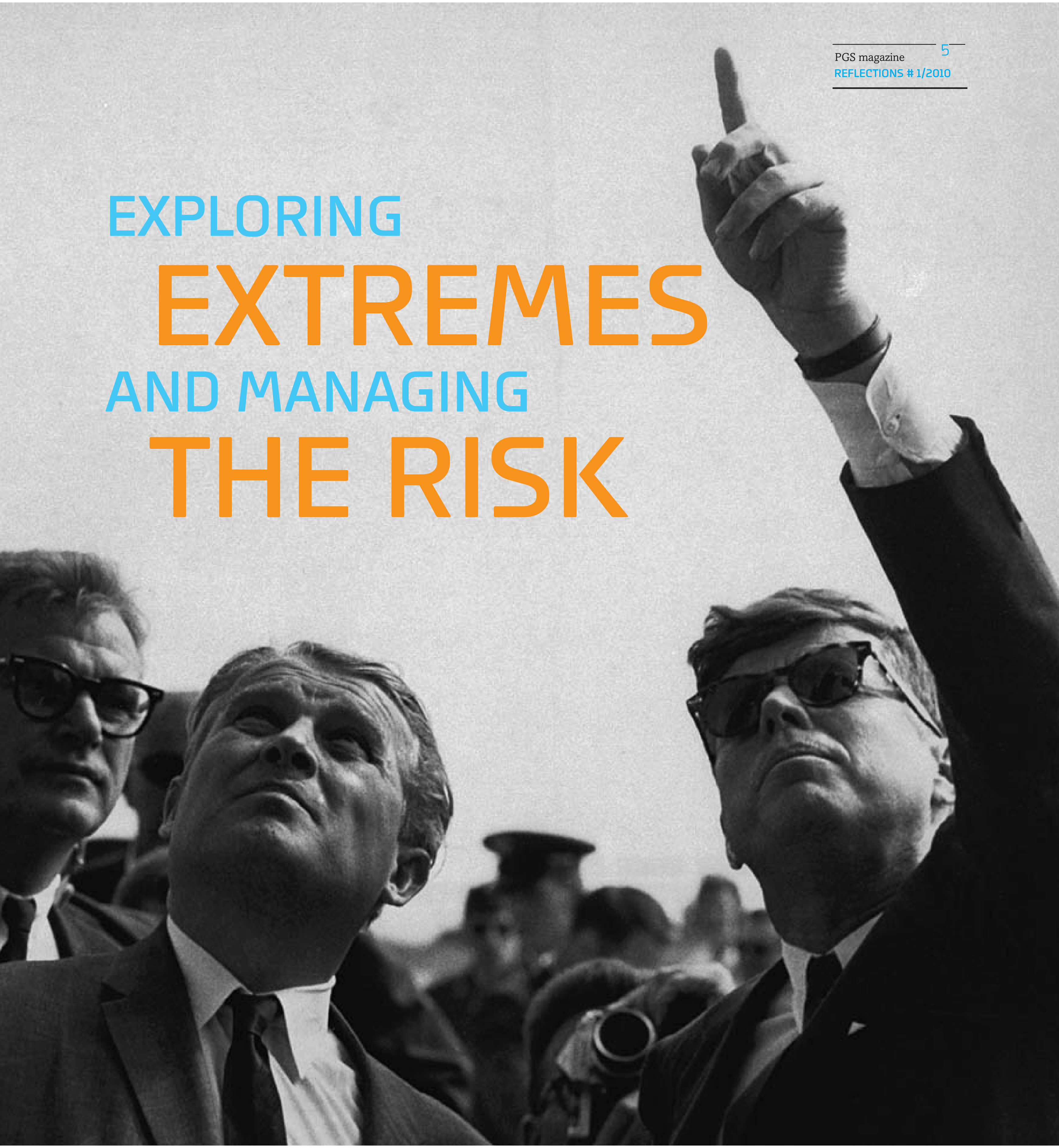
After the Russians had taken the initiative in the space race, president Kennedy formulated the mother of all technological visions at Rice University Houston, Texas on September 12, 1962: “We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win….”

Kennedy was assassinated on November 22, 1963, and fulfilling his vision immediately became a national agenda. The goal was achieved on July 20, 1969. Forty years later, NASA still carries out manned space missions and the International Space Station is watching us from above, 24/7.

But what has space exploration taught us about our planet? What does it take to explore the extremities of space and handle the risks and danger involved? And most important: what are the lessons learned from more than sixty years of space research and development?

To find out, we met Dr. Mike Hawes, NASA Associate Administrator of Independent Program and Cost Evaluation and Christer Fuglesang, a former European Space Agency astronaut and now Head of Science and Application at the Directorate of Human Spaceflight and Exploration (part of the European Space Research and Technology Centre). Hawes and Fuglesang are both born in the fifties and they are still committed to the art of exploring the extremes.

EXPLORING EXTREMES AND MANAGING THE RISK



Dr. Mike Hawes

LESSONS FROM THE SPACE RACE

AUTHOR: STEIN ARNE NISTAD PHOTO: NASA

Mike Hawes has climbed almost every rung at NASA, and experienced successes and accidents along the way. He landed Skylab safely and was vital to the work on the International Space Station. Now he is responsible for providing objective studies and analyses to support policy, program, and budget decisions by the NASA administration.

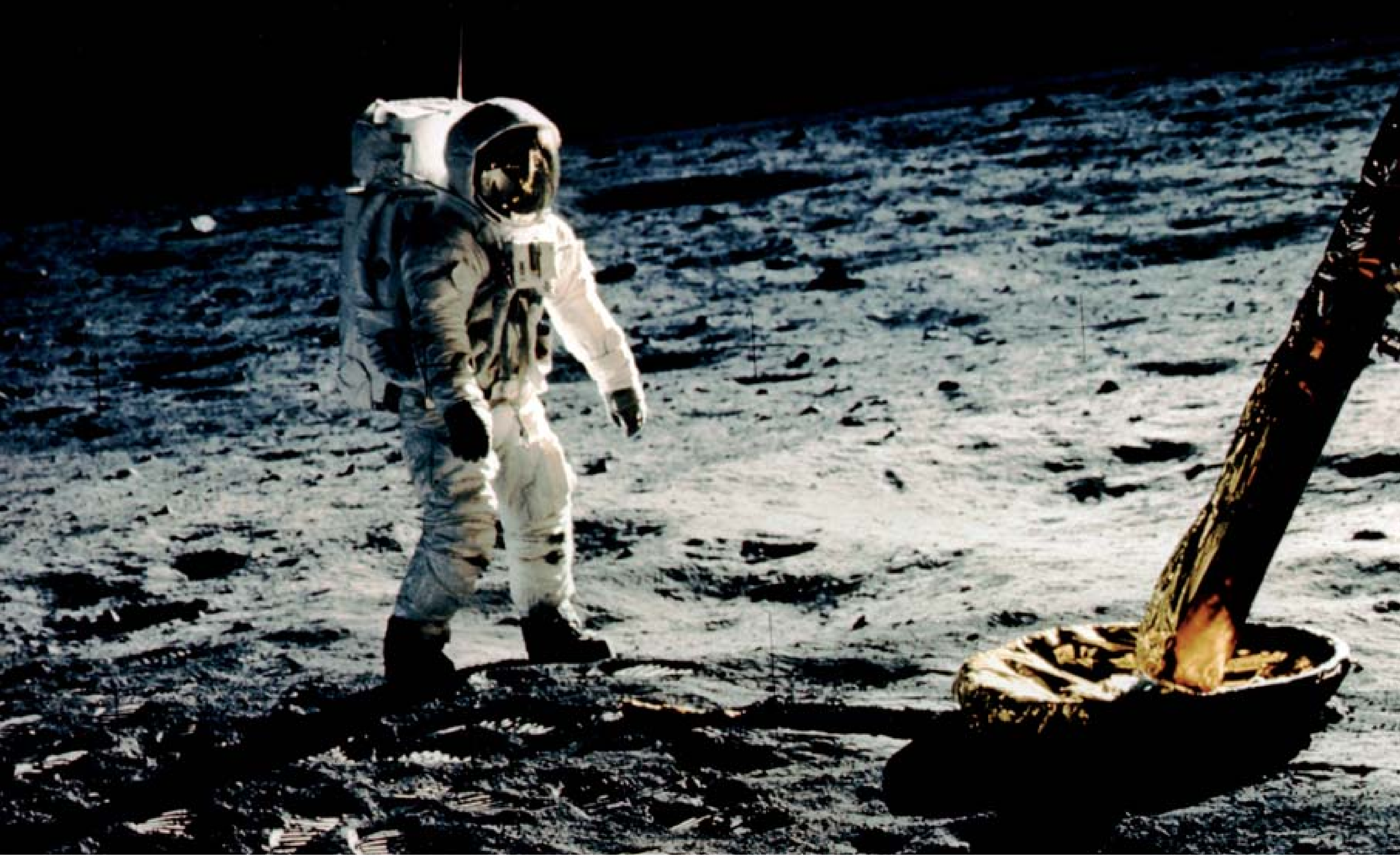
Dr. W. Michael Hawes currently serves as the Associate Administrator of the Office of Independent Cost and Program Evaluation at NASA.

We met Dr. Hawes at NASA headquarters in Washington DC. Born in 1956, he was thirteen when the moon landings took place. Like teens around the world, he sat up late following the drama, waiting to see the first human being step onto the moon. From that moment he was determined to work on the space program. But it was a brochure – recently re-discovered among his old high school memorabilia – entitled "So you want to be a rocket scientist" that made him realize his dream was a realistic possibility. Hawes graduated as an aerospace engineer and his first job was at NASA's space center in Houston. From there he has worked his way upward to his current position as Administrator for Independent Program and Cost Evaluation.

A Small Step

We start with the moon landing. Dr. Hawes tells how the first major NASA accident in 1967 made a profound impression upon him, even though he was only 11 years old. Three astronauts died after a disastrous fire in an Apollo spacecraft during practice on the ground. After the accident, everyone doubted whether NASA could manage to put a man on the moon during the sixties. However, 909 days and five space missions later they did just that. It involved an insane pace. When the accident happened, no Apollo spacecraft had even been into space. Every nut and bolt had to be tested. The first mission took place more than a year after the accident. During a period of 282 days NASA launched Apollo 7, 8, 9 and 10, and achieved Kennedy's goal when the Apollo 11 landing craft 'Eagle' touched down in the Sea of Tranquility on July 20, 1969.

It would not have been possible today for several reasons, says Hawes. "Firstly, the willingness to take risks is much lower today. The risk level and margins for the



The space race began with the Soviet launch of Sputnik 1 in 1957 and ended with detente and the Apollo-Soyuz joint mission in 1975. It sparked unprecedented increases in spending on education and pure research.

Apollo program would not be accepted. Moreover, the complexity and bureaucracy today is much more difficult to handle. The pace of the old days would be impossible to achieve. We know a lot more now and have to take into account many factors they didn't know about back in the sixties."

A Runaway Space Station

Mike Hawes knows what he's talking about. His first major task was providing critical support to the project that made the first "controlled" Skylab re-entry into the atmosphere. "The problem with Skylab was that we didn't have the knowledge to understand that the re-entry would happen earlier than we expected," admits Hawes. NASA knew that Skylab's orbit would decline, therefore two engine firings were planned to nudge it into a higher orbit. The second was not conducted, due to excessive vibrations on the Skylab. In addition the Space Shuttle was in development which meant new plans. These involved using the shuttle to connect a rocket module to Skylab. The new module could either push the station to a higher orbit, or steer it into a controlled return to Earth. However, the Space Shuttle program was delayed and there was also a peak in the solar cycle.

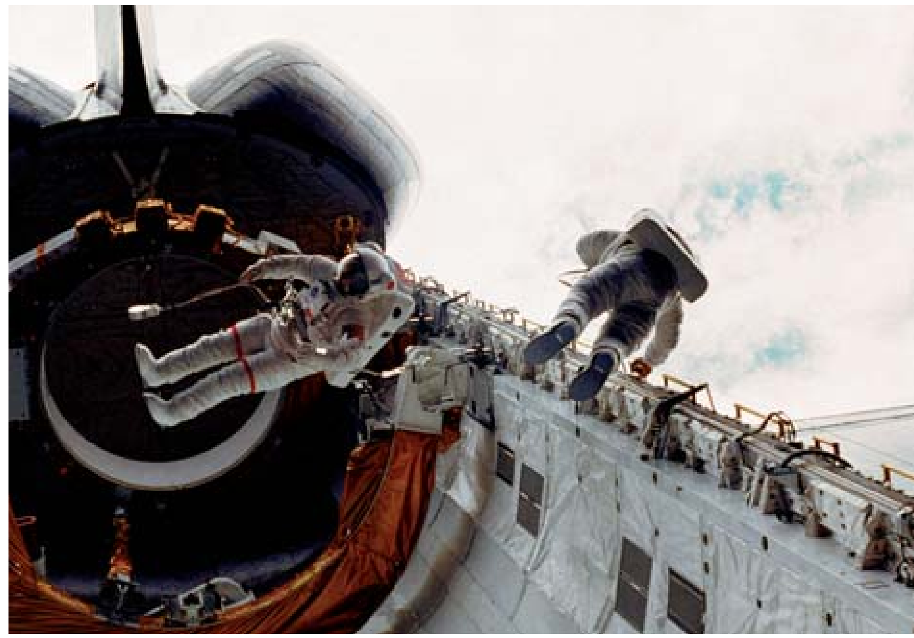
"We underestimated the impact of the sun's cycle which peaks every twelfth year, heating up the atmosphere and making it swell outward. This slowed down Skylab, making it fall even faster towards the Earth. We literally had a runaway space station on our hands," says Hawes.

Hawes' team had to force Skylab into a low-risk return path. They began mapping possible scenarios and paths, analyzing the risk of damage to people and property in order to define the low-risk paths. The problem was that no traditional rocket engines were available to deflect the station's re-entry. The solution was to make Skylab rotate by using its positioning rockets. "The rotation led to a kind of controlled retardation that brought Skylab into one of the optimal paths," says Hawes, "It burned up over the Pacific while some parts fell down in Australia. Therefore, we succeeded; although we never planned that Skylab would end its days like that!"

Train As You Fly, and Fly As You Train!

Today, NASA's main philosophy when it comes to dealing with risk is embedded in the statement 'Train as you fly, and fly as you train'. "The point is that we have to be able to handle everything that can happen," says Hawes, "Therefore we do tests, simulations and reviews to avoid failure. We try not to distinguish between simulations and missions. An error in a simulator is, in principle, just as serious as one during a journey. It's about the ability to tackle all challenges and daring to face up to

Some of the engineers foresaw the accident. Their objections were ignored and filtered out by their organization. The consequences were fatal. ❝



Challenger broke apart 73 seconds after the launch of its tenth mission in 1986.

mistakes, no matter how malicious and difficult situations created by the instructors are. We train in giving honest and accurate feedback. We debrief and review what happened and, critically, why and how it could have been avoided. Despite training and reviews, errors still happen and two Space Shuttles have been lost."

Challenger

The first Space Shuttle launch was an almost unfeasible task. All components were tested separately, but a complete system test could not be implemented without a manned mission.

The first missions went well. Then Challenger exploded in 1986. The technical reasons for the disaster were pretty easy to eliminate. Nevertheless, the entire concept was reviewed. "The accident gave us a new perspective and new insight. We realized that a large number of components had to be changed before we could be confident that the ferries would fly safely," explains Hawes. It took NASA over three years to get the shuttle operational again. Far more challenging than the technical causes of the accident were the organizational issues. Some of the engineers in the company that produced the solid rocket foresaw the accident. They claimed that if the shuttle was launched under prevailing weather conditions with low temperatures it might explode. Their objections were ignored and filtered out by their organization, and the information never reached NASA. The consequences were fatal.

Columbia

When the Colombia shuttle disintegrated over Texas, the reasons for the disaster were far more complicated. One problem was that NASA lacked efficient control of its parallel projects. The investigation discovered that project integration challenges and issues were not handled satisfactorily. The core problem was the integration of sub-projects, not the sub-projects themselves. The second problem was that NASA engineers had simply misunderstood important physics. The cause of the accident was a piece of foam that fell off the large fuel tank during launch, damaging the shuttle's wing. Foam had spun off before without causing damage. Experts assumed that this foam had approximately the same speed as the Space Shuttle when it hit. However, it turns out that the foam was almost instantaneously frozen in the air stream. Which meant that the collision didn't occur between two objects with approximately equal speed. At the point of contact, the foam had zero velocity and was hit by the Space Shuttle speeding at 1500-2000 km/h. Tiles on the shuttle's wing were cracked or knocked loose, leaving it unable to withstand the heat when it re-entered the Earth's atmosphere.

Open and Transparent
Since the Challenger and Columbia accidents, NASA has increasingly focused on reducing risk and avoiding incidents. It has established a doctrine of 'Listen to the hardware'. "If something behaves differently today than yesterday, there must be a cause," says Hawes, "When a discrepancy occurs we are committed to finding the cause. If not, it can lead to serious accidents."

Information flow was also a contributing factor in the Challenger and Columbia accidents. Information was withheld or unable to flow through the organization. NASA has introduced radical changes to maintain critical information flows, including redundant organizational reporting paths for critical information. Staff should always be able to communicate their concerns, and if necessary bypass the normal organizational lines. Sanctions are completely banned. If someone communicates a concern, regardless of the cause, or how unpopular or irrelevant it might be, they can do it without any risk of losing their job or reputation. "Every concern is reviewed," says Dr Hawes, "However, the success of a review is entirely dependent on a knowledgeable and open review leader. The leader has to have the knowledge to ask the right questions, extract information and dig deep to unveil the concern."

Rescue Window Upon Launch
NASA has also changed its Space Shuttle launch strategy. In the old days there was no way to save astronauts if something unforeseen should happen in space. Today missions are launched in a time window that allows NASA to rescue astronauts from space. It can either be done from a Space Shuttle or from the International Space Station. The Space Station is equipped with plentiful supplies, so a shuttle crew can stay there for some time before another Space Shuttle or a Russian spacecraft rescues them. The key is to have spacecraft on the ground and ready to launch within a defined timeframe.

International Cooperation
Dr. Mike Hawes has been responsible for the development of the International Space Station. "For those of us who grew up during the Cold War, it seemed almost absurd to launch a partnership with Russia," he says. "The first time I traveled to Russia, it was almost surreal. But we quickly got used to it. The International Space Station is a global project involving the US, European nations, Japan, Canada and Russia. Nevertheless, cooperation with the Russians provides the greatest challenges, due to different approaches to solving or defining a problem."

One example is spacecraft windows. Whereas NASA uses few and small windows because they are so challenging to build and protect, the Russians have a totally different approach. They consider it natural for people to have windows and therefore make many of them, despite the difficulty. Another example is pressure testing: do you get the same result if you pressurize a spacecraft from the inside and measure how much is leaking out (the US method), as when you measure the capsule leakage under pressure in a vacuum chamber (the Russian method)? According to Hawes, the upside of this is that when the partners understand the different approaches they also learn more and are able to challenge each other's opinions.

"The collaboration has to move forward regardless of political currents and conflicts," says Dr Hawes. "The astronauts are up there and have to be supported whatever is happening on earth. You can say that the International Space Station is a truly global project!"

Every concern is reviewed. The leader has to have the knowledge to ask the right questions, extract information and dig deep to unveil the concern. "

MAJOR FATAL EVENTS INVOLVING NASA ASTRONAUTS

January 27, 1967:
Three astronauts killed at Cape Kennedy in a training exercise for the Apollo 1 mission. The crew died as a result of a fire in the spacecraft cabin.

January 28, 1986:
Seven astronauts killed when Space Shuttle Challenger (STS-51L) exploded 73 seconds after takeoff. Cold temperatures contributed to a launch failure on one of the solid rocket motors. As a result, hot exhaust gases escaped, creating a major structural failure in the launch vehicle.

February 11, 2003:
Space Shuttle Columbia (STS-107) exploded over North East Texas. The spacecraft was at an altitude of about 203,000 feet (approx. 39 mi. or 63 km) and traveling at about mach 18 (roughly 12,500 mph or 20,000 km/h). Foam hitting the wing during launch caused the disaster.

Christer Fuglesang:

A VIEW FROM THE TOP

AUTHOR: STEIN ARNE NISTAD PHOTO: NASA

Some people realize their dreams. Christer Fuglesang is the only Nordic astronaut who has visited space. He has participated in two Space Shuttle missions and walked weightless in space for more than 30 hours. Floating between earth and eternity, his sole reference point was a 100-meter-long space station. He knows what extreme exploration is all about.

We met Christer Fuglesang in Amsterdam at the ESA (European Space Agency) and ESTEC (European Space Research and Technology Centre) in Noordwijk. His full name is Arne Christer. It fits: Arne is Old Norse and means "eagle" or "eagle ruler". It brings to mind both free flight and the Eagle, the first spacecraft to be landed on the moon.

Physics at CERN

Christer Fuglesang had a long career before he signed up as an astronaut. He received an MSc in engineering physics from the Royal Institute of Technology (KTH), Stockholm in 1981, a Doctorate in experimental particle physics in 1987 and became a Docent in particle physics at the University of Stockholm in 1991. Fuglesang worked at CERN in Geneva on the UA5 experiment, which studied proton-antiproton collisions and the CPLEAR experiment. By 1989, he was a Senior Fellow of CERN.

When ESA began recruiting astronauts Fuglesang decided to apply. Two years later, in May 1992, he was selected to join the European Astronaut Corps based at the European Astronaut Centre (EAC) in Cologne, Germany. He underwent long periods of training both in Russia and the United States, but he says the most difficult thing was learning Russian. In February 2002, he was assigned as a Mission Specialist on the STS-116 Space Shuttle mission to the International Space Station. The mission was launched on December 9, 2006. His second flight, the STS-128 Space Shuttle mission to the International Space Station, was launched on August 29, 2009.

Fear is Irrelevant

What makes a man volunteer to occupy a vehicle consisting primarily of explosives providing 500 million horsepower? Fear is irrelevant, according to Fuglesang: "Fear arises from feelings and not logical thinking. In the Space Shuttle, I did not think about risk. We were so well trained, had been through all the procedures, and trusted both the shuttle and the organization."

Objectively, the risk of space travel is significant. The Space Shuttle's casualty statistic is currently around 1/100. That's about the same as the risk involved in a Mount Everest expedition, but much lower than for K2. Moreover, Space Shuttles are constantly being improved to reduce risk. At the time of the Challenger accident, in which evidence suggests that

Among other things, minimizing risk involves creating an open organizational culture where employees can communicate safely. But economics can also trigger accidents. “

the astronauts survived until the shuttle crashed into the sea, there were no rescue systems. Now there are parachute systems that provide at least a theoretical possibility of escape if an accident should happen.

Systemic Risks

“With risk and risk management, it is certainly important to rely on the organization,” says Fuglesang. The Challenger investigation revealed that junior engineers at a supplier of the booster rockets had tried to warn of a possible accident if the shuttle was launched at temperatures close to zero centigrade. Managers ignored the information and the fatal accident occurred. Among other things, minimizing risk involves creating an open organizational culture where employees can communicate safely.

But economics may also trigger accidents. The first Ariane rocket failed when it went off course and had to self-destruct. The analysis later showed that the problem would have been discovered if simulations had been carried out as planned. But they were canceled due to budget and time issues. As if this were not enough, the first Ariane rocket was carrying a payload, something that is quite unusual for a test flight. The financial consequences of canceling the simulations were therefore astronomical.

Cultural Diversity

The International Space Station is a challenging project in many ways, says Fuglesang, “Many countries with different technology and cultures participate to demonstrate their capabilities and willingness. Cultural and organizational differences become visible. Take, for example, American and Russian organizational structures. The Russian organization is relatively small, with little hierarchy and bureaucracy. It includes people who are experts in several fields. This means that if a problem arises, they can resolve it quickly and effectively if the right people are present. If the correct expert is not available, however, it is difficult to get things done.”

According to Fuglesang, the U.S. organization is almost exactly the opposite. It is far more formal, bureaucratic, and focused on documenting everything. This means that one does not rely on single experts because information is documented and available. Its disadvantage is that the bureaucracy and documentation takes time. The U.S. rules for export of technology also made collaboration with the Americans much harder than with the Russians, simply because of the complex regulatory framework. After 9.11, the regulations have become even more demanding and heavy going.

Space Provides Insight and Value

Christer Fuglesang is a true believer in space exploration, and the ability of its bewildering scope to give us insight and development in other fields. He describes it as an expanding circle: “When we discover

NASA and ESA veteran Christer Fuglesang has logged over 641 hours in space, including five extra-vehicular activities (spacewalks) totaling 31 hours and 54 minutes.

new answers, the circle is slightly expanded, but at the same time we increase the interface to what we do not know."

The insight and the technology developed through the space program cover everything from crop monitoring to communication and positioning. Some of the experiments carried out on earth are much easier to do in a weightless state, which means the space stations are invaluable.

Space, says Fuglesang, allows us to look inwards and outwards: "We constantly get new information about our planet. And we look beyond to search for new planets, extraterrestrial life and the origins of the universe. Space missions create understanding and order. And I am convinced that mankind will colonize the solar system, utilize its resources and live on other planets. I believe we will colonize the moon, and Mars relatively soon, and other planets' moons eventually."

Mission to Mars

Fuglesang is involved in a research project simulating a future trip to Mars. A group of astronauts inhabit a "spaceship" where everything they use has to be in place from the start or be recycled. If something breaks, they must fix it. One of the most exciting challenges is simulating the time delay in mission control communication. Voice messages were only used for the first month, when the "ship" was still close to Earth. After that only written info could be exchanged, like email. At the furthest point, a message will take 20 minutes to arrive, and the minimum time for an answer to a question will be 40 minutes, more like an email chain than a dialog. Remote and alone, sealed in a building in Russia, they rehearse the challenges that arise on their journey.

Walking in Space

Then we talk about walking in space. "It's like diving, but without water," says Fuglesang, "There are no references to up or down, and no resistance. A movement started is, in principle, going to last forever."

The view from space gives tremendous perspective. Each orbit of the Earth takes 90 minutes; at a speed of 28 000 km/h you experience a sunrise, a sunset and a night. Earth is very small from space. You see no borders or countries. Only a globe surrounded by a thin membrane, an atmosphere that human life is totally dependent on. Space begins at an altitude of 100 km. The Space Station orbits at an altitude between 420 and 330 km. "We have to care for and manage our fragile planet," says Fuglesang, "It is no coincidence that one of the world's most famous photos is the earth rising over the moon, as a small blue ball far away. I got the same feeling when I hovered outside the space station. Earth is a vulnerable little planet surrounded by a thin life-giving atmosphere. I consider space exploration and the International Space Station as one of the human endeavors that unites nations and puts our sights on a higher goal," he concludes.

RISKY BUSINESS

PERSONAL RISK

While industry strives to mitigate or avoid hazards, recreational risk is a growing business. Some suited and safe office rats and feisty field workers transform into "adrenaline junkies" when they leave work: dangling from hang gliders, diving the oceans, climbing peaks and parachuting off skyscrapers. Psychologists say that sensation seeking is in our genes. It is also age related. From 16 to 60, our quota of sensation-seeking brain receptors is halved. Still, extreme sport is for the minority, the most common sensation seeking activities are driving and romance.

Does this encourage or prevent safe thinking on the job? It's about balance, say the experts, between today's gratifications and tomorrow's consequences.

DIVING:
TRAINING AND ATTITUDE

Sensation seeking doesn't have to be high risk. Modern diving equipment is easy to use and reliable, and people all over the world enjoy scuba diving safely. However, it does entail risks – from the scary arterial air embolism and nitrogen narcosis to the mundane reality of drowning. Reckless behavior can be risky, however, with proper training, preparation and a responsible attitude, scuba diving is fairly safe.

RISK-O-METER

low med. high

CLIMBING: CONTINGENCY PLANNING

More than five miles high, K2 is the most feared mountain on Earth. Statistically, for every four people who successfully climb it there will be one fatality. This is not for the average climber. Despite the statistics, K2 remains a cherished goal for the elite and those who conquer it push their physiological limits. The survivors are superb risk managers who plan for all the contingencies of terrain, weather and competency at extreme altitude. As mountaineering guru Sir Chris Bonnington says, "Risks are only relevant in their context and need to be kept specific and in perspective."

RISK-O-METER

low med. high

BASEJUMPING: COURAGE OR CRAZY?

Jumping BASE —from Buildings, Antennae, Spans and Earth (cliffs) — is one of the most dangerous extreme sports, with over 150 fatalities since the sport began in 1981 and fifteen this year so far. Falling at around 190 km/h, usually from less than 600 meters, the ground is around 11 seconds away. Fans say survival depends on daring and split-second timing. Sensation seeking does not get crazier than this. Beware: these individuals may indulge in other risk-prone behavior!

RISK-O-METER

low med. high

OCEAN RACING: TEAMWORK

Ocean Racing can be hazardous and accidents do happen. Round-the-world yacht racers, who brave some of the globe's most treacherous weather and waters, risk injury and broken bones, as well as losing crew members, collision, and piracy. The Volvo Ocean Race uses two security agencies to handle risks onshore and offshore. Insurance companies see hurricanes and the quantity and quality of the crew as ocean racing's main risk factors. The prospect of running into trouble in a sound boat with a good crew is slight. Competence and teamwork are the keys to both success and safety.

RISK-O-METER

low med. high

REVEALING THE INNER LIFE OF RESERVOIRS

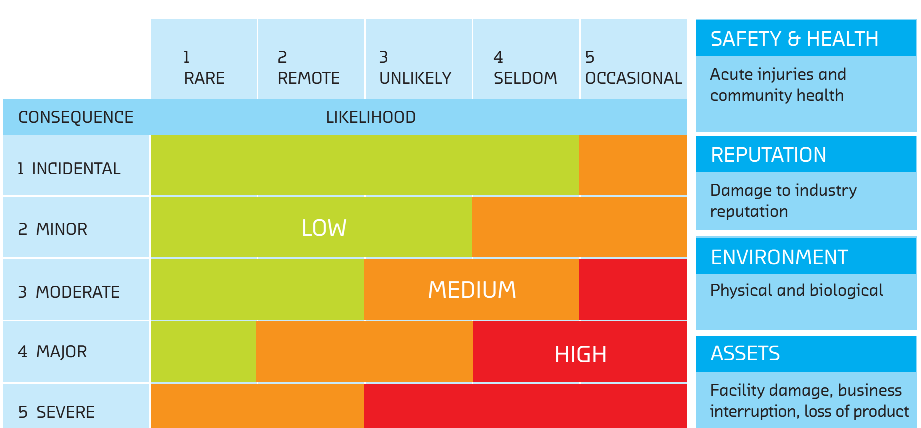
Permanent seismic monitoring has enormous potential, but the industry has still not adopted it on a grand scale. A new PGS development based on fiber-optics might be the game changer.

AUTHOR: KEVIN REEDER

Oil and gas companies spend years and millions of dollars looking for new fields, gaining exploration and production licenses and bringing the payload on-stream. Yet, more than half of the oil originally in place in the reservoir is left behind after production is has shut down. One of the challenges facing asset managers seeking to optimize the life of a field is that reservoirs vary and can be difficult to model. A further complexity is that they change after production starts.

It is often said that the cheapest oil to find is hidden in reservoirs you have already found. The cost of production is lower, and so is discovery risk as you are looking in a reservoir where hydrocarbons are known to exist.

RISK MATRIX OF FMECA
FAILURE MODE EFFECTS AND CRITICAL ANALYSIS



Det Norske Veritas (DNV) qualifies new technology using testing procedure RP-203, based on a matrix (Fig 1) containing various failure scenarios ranked by severity and likelihood. Accelerated ageing techniques are employed and exposure to variations in temperature and pressure.

4D seismic is directed at this kind of exploration. A program of 4D seismic surveys is repeated at regular intervals, to show how conditions are changing, and to help maintain an accurate model of the reservoir. Finding the correct recording system will depend on the scale of the alterations expected, the sensitivity of the systems needed to measure them, and the frequency of the repetitions.

Where the repeat rate is low, and the changes can be seen on p-waves, then towed seismic probably offers the best deal. If you want to monitor conditions frequently, or your reservoir is complex and you need illumination from a variety of angles and offsets, cost becomes a significant factor. It then becomes worthwhile to install sensors permanently on the seabed. This also enables the use of s-waves.

This kind of permanent reservoir monitoring was tried as early as 2003 in the North Sea. BP estimates the potential increase due to reservoir monitoring at Valhall to around 60 million barrels. Unfortunately,

Testing durability: Although many of the fiber-optic components used in the OptoSeis assemblies are common in the telecommunications industry, the particular circumstances of operating within a seabed seismic monitoring system required thorough investigation.

the first generation of installations, using electrical systems were rather less than permanent. The salty, pressurized environment of the seabed is not the best site for sensitive electronics.

How Long is Life-of-Field?
The answer to the problems of permanence lies in optical technology. Fiber-optic systems rely on the transmission of light through a thin, flexible, transparent fiber that acts as a waveguide, or "light pipe". Signal loss is lower than traditional cables and they are immune to electromagnetic interference.

Applied to 4D monitoring they could combine the promises of better reservoir data, and recovery, along with better return on investment. But is it possible to create geophysical sensor technology that is similarly free of electronic parts?

PGS has come up with an answer in OptoSeis. The system has no in-sea electronics. Instead, lasers transmit light down through fiber optic cable to hydrophones and accelerometers made of glass-fiber and silica. There are no corrosion-prone electronic components in the sensor stations. The "electronic brains" are located at the surface, on a platform or FPSO.

PGS has been testing and developing the technology since 2003 with good results. Functionality is assured — but what about durability? How can you evaluate the lifetime of a new system before it has been deployed? Det Norske Veritas (DNV) has granted the system a DNV-RP-203 reliability certification, signaling a minimum 20-year life span. All the components have been DNV certified for deep water operations down to 3000m. Materials, components, sub-assemblies and modules have each undergone a rigorous procedure that assesses the system's ability to perform as expected in the extreme temperatures and pressures encountered on the seabed.

Offshore & Onshore
The timing of the certification is significant. OptoSeis has already grabbed the attention of oil industry giants Petrobras and Shell. Initial installation on Petrobras' Jubarte field in the Campos basin offshore Brazil will cover 9 km^2, in depths down to 1500m meters. If the pilot is successful both operationally and from a geophysical point of view, then the project may grow to cover a larger portion of the field. This would represent a significant step forward in the use of 4D4C seismic to map the flow of fluids in Brazil's deepwater reservoirs.

With no electronics in its sensors, OptoSeis is lightweight, making the logistics of transporting the equipment far easier. Shell spotted this potential and asked PGS to develop a similar system for use on land. Onshore, this will enable scalability far beyond what is currently available and lower weight will help overcome field deployment challenges that are common when raising the number of recording channels. Given that most of the technology used in OptoSeis is already tried and tested, development risk is rated as relatively low and early deployment is anticipated. Shell will have exclusive use of the new technology for an initial period.

Put it in Your Tool Kit
With oil and gas getting harder to find, it's becoming ever more important to harvest the resources at hand as efficiently as possible. Seismic data is an essential tool for achieving that. Will OptoSeis overtake GeoStreamer as the preferred acquisition system worldwide? Probably not, but if you are seeking a reliable alternative for high quality, high frequency 4D seismic, for new or mature fields, this should be at the top of your list.

Portrait interview

By Pamela Risan

EIVIND FROMYR

DOWN TO EARTH

AUTHOR: PAMELA RISAN PHOTO: LINDA CARTRIDGE

Clearly it is the oil company who carries the risk in offshore exploration, but how much responsibility hangs on the contractor? In the course of his career PGS Chief Geophysicist Eivind Fromyr has seen the balance change as oil companies hone in on their core competence. The role of seismic can still shift a few more notches closer to the well, he says.

EIVIND FROMYR

Eivind Fromyr. Norwegian-born Chief Geophysicist at PGS. He was a co-founder of Read Well Services and holds a BSc Economics, and MSc in both Physics and Cybernetics. Eivind has more than 25 years experience of the oilfield service industry. He recently relocated with his family to the UK.

"We cannot change the Earth, and there are basically just two aspects of seismic we can improve on," says Eivind Fromyr, "source receiver combinations that address illumination and penetration, and more bandwidth to get more accurate models."

Fromyr is Chief Geophysicist. He was brought into PGS in 1995 to drive developments within 4C seismic. With experience from Geco and Read Well Services, he soon became the company's technology interface with customers informing the market about PGS technology and influencing PGS research and development to mirror market trends. He combines a profound understanding of the minutiae of subsurface imaging with an ability to open up its secrets in a way that is accessible for the uninitiated and engaging for the more knowledgeable.

If cost wasn't an issue – how do you think seismic would evolve in the future? "The greatest remaining limitation in geophysics today is probably our ability to process data. The tools simply aren't good enough, even the best ones. We need to move toward less assumption and more data. And we need to let the data speak for itself. An emerging technology here is Full Waveform Inversion (FWI)," he elaborates.

"In the future, we will take field data and put it straight into powerful computers and earth models will come out the other end. That isn't a new idea. Albert Tarantola was talking about it in the late 1970's at Stanford but it's only recently that we have been in a position to realistically do it."

"Achieving this goal," he points out, "requires not just better computers and better algorithms, it is dependent on better input data."

"The key challenge now is acquisition geometry. Though onshore acquisition has a greater variety of neighborhood noise to contend with, on land the geometry is easier to tweak. "

"In the early eighties, we calculated how long it would take to invert a typical 3D survey on the then state of the art super-computers. Though the surveys were not that big then, the answer was hundreds of years. So it is really exciting to watch what PGS is doing right now, moving streamers and sources towards ghost free recording. Because what we were missing then, and have been for 40 years, is the low frequency data required to make FWI possible," Fromyr says.

Super Models

Seismic companies spend a lot of their time talking about time and depth processing, but really what the oil companies are after is the earth model. Are contractors too focused the processing to see the big picture?

"Well we haven't had the computing power and we haven't had the right data to focus on anything else. What this industry needs is more low frequencies. We've sorted the streamer, now we need to get the source, and then we need to get the processing right," maintains Fromyr.

"I think FWI will be a commercial reality within 5 years. The industry is already doing it semi-commercially now. The De Soto Canyon GeoStreamer FWI, from the Gulf of Mexico, shows very encouraging results. Maturing and optimizing the process will probably take another three to five years."

What implications does that have for future workflows and recruitment? "Right now we need real experts to do advanced processing and inversion, and in the short term we will need highly qualified people, even in the production phase. But long term it will become more automated and there will be less data interaction. Then geophysicists can concentrate on deriving rock and fluid properties, not just picking velocities and managing the mechanics of data throughput. Our goal should be to deliver data directly from the computer center to the desk of the reservoir geologist," he says.

Will that change the relationship we currently have with our clients the oil and gas companies? "That will mean getting closer to the asset, closer to well planning, which is the core competence of the oil companies. They should be pushing us for a more finished product, ready for use. Really that would be the logical continuation of the trend that has been ongoing as long as I have been in this business. The oil companies have narrowed down their area of core competence and pushed more responsibility for the peripheral areas over to the geophysical contractors. This is the next step," Fromyr predicts.

Investing and Advising

Seismic data remains one of the most significant risk reduction tools for oil exploration but it is regarded more as a commodity than a core competence for exploration and production companies. Thirty years ago, oil companies employed seismic experts to design and manage the detail of geophysical acquisition. In the eighties they began to pare that G&G role down to the core. In the process, a lot of responsibility was pushed onto the contractors. Research, development and acquisition were outsourced. But results still matter.

While the results of seismic acquisition are essential to success, the acquisition process is no longer seen that way. It's the data and what it's used for that is interesting. Seismic data is delivered to the oil company interpreters, who advise on make or break million dollar decisions.

Seismic is used by oil companies to calibrate and reduce financial, exploration and operational exposure. The biggest challenge for our clients is to find and drill prospects with the lowest possible risk. The cost of drilling can amount to 50-250 million dollars but it is nothing compared to failing to find a reservoir.

Are oil companies becoming a bit like investment banks – making decisions based on reports and advice? Does this color how they view and manage risk?

"Oil and gas companies generally focus on key processes. They limit their G&G staff to where the value decisions are made. Over time they have narrowed down the expertise they require to an extremely specialized skills set. There are of course a few anomalies to that but those will probably also disappear over time. Geophysical data is largely seen as a commodity . But they haven't commoditized interpretation. That will remain their core G&G workflow. Increasingly, geophysical companies like PGS will be expected to supply a product that can go straight to the interpretation team. Full Waveform Inversion is key to that product," says Fromyr.

What about the marine acquisition process? It has hardly changed for forty years. In the future will we still be using a boat to pull a source and cables filled with sensors through the water?

"The key challenge now is acquisition geometry. Though onshore acquisition has a greater variety of neighborhood noise to contend with, on land the geometry is easier to tweak. The reason is that source and receivers are decoupled. That makes it relatively simple to arrange the optimal combination to fit the terrain and the geology! We can obviously do it with seabed sensors. Now we can do the same with towed streamers. PGS pioneered multi-azimuth (MAZ) acquisition on the Varg field. Then wide-azimuth (WAZ) introduced the concept of independent source vessels, and it became possible to tailor the geometry at sea too," he points out.

Worth its Salt

It is more expensive but is it worth the extra cost? "Around $1 billion has been invested so far, in the Gulf of Mexico and in West Africa. That amounts to 100,000 km² of seismic over a four year period. The trigger was the images from BP's Mad Dog survey. Today, most people would be very reluctant to drill a well in a complex structure without wide azimuth seismic."

What was the tipping point between the dawning of this new technology and its acceptance. How clear does the risk reduction have to be for that to happen?

"I think it was very simple in this case. BP did it and it worked. That changed the balance of the argument from how much will this increase the cost of the data, to when can we have it and how cheaply can you provide it? Once an oil company had proved that the science worked, the market moved the efficiency question back to the contractors, to push down prices."

"It requires oil company buy-in," he maintains. "Contractors do not have the financial strength to prove geophysics on such a scale. To build the body of scientific evidence probably requires acquisition of hundreds of square kilometer of data. Though on a smaller scale that is what we did with the GeoStreamer, in general, we need partners to establish and prove the technology."

Managing the Mix

"Addressing geometry has led to some new ideas about how to do seismic acquisition, like blended acquisition," Fromyr explains. "Berkhout and the Delft group have applied a theoretical framework to this idea, but basically it is about better utilization of space and time."

"Currently seismic is a serial process. First we need silence, then we send out a signal and we record the reflected data. Then we repeat the process. The shot point interval permits separation of the end of one signal and the start of the next. But is it really necessary to wait, or could we simply pick out the relevant signals by tuning the receiver? In land seismic simultaneous sources are now standard, and as long as the various source contributions can be separated at the receiver, noise is not a problem. What you need is a signal to noise budget, in other words, it is not so important where the noise is coming from, as long as the overall background sound is within an acceptable limit and it doesn't detract from the data," says Fromyr.

"Will we still be towing seismic cables in another 40 years? Probably, but we will do it more effectively, with more diverse source receiver combinations to address illumination and penetration, improved bandwidth with lots more lower frequencies, and more accurate results."

The Earth won't change but we will be able to reduce a few more of the risks of the unknown.

NEED FOR SPEED

Industry pundits recently secured the PGS hyperBeam an E&P Innovation Excellence Award, why? This engineering innovation has the potential to revolutionize how exploration teams will work from now on, with enticing commercial implications.

AUTHOR: JOHN GREENWAY, OSLO

A unique combination of a unique beam migration and immersive visualization technology, this has the potential to slash months off the time from seismic survey to production. PGS hyperBeam brings processing and interpretation together in near real-time, reducing the cycle time for velocity model building from months to days, with significant implications for depth imaging of seismic data.

Many of the world's remaining large potential fields lie hidden within complex geological regimes. This is especially true in the deep waters of the Gulf of Mexico, West Africa and Brazil, where thick salt deposits play havoc with conventional seismic imaging techniques. The industry has attacked these challenges with a series of data acquisition strategies, such as Wide Azimuth (WAZ) surveying, allied with sophisticated, though increasingly expensive, depth migration solutions.

A traditional pre-stack depth migration project will use any one of countless migration algorithms, dictated by the available time and project budget. Time is money in the period between seismic survey and first oil, and depth imaging is a time consuming business. This is where PGS hyperBeam makes its mark.

"It is an unfortunate paradox with depth imaging algorithms," explains Andrew Long, PGS Geophysical Advisor, "that in order to derive a good result, we need to know quite a lot about the subsurface in the first place. Chief amongst these need-to-know elements is acoustic velocities in the various rock formations in the area."

All imaging algorithms, notably "wave equation" algorithms, demand an exceedingly accurate input velocity model of the subsurface, preferably within +/-1% of the true model, but the seismic data is typically very poor. Building the model is a painstakingly arduous, iterative process. Traditionally, it requires input from highly trained geophysicists, as well as massive computing resources.

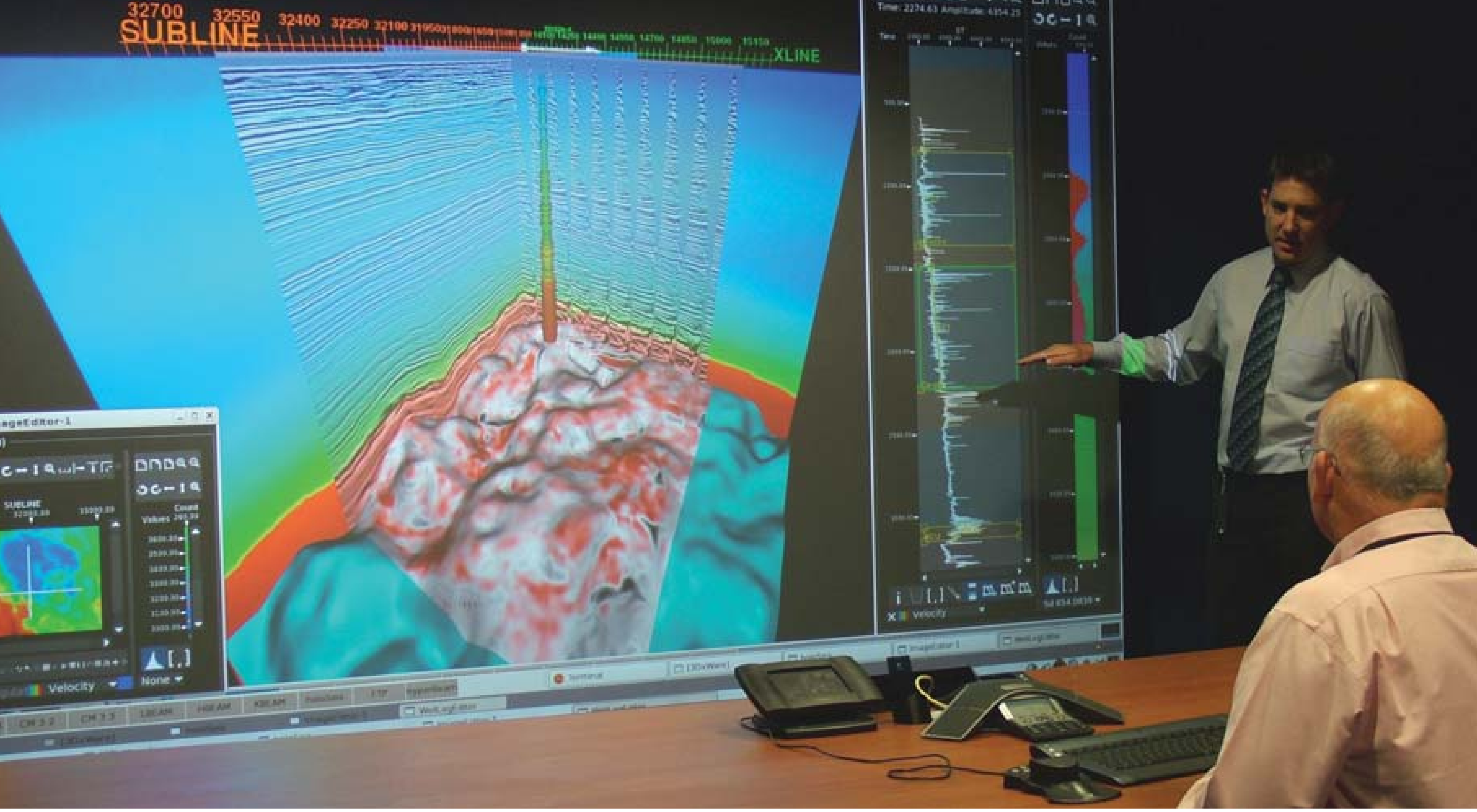
A large sub-salt depth migration project in the Gulf of Mexico typically takes more than six months to complete. Wide-azimuth acquisition, which is becoming the de-facto solution in this area, vastly increases the volume of data. The resulting wave equation depth migration can take more than a year to complete.

Model Building at Warp Speed

The PGS hyperBeam solution has solved both key challenges related to developing accurate velocity models fast – the compute intensity and the efficient integration of seismic interpretation. The PGS software engineers have melded their in-house beam algorithm and PGS holoSeis visualization technologies, to yield the PGS hyperBeam platform. Andrew Long explains, "It enables near real-time velocity model building, and near real-time migration and screening of multiple velocity model scenarios. A small PGS hyperBeam machine with only 30 PC compute nodes can turnaround 300 square kilometers in less than four minutes. The tomographic routine also runs on the same server hardware. The beauty of the holoSeis visualization platform is its ability to enable true integration of all tools into one environment. Sitting on any user's desktop, the system is fully scalable. Several vast and independent 3D volumes and attributes can be manipulated and rendered in real-time. Which means an interpreter can test literally tens of depth imaging scenarios in the time it would historically take a conventional depth imaging team to deliver only one depth imaging scenario."

Light Years Ahead

In the scenario where a project starts from scratch, with no pre-existing depth velocity model, a medium-sized project of 600 km^2



The PGS beam migration is not only dramatically faster than other depth imaging solutions, the unique two-step design of the PGS beam algorithm has yielded results that surpass alternative solutions.

could deliver a full PGS hyperBeam solution, including one pass of full 3D azimuth-offset tomographic velocity model building, in a day. Each subsequent alternative velocity model would take just a matter of minutes to yield a seismic image. With eight passes of full tomography, the entire process would take less than three days to complete. This order of savings scales to several months of reduced project turnaround for a large modern wide-azimuth project.

The PGS beam migration is not only dramatically faster than other depth imaging solutions, the unique two-step design of the PGS beam algorithm has yielded results that surpass alternative solutions. "The key is the dipscan process. Andrew elucidates, "This reviews a vast array of 3D kinematic and dynamic data attributes, and picks those components that will usefully contribute to the final seismic image. Multiple and other noise removal is included, no assumptions are made about acquisition geometry and sampling, and it handles geological dips in excess of 90 degrees, as well as multiple arrivals, unlike competing migration solutions."

Full anisotropic (VTI and TTI) imaging capabilities are also included, with immediate relevance for all narrow-azimuth (NAZ), multi-azimuth (MAZ), and wide-azimuth (WAZ) acquisition geometries; both land and marine.

The Next Generation

More thorough testing of velocity models has obvious implications for the reduction of drilling risk, and the fast ranking and analysis of drilling prospects. This flexibility can be critical in complex geological areas such as salt prone provinces, where the risks are demonstrably higher and of greater consequence.

The implications for asset managers are clear. From here on, interpreters, geologists and engineers have control of depth imaging, on their desks, working in direct partnership with depth imaging and velocity model building experts. They can review a vast array of model realizations on a daily basis. The result is better and faster identification of drilling targets. This is a new playing field for seismic depth imaging and is already making a major impact on how the industry approaches the challenge of exploration and production in some of the potentially highest impact emerging provinces.

BEAM ME UP!

Beam migration is a Kirchhoff-like PSDM technique that offers a unique seismic imaging solution which can create accurate subsurface images in complex geological environments in a matter of days instead of months. It handles multiple arrivals, steep dips, vertical transverse isotropy (VTI) and tilted transverse isotropy (TTI). Making it very well suited to application in areas with highly complex geology, such as provinces characterized by salt deposits, or other complex overburden.

WHY BROADBAND ROCKS

What is the holy grail of oil and gas company geologists seeking to find the best places to sink exploration wells? To be able to discern the physical properties of rock formations in the earth before they drill. Ideally, they would like to have quantitative information about both rock properties and fluid content of potential reservoirs.

AUTHORS: CYRILLE REISER, FOLKE ENGELMARK, ANDREW LONG

In the past, seismic images have stopped short of delivering that. Broadband data is now bringing us a step closer. In this article we look at some of the newest and most exciting advances in reliably unravel-ing the rock properties from 3D data.

Seismic uses reflected sound waves from the subsurface to give a picture of what the earth looks like deep down within the crust. These images are very successful in giving us a structural picture – we are able to see the shapes and extent of geological structures, and many other physical features such as faults, unconformities, and channeling. And broadband data dramatically improves the structural and stratigraphic resolution. This is enough to excite geophysicists, but oil and gas company geologists would like more.

Most of the easy oil, held in “simple” traps, has already been discovered. Now the oil and gas industry is moving towards more challenging areas, where we need to detect and properly image very complex reservoirs, and resolve very thin remaining hydrocarbons columns. For these reasons, reservoir geoscientists always aim for a bandwidth that is as wide as possible, to achieve a detailed interpretation and accurate reservoir characterization. GeoStreamer turns out to be the ideal solution.

Reservoirs Rock!
For a geologist, one of the first steps in understanding reservoirs within a 3D data set would be to interpret the final processed seismic image. Seismic interpretation and subsurface mapping are key steps that are extensively used in the oil and gas industry. Seismic interpretation consists of interpreting lithological boundaries on the 2D and/or 3D seismic data, within which the selected seismic horizons correspond to contacts between different types of sediments with different physical properties. These physical rock properties are the “specific acoustic impedance” generally referred to simply

as "impedance". Impedance is the most important elastic property to characterize the subsurface. Acoustic impedance is simply the product of the compressional velocity (of sound) and the density of the rock under consideration. Shear impedance is the product of shear velocity and density. The ratio of acoustic and shear velocity is an important key to unlock the lithologies, porosities and fluid content of reservoir rocks.

If seismic data contains very strong low-frequency information, and the seismic image is of high quality, it is possible to directly estimate the absolute impedance at each point on a seismic image. If this low frequency information is deficient, however, the estimated impedance values will be incorrect and so will the subsequent identification of the lithology–fluid combination.

If high frequencies are also available in the seismic bandwidth, we will in addition be able to identify thin geological strata, which could be of importance.

Absolute Rock

The identification of the absolute rock properties has significant implications for the likely success of any drilling exercise. Figure 1 illustrates the importance of low and high frequencies in forming that picture.

The top of Figure 2 shows a seismic image of a reservoir, from conventional streamer acquisition, using the standard display parameters that identify where there are impedance contrasts between overlying geological strata. An experienced seismic interpreter can infer a lot about the geological structures and the physical processes that have acted over geological time to create the vertical sequence of geological features observed in the image. However, this information will not allow us to infer what rock (or fluid) types are present.
In contrast, when the seismic volume is appropriately analyzed (bottom), a color scale is applied representing the acoustic impedance of the rocks at every point in space. Now the interpreter can begin to understand the associations between common rock types, and can begin to gain an understanding of the "petroleum system" – the possible convergence of features that may host hydrocarbons within an identifiable trapping mechanism in the subsurface. High quality broadband data further improves the result.

With the conventional streamer data, however (lower left side), the impedance values in Figure 2 are incorrect. The broadband

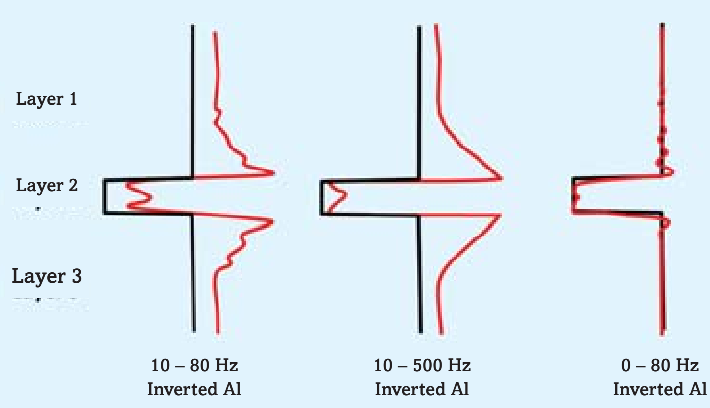


Figure 1. The black line corresponds to a schematic acoustic impedance representation of three geological strata. Layer two has been inverted for three different frequency ranges. The Acoustic Impedance model has been convolved with a Ricker wavelet corresponding to each of these frequency ranges to generate a synthetic seismic trace which was then inverted to produce the acoustic impedance traces shown in red.

Left: (10-80 Hz - conventional data) This result gives us an accurate image of the approximate layer thickness, but absolute impedance values and interface shape are incorrect.
Middle: (10-500Hz) With limitless high frequencies, the impedance boundaries are better defined but still without gaining information about absolute impedance values.
Right: (0-80 Hz) Focusing on lowest frequencies the interpretation of both the structure and the impedance value are very good.

Note: 0 to 5Hz data are derived from well information. Therefore, even though the high frequencies gave us a slightly better structural model, it is the low frequencies which give us the information required to pursue a quantitative interpretation of the rock properties.

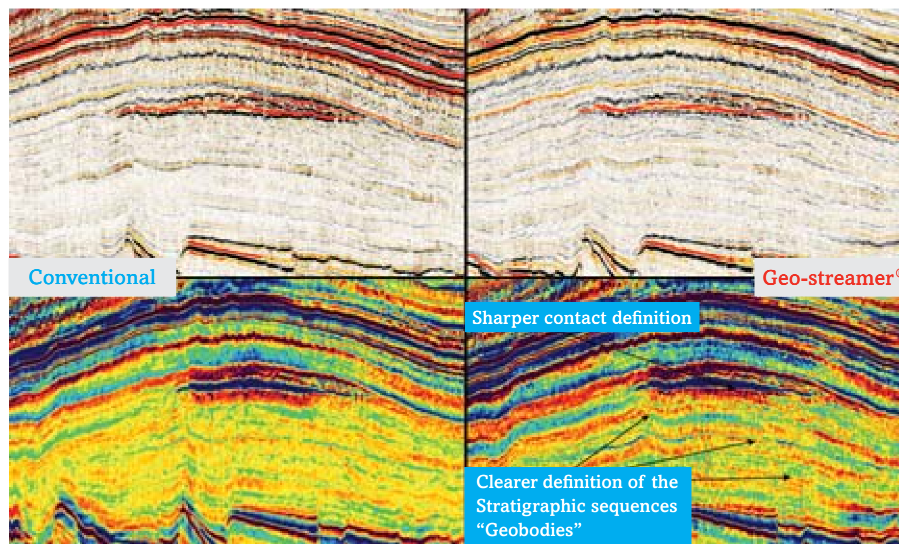


Figure 2. Illustrates two versions of the same reservoir image. A large gas discovery sits in the middle of each image. The top images correspond to conventional streamer and GeoStreamer images, where the color intensity represents the amplitude of the seismic wave field reflected from geological strata. The bottom images use a color scale that corresponds to the impedance at each point in the subsurface, and have been computed from the seismic data using a sophisticated form of data analysis known as "seismic inversion". If the impedance values are correct the lower inverted image is more representative of local rock and/or fluid properties. The difference between the conventional and GeoStreamer data can easily be evaluated with this side by side comparison.

GeoStreamer data (lower right Figure 2), provides a much better image, particularly at the reservoir level. The top and base of the reservoir and the various geological strata are far better identified. It may seem a paradox, but very low frequency data is of crucial importance to yield accurate information about the reservoir properties.

Rocking Low – Rocking High

Before you can derive the accurate impedance values required for inversion from seismic data you need to construct an extremely detailed seismic velocity model, rich in both high and lower frequency data. One technique for producing this is a high-end application called Full-Waveform Inversion (FWI).

Until recently, FWI was regarded as strictly for the academics and impractical in the real world. It is time consuming, extremely computer intensive and dependent on data from a broad frequency bandwidth. Conventional seismic data are deficient in low frequencies. However, with appropriate low frequency signal, FWI can greatly improve the detailed understanding of the seismic velocity variations in the subsurface, and ultimately, also improve our understanding of how rock density varies in the subsurface.

When FWI is applied to GeoStreamer data it has yielded a highly detailed understanding of the seismic wave velocity in the subsurface –- the velocity model (Figure 3).

Pore Pressure – on the Rocks

Pore pressure prediction is another important aspect of well planning that is facilitated by broadband seismic input. If a planned well trajectory encounters abnormally high pore pressures, it must be managed with matching mud weights and an optimal casing program. In the worst case scenario, the drilling operation can result in a blowout. Seismic velocities in the form of interval velocities extracted from stacking are routinely used to predict pore pressure in the subsurface. The conventional streamer bandwidth is typically very limited and the uncertainties in the extracted velocities are quite large. However, broadband GeoStreamer acquisition captures very low frequencies. These can be inverted to velocities using FWI, as outlined above, or recovered by deterministic inversion. We can get a full bandwidth velocity field, ideal to evaluate pore pressure before drilling, by merging inversion velocities with stacking velocities of the very lowest frequencies.

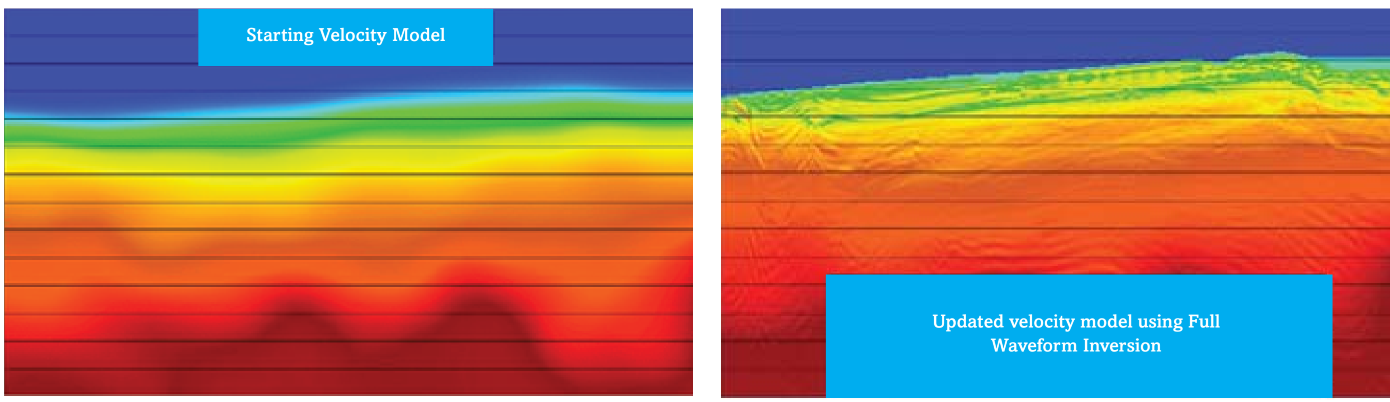


Figure 3. The initial and final subsurface velocity model after the application of Full-Waveform Inversion (FWI) to GeoStreamer data. Note the great detail achieved on the right. This will translate to higher resolution seismic images, and a better understanding of the geological details.

Velocity as a function of depth under hydrostatic pore pressure follows a normal compaction trend, whereas elevated pore pressure results in velocities that are slower than expected.

The velocity difference between the over-pressured trend and the normal compaction trend can be scaled as a pore pressure estimate. The reason is that velocity is a function of porosity and porosity is a function of effective stress, in other words, the force that compacts the rock eliminates porosity.

Figure 5 illustrates normal pore pressure where the pore fluid is allowed to drain, maintaining a pore pressure equal to the hydrostatic gradient, which in turn allows the rock to compact under increasing effective stress generated by the thickness and weight of the overburden.

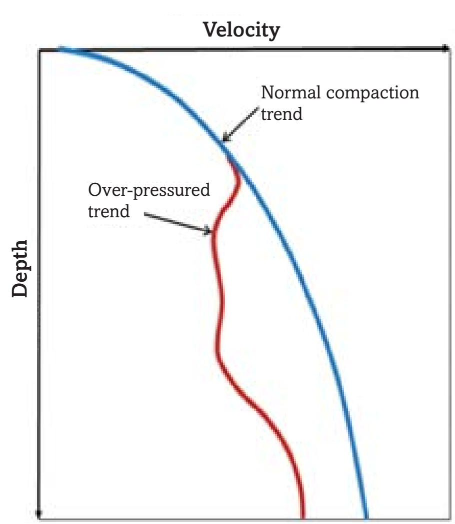


Figure 4. The velocity as a function of depth follows a characteristic curve known as the normal compaction trend. When pore fluids are trapped in the rock preventing the sediment from draining under compacting stress, the pore pressure is increased above the hydrostatic gradient. This results in preserved porosity and under-compaction of the sediments where the velocity is lower compared to the normal compaction trend. The difference in velocity between the over-pressured trend and the normal compaction trend can be scaled as a pore pressure estimate.

The scenario of abnormally high pore pressure is illustrated in Figure 6. Fluid is unable to drain from the rock and the grains are prevented from compacting. The porosity is preserved and the velocity is lower than the compacted rock under normal pore pressure.

Rock 'n' Fluid
The ability to predict reservoir properties away from the well using seismic information is a key element in reservoir characterization. Well data offers high resolution vertically but does not provide lateral information, whereas seismic has the opposite characteristic: densely laterally spaced traces with "limited" vertical resolution.

Seismic information plays a key role in this prediction process away from the wells, and the aim of the reservoir geoscientist is to calibrate the seismic information with the well data, to derive absolute rock properties away from the well without introducing too much low frequency a priori information. The accuracy of the reservoir property prediction and the chances of drilling the optimal target are improved by having more low frequency seismic information and less well information (a priori information) included in the process.

Figure 7 illustrates the benefit of using a significant amount of low frequency seismic to estimate elastic properties. It demonstrates that the acoustic impedance estimated at Well B is nearly identical whether the well is included as a priori information in the model or not. This observation shows that our ability to predict the reservoir properties is much improved due to the availability of a broader seismic bandwidth offered by GeoStreamer.

The analysis presented in Figure 7 is an example of seismic inversion, based on GeoStreamer data and representing a high-end product ideal for seismic data interpretation. In practice, conventional streamer data are unable to deliver reliable impedance estimates, and geophysicists must use the low frequency information from available well data to constrain or calibrate the result of the inversion. The GeoStreamer data, however, are much richer in low-frequency signal content than conventional streamer data. Inversion using GeoStreamer data has been proven to depend less upon the introduction of well data as a background model.

Note, that whilst conventional streamers can, in principle, be towed very deep to deliver comparably strong low frequency signal, the high frequency information would be lost, as a result of the physics of conventional streamers. Thus, it would be impossible to produce seismic images with any high resolution detail. In contrast, the GeoStreamer output is rich in both low and high frequencies, and allows a high resolution image of the subsurface, complemented by an improved characterization of the rock and fluid properties. Consequently, GeoStreamer technology is attracting great interest not only in the area of acquisition and seismic processing but also based on its ability to enhance prediction of reservoir properties.

GeoStreamer: King of Rock
Overall, GeoStreamer is delivering upon its promise to improve acquisition efficiency, processing, seismic velocity model building (improvement with the Full Waveform Inversion), and now estimation of reservoir properties. GeoStreamer is also on the brink of becoming the ultimate tool

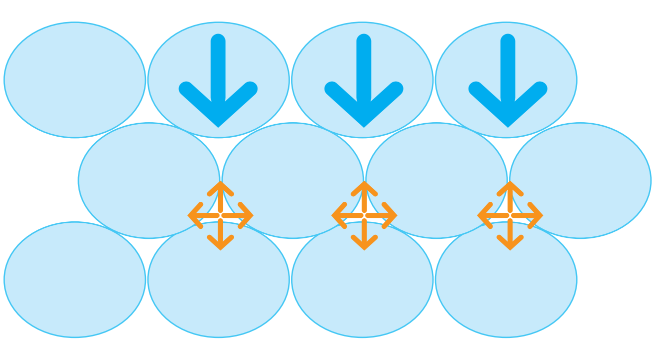


Figure 5. Clastic grains in a reservoir rock. The normal or hydrostatic pressure is shown by the orange arrows and the effective stress is shown by the blue arrows. Fluid is allowed to drain from the pore-space and the porosity is in compaction equilibrium characterized by the normal compaction trend. The grains flatten under the compacting stress reducing porosity

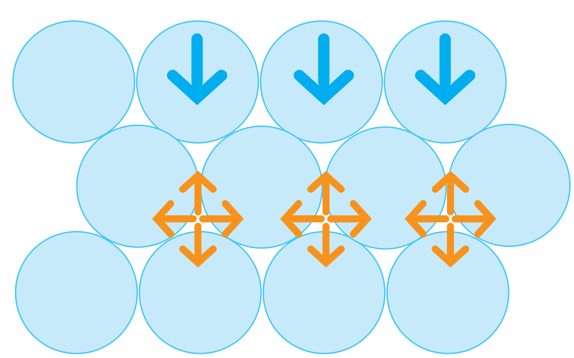


Figure 6. Abnormally high pore pressure is illustrated by the elongated orange arrows that counterbalance the lower effective stress shown by the shortened blue arrows. Porosity is preserved due to the lower effective stress which in turn results in lowers than expected velocity.

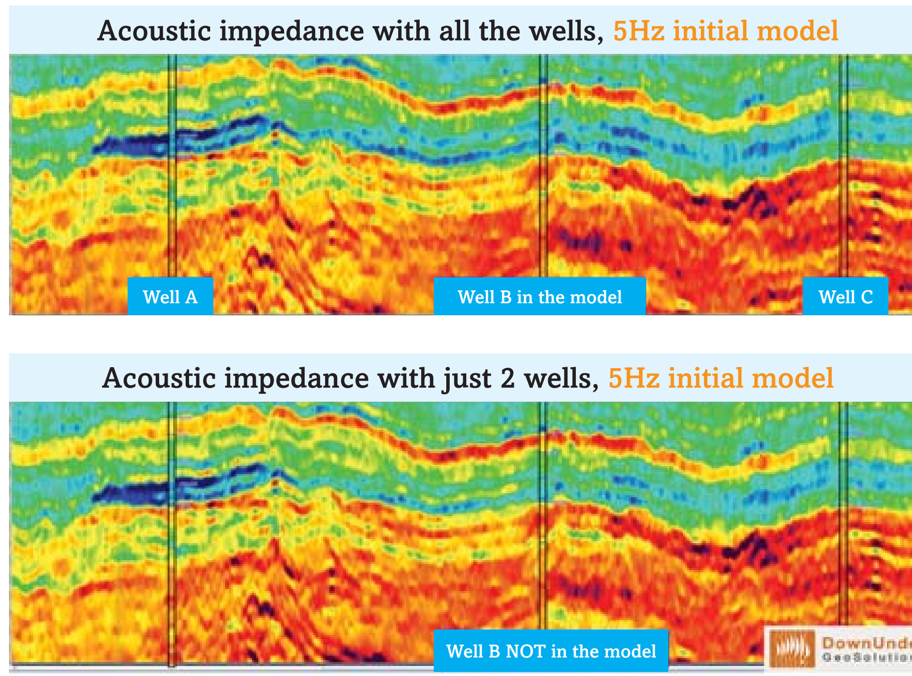


Figure 7. Comparison of two acoustic impedance results using GeoStreamer and with two different initial models, where a priori low frequency well information supplements the seismic as a starting model for the seismic inversion process. The results of the acoustic impedance (represented by the colored image) at the well locations are extremely similar using either three wells (top figure) or just two wells (bottom figure). The results at Well B are identical for the top and bottom figure, demonstrating that the reliability of the estimated reservoir properties are dramatically enhanced with GeoStreamer.

to estimate pore pressure in the subsurface, with simultaneously boosted low and high frequencies.

The extended bandwidth and improved signal-to-noise has proven to be an indispensable tool for reservoir characterization. GeoStreamer will also be the ultimate tool in the 4D or time lapse domain, to monitor saturation and pore-pressure changes due to production or fluid injection, as well as the burgeoning business of monitoring CO_2 sequestration.

Since the launch of broadband, dual-sensor GeoStreamer in 2007, it has been used worldwide to acquire more than 100,000 line km of 2D seismic and more than 10,000 square km of 3D in a variety of geological settings. GeoStreamer has been commercially available for 3D acquisition since late 2009. In all cases, the operational and seismic data benefits have been clear and substantial.

We are only just beginning to analyze and quantify the real benefits of GeoStreamer data for interpreting and characterizing reservoir properties and architecture. Furthermore, dual-sensor seismic is providing the platform for high-end supporting technologies that have been incorporated after waiting in the wings for several years. In its ability to deliver a clearer image and an improved understanding of lithology and fluid properties, GeoStreamer is a definitive step-change for the industry.

INVERSION – GOING BACK TO THE ROCK

The process of deriving physical rock properties from seismic data is known as seismic inversion. It is so called, because seismic images are the result of an impulse to the earth (a pulse of acoustic energy) which has been acted upon by something in the earth before being recorded. Inversion is simply the method of going back to find out what that “something” was.

If seismic data were perfect, inversion to several important rock properties would be quite straightforward. However, since it is not perfect, the study of inversion has spawned many different methods and approaches which seek to overcome the limitations imposed by seismic data in the real world. Chief amongst these limitations is the fact that seismic signals have a restricted frequency bandwidth. In other words, they contain information from just a restricted range of frequencies from low to high. Broadband seismic input, such as GeoStreamer, offers a step change in the quality and reliability of the output.

A SOUND POLICY FOR MITIGATING RISK

Environmental disasters create screaming headlines that capture everyone's attention for a season but we should also beware the slow rumble of risk. Once identified, we have a duty to assess the probability of an undesirable event happening and the potential severity of the outcomes.

/////////////////// **AUTHORS:** DAVID HEDGELAND AND PAMELA RISAN **PHOTO:** ISTOCKPHOTO

2010 has brought this into focus. The incident at Macondo in the Gulf of Mexico was followed by drilling moratoria and a raft of new regulation proposals. But this is far from the only area where the oil and gas industry needs to control the impact of its environmental footprint. The interaction between underwater sound and marine ecosystems is also generating increasing levels of interest: from international organizations like the United Nations, national governments, regulating authorities, non-government organizations, scientific research and commercial business communities, as well as the general public.

The scale and nature of environmental risk, and its associated regulatory landscape, is changing. More and more the issues such as climate change, habitat and biodiversity are not confined to geographic areas or national boundaries. Assessments of potential severity are also difficult to measure and assess, and scientific uncertainties shadow long-term environmental, social and economic impacts. Occasionally, this makes causality rather difficult to assess but it should not stop the pursuit of improvement.

It is time for our industry and individual companies to think outside the easily measurable environment box, in order to understand the potential risks and opportunities associated with such global issues. When we work together, proactively and reactively, we have shown that we can minimize and manage risks and consequences.

Reducing Uncertainty

The oil and gas industry must cooperate

In 2006, the E&P Sound and Marine Life Joint Industry Program was established. This is a multi-million dollar, multi-year commitment to support research activities that improve our understanding of the potential interactions between marine life and E&P operations offshore.

to support scientific research activities on underwater sound and marine life. There are still plenty of knowledge gaps. By filling them we help to remove some of the uncertainty about possible effects of E&P sound on fish and marine mammals. Reducing such uncertainties will also help to ensure that appropriate and practical regulatory requirements are applied to E&P operations in the future.

In 2006, the E&P Sound and Marine Life Joint Industry Program (or JIP) was established. The JIP is a multi-million dollar, multi-year commitment to support research activities that improve our understanding of the potential interactions between marine life and E&P operations offshore. It is currently supported by multinational exploration and production related organizations (including the International Association of Geophysical Contractors, IAGC, representing the geophysical industry). The program is administered by the International Association of Oil & Gas producers (OGP).

One of the first concrete outcomes of this joint industry project has been the development of the PAMGuard software. Developed over the past five years this now provides industry and the research community with a standardized user interface for passive acoustic monitoring of marine mammals at sea. This software is now in regular use around the world, though it is still seldom required by either the oil and gas companies or regulators.

Another initiative, the Svein Vaage broadband airgun study, has accumulated a data library that can be used to improve and expand industry capabilities to model the output of seismic source arrays at higher frequencies, within the hearing sensitivity of marine mammals. This dataset will also be used to update the PGS Nucleus seismic modeling package.

The JIP has now been extended and is supporting ground breaking studies into potential behavioral responses of marine mammals relative to underwater sound.

The geophysical companies shoulder the burden of developing new solutions, supported by collective research efforts such as the JIP. When developing new seismic sources, like the marine vibrator and others on the test bench, the potential impact on marine life is always a consideration. Innovative technologies may offer the potential for a step change to the current alternatives. The geophysical industry leads and funds the development but change has a price, and our advances are not always employed if they impact on survey cost. Is it time for E&P companies and regulators to do more to encourage progress? PGS and the geophysical industry are ready to act as partners.

In a world of uncertainties one thing is clear, society expects responsible operators to think through the risks and act before their activities impact the environment, even if this means going beyond what current regulations require.

For further information regarding PGS and the marine environment, the JIP or the sound/marine environment subject, contact david.hedgeland@pgs.com and/or visit the JIP website www.soundandmarinelife.org

GLOSSARY

Accelerated ageing techniques Testing with aggravated conditions of heat, oxygen, sunlight, vibration, etc. to speed up the normal aging processes. It is used to help determine the long term effects of expected levels of stress within a shorter time, usually in a laboratory by controlled standard test methods, and to estimate the useful lifespan of a product when products that have not existed long enough to have gone through their useful lifespan.

Blended acquisition – Densely sampled, wide-azimuth source distributions, with relatively small time intervals between shots results in a blended, overlapping signal with interference. Separating the overlapping information, would produce far richer data. Currently marine seismic surveys are designed such that the time interval between shots is sufficient to avoid interference (zero overlap in time). The result is that the source domain is poorly sampled.

Broadband acquisiton – Seismic recording that picks up a wide range of signal response frequencies (low as well as high). Low frequency data provides deeper penetration useful for imaging deep targets, and provides greater stability in inversion. Broader bandwidths produce sharper detailed definition. Both low and high frequencies are required for high resolution imaging of important shallow features such as thin beds and small sedimentary traps.

Dipscan – Dipscanning is a method for automatically deriving a structural model from seismic data. The process identifies differences in travel times for wavelets on adjacent traces and calculates dips by measuring the maximum coherence along the seismic event. It is rather complex, because amongst other things, it also has to recognize edges of events in order to recognize structural discontinuities such as faults and pinchouts.

Fiber optics – A thin, flexible, transparent fiber acts as a waveguide, or "light pipe", to transmit light between the two ends of the fiber. Fibers are used instead of metal wires because signals travel along them with less loss and are immune to electromagnetic interference, data transfer rate is also higher with fiber.

Full waveform inversion – See also "inversion". A method of inverting for one important rock property – acoustic velocity. In FWI the solution of the wave equation is more advanced than other inversion approaches, solving for acoustic propagation both from the earth model and from the seismic data. This uses what is known as forward modeling (creating a synthetic seismic dataset based upon a certain geological model) and also the inverse of that, reducing a seismic dataset itself to a geological model. The output of FWI is highly dependent on the accuracy of the input data. Hence, it requires broad bandwidth and rich azimuth distributions. Considerable compute resources are employed. FWI promises more accurate and higher resolution velocity inversion than other methods.

Impedance (of sound) – The product of density and seismic velocity, which varies among different rock layers, commonly symbolized by Z. The difference in acoustic impedance between rock layers affects the how much energy is reflected.

Inversion – The process of deriving physical rock properties from seismic data. Inversion methods seek to describe mathematically how acoustic waves propagate through the earth, in order to create a physical model of the earth which matches the observed seismic. This is done by using something called the elastic wave equation, or an approximation to it.

Kirchhoff – A method of seismic migration that uses the integral form (Kirchhoff equation) of the wave equation. All methods of seismic migration involve the backwards propagation of the seismic wavefield from the region where it was measured (Earth's surface or along a borehole) into the region to be imaged. In Kirchhoff migration, this is done by using the Kirchhoff integral representation of a field at a given point as a (weighted) superposition of waves propagating from adjacent points and times. Because of the integral form of Kirchhoff migration, its implementation reduces to stacking the data along curves that trace the arrival time of energy scattered by image points in the earth.

Life of field seismic – A permanent seafloor deployment that monitors the long-term performance and development of subsea producing reservoirs from commencement of production until the field is abandoned. In addition to conducting regular repeated 3D sourced surveys, the system monitors all seismic activity in the vicinity of the reservoir continuously, in real-time.

Migration – By this process geophysical events (changes in energy) are geometrically re-located in either space or time to the location the event occurred in the subsurface rather than the location that it was recorded at the surface, thereby creating an accurate image of the subsurface. This process is necessary to overcome distortions imposed by complex geology, such as: faults, salt bodies, folding, and the limitations of geophysical methods.

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.

Narrow azimuth survey (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.

PSDM – Prestack depth migration is a key technology for improving seismic imaging where geological heterogeneity such as salt domes and fault complexity create special imaging challenges. In particular, depth migration is able to handle acoustic velocity fields with strong lateral variations. Depth migration pre-stack is highly compute intensive, as the volume of data is very high, and has only become a routine process in recent years. It also requires a greater degree of interpretational input into the process.

Stacking – Adding seismic traces together from different records to reduce noise and improve data quality. The number of traces that have been added together during stacking is called the fold.

Warp speed – In Star Trek speed is generally expressed in "warp factor" units, which – according to the Star Trek Technical Manuals – correspond to the magnitude of the warp field. Achieving warp factor 1 is equivalent to breaking the light barrier, while the actual velocity corresponding to higher factors is determined using an ambiguous formula.

Wave equation depth migration – All forms of seismic migration try to obey the "wave equation", which describes where a pressure wave is in space at every point in time during its propagation through the earth. But the mathematics have historically been simplified to save computational cost and turnaround time. Modern computers and sophisticated algorithms are finally allowing PSDM solutions that accurately obey the wave equation, and can produce accurate seismic images in complex geology, which was historically impossible using simplified migration solutions.

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.

Reflections is published by Petroleum Geo-Services.
Editor: Senior Vice President Group Communications Tore Langballe
Editorial Board, PGS: Pamela Risan, John Greenway, Eivind Fromyr, Andrew Long
Desking: Kevin Reeder/Wordz **Design:** IteraGazette

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