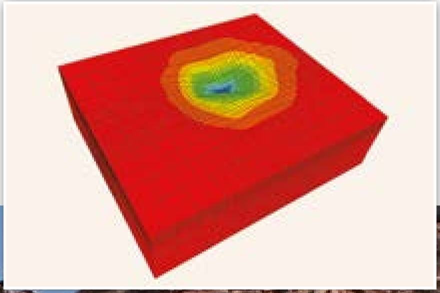
VOL. 16, NO. 2 – 2019

GEOExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED



geoexpro.com

RESERVOIR MANAGEMENT
An Introduction to Geomechanics

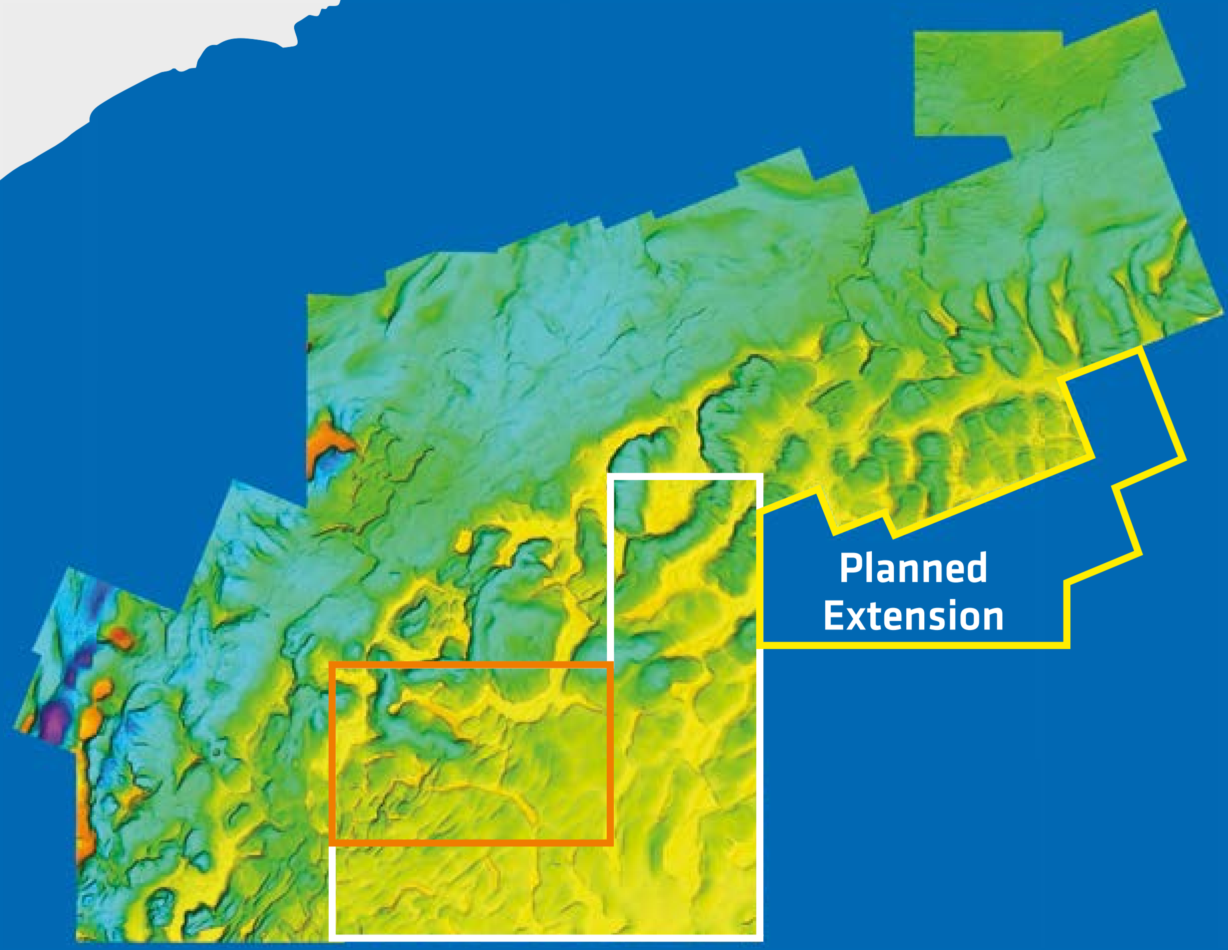
GEOTOURISM
Canada's Ocean Playground

INDUSTRY ISSUES
Data, the Cloud and Me

GEOEDUCATION
Basin Classification

TECHNOLOGY EXPLAINED
Pie in the Sky

Make Better Decisions
with Santos Vision, Brazil



Better presalt images using advanced model building and imaging techniques.

34 000 sq. km: Available now
4 000 sq. km (orange outline): Early out available now
11 600 sq. km (white outline): Final products available October 2019

Book a data show, email: nsa.info@pgs.com

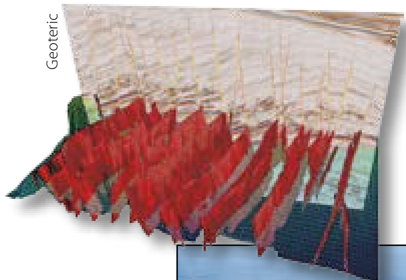
A Clearer Image | www.pgs.com/SantosVision

PGS

Previous issues: www.geoexpro.com

GEO ExPro

GEOSCIENCE & TECHNOLOGY EXPLAINED

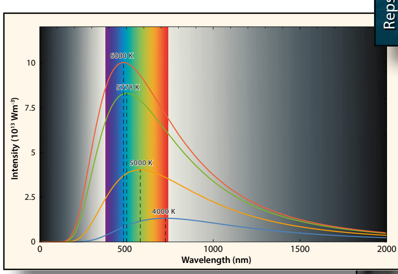


20

Even with machine learning, the key to all interpretation is still the interpreter's experience and knowledge.

24

A Special Interest Group has been set up to maximize economic recovery from the Outer Moray Firth area of the North Sea.



40

The first of a new series on issues around CO_2, looks at blackbody radiation and Milankovich cycles.

64

Tolulope Ewherido is the first black female Vice President in any ExxonMobil upstream company.

68

What causes a rock to fault or fail? The science of geomechanics can help explain it.

Contents

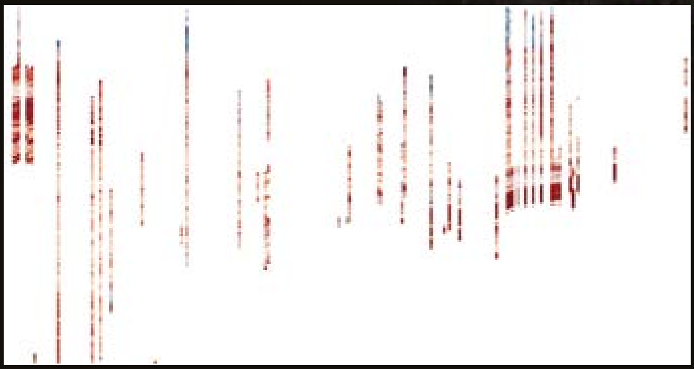
Vol. 16 No. 2

This edition of *GEO ExPro* is focused on North America; Rejuvenating Exploration; Machine Learning and AI; and Geomechanics

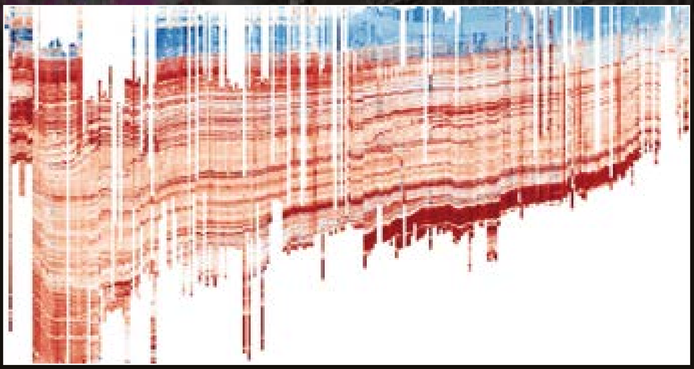
Get to your target faster with TGS' Machine Learning technologies

Access the world's richest analytics ready data set

TGS has developed Machine Learning algorithms that predict missing curve responses in today's digital well log data. With nearly 2,000,000 wellbores digitized throughout North America, TGS' Analytics Ready LAS (**ARLAS**) illuminates the subsurface like never before.

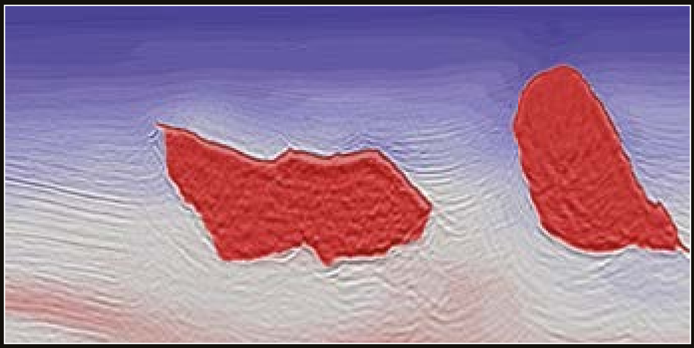


Commercially Available Sonic Curves

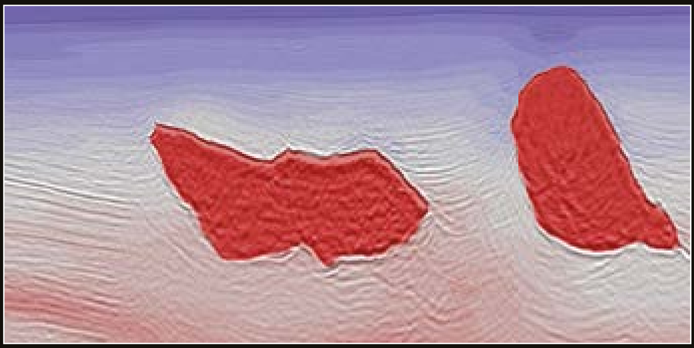


Predicted Sonic Curves

TGS has developed a modern analytics workflow, SaltNet, that proves to reduce cycle time by up to 80% when picking top and base of salt within a seismic dataset. With TGS' new predictive workflow, operators can automatically build salt models which can be efficiently integrated into the salt prediction process.



40 Gulf of Mexico Blocks – Hand Picked
Top of salt picked in 19 days
Base of salt picked in 11 days



40 Gulf of Mexico Blocks – Machine Picked
Top of salt picked in 3 days
Base of salt picked in 3 days

TGS

See the energy at TGS.com

© 2019 TGS-NOPEC Geophysical Company ASA. All rights reserved.

A View from Brexitland

Here in the (not very) United Kingdom there is – and has been for some months – only one major topic of conversation: Brexit. Whether by the time this magazine is published Britain will have crashed out of the European Union, or be undergoing an orderly planned exit, or will have agreed to remain in the organization for a definite or indefinite time period, is still a great unknown. One of the few things that most people agree on, however, is that Brexit will bring about significant changes in the way the country does business with both Europe and the rest of the world – although whether these will be to the advantage or detriment of Britain many will dispute at great length.

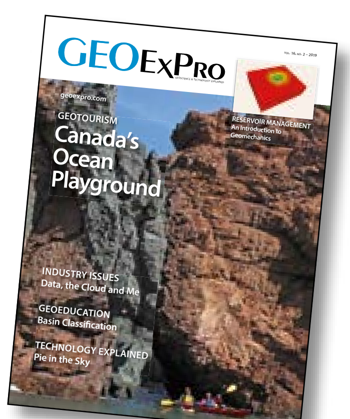
Though global in nature, the oil and gas business will not be totally immune to these changes. A report by EY commissioned by Oil & Gas UK suggests that if the country reverted to World Trade Organization tariffs, it could add something in the region of £500 million a year to the cost of trading oil and gas, possibly doubling the annual trade bill with the EU. Just as the industry seems to be emerging from a two-year slump, such a scenario would be 'unwelcome', as the report says. The possibility of border procedures slowing imports of drilling and other equipment, at least in the immediate aftermath of a no-deal Brexit, could also have cost and efficiency implications, as could restriction of the employment of skilled foreign labor.

Worries have been expressed as to whether leaving the EU will result in major regulatory changes for the O&G industry. However, as the largest producer of offshore oil and gas in the EU, Britain took a leading role in shaping the existing regulations, all of which will convert into British law on Brexit, so there is little cause for concern on this issue – although future changes by the EU, especially looking towards a low carbon energy future, may adversely impact it. So: many questions, concerns and considerations, whatever the final outcome.

However, those of us who have been living through this turmoil can take some lessons from it that have nothing to do with oil and gas but are still very relevant for the industry. Firstly: detailed rigorous planning for every possible scenario is vital at all stages of a decision-making process.

And secondly: for all negotiations, whatever the topic, a willingness to compromise and collaborate is essential on all sides.

Jane Whaley
Editor in Chief



CANADA'S OCEAN PLAYGROUND

Nova Scotia's spectacular geology is made for the adventurous geotourist - like these kayakers near the seastacks known as the Three Sisters in the Cliffs of Fundy Geopark, where a mafic dyke can be seen intruding into the early Carboniferous Cape Chignecto pluton.

Inset: Geomechanics is becoming increasingly important in the exploration and production of oil and gas.

© 2019 GeoPublishing Limited.
Copyright or similar rights in all material in this publication, including graphics and other media, is owned by GeoPublishing Limited, unless otherwise stated. You are allowed to print extracts for your personal use only. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means electronic, mechanical, photographic, recorded or otherwise without the prior written permission of GeoPublishing Limited. Requests to republish material from this publication for distribution should be sent to the Editor in Chief. GeoPublishing Limited does not guarantee the accuracy of the information contained in this publication nor does it accept responsibility for errors or omissions or their consequences. Opinions expressed by contributors to this publication are not necessarily those of GeoPublishing Limited.

GEO ExPro

www.geoexpro.com

GeoPublishing Ltd
15 Palace Place Mansion
Kensington Court
London W8 5BB, UK
+44 20 7937 2224

Managing Director
Tore Karlsson

Editor in Chief
Jane Whaley
jane.whaley@geoexpro.com

Editorial enquiries
GeoPublishing
Jane Whaley
+44 7812 137161
jane.whaley@geoexpro.com
www.geoexpro.com

Sales and Marketing Director
Kirsti Karlsson
+44 79 0991 5513
kirsti.karlsson@geoexpro.com

Subscription
GeoPublishing Ltd
+44 20 7937 2224
15 Palace Place Mansion
Kensington Court
London W8 5BB, UK
kirsti.karlsson@geoexpro.com

GEO EXPro is published bimonthly for a base subscription rate of GBP 60 a year (6 issues).
We encourage readers to alert us to news for possible publication and to submit articles for publication.

Cover Photograph:
Main Image: John Calder
Inset: Geomechanics Technologies

Layout: Winslade Graphics
Print: Stephens & George, UK

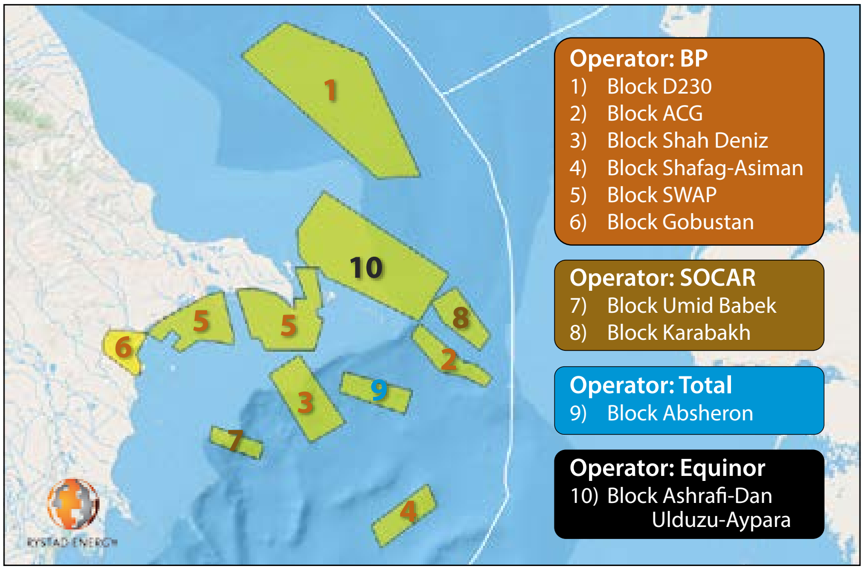
issn 1744-8743

Scan me

RYSTAD ENERGY

Azerbaijan:
Back in the Saddle Again

A number of high value prospects in the Azeri sector of the Caspian Sea have piqued the interest of major operators – BP in particular – fostering a resurgence of exploration activity that could reverse the decline of Azerbaijan's large resource base. Several operators are also pushing forward plans to develop numerous existing discoveries in Azerbaijan over the next ten years, potentially tapping into more than 4 Bboe.



Azerbaijan blocks with planned exploration and appraisal activity.

BP will drill four exploration wells in Azerbaijani waters this year and another two in 2020. Highest hopes are pinned on the deep exploration well scheduled for the second quarter this year in the Shafag-Asiman gas play, classified by Rystad Energy as a 'high impact well' given its close proximity to the giant Shah Deniz field. BP holds a 50% working interest in Shafag-Asiman and hopes to replicate the success of Shah Deniz. The company will continue exploration in the area by testing an ultra-deep target beneath the Shah Deniz field in 2020. BP plans to soon conduct 3D seismic studies on its recently-awarded relatively unexplored Block D230, north-west of the company's giant ACG project, in waters ranging from 100 to 800m. The first well is expected to spud in the first half of 2021. Moving closer to shore, BP plans to drill three wells in the Shallow Water Absheron Peninsula (SWAP), and will drill an onshore well in the second half of this year on the Gobustan South West block, having acquired a 61% working stake in 2018. The block contains the Duvanni and Dasgil mature oil and gas fields, and exploration activities are likely to target deeper Cretaceous and Jurassic carbonate reservoirs.

Equinor, the Norwegian company, will drill an appraisal well on the Karabakh prospect later in 2019. Equinor has also signed a production sharing agreement for the Ashrafi, Dan Ulduzu and Aypara area, not far from the ACG field, and will commence a seismic survey imminently. It aims to drill an exploration well in 2020 or 2021.

In addition to the uptick in exploration efforts in Azerbaijan, operators have lined up development plans on existing oil and gas-condensate discoveries in the region. Rystad Energy forecasts that six of these projects will come online during the course of the next decade, holding collective recoverable resources of about 4.4 Bboe.

National oil company Socar is increasing its presence in the upstream sector and is working with international E&Ps, such as Total and Equinor, in an effort to develop more resources and thus arrest the decline in Azeri production. Precluding any new oil discoveries, Azerbaijan is likely to see an equal production contribution from gas and liquids during the course of the next decade.

Swapnil Babele, Senior Analyst, Rystad Energy

ABBREVIATIONS

Numbers
(US and scientific community)

M: thousand = 1×10^3
MM: million = 1×10^6
B: billion = 1×10^9
T: trillion = 1×10^{12}

Liquids

barrel = bbl = 159 litre
boe: barrels of oil equivalent
bopd: barrels (bbls) of oil per day
bcpd: bbls of condensate per day
bwpd: bbls of water per day

Gas

MMscfg: million ft^3 gas
MMscmg: million m^3 gas
Tcfg: trillion cubic feet of gas

Ma: Million years ago

LNG

Liquified Natural Gas (LNG) is natural gas (primarily methane) cooled to a temperature of approximately -260 °C.

NGL

Natural gas liquids (NGL) include propane, butane, pentane, hexane and heptane, but not methane and ethane.

Reserves and resources

P1 reserves:
Quantity of hydrocarbons believed recoverable with a 90% probability

P2 reserves:
Quantity of hydrocarbons believed recoverable with a 50% probability

P3 reserves:
Quantity of hydrocarbons believed recoverable with a 10% probability

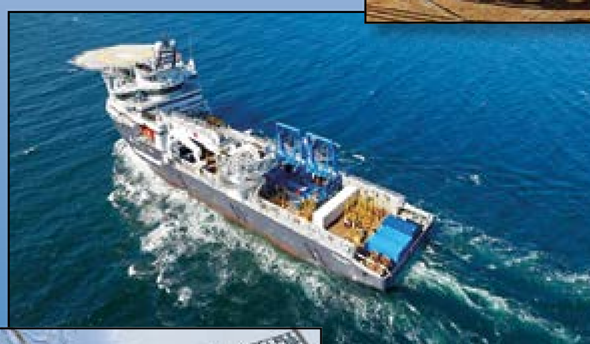
Oilfield glossary:
www.glossary.oilfield.slb.com

PetroMarker

The CSEM Company

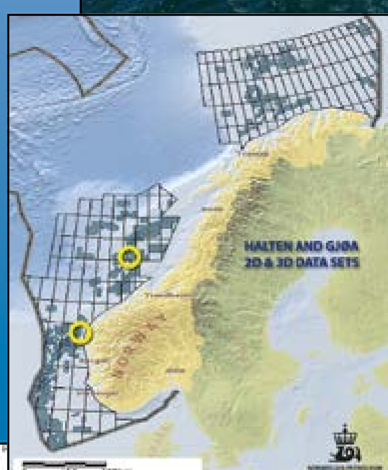
We see deeper

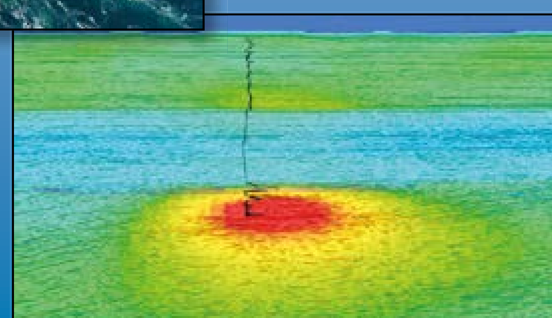
- Flexible Acquisition Platform
- Tailormade Design
- Global Presence



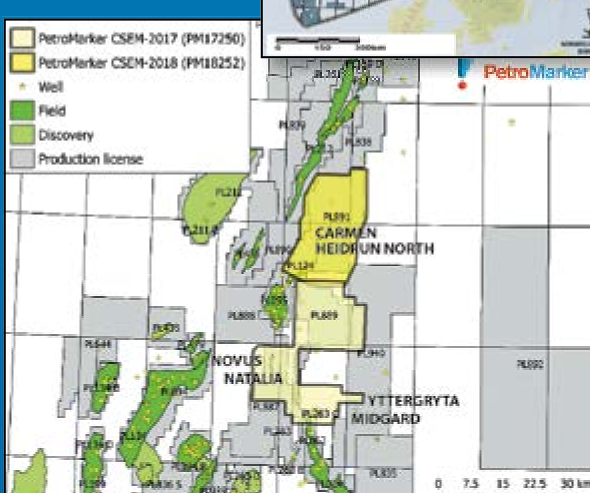
- DeRisk Leads & Prospects
- Appraise Discoveries and Fields
- Nearfield Exploration
- Open Acreage & Prebidding Screening

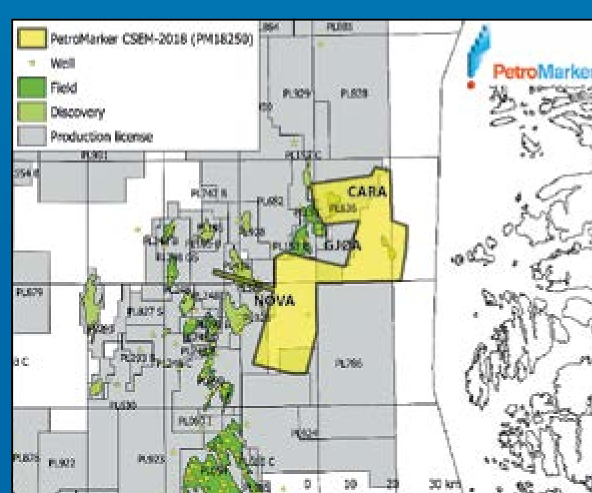
- 3D Multi-Client data Norwegian Continental Shelf
- Resistivity Volumes Available Now





- Sensitive to Hydrocarbon Accumulations





Petromarker@Petromarker.com

US Gulf of Mexico

Between them, two region-wide lease sales in 2019 offer thousands of unleased blocks.

In March 2019 the United States Department of the Interior and the Bureau of Ocean Energy Management (BOEM) announced a proposed region-wide lease sale of 78 million acres (315,655 km^2) which includes all available unleased areas in federal waters of the Gulf of Mexico. Lease Sale 253, the fifth offshore sale under the 2017–-2022 National Outer Continental Shelf Oil and Gas Leasing Program, will be livestreamed from New Orleans on August 21, 2019. Under this program, ten region-wide lease sales are scheduled for the Gulf. Two will be held each year and will include all available blocks in the combined Gulf of Mexico Planning Areas.

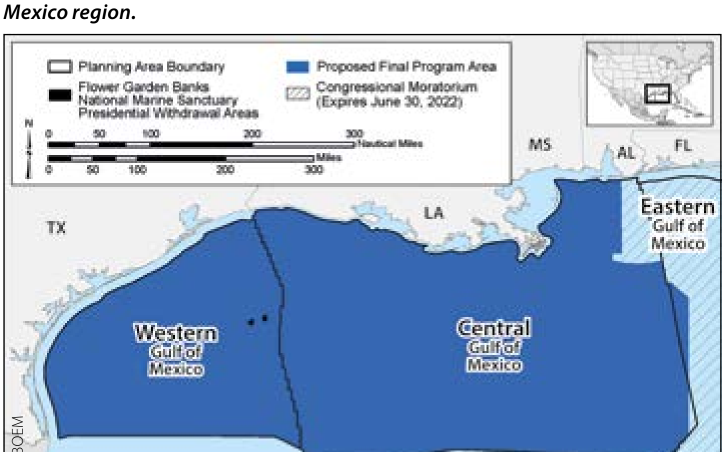
Lease Sale 253 includes almost 14,700 unleased blocks in the Gulf's Western, Central and Eastern planning areas in water depths ranging from 9 ft to more than 11,100 ft (3 to 3,400m). Blocks subject to the congressional moratorium established by the Gulf of Mexico Energy Security Act of 2006, and those adjacent to or beyond the US Exclusive Economic Zone in the area known as the northern portion of the Eastern Gap, are all excluded from the sale, as are blocks within the Garden Banks National Marine Sanctuary. The lease awards will include stipulations to protect biologically sensitive resources, mitigate potentially adverse effects on protected species, and avoid potential conflicts associated with oil and gas development.

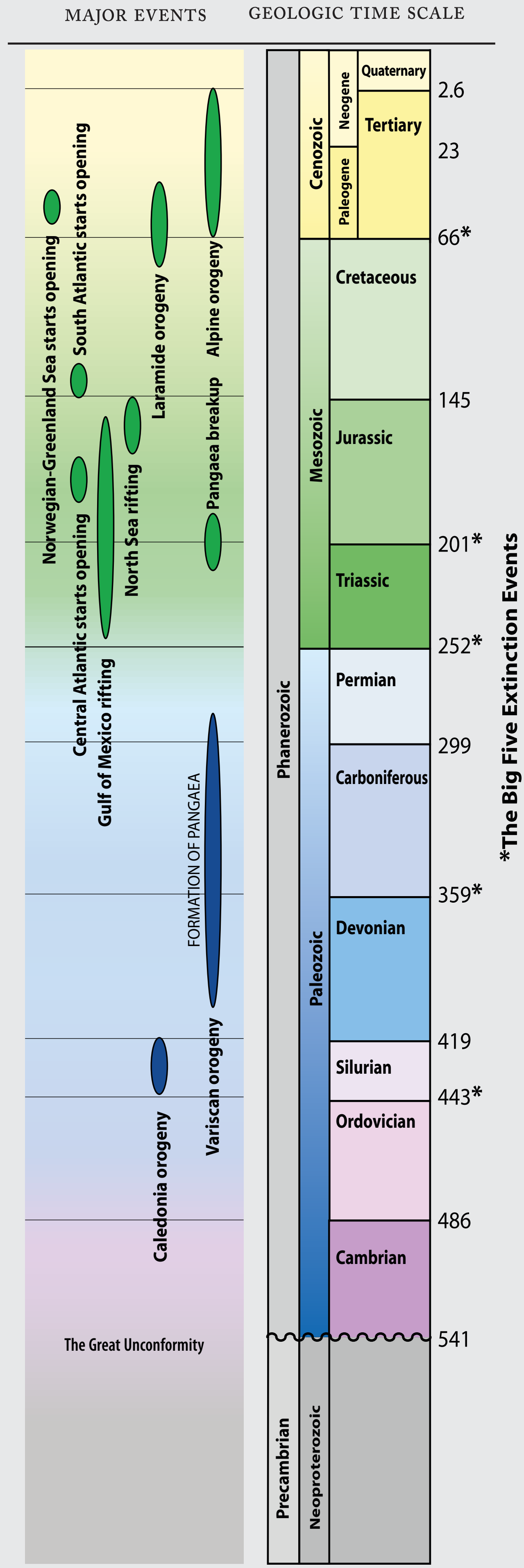
The fiscal terms offered include a royalty rate of 18.75% for leases in over 200m of water depth. In recognition of the marginal nature of remaining Gulf of Mexico shallow water resources and also the current hydrocarbon price conditions, the royalty rate for leases in less than 200m of water has been reduced to 12.5%.

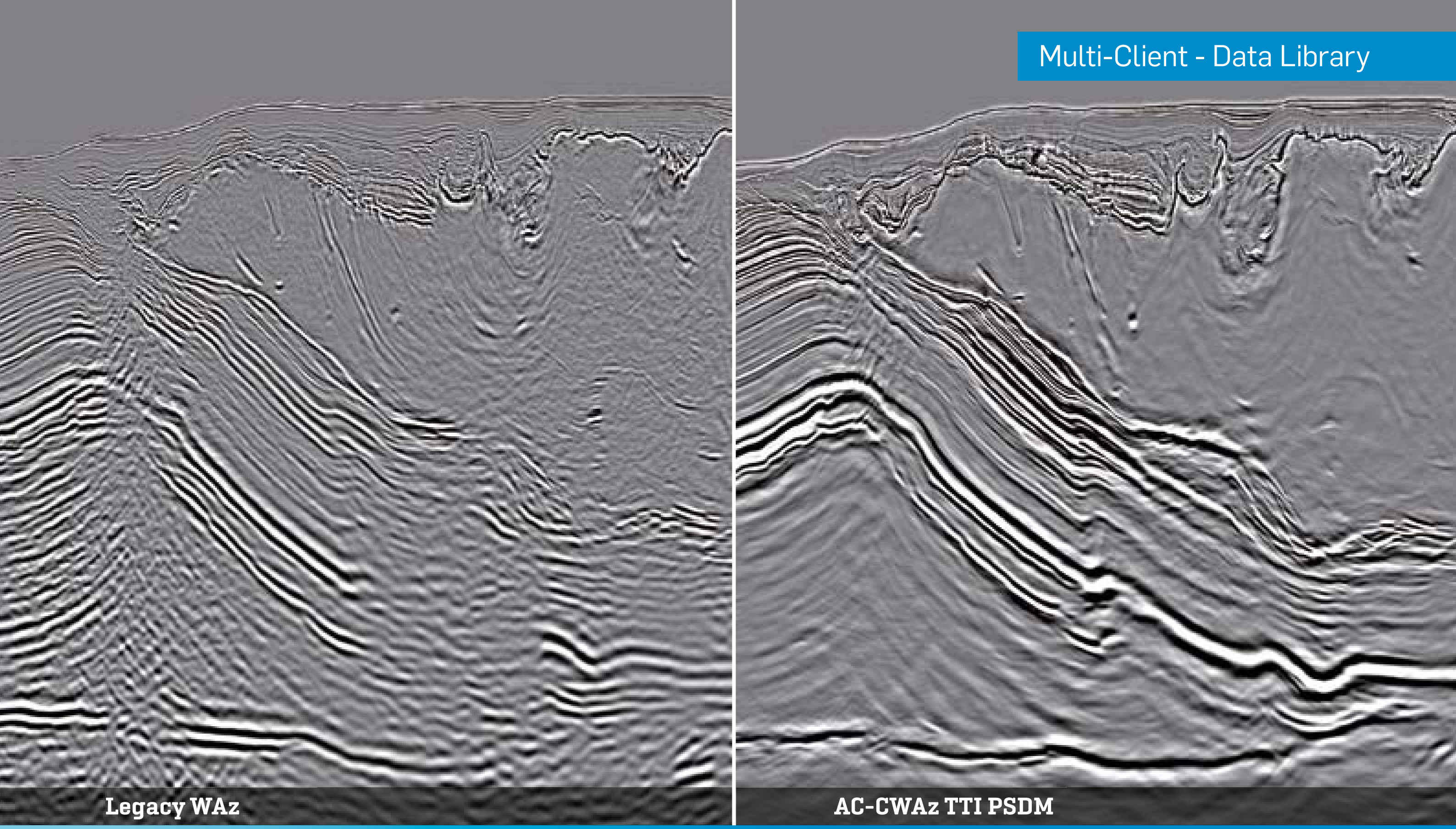
In March the BOEM also announced that the previous region-wide Gulf of Mexico Lease Sale, no. 252, had generated $244,299,344 in high bids for 227 tracts covering 1,261,133 acres (5,100 km^2). A total of 30 companies participated in the lease sale, submitting over $283,782,000 in bids, a 37% increase in revenue generated. Shell was the highest spender, picking up acreage across the entire region. Lease Sale 252 included 14,699 unleased blocks.

The offshore continental shelf associated with the Gulf of Mexico is estimated to contain 48.5 Bb of undiscovered technically recoverable oil and 141 Tcf of undiscovered technically recoverable gas. ■

2017–2022 Oil and Gas Leasing Proposed Final Program Area for the Gulf of Mexico region.







ADVANCED IMAGING IN ALAMINOS CANYON

Complementary data delivers clear benefits

CGG's Alaminos Canyon Complementary Wide-Azimuth (AC-CWAz) 3D survey is now available for license. It provides exceptional imaging of complex sub-salt structures in the Gulf of Mexico:

- Designed to incorporate underlying narrow- and wide-azimuth surveys of varying orientations with new acquisition
- Delivers improved illumination and attenuation of noise and multiples using broadband data with extra-long offsets up to 15.1 km and full-azimuthal coverage up to 8 km
- Imaged by CGG using cutting-edge technology with advanced 3D deghosting and velocity modeling techniques, including FWI, RFWI, and Time-Lag FWI

The right data, in the right place, at the right time

datalibrary.nala@cgg.com

cgg.com/AC-CWAZ

CGG

AAPG ICE in Buenos Aires

The **American Association of Petroleum Geologists** and the **Argentine Association of Geologists and Petroleum Geophysicists** will host the **AAPG 2019 International Conference and Exhibition (ICE)** at the **Hilton Buenos Aires Hotel** in **Buenos Aires, Argentina, August 27–30, 2019**. The event centers around ‘Expanding Frontiers and Unlocking Resources for Future Generations’ and will gather a truly global audience of energy professionals to exchange knowledge, data, and innovation.

This year’s program encompasses eight themes: Basins and Petroleum Systems; Unconventional Resources; Structural Geology; Tectonics and Geomechanics; Stratigraphy and Sedimentology; Geophysics; Deepwater Exploration and Production; Mature Fields; and Energy and Environment. There are also special sessions dedicated to Global Super Basins and Challenges and Opportunities for Unconventional Reservoirs. As usual, the event will offer short courses, field trips, and special programs for students and young professionals.

For a regional view there are special country sessions, and regulator, NOC and IOC forums will provide insights from the organizations tasked with implementing energy policies and from

company leaders facing the challenges of future energy scenarios.

Register today for the most important geoscience knowledge exchange of the year. Exhibition and sponsorship opportunities, as well as the full technical program, are available now. Visit the ICE 2019 website for more information. ■

Seismic Vibrator Auto-Guidance

Sercel, a leading designer and manufacturer of innovative seismic equipment and reservoir monitoring instruments, recently launched the world’s first **automatic guidance system** for **vibrator trucks**. This optimizes a truck’s travel time between vibrating points by adjusting and controlling

its deceleration automatically, thus reducing its travel time, as well as any operator-induced delays. Additional savings are made by reducing dead time spent on deploying and recovering the baseplate, because the descent of the baseplate is anticipated by the system and commences before the truck has come to a complete standstill. It is believed that this system will increase vibroseis productivity by up to 10%.

Accuracy will also be improved, as the auto-guidance can position the vibrator within 1m of the surveyed position, to ensure that the data collected is of the highest possible quality.

The device can be fitted to all **Sercel Nomad** vibrator trucks, which are renowned for delivering high performance broadband vibroseis in the harshest environments. Boasting the latest innovations in shaker and hydraulic circuitry design, they are recognized for their environmental credentials, with low-emission engines and an intelligent power management system, which optimizes engine efficiency to reduce fuel consumption. ■

New OBN Contractor Driven by Efficiency

iSEISMIC AS is a new **Ocean Bottom Seismic (OBS)** acquisition specialist led by some of the most experienced pioneers in the industry. Formed in 2018, restructured in the beginning of 2019 and part of the **iSURVEY Group**, whose track record in seabed mapping, ROV operations, accurate subsea positioning and multi vessel operations complements OBS operations, the new iSEISMIC company is focused on meeting the increasing demand for OBS data as the future of oil and gas relies ever-more on higher quality seismic data.

The team at iSEISMIC has an unparalleled track record within the OBS industry and is introducing new state-of-the-art fully automated handling technology. This will drive forward Ocean Bottom Node (OBN) deployment and recovery efficiency and therefore allow exploration seismic to benefit from the OBN technique and not just the development and production phases.

With a fleet of dual-purpose cable and ROV deployment vessels being planned, industry-leading expertise in acquisition geophysics, seismic processing, 4D/reservoir monitoring and OBS sensor technology, iSEISMIC is combining efficiency and quality in order to make OBS far more accessible and the predominant technology in the offshore seismic sector. ■

Record Breaking Milestone

Johan Sverdrup, discovered in 2010, is one of the five largest oil fields on the Norwegian Continental Shelf. With expected resources of between 2.1 and 3.1 Bboe, it will also be one of the most important industrial projects in Norway in the next 50 years – **a major engineering undertaking**.

An important step in this development was made in mid March when the last four pieces of the Phase 1 platform – the two final platform topsides, a bridge and a flare stack – were lifted into place, creating a record in the process, as moving the 26,000 tonne processing platform into place was the heaviest lift ever performed offshore. It was undertaken by the specialist heavy lift vessel *Pioneering Spirit* and took just four hours. During the same period, the final flare stack and the bridge that links the processing platform to the drilling platform were put in place by the heavy lift vessel *Thialf*. The final bridge that will connect the utility and living quarters topside to the rest of the field center will be installed soon.

This means that Johan Sverdrup looks to be on track to start producing in November 2019 as planned. ■

Equinor ASA

URTeC 2019 – A Fast Growing Event

With record-breaking attendance, over 300 technical presentations and an incredible industry response, the sixth edition of URTeC was an overwhelming success. **URTeC 2019** in **Denver** looks to push the boundaries and continue as the premier event focused on the latest science and technology applied to exploration and development of unconventional resources. It features technical papers covering geosciences, drilling, production engineering, well stimulation, reservoir engineering, material science and much more.

In addition to nearly 400 technical sessions, noteworthy planned events include the opening session, where industry leaders will discuss our energy future; the operators' forum, presenting solutions to challenging issues; and panel discussions addressing emerging technology, artificial intelligence, sustainable development, induced seismicity, well integrity, and what makes shale plays successful. The Exhibit Hall features over 170 companies with the latest technology to help safely produce more for less with an eye to environmental stewardship, as well as the U-Pitch forum connecting technology entrepreneurs with potential partners and investors.

URTeC brings the entire asset team together under one roof to connect all things unconventional. A combination of the world's leading professional societies brings both depth and breadth to the technical base of the conference, contributing to URTeC's collaborative platform and innovation exchange and sustaining and propelling our industry's ongoing success. ■

ENVOI

delivering energy opportunities

ENVOI specialises in upstream acquisition and divestment (A&D), project marketing and portfolio advice for the international oil and gas industry.

ACTIVE PROJECTS

CENTRAL ASIA
(Onshore production/exploration)

COLOMBIA
(Onshore exploration)

GABON
(Offshore exploration)

GHANA
(Offshore exploration)

KAZAKHSTAN
(Onshore appraisal/development)

NAMIBIA
(Offshore exploration)

SOUTH AFRICA
(Offshore exploration)

UK: EAST MIDLANDS
(Onshore appraisal/development)

UK: NORTH SEA
(Offshore exploration)

UKRAINE
(Onshore appraisal/development)

VISIT **WWW.ENVOI.CO.UK**
FOR MORE INFORMATION

Africa Is Back: Smarter, Better, Stronger

The **18th PESGB/HGS Africa E&P Conference 2019**, the primary technical E&P conference and exhibition on Africa, will be moving to **Olympia London** this October. A collaboration between the **Petroleum Society of Great Britain** and the **Houston Geological Society**, the event brings together leading industry professionals from IOCs, NOCs, regulators, academics and service companies to discuss and support the future of exploration in Africa.

The Africa E&P Conference 2017 in London was attended by over 600 delegates, with more than 30 countries represented, including Congo, Gabon, Madagascar, Mozambique, Namibia, Nigeria and South Africa. Reflecting the high quality technical content, more than 50% of the audience were geoscientists, with 30% of the audience identifying themselves as C-level executives.

With a technical program primed to highlight the latest developments and new insights in exploration, appraisal and development, Africa E&P Conference 2019 will cover key topics, including opening new plays, lessons learned, maximizing recovery and extending field life in established plays and basins.

Africa E&P Conference 2019 runs from **October 1–2**, 2019, with a one-day course taking place on September 30th. Registration is open now. With a rigorous technical program, bustling exhibition floor and numerous opportunities for networking, why wouldn't you attend? ■

PESGB

Major Brazil Survey

Seismic companies **TGS** and **Shearwater GeoServices** are working together to undertake a major multi-client survey in **Brazil** to provide contiguous 3D coverage over the highly prospective Brazil Round 16 blocks located in the outer **Campos Basin**. The data will be acquired by Shearwater's *Amazon Warrior*, which has a unique vessel design created for the purpose of high-capacity seismic operations in any environment, including the South Atlantic, where the stable vessel design enables low noise data to be acquired through an extended operational window.

The survey will cover 11,200 km^2 and is expected to last approximately eight months including transits. The data will be acquired using industry-leading single sensor Qmarine technology and will be processed by TGS using advanced imaging (RTM) and velocity model building (FWI) technologies to create accurate and high-resolution images of the prolific pre-salt objectives. ■

The Greatest Show in Earth Sciences!

Returning to **London's ExCeL Centre**, **EAGE's Annual Exhibition** again offers delegates a great show of the latest equipment and services related to geoscience and engineering. There will be over 350 booths to visit, kicking off with the Icebreaker Reception immediately after the opening session, with drinks, appetizers, music and entertainment.

The wide variety of exhibitors from geoscience, engineering and energy companies offers opportunities to learn about the latest products and technology, make new contacts and network with professionals from across the globe. There will be the popular International Prospect Centre, where national oil companies, licensing agencies and key players promote the latest exploration opportunities around the world. The Digital Transformation and Start-Up exhibition areas should also attract anyone interested in technological advances.

A schedule of activities can be found at the EAGE Annual website, including exhibition floor events like the Student Travel Grant Hunt! The best place to start your Exhibition tour is the EAGE Hub, where the daily program is available and staff can steer delegates to what they are looking for. The event runs from **June 3–6** and you can register for the EAGE Annual 2019 at the regular rate until May 15, 2019. ■

Meet 'tNav Tim'. He's a Reservoir Engineer who finally broke free from the pain of single core simulations, to running a fit for purpose model on 100's of CPU's and 1000's of GPU's with a fully interactive, synchronised GUI.

His life changed for the better in just a couple of clicks...

GEOLOGY » SIMULATION
UNCERTAINTY « NETWORK MODELLING

POWERED BY
RFD Rock Flow Dynamics

Follow Tim's adventures at
www.tNavigator.com/Tim #tNavTim

Canada's Ocean Playground

Exploring Nova Scotia's spectacular geology – made for the geotourist.

TIM FEDAK, Nova Scotia Museum, and **JOHN CALDER**, Nova Scotia Department of Energy and Mines

Nova Scotia – the land of lobster, the Bluenose and Celtic music – is jam-packed with geological vistas. Now known as Canada's Ocean Playground, Nova Scotia has long been recognized by geologists as a showcase of Earth history, its diverse terranes and formations put on full display by the relentless waves of the Atlantic and highest tides on Earth in the Bay of Fundy.

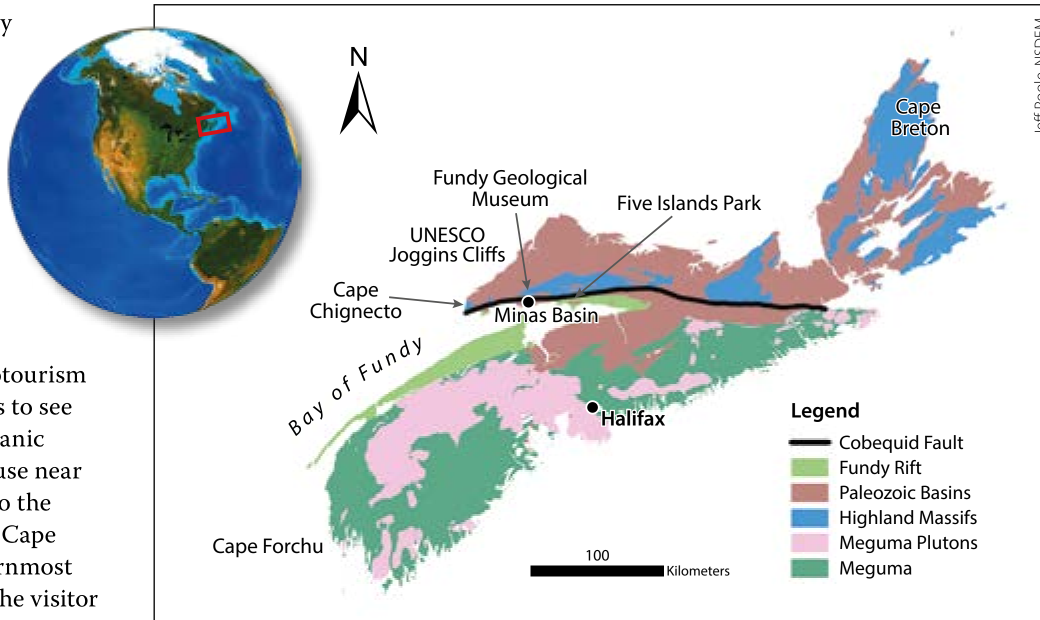
This is also the land of Mi'kmawey, with artifacts that document over 13,000 years of habitation by the Mi'kmaq. Points made of agate mounted on the tips of throwing spears (atlatl) demonstrate the Mi'kmaq harvested and used the geological resources of Nova Scotia's coastlines. The basalt headlands and islands also hold special places in the Kluscap legends and stories of Mi'kmaw culture.

The first geotourists to Nova Scotia – at least the first to write a journal about their visit – were Messrs. Jackson and Alger, who essentially did a 'sail by' of its coastal waters in 1828. Their journey along coastal cliffs and rocky shores resulted in the earliest published geological map of Nova Scotia. Their words were then 'sampled' (to the chagrin of the aforementioned gentlemen) by native son Abraham Gesner in his publication *Mineralogy of Nova Scotia*.

Gesner, a medical doctor, pioneering geologist and inventor of the first process to distill petroleum into kerosene, was not shy in using hyperbole when it came to descriptions of Nova Scotian geology, which sometimes set him at odds with the likes of other visiting emissaries like Sir Charles Lyell. And so began the differing opinions that are the hallmark of every good

The sea arch at Clarke Head and distant view of Wasson Bluff, near Parrsboro, Nova Scotia.

geological field trip. And many trips have followed, including the International Geological Congress in 1913, as well as countless societies and, increasingly, citizens who hunger for knowledge and to be thrilled by the pages of the 'Big Volume', as the cliffs of Joggins were so aptly described by Lyell.



Today, Nova Scotia is a geotourism paradise. There are many sites to see and experience, from the volcanic rocks at Cape Forchu lighthouse near Yarmouth in the south-west to the geology of the Cabot Trail on Cape Breton, the province's northernmost point. Resources abound for the visitor to Nova Scotia's geology, and a few are listed at the end of this article.

The Heart of the Matter

The reason for Nova Scotia's geological brilliance is, of course, its history, which includes slivers of terranes that originated on distant and ancient continents and oceans that have shape-shifted into later incarnations thanks to the great power of plate tectonics. The most striking feature of its geology today is the east-west trending Cobequid-Chedabucto fault, along which oceanic sediments offshore North Africa – then Gondwana – slid by northern Nova Scotia's ancient Avalon on its way to a collision with Laurentia (North America). This

The Cobequid-Chedabucto fault divides mainland Nova Scotia in two, splitting the Avalonia terrane in the north, formerly part of Laurasia and predominantly Carboniferous, from the Meguma terrane of Gondwanan affinity in the south. The Clarke Head Fault seen here is part of this complex fault system.

Igneous rocks outcrop at Three Sisters, near Cape Chignecto Park – exploring the coastal geology of Nova Scotia by kayak is an exhilarating experience.

collision of Gondwana and Laurentian North America figured in the uplift of the Appalachian mountain chain.

Not only is the assembly of the great supercontinent Pangea recorded in the geoscapes of Nova Scotia, but so too is the breakup of that supercontinent some 100 million years later. The record of that event is found in the spectacular exposures of rift basin geology, the sandstones and basalts along the margins of the Minas Basin, Bay of Fundy. These basalt headlands record the largest outpouring of lava in Earth's history, an event that has been linked to the end-Triassic mass extinction event that ushered in the reign of the dinosaurs.

A Global Geopark for Nova Scotia

It is fitting given the storyline above that the north shore of the Bay of Fundy's Minas Basin has been identified as a prime candidate for a cherished UNESCO Global Geopark destination, for it is along this shore that the story of Pangea's assembly and later breakup is showcased perhaps better than anywhere else in the world.

At the center of the Cliffs of Fundy aspiring Global Geopark is the Fundy Geological Museum, a small community-run site that includes exhibits of the region's minerals and fossils, including the oldest dinosaurs in Canada. The museum is a popular destination, offering guided beach tours and a new 'Tidal Reveal Dinosaur Dig' experience. The museum's meeting rooms and local accommodations in Parrsboro make this area a great base camp for geological field trips, with fresh Fundy lobster for dinner, of course. For the camper, Five Islands Provincial Park provides unforgettable seascapes of the Bay of Fundy, as does Cape Chignecto Provincial Park, with hiking trails along breathtaking coastal cliffs.

The rich diversity of geoheritage sites here and across the Province of Nova Scotia has been recently compiled in Nova Scotia's Geoheritage Sites list and map products, available online (https://novascotia.ca/natr/meb/geoheritage-resources/). It was this list that was used by local citizens of the Parrsboro shore to recognize the potential for establishing a Global Geopark in their part of Nova Scotia. The opportunity to link spectacular geological sites with unique tourism experiences and cultural destinations gives Nova Scotia a new opportunity to share this rich geoheritage with a growing global tourism community.

Exploring life exposed at low tide – but watch for those waters returning!

A Full Service Provider of Seismic Solutions

AGS

AGS proprietary systems are automated, our solutions flexible, and options scalable. AGS is system agnostic, meaning we have the ability to handle any system, keeping your survey on the move all while increasing safety and production without conventional or station interval constraints.

UNIQUE Technology

Pioneering new technologies and methodologies for ocean bottom node operations and offering innovative acquisition configuration options.

SCALABLE Source Vessels

We provide acquisition solutions to meet all your requirements – large turnkey projects or smaller targeted jobs from transition zone to deep water. Our global operational management will always be fully committed.

EFFICIENT Multi Purpose Vessels

Hybrid ships can function independently to acquire marine streamer data, as a source vessel on OBN or WAZ surveys or OBN deployment and recovery or any combination.

SOLUTIONS & Multi Client

AGS will acquire a fully imaged, quality broadband, full azimuth, high fold 4C dataset you can use for exploration or oil recovery enhancement over your existing fields.

www.axxisgeo.com

Joggins Fossil Cliffs World Heritage Site.

For those who prefer 'hard copy' resources, the *Nova Scotia Geological Highway Map* and *Nova Scotia Rocks* brochure are high-quality products that have been produced by the Atlantic Geoscience Society. *Geology of Nova Scotia* by Sandra Barr and Martha Hickman Hild (Boulder Press) is another excellent guide to some of the province's geological 'gems'. With these in hand, the Geoheritage StoryMap on your device, and taking note of the tide times, Nova Scotia's seascapes and geological wonders await you. In places like Advocate Harbour, it's possible to explore the coastal geology by sea kayak – an experience like no other.

Never Forget the Tides

The world's highest tides are recorded along the shores of the Bay of Fundy at Burntcoat Head Park, reaching over 16m or 52 feet! These powerful tides create ever-changing vistas that include expansive sand and mud flats important for migrating shorebirds, as well as sharp basalt headlands that offer no place to stand at high tide: be sure to always consult tide tables during your travels. In some places, the tide approaches so fast that it can surprise you and leave your return route under water.

Every day, twice a day, the Bay of Fundy tides carve a fresh exposure of the Carboniferous and Mesozoic rift basin geology that line its shores. It is this relentless erosion that produces new fossil discoveries, including the fossil 'forests of Joggins', and the oldest dinosaurs in Canada.

The upright fossil trees of the 'Coal Age', long ago made famous by the ongoing discovery of the world's oldest reptiles and other creatures, are the hallmark of the Joggins Fossil Cliffs UNESCO World Heritage Site. A delightful interpretive center and museum, and a variety of guided tours of the cliffs, invite the visitor to follow in the footsteps of the 'giants of geology' and to make their own discoveries of life 300 million years ago.

Rift Basin Field Trips

The coastal exposures of the Bay of Fundy are excellent sites for academic, professional or conference field trips. The rift basin sedimentation and tectonic structures clearly visible in the daily refreshed outcrops of the Fundy shore provide real world ground-truthing that is vital to the interpretation of seismic profiles. A popular destination for such field trips is the 'Old Wife', at Five Islands Provincial Park. The dramatic faulting and stratigraphic relationships between rift basin sedimentary rocks and basalt flows are both easily accessible and never to be forgotten.

You're Invited!

Whether you are looking for a stellar field trip destination, or a place to quietly explore while peregrine falcons and bald eagles soar overhead, Nova Scotia and the Bay of Fundy cliffs are calling to you.

More Information and Resources:

Fundy Geological Museum – https://fundygeological.novascotia.ca/

Burntcoat Head Park – https://www.burntcoatheadpark.ca/tides/

Joggins Fossil Cliffs World Heritage Site https://jogginsfossilcliffs.net/

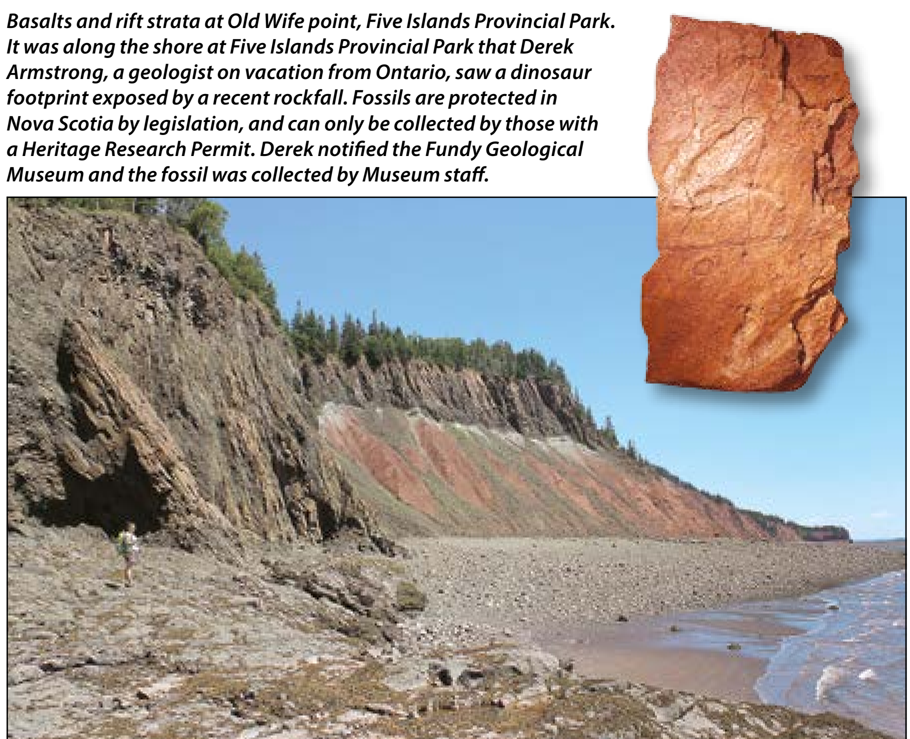
Cliffs of Fundy Geopark http://fundygeopark.ca/

Nova Scotia Provincial Parks https://parks.novascotia.ca/

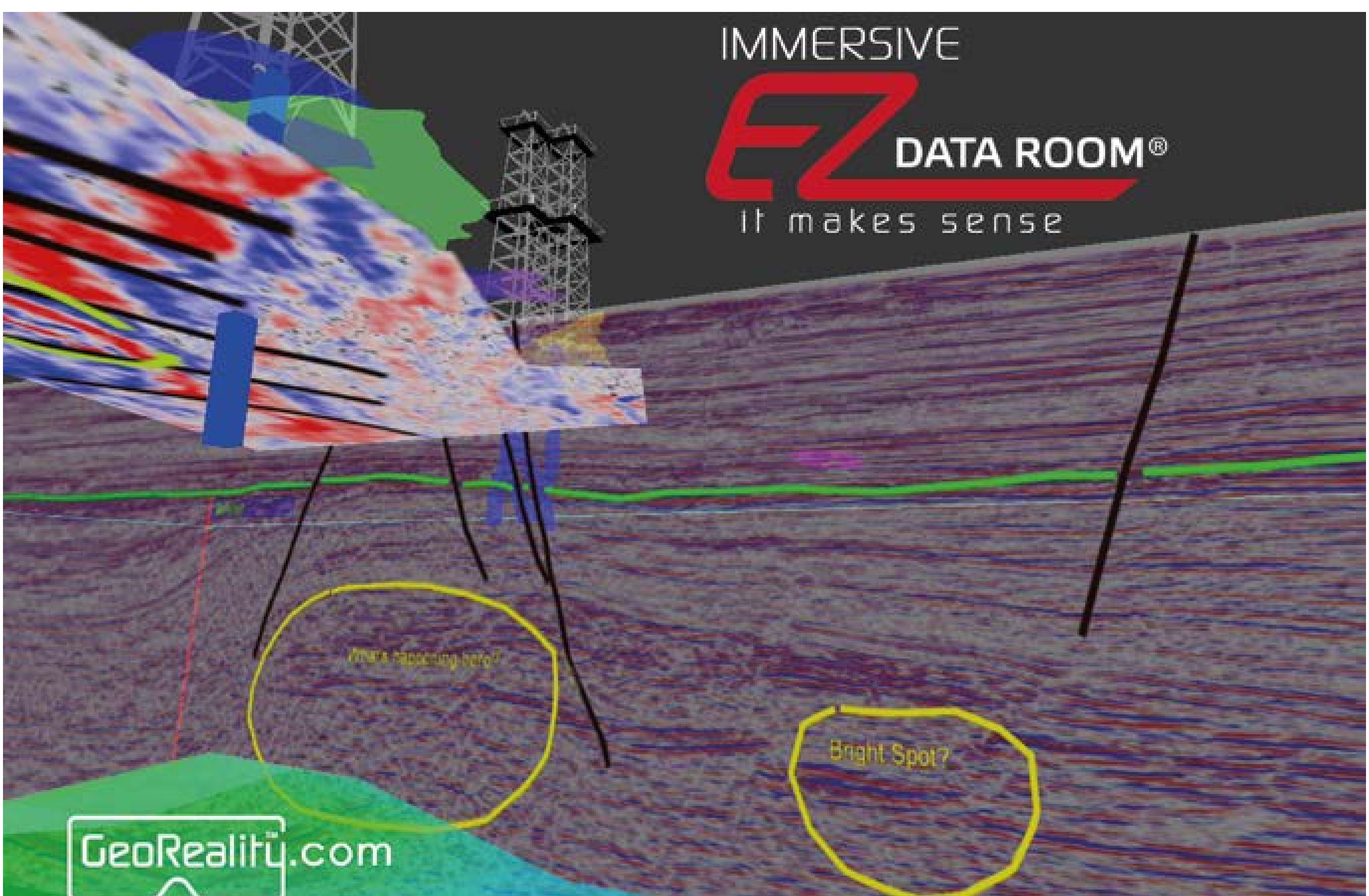
Tourism Nova Scotia http://novascotia.com

Nova Scotia Geoheritage https://novascotia.ca/natr/meb/geoheritage-resources/ ■

Basalts and rift strata at Old Wife point, Five Islands Provincial Park. It was along the shore at Five Islands Provincial Park that Derek Armstrong, a geologist on vacation from Ontario, saw a dinosaur footprint exposed by a recent rockfall. Fossils are protected in Nova Scotia by legislation, and can only be collected by those with a Heritage Research Permit. Derek notified the Fundy Geological Museum and the fossil was collected by Museum staff.




NCS Exploration 2019
Recent Advances in Exploration Technology
May 21-22 2019 | Scandic Fornebu | ncs-exploration.com | #ncsexploration
NCS EXPLORATION
RECENT ADVANCES 2019
GEO PUBLISHING
GEOLOGI FOR ALLE
GEOLOGICAL SOCIETY OF NORWAY


IMMERSIVE
EZ DATA ROOM®
it makes sense
Bright Spot?
GeoReality.com

Strong Foundations, Deep Integration, Infinite Possibilities

The key to all interpretation is the interpreter's experience and knowledge, so why should artificial intelligence change that? The reality is, it shouldn't.

JAMES LOWELL, PETER SZAFIAN and NICOLA TESSEN; GeoTeric

After a slow start, the adoption of artificial intelligence (AI) throughout the oil and gas industry is growing. Identified as the solution to many challenges across the industry, few avenues have been left unexplored to see the impact AI may have. However, AI application to the complexities of subsurface data has to date been slow.

So far, many AI proof-of-concept examples have been theoretical, presenting black box results. As a consequence, it has been difficult to accept the results of these processes, which fail to address that the key to building an effective, accurate, and appropriate geological understanding is to ensure that the interpreter sits at the heart of the whole process – and for good reason.

Human Reasoning

The traditional approach of manually picking faults and horizons on sections has been used for many years and is effective for building a conceptual model of the geology and QC'ing the individual faults and overall interpretation whilst picking. This workflow can be qualitatively enhanced by incorporating seismic attributes such as structurally-oriented semblance, tensor, dip, etc. to highlight the fault structure within a seismic dataset.

Given appropriate data quality, recent developments in this area illustrate that very high-quality attributes can sometimes be generated. Such attribute-based workflows are a significant step forward in both quality and speed for fault interpretation processes; however, there are cases when standard attribute analysis disappoints. One of the enduring problems with the established attribute analysis is noise (e.g. from poor signal quality) that can be detected in the attributes. All edges are identified, often resulting in little separation between faults, processing artefacts and stratigraphic edges.

Therefore, the industry requires technology that can see past false signals which give unclear or disappointing results in traditional fault detection attribute analysis. Recent developments prove AI can be closely aligned with an interpreter's way of working. Allowing for tightly coupled interaction as appropriate for the dataset and the individual interpreter's workflow, an integrated deep learning environment has been created to work alongside traditional fault-picking methods. This bridges the gap between an interpreter's understanding and expertise, placing emphasis on the interpreter via a limitless workflow.

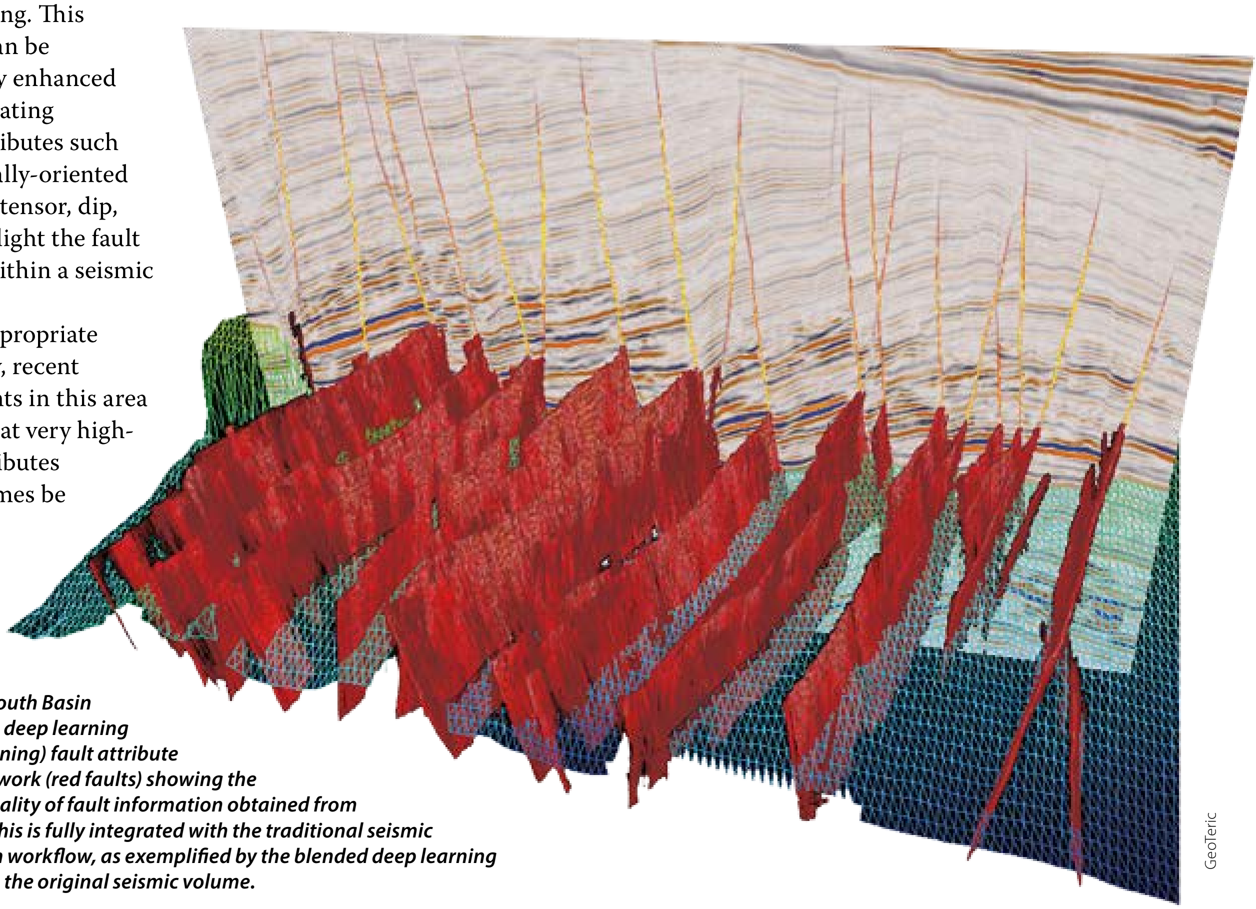


Figure 1: Exmouth Basin section with a deep learning (machine learning) fault attribute blend. 3D network (red faults) showing the clarity and quality of fault information obtained from the process. This is fully integrated with the traditional seismic interpretation workflow, as exemplified by the blended deep learning attribute with the original seismic volume.

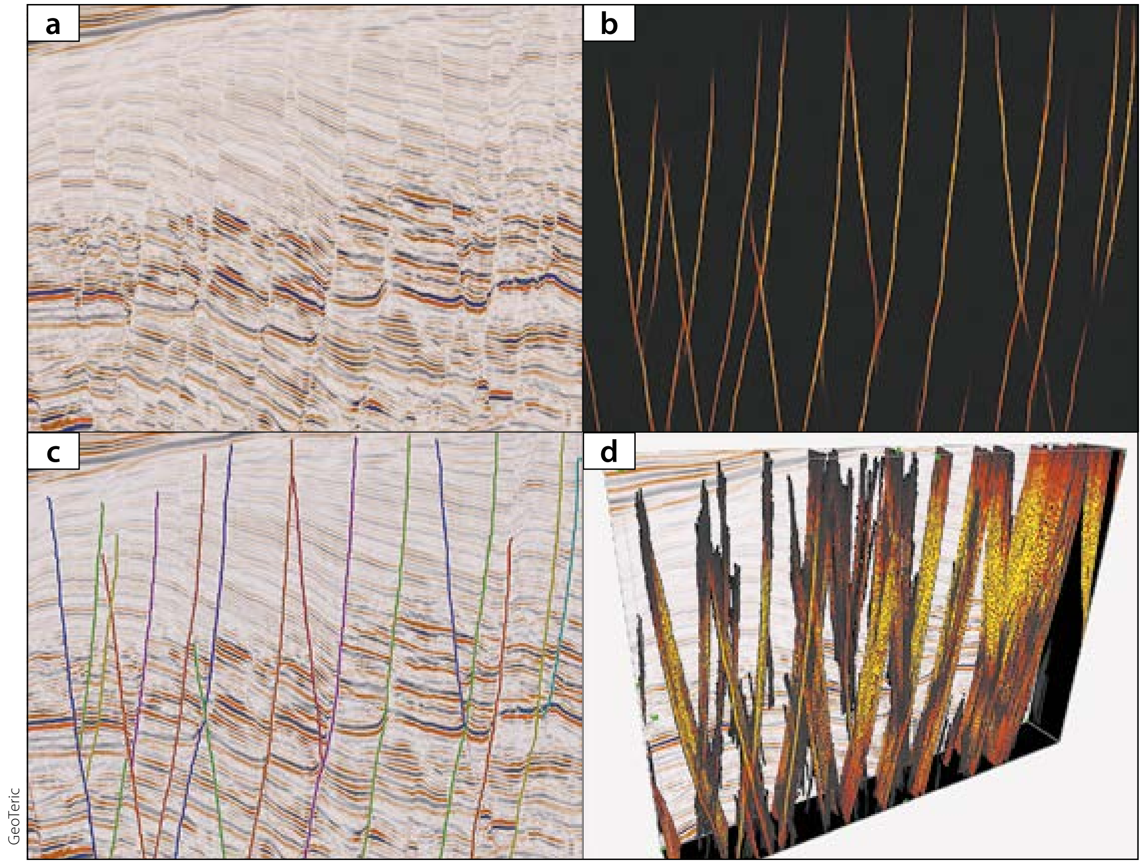


***Figure 2:* Standard seismic data (a) is taken into the deep learning environment which highlights the fault network (b). Using traditional fault interpretation (if deemed necessary), the user modifies the network via real-time training (c) for subsequent 3D interpretation (d).**

Artificial Intelligence

Human reasoning is influenced by experiences and lessons learned over time. As an individual's competence grows through experience and learning, confidence in their decision-making increases.

Deep learning, also known as deep structured or hierarchical learning networks, adopts the same theory. Deep learning algorithms are inspired by biological learning of the brain; its decisions carry with it the quality and values of what created it within a network that continues to improve as the size of its data input increases.

As artificial neural networks similarly learn by example and can solve problems with diverse, unstructured and interconnected data, such qualities make deep learning an exciting technology for seismic interpretation. However, the flexibility and power of deep learning networks does have a cost, which is the amount of labeled data required to understand how to interpret seismic data.

To overcome the need for large amounts of labeled interpreted data, deep learning models can be trained with synthetic data. For example, Pochet et al. (2018) trained a 2D Convolutional Neural Network (CNN) on patches of a synthetic dataset with simple fault geometries and saw encouraging results when tested on real sections offshore Netherlands. Huang et al. (2017) proposed training a 3D CNN on fault attributes generated from synthetic seismic cubes with simple fault configurations.

However, when a CNN is evaluated on unfamiliar data with characteristics that differ from training, the accuracy tends to drop significantly. To maintain accuracy, it is often necessary to calibrate the network to the nuances of the unseen cube. Therefore, a deep learning platform that allows real-time training with the interpreter at the heart of the process is necessary for fault, horizon or geobody interpretation.

Artificial Intelligence and Human Reasoning

One truth remains: no tool will fully replace the art of interpretation. It is the experience of the interpreter and their understanding of how the results fit into their conceptual model which makes the difference between a good or bad prospect assessment.

Part of an interpreter's toolkit is to not only produce good quality swift interpretation but also to continue to learn from their experience and interpretation. In addition, interpreters are supported in providing an assessment of confidence for each feature, which delivers an improved assessment of risk to aid more effective exploration, appraisal, and development decision-making.

Used in combination, traditional interpretation together with deep learning techniques have the power to improve the quality, speed and understanding for the interpreter through the following methodology:

Pre-trained models: The new deep learning architecture has been developed and trained on labeled images including many fault signatures from different geological environments across varying data quality. Requiring little training for the interpreter to use the workflow, the pre-trained foundation network can be applied directly onto unseen data cubes where, if necessary, they can be calibrated to the nuances of the new environment using an interpreter-centric workflow.

Interpreter-centric AI: The first step of an integrated interpreter AI workflow is the selection of a pre-trained deep learning network. The interpreter can evaluate the accuracy of the network on any slice within a seismic cube in real time. To increase the accuracy further, fault sticks can then be automatically extracted on the AI fault attribute to allow user edits.

Continuous learning: Critically, any changes to the results made by the interpreter can be captured within deep learning training, allowing the network to learn from the interpreter's experience and tailoring it to align with their geological expertise for deployment on future datasets.

By ingesting the clarifications from the interpreter, the results from the network not only improve, but it learns those improvements for the future. Importantly, through this interaction, interpreters can gain confidence in its output and, importantly, trust its judgment.

Testing the Method

Entirely down to user discretion, analysis can be focused on areas of specific interest in a seismic volume or run over the complete volume. This has been tested on datasets globally, including from the Exmouth Plateau, in the Northern Carnarvon Basin, offshore north-west Australia.

Standard seismic data (Figure 2a) is brought into the deep learning environment where the interpreter can clearly see the deep learning fault network in Figure 2b. Through easy interaction with the CNN workflow, if deemed necessary the interpreter can sequentially clarify and adjust using traditional interpretation tools, adding data specific training to the CNN (Figure 2c) and modifying its behavior. Subsequently, the 3D interpretation of the fault network (Figure 2d) can be extracted and QC'd with associated confidence measures and filters. Not only does the interpreter maintain complete control of the interpretation, but the deep learning algorithm performance improves via this approach.

Applying this training method on restricted and complex layers, the comprehensive 'out of the box' result of the CNN is presented in Figure 3a. Detailed changes by the interpreter are then added (Figure 3b) from a different line to that interpreted, again adding data specific training to the foundation algorithm. The impact of the training is seen in (Figure 3c); such training can be applied to a stratigraphic interval (as seen here) or a complete volume.

This limitless analysis approach proved to be significantly faster than traditional interpretation techniques, saving in the order of 80% of total interpretation time, even in cases requiring additional training of the foundation network by the interpreter.

The Key to Adoption

Such user improvements to the foundation algorithm or to previously evolved algorithms by other users can be applied to different datasets, transferring the learning between different geological units and regions. This opens up the ability, if desired, to have workflows designed to avoid anchoring and single views of complex systems.

Soon to be released, this method captures and integrates both the deep learning CNN environment, as well as more established workflows such as CMY attribute blends.

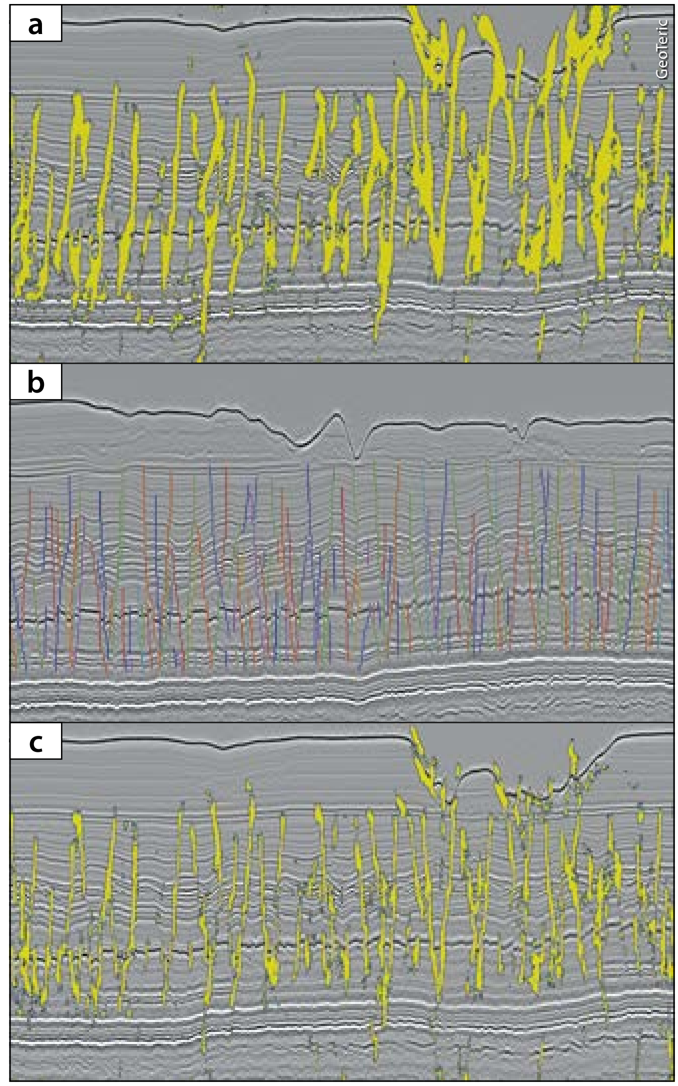


Figure 3: 'Out of the box' network result highlights fault network (a). Detailed traditional fault interpretation is applied (b) which modifies the network for subsequent training and an improved output (c).

Critically, the whole process is centered around the interpreter. The most appropriate tools can be selected for the most effective outcome when answering the questions at hand: supporting interpreters' decision-making and, significantly, maintaining control. This entirely customizable workflow can be applied in a variety of ways, meaning if users choose to lift the lid on deep learning, not only do they have a deeper insight into the process, they can benefit from its increased speed and effectively QC its results.

Without interpreter confidence in the results, deep learning will struggle to get out of the starting blocks. Putting the interpreter at the heart of the process, as this workflow does, presents an opportunity for a deep learning environment to be adopted in the subsurface arena where its benefits can be leveraged to aid effective, accurate and appropriate understanding.

Acknowledgements: *Examples presented in this article were obtained using GeoTeric™ software. The authors would like to thank Geoscience Australia for their permission to publish HCA2000A and Thebe 3D data.*

References available online. ■

INFINITE POSSIBILITIES WITH GEOTERIC

We've developed an integrated deep learning environment to work alongside traditional fault picking methods which delivers an improved assessment of risk to aid more effective exploration, appraisal and development decision making.

Putting the interpreter at the heart of the process, our entirely customisable workflow ensures the most appropriate tools can be selected by the interpreter to achieve the most effective outcome when answering the question at hand.

AVAILABLE JUNE 2019

GEO TERIC

Collaborating for MER

OUTER MORAY FIRTH SPECIAL INTEREST GROUP

Maximizing Economic Recovery in the Outer Moray Firth through a Special Interest Group.

The Outer Moray Firth (OMF) is a prolific hydrocarbon basin on the UK Continental Shelf (UKCS) with declining production and a number of fields that have now been abandoned. The basin has, however, previously seen declining production, only to be followed by rejuvenation as significant new discoveries have come onstream. Some of these discoveries had already been penetrated by early, poorly placed, exploration wells that misled geoscientists into greatly underestimating the size of the pool at the time.

Special Interest Group

In 2017 a Special Interest Group (SIG) was set up to maximize the economic recovery of hydrocarbons within the basin. This is in line with UK's Oil and Gas Authority (OGA) objectives for the UKCS, and the OGA assisted in helping get the SIG up and running, but once active then stood back from the process.

It had been recognized by the various companies active in the basin that over the coming years much of the infrastructure within the basin would be decommissioned, potentially resulting in resources remaining in the ground. It was this dilemma that drove the case for the formation of a Special Interest Group and the development of an Area Plan to try and maximize recovery.

As mentioned previously, the production history of the basin is interesting; it has three production humps, rather than a production plateau followed by decline (see figure bottom of page 25) .This can be attributed to the complexity of play types within the basin, and the underestimation of the size of early discoveries due to the poor positioning of the initial exploration well (e.g. Scott, Buzzard and Tweedsmuir fields). One of the questions raised in forming the SIG was: does this complexity mean that there is the potential for a fourth production hump?

In setting up the SIG, a decision was made very early in the process that, rather than have one or two E&P companies leading the Group, it was to be facilitated by a consultancy (1st Subsurface) with the relevant experience. This stopped any one company appearing to dominate and made collaboration between the companies easier. Importantly, it also provided manpower to a slimmed down E&P workforce, with a dedicated facilitator having the advantage of providing focus to help coordinate and move work forward.

Unlike some hydrocarbon producing basins, the OMF is not dominated by a single company with an overall understanding of basin production, resource and infrastructure. This lack of a dominant player helped further make the case for collaboration and the formation of the SIG.

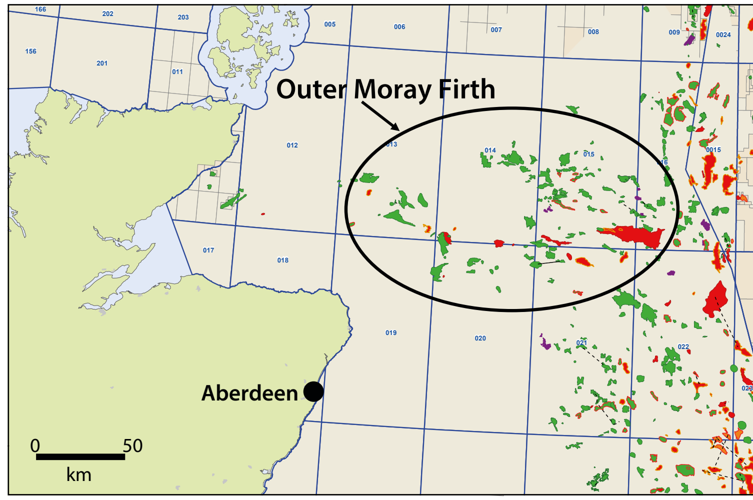
Repsol Sinopec Resources

The Claymore field in the Outer Moray Firth was discovered by Occidental in 1974 and came on production in November 1977. It is currently operated by Repsol Sinopec Resources, who are part of the Outer Moray Firth Special Interest Group.

Setting Up an Area Plan

After significant discussion within the SIG, it was decided that a phased approach should be taken to executing an Area Plan, with the first phase primarily focused on building a shared understanding of the remaining resource potential of the basin.

The SIG had a diverse membership of E&P companies for Phase I of the Area Plan, ranging from the major operators of mature assets to start-up niche players, both with and without acreage in the basin. The companies involved in this phase were CNOOC, Equinor, Kimmeridge Energy, MOL Group, Parkmead Group, Ping Petroleum, Pharis Energy, Repsol Sinopec Resources and Spirit Energy, with Suncor subsequently backing into the first phase of the study. Membership costs were structured to help maximize collaboration and encourage diversity of company size.



Location of Outer Moray Firth.

It was decided that the SIG would build its own database, which was to cover producing and abandoned fields, discoveries, and prospects and leads. This database (now called Trove) would provide a basis on which to estimate the contingent and prospective resource within the basin, as well as a database of potential opportunities within the basin and a toolkit to both help provide parameters for volumetric estimations and assist in peer-reviewing opportunities.

Trove Database

With competition law in mind, it was decided that the database would initially be based on public domain data. It was important for the membership that Trove was a structured database, with an audit trail showing a collation of all interpretations from the various evaluating companies and the nature of that documentation (e.g. relinquishment report versus farm-out flyer). The audit trail was the main driver in the decision to build the database, as it allowed individuals to make judgement calls on the quality of the resource and risking numbers.

Public domain data is particularly good in the UK because of the OGA relinquishment report requirements. In addition, the willingness of companies to publish field data and the richness of smaller to moderate size E&P company information on their websites give a solid basis on which to construct a database. To enhance the database, SIG Members made available non-confidential data that was not in the public domain.

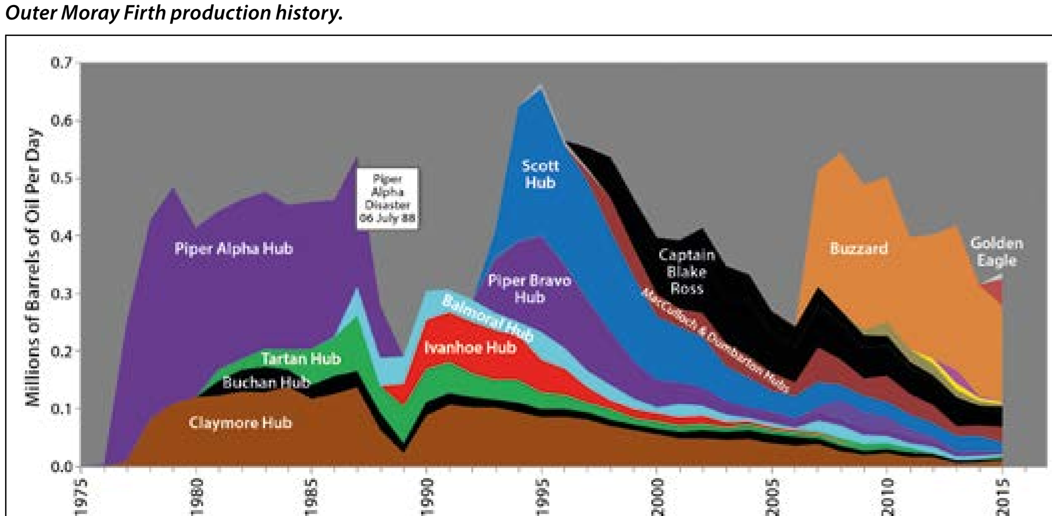
As the SIG moves into Phase II of the Area Plan, the database is being used by members to have conversations around resource numbers, comparing them with their internal evaluations, and then agreeing to update the database as necessary. Again, this is non-confidential information, but currently not in the public domain. Where confidential information needs to be used, the SIG have developed a toolkit which they believe complies with competition law, and are ready to bring that before the Competition and Mergers Authority when necessary.

Resource Potential

At the end of Phase I, a total of 375 prospects and leads were identified within a 30 km tie-back distance of the OMF infrastructure, with 77 considered downgraded leads. These had a prospective resource of 5,856 MMboe, with a risked prospective resource of almost 1 Bboe. A total of 95 discoveries were identified, with a contingent resource of 1,171 MMboe.

In understanding how best to develop the remaining potential within the basin, documenting the fluid types is essential for both the contingent and prospective resource. The fields and discoveries within the basin are dominated by light and medium oil, with a significant portion of heavy oil, lesser amounts of sour crude, and gas and gas condensate. Heavy oil was split into those crudes with a specific gravity of less than 20° API, and those between 20° and 25° API. The

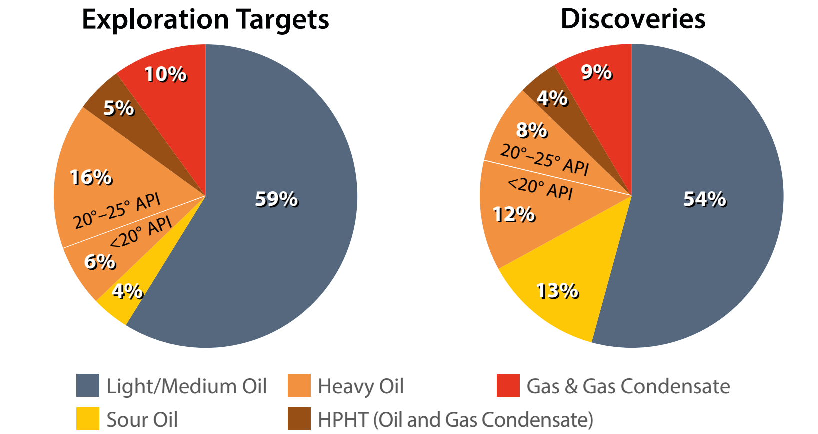
Outer Moray Firth production history.



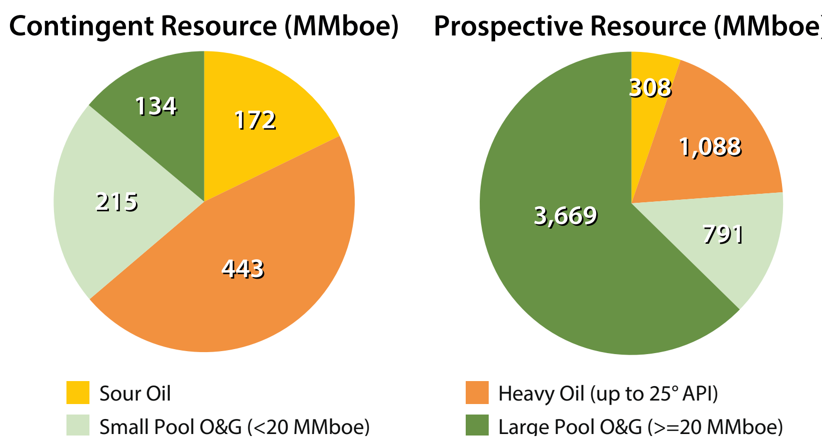
inclusion of the latter grouping reflects some of the development challenges they present on the UKCS. HPHT oil and gas condensate made up a very small portion of discovered resource.

To the Group's knowledge there had been no previous attempt to systematically quantify the likely fluid types in the exploration targets across the basin. Predictions were based on nearby fluids, depth, pressure cells, and migration routes. The result was a distribution similar to the discoveries. Some differences may be expected in that sour fluids are less likely to have been developed and shallow targets that are likely to contain biodegraded heavy oil remain disproportionally undrilled.

Analysis of the data identified three categories of contingent resource on which future SIG work should focus: sour oil, heavy oil and small pools. HPHT and gas did not show as having much significant remaining potential. There is also exploration potential in these three categories, though until the challenges of tying in small pools has been solved, they are unlikely to become an exploration target.



Fluid types for exploration targets and discoveries by count.



Contingent and prospective resources for SIG high-graded fluid types.

Unlocking the Potential

At the end of Phase I of the Area Plan, the three high-graded contingent resource categories based on potential resource size and to a lesser extent on the membership focus were sour crude, heavy oil, and small pools. For Phase II of the Area Plan, a focused work program was pulled together to better define each of the three high-graded contingent resource categories, identify barriers and drive actions to move towards development. The SIG has initiated the first of these three work programs.

In addition, four enabling workstreams have been identified: exploitation, investability, technology, and infrastructure criticality. Again, these are being executed in a rolling manner, with the technology scope being worked on with the UK Oil and Gas Technology Centre (OGTC). The investability workstream addresses the capital cost elements of wells, trees, and tie-back pipelines. This will seek to produce a *Which*-type reliability guide and look at cost savings through standardization.

The OGTC has become progressively involved with the OMF Special Interest Group. By defining the remaining potential of the basin, alongside a rich database around which a technical conversation can take place, the impact of the technologies required to unlock that potential can be quantified and R&D spend justified. This then feeds back into a willingness and alignment of the SIG Members to support OGTC initiatives such as 'Tie-back of the Future' (https://www.theogtc.com/newsroom/videos/2018/tie-back-of-the-future), with studies of particular focus on the issues facing the OMF. Joint SIG Member funding has the potential to be matched by the OGTC, with further funding from industry bodies such as Scottish Enterprise.

The Outer Moray Firth Special Interest Group is in the early stages of the second phase of the Area Plan, and is looking to recruit new members, irrespective of their size. Further details on the SIG and various papers presented can be found on the OMF SIG website at www.omfmer.uk. ■

Scopes of Work – Theme matrix for Phase II of the Area Plan.

		Themes		
		Small Pools	Sour Oil	Heavy Oil
Enabling SOWs	Exploitation	• Further refinement of each theme's Prize • Accelerate Opportunity Delivery if blockers removed		
Enabling SOWs	Cost Elements (Investability)	• Cost base • Investment risk management		
Enabling SOWs	Technology / OGTC	• Recovery Factor Improvement • New production facilities • Safe operations		
Enabling SOWs	Infrastructure Criticality	• Importance of satellites to hosts • Identification of "stranded" hotspots		

LAST CHANCE TO REGISTER

Geoscience Knowledge Exchange at an Elite Level

Why are thousands of geoscientists going to ACE? With over 900 technical presentation, ACE delivers the science and expert knowledge necessary to locate and produce tomorrow's hydrocarbons. Take what you learn at ACE and apply it directly to your day-to-day projects for increased efficiency, higher profitability, and maximized production. ACE helps drive your success!

ACE.AAPG.org

Santos Vision:

Innovative Seismic Data Processing in a Super Giant Oil Basin

PGS has rejuvenated its Santos portfolio and final products from the reprocessing effort are available now. Covering around 34,000 km², the Santos Vision program delivers the most comprehensive and geologically conformable dataset to date, mitigating exploration risk in the prolific pre-salt play of the basin. The latest in broadband processing has been applied and the single data volume represents the largest Reverse Time Migration (RTM) and Kirchhoff prestack depth migration (KPSDM) successfully completed by the industry. Extension of the dataset to more than 60,000 km² of full and seamless coverage is in progress. The recent application of PGS Least-Squares Migration (LSM) to a subset of the seismic data demonstrates a further uplift in image resolution that provides unprecedented resolution in post- and pre-salt imaging.

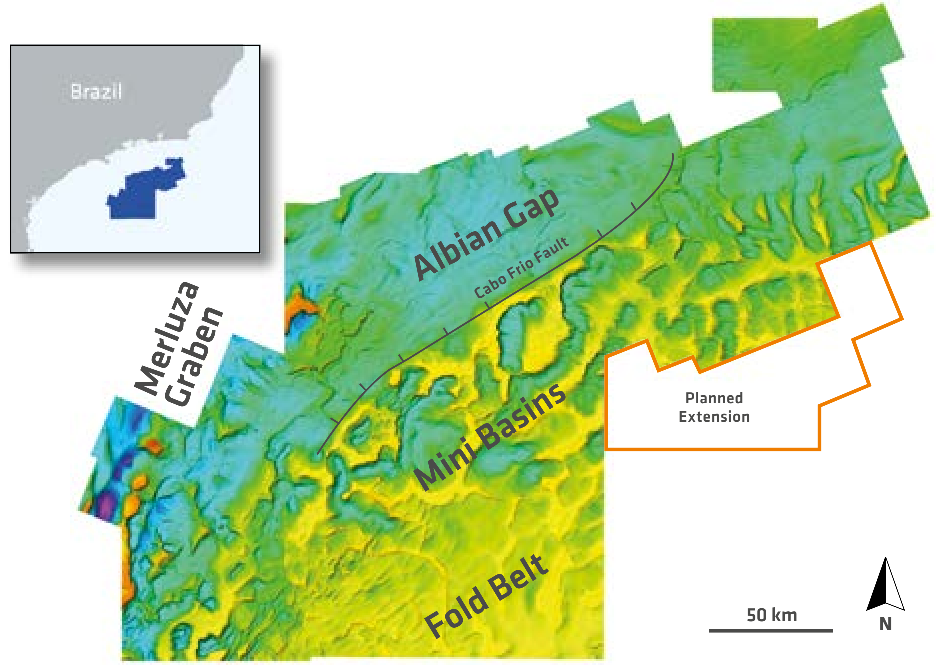
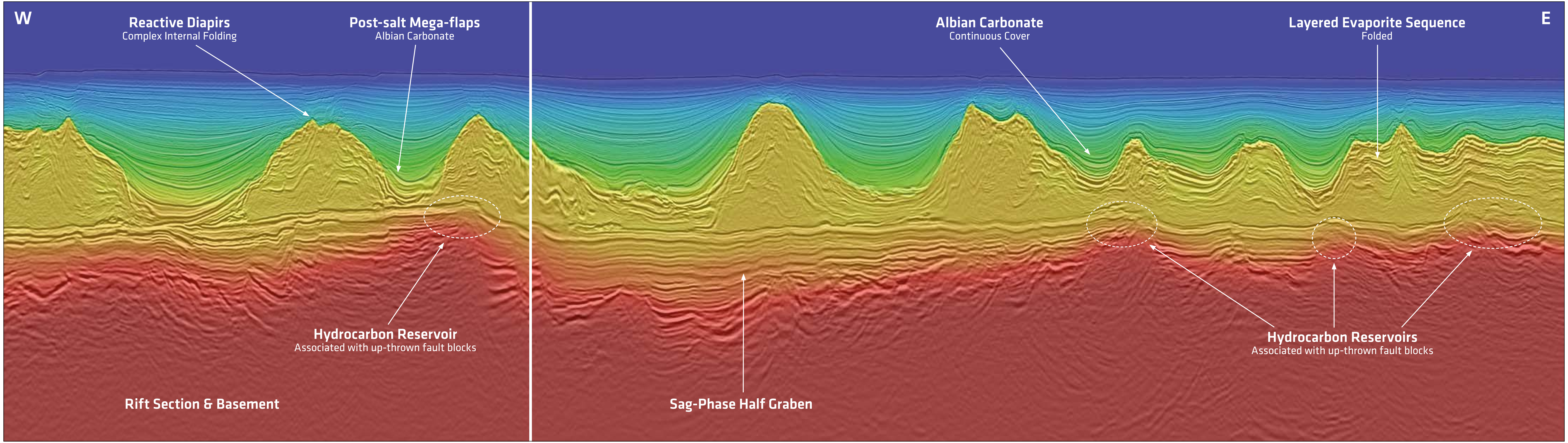


Figure 1: Structural map of the top of salt encompassing the 34,000 km² of the Santos Vision program and including the outline of the next phase extension. The survey covers the São Paulo Plateau, which hosts huge hydrocarbon discoveries such as the Lula field, Buzios and Carcara and with more yet to come. The Plateau is subdivided into three tectonostratigraphic domains and the new images reveal the architecture and internal structures of the Aptian salt.

Two domains of the São Paulo Plateau are shown in the foldout seismic line. Firstly, there is the mini basin domain with thickened salt walls which separate partially grounded mini basins containing post-salt Albian carbonate mega-flaps. The second domain is characterized by harmonically folded and layered salt sequences that carry a rather undisrupted Albian carbonate cover. Potential hydrocarbon reservoirs are associated with normal fault highs of the pre-salt sequence.



One Single Volume for the Best Geological Insight

Delivering better fault definition and seismic stratigraphy for improved reservoir characterization

HERMANN LEBIT, SRIRAM ARASANIPALAI, JEFF TILTON and PASCAL OLLAGNON; PGS

Seismic data have many applications throughout the life cycle of hydrocarbon exploration and production. From regional reconnaissance to prospect maturation and field development, the impact of seismic data is closely linked to their quality, resolution and fidelity. These key objectives resonate throughout the energy industry, including Brazil, and demand superior seismic quality. Our answer is the deployment of innovative technologies for reprocessing existing seismic data from the Santos Basin offshore Brazil that reveals striking detail of the petroleum systems in the pre-salt and post-salt sequences of this extremely prolific basin.

The Santos Vision product provides high resolution seismic images for better delineation of potential trap architectures, enhances reservoir characterization capabilities and emphasizes critical observations impacting the understanding of the petroleum system and salt displacement in the Santos Basin.

The velocity model building adopts a domain approach guided by the major tectono-stratigraphic units, including the Aptian salt architecture. The focus is on a seamless geologically conformable velocity model and integrates data-driven processing results based on hyperTomo velocity updates and subsequent refinement by PGS' unique Full Waveform Inversion (FWI) approach.

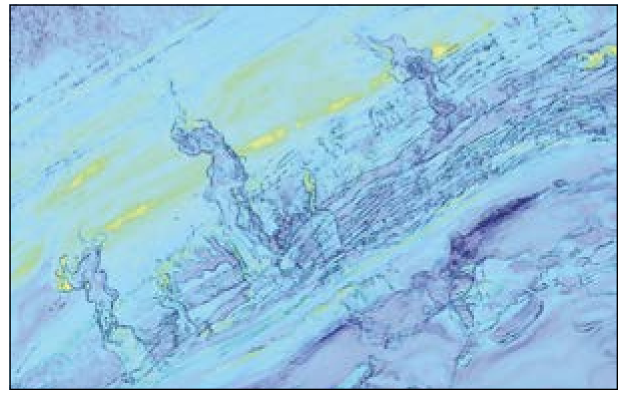


Figure 2: Depth slice at 2,000m through a coherence cube, co-rendered by RMS amplitude colors utilizing the high resolution PSDM Kirchhoff dataset. Paleogene sub-aquatic canyons along the Santos Basin paleo-shelf, truncated by en echelon normal faults related to subsequent shelf instabilities.

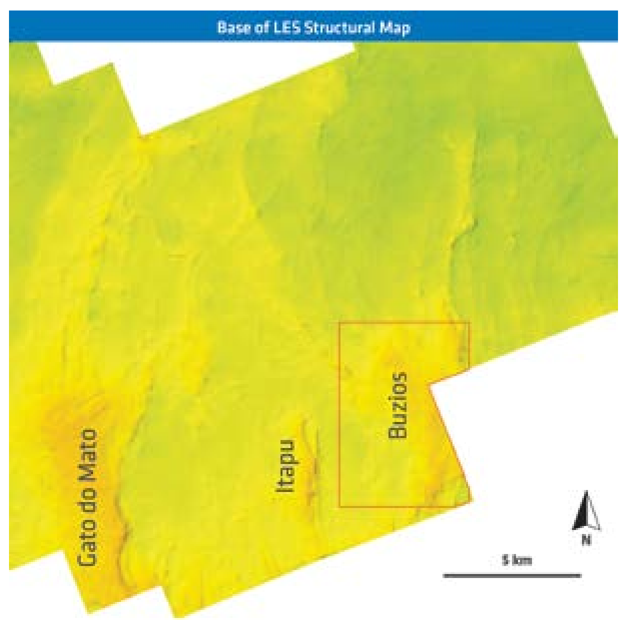


Figure 3: High resolution base of salt map highlighting the structural highs associated with the pre-salt fault patterns. The major pre-salt hydrocarbon reservoirs are localized at these highs and formed by carbonate buildups along the up-thrown fault blocks. The red outline marks the area for the LSM migration in Figure 4.

Understanding the Geological Setting

Located in the Santos Basin offshore Brazil, the survey area comprises over 34,000 km^2 of continuous high-resolution broadband seismic data, which have been calibrated by an increasing number of pre-salt well penetrations. The combined seismic surveys cover the São Paulo Plateau, a rift-related basement high that is subdivided into three tectono-stratigraphic domains based on the salt and post-salt architecture (Figure 1). The inboard north-western domain comprises the Albian Gap, an approximately 40 km-wide zone of Upper Cretaceous roll-over clinoforms. Its sedimentary loading displaced most of the underlying Aptian layered evaporite sequence (LES) including the post-salt Albian carbonates. The Albian Gap terminates against the Capo Frio Fault, a predominately counter-regional normal fault that reveals thick sections of Aptian LES in its footwall. The thickened salt sequence is frequently disrupted by down-building mini basins, which occasionally ground against the pre-salt sequences while carrying mega-flaps of post-salt carbonates at the base (see foldout section, left-hand side). These post-salt carbonates play a key role in creating an accurate velocity model as their interval velocities are controlled by overburden (confining pressure) and vary significantly along the Albian mega-flaps.

Within the LES, highly reflective layers of evaporites indicate complex internal folding, whereas rather transparent sections are interpreted as accumulations of intra-formational mobilized halite. The occurrence of mini basins diminishes towards the south-eastern domain of the São Paulo Plateau and increasingly well imaged fold patterns within the LES can be found that are gradually transient into asymmetric and then upright folds. When approaching the most distal sections relative to the Albian Gap, little to no internal deformation is imaged in a well stratified layered evaporite sequence. The inferred original thickness of about 1,500m contrasts with the more than 4,000m thickness measured at the salt walls and diapirs separating the mini basins. It was found that displacement loading of the propagating sedimentary wedge at the Albian Gap caused lateral outward flow and frontal thickening of the layered evaporite sequence. The frontal bulging of the LES tapers out with increasing distance from the Albian Gap, as documented by the decreasing internal salt (LES) deformation towards the distal domain.

In contrast to the passive behavior of the salt/LES on the São Paulo Plateau, the Merluza Graben reveals active diapirism and allochthonous salt sheets. The graben system is located inboard and separated from the São Paulo Plateau by normal faults that may exceed 3,500m in throw. It appears the faults have been active during the deposition of up to 4,500m of LES inside the half grabens, while the plateau has received merely 1,500m of evaporite deposits. The grabens reveal a north-north-east to south-south-west trend, which is also reflected by the rugose base of the LES at the São Paulo Plateau. There, the pervasive fault system forms the grain of the major pre-salt hydrocarbon reservoir facies associated with carbonate buildups that nucleate along up-thrown fault blocks.

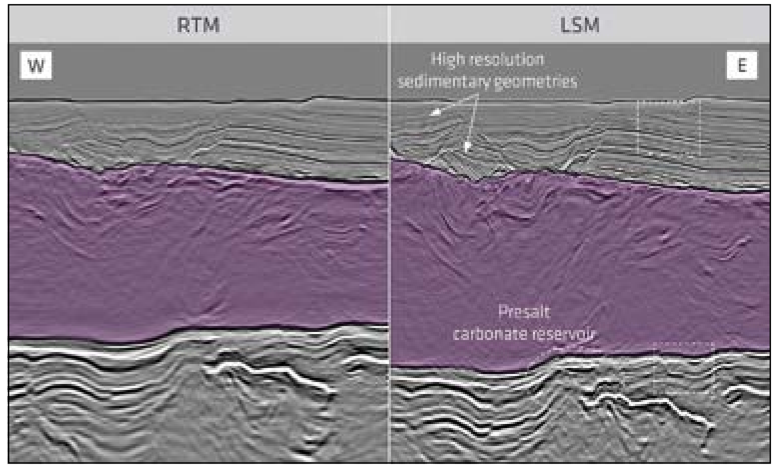


Figure 4: Comparison between RTM and LSM highlighting the stunning improvement in imaging the fault patterns (square boxes) in the post-salt and pre-salt sequences. Note also the granularity in the cap rock sequences above the salt (magenta) and the resolution of sedimentary geometries in the post-salt achieved by LSM. The stratal resolution and fault recognition at the pre-salt reservoir section on the LSM image enables detailed analysis in seismic stratigraphy and reservoir characterization.

Better Seismic Images

The post-salt sediment velocity model building process utilized a combination of data-driven traditional tomography and FWI. Our proprietary, unique implementation of FWI is based on the full wavefield and includes both reflection and refraction wavefields. This approach allowed iterative velocity updates of the post-salt Cenozoic sediment sequence up to 6 km depth. A geologically consistent post-salt sediment velocity model for the entire dataset was built and accurately captures the depth-dependent velocity variability of the Albian carbonates within the mega-sequences of overlying Upper Cretaceous clastic sediments (Figure 2).

Following the successful results updating the velocities in the post-salt sediments, the FWI approach was extended to capture the velocity variations in the layered evaporite sequence and subsequently to update the pre-salt velocities. This data-driven approach over 34,000 km^2 generated continuous velocity model updates through the salt and into the pre-salt, avoiding an imprecise horizon-based velocity boundary at the base of the salt. The resulting seismic image allows for a high resolution base of salt interpretation, as shown in Figure 3.

Enhanced imaging in the Santos Basin was achieved by utilizing a full bandwidth Kirchhoff migration and a 35 Hz RTM, outputting angle gathers at every image location. Usage of angle gathers in the post-imaging workflows results in an excellent pre-salt image.

Improved Definition of Targets

Current imaging technologies (RTM, Kirchhoff Migration) provide a level of seismic resolution that suits the industry's expectation for capturing hydrocarbon reservoirs and outlining prospects. For further improvement in resolution, PGS developed a LSM technology that corrects for acquisition effects, limited aperture and variable illumination. In this particular approach, the difference between the observed data and the synthetic data, modeled using a migrated stack and a velocity model, is minimized in a least-squares sense to update the image.

The result of this application has enhanced resolution of fault patterns and sedimentary geometries in the shallow section as well as in the pre-salt section, improved imaging of the complex fold interference pattern within LES and provided a significant improvement in resolution of the carbonate reservoir section. The LSM stack also provides high granularity in attribute patterns and results in better definition of hydrocarbon reservoir targets (Figure 4).

Fault patterns and stratigraphic geometries are better resolved with PGS LSM. It also provides significant uplift for prospect maturation and reservoir characterization. The enhanced seismic resolution supports mitigating compartmentalization risk, resolves depositional signatures and limits uncertainties in seismic stratigraphy characterization of reservoir facies variation. This technology proved to be beneficial at all stratigraphic levels, but most importantly in the prolific pre-salt play of the Santos Basin and elsewhere.

Santos Vision

This new regional contiguous volume accurately images the passive margin and rift section of the Santos Basin, reducing prospect risk and allowing explorationists to verify and extend their own vision of this prolific basin. The inclusion of a geologically conformable velocity model results in uplift in the pre-salt image, resolving the complexity of the layered salt and the variability of the post-salt carbonate velocities. Santos Vision delivers high granularity imaging of the base salt morphology and reveals reservoir presence. It also accurately images the faults beneath the salt, mitigating reservoir integrity risks and supporting petroleum system assessment, including gas invasion. ■

NAPE
Where Deals Happen

SUMMER NAPE

21–22 AUG 2019 | HOUSTON, TX

GEORGE R. BROWN CONVENTION CENTER

EXPLORE THE HOTTEST TOPICS

BUSINESS CONFERENCE

The NAPE Business Conference features presentations that explore the industry's most pressing topics. This year's Business Conference will cover topics ranging from "Horizontal Drilling in the Permian Basin" to "Mineral Acquisitions" as well as a luncheon keynote from Kimberly McHugh, Chevron's vice president, upstream drilling & completions.

LAUNCH YOUR NETWORKING AND DEAL-MAKING OPPORTUNITIES

CONNECTIONS & CONVERSATIONS: YOUNG PROFESSIONALS IN ENERGY

Connections & Conversations is a new event designed to bring together specific groups within the energy industry to network and form professional relationships. This summer the program will be tailored to professionals who are early in their careers and looking for advice and inspiration from industry leaders. The event is free but requires an RSVP during registration.

JOIN THE SPACE RACE

EXHIBIT AT NAPE

Secure the best available booth space on the show floor before it fills up. Better yet, upgrade your experience by purchasing a sponsorship and receive priority placement for maximum exposure. Don't miss your opportunity to get the best spot available — sign up today!

REGISTER & LEARN MORE AT
www.NAPEexpo.com

Basin Classification

Oil and natural gas (as well as groundwater) are all found in sedimentary basins. Basin classification based on tectonic settings provides a framework not only for understanding the genesis and evolution of petroleum basins and their sedimentary fill but also process-based analogs for the exploration of frontier basins.

RASOUL SORKHABI, Ph.D.

"Classifications are theories about the basis of natural order, not dull catalogues compiled only to avoid chaos."

Stephen Jay Gould
Wonderful Life: The Burgess Shale and the Nature of History (1989)

Basin: What's in a Name?

The term 'basin' has different meanings depending on its location and containment. Groundwater basin is for aquifers; drainage basin delineates a river system; oceanic basin refers to the abyss; and sedimentary basin is a depression in the earth's crust filled with sediments.

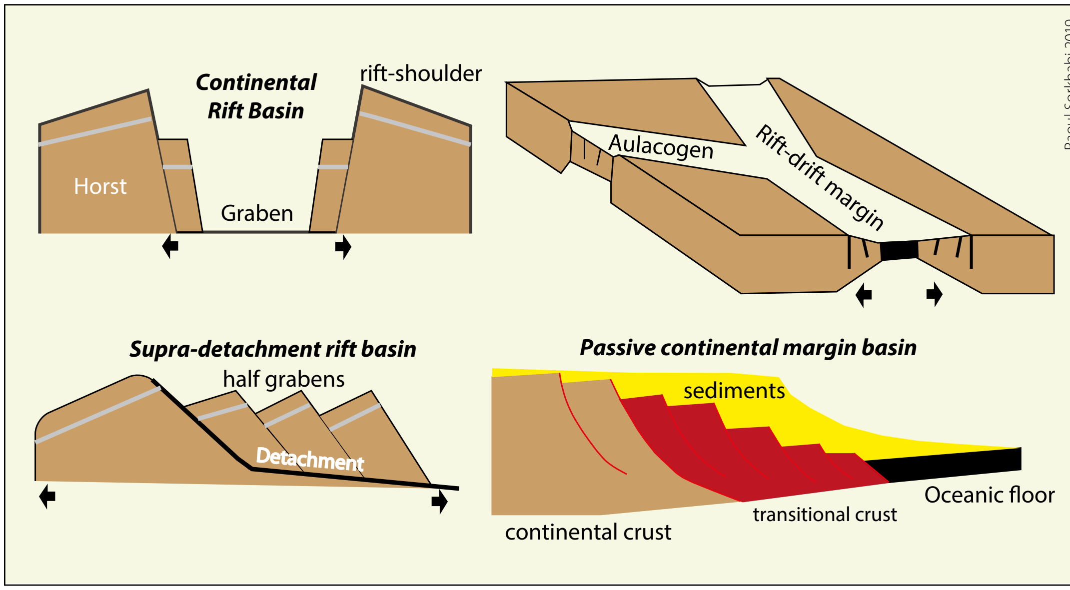
Sedimentary basins are on the scale of tens to hundreds of kilometers in length and width, and thousands of meters in depth. As such they are usually tectonic basins formed by plate tectonic processes. A. G. Fisher distinguishes between 'starved' (partially filled with sediments), 'stuffed' (fully filled), and 'overfilled' basins. Gerhard Einsele distinguishes between 'active' (still subsiding and receiving sediments), 'inactive' (with no deposition), and 'deformed' (uplifted, eroded, and structurally deformed) basins. Basins may be 'closed' (e.g., a lake) or 'open' (e.g., marine shelf); they may be located onshore, offshore or deepwater (below the shelf-slope break).

Basins may also be described in terms of depositional environment (fluvial, eolian, deltaic, lacustrine, continental, marine, reefal, abyssal) or sedimentary fill (clastic, carbonate, evaporate, turbidite) or what economic resource they contain (petroleum, natural gas or coal). A vast majority of sedimentary basins are also petroleum basins, which may be 'mature' (well explored and produced) or 'frontier' (little explored or drilled). Sometimes we refer to basins in terms of their geographic location, e.g., North American or Southeast

A view of the Grand Canyon in Arizona incised by the Colorado River.

Jane Whaley

Asian basins; or the particular stratigraphic period when they formed, such as Silurian or Jurassic basins.



Basins of divergent plates.

Plate Tectonics and Sedimentary Basins

Only a tectonic classification explains the origin and evolution of sedimentary basins and their sediment fill. Before the plate tectonic revolution of the 1960s, sedimentary basins were viewed as 'geosynclines' and were described by a terminology that was sometimes confusing and misleading. In the mid-1970s and early 1980s, thanks to the efforts of William Dickinson, Albert Bally, Doug Klemme and others, plate tectonic approaches to classify sedimentary basins were developed (see references online *Geoexpro.com*).

A plate tectonic approach considers five main factors:

1. Nature of the crustal basement underlying the sedimentary basin. The basement may be continental (with a granitic composition, density of 2.7 g/cm^3, and an average thickness of 30–40 km), oceanic (with a basaltic composition, density of 2.9 g/cm^3, and average thickness of 6 km), or transitional, as typically found along the rifted continental margins.
2. Position of the basin in the plate interior, plate edge or continental margin (intra-cratonic, passive margin, active margin or suture zone).
3. Plate tectonic setting, i.e. the nature of plate boundary associated with the basin. This may be divergent, convergent or transform.
4. Orientation (parallel or perpendicular to the tectonic plate boundary) and shape of the basin (wide or narrow, elongated, circular, triangular or quadrilateral).
5. Mechanism of basin subsidence including crustal stretching (extension), compressional tectonic loading, crustal bending by sediment overload, and thermal (cooling) subsidence of the crust.

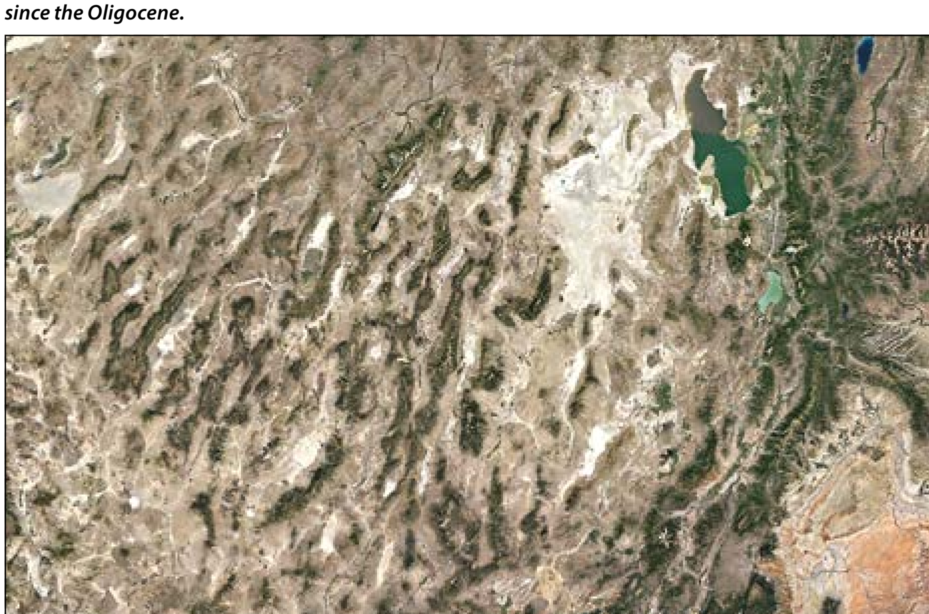
It is important to note that sedimentary basins are composite in their nature and complex in their histories. A basin may start as a continental rift and then proceed over tens to hundreds of millions of years to become a foreland basin in front of a lofty mountain. In other words, a tectonic and facies analysis of the sedimentary record of a basin may reveal various types of tectonic settings. Usually the latest tectonic setting is used to categorize a basin.

The following is a brief description of sedimentary basins based on plate tectonic settings and with emphasis on petroleum prospectivity.

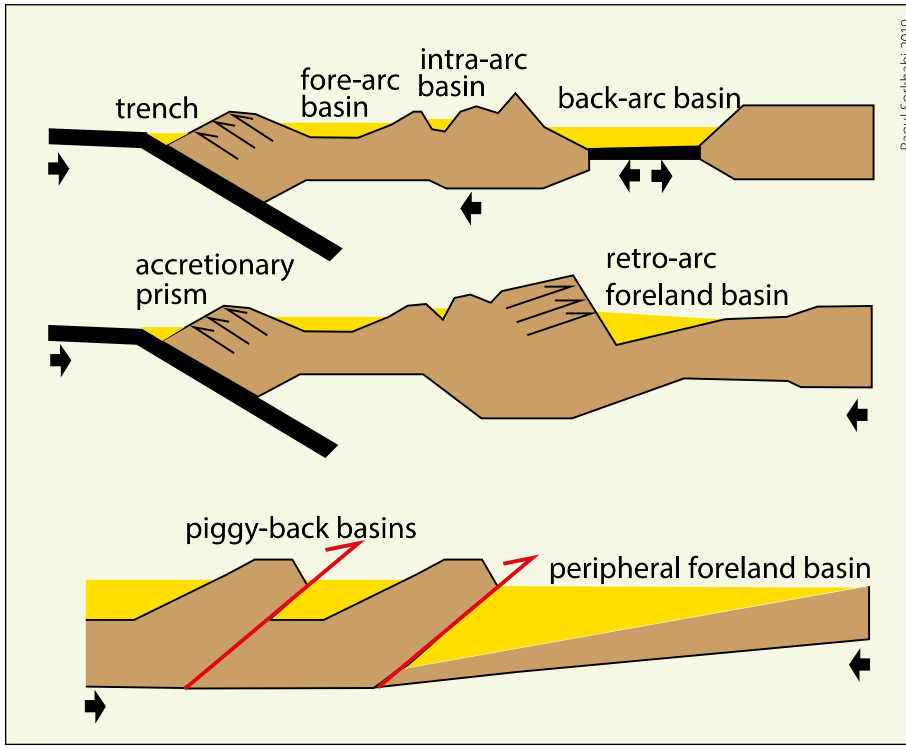
Cratonic Basins

A craton includes an igneous-metamorphic core or a stable basement, called the 'Precambrian shield' covered by a **continental platform** with sediments deposited over hundreds of millions of years. Within a craton there may also be **intra-cratonic basins**. Examples include the Illinois, Michigan and Williston Basins of the North American craton.

A Google Earth image of the Basin-and-Range in south-west USA, formed by tectonic extension since the Oligocene.



Intra-cratonic basins initially formed in proximity to plate margins (rifting or convergent) but are currently far from plate boundaries. These long-lived basins are sustained by a low degree of crustal stretching and thermal subsidence affecting the plate interior over geological time.



Basins of convergent plates.

Basins of Divergent Plates

The extension and thinning of continental lithosphere leads to continental rifting, which involves volcanic eruptions and normal faults. High-angle normal faults produce horsts and grabens (basins) parallel to the rifting. Modern examples of **continental rift basins** include the East African lakes and the Rio Grande in New Mexico. In low-angle normal faulting, the basin lies above a major detachment fault at mid-crustal depths; this **supra-detachment basin** is characterized by a series of elongated ranges and half-grabens. The Great Basin in south-west USA is a well-studied example of this type of continental extension.

As the extension progresses and mantle asthenosphere rises, a juvenile oceanic crust splits the continent into two divergent plates. The Red Sea between Africa and Arabia is a typical example of this **proto-oceanic** (or **nascent ocean**) **basin**.

In continental rift settings, three rift faults at 120° form a triple junction. Of these, two rift arms continue to extend and separate the continent while the third arm fails to do so. These **failed** (or **fossil**) **rift basins** are usually perpendicular to the rifted continental margin. Also called **aulacogens** (from the Greek *aulax*, 'furrow') by the Russian geologist Nikolay Shatsky, failed rift basins are well recorded along the East and West Africa margins. They are often overlain by major river deltas and are excellent basins for oil and gas exploration.

Continental rift basins may eventually evolve into ocean basins with a mid-ocean ridge forming the boundary of the two divergent plates. In this case, the **passive continental margin** in the interior of the plate develops a shelf-slope-rise configuration with a wedge of sediments thinning toward the ocean floor. Passive continental margin sits on top of the initial continental rift structures and thinned crust, and its sedimentary history is largely controlled by sea level transgressions and regressions as well as thermal subsidence (cooling and sagging) and sediment overloading (bending) of the thinned continental crust. Passive continental margins have very long, wide and thick shelves made up of sandstone, carbonate and mudstone as well as slope turbidites and rises as observed along the Atlantic margins.

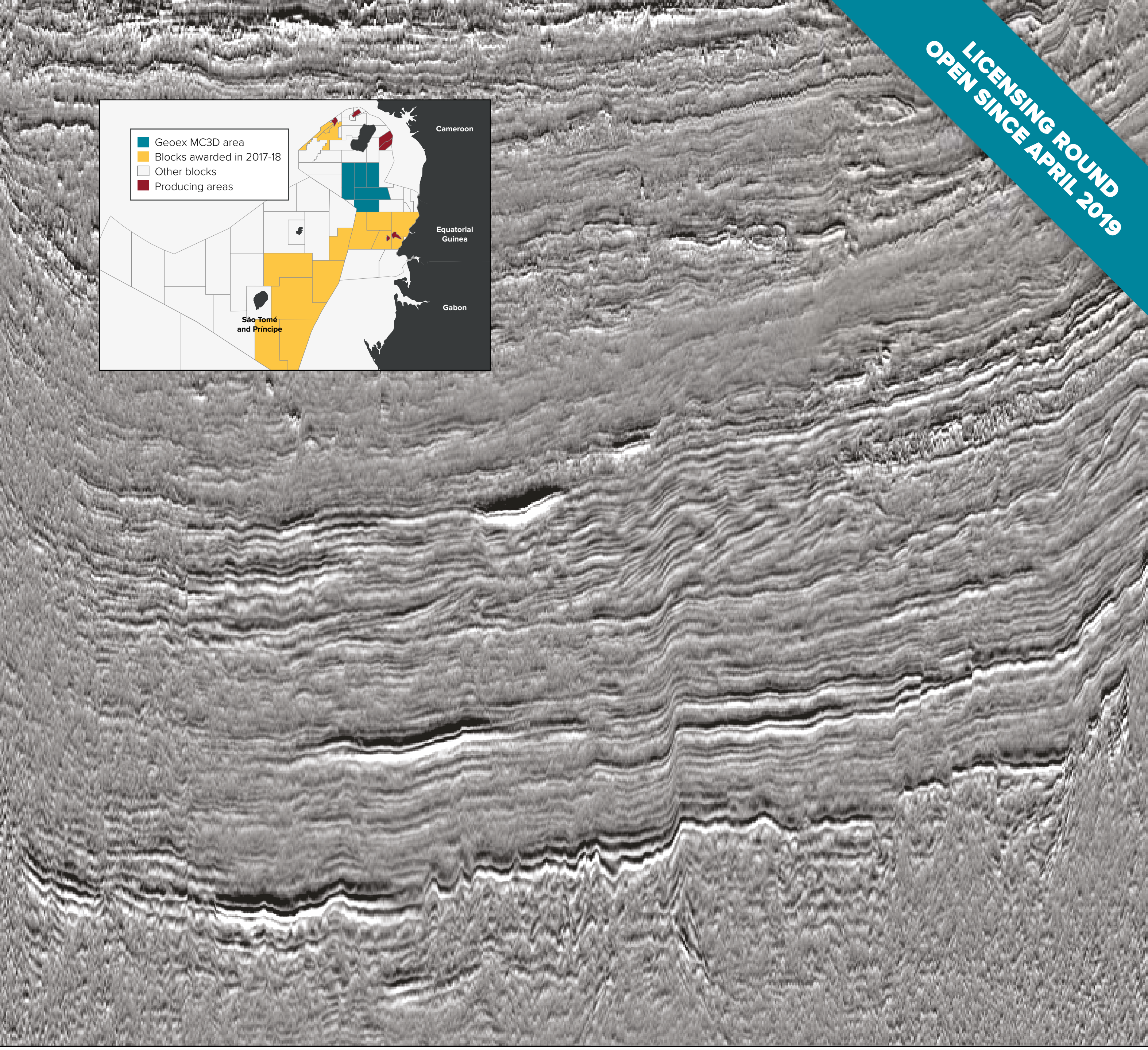
Oceanic sag basins are floored by oceanic basalt and lie at deep waters between the mid-oceanic ridge and the continental margins (either passive continental margins like the Atlantic or active continental margins like the Pacific). As the oceanic floor spreads, cools and subsides with age the oceanic basin deepens and receives pelagic sediments as well as carbonate oozes. Despite covering vast parts of the world's ocean, these oceanic basins are not favorable for conventional petroleum exploration for a variety of reasons, including deep waters, thin sedimentary cover, relatively cold oceanic crust, and lack of traps.

Subduction-related Basins

As the dense oceanic plate converges with a continental plate, it eventually subducts beneath the continental plate along a trench. The partial melting and dehydration of the subducting slab produces molten buoyant magmas which rise and create a volcanic arc on the overriding plate. The subduction is also associated with various types of sedimentation.

These include **trench-slope basins** on the downbent oceanic floor and **accretionary wedges**, which are a thrusted mixture of ocean floor basalt and deep-sea sediments scraped off from the downgoing oceanic slab. Other examples include **forearc basins** lying in front of the magmatic arc, and **intra-arc basins** (within the magmatic arc) lying on the continental plate. Although DSDP-ODP drillings have detected hydrocarbons shows in the arc-trench gap basins, these basins have not proved favorable for petroleum exploration because of their deep water environments, low geothermal gradients (cold crust), and intense tectonic activities that are destructive of petroleum systems. Arc-trench gap basins are well developed along the Pacific.

Back-arc basins form behind the magmatic arc, either in intra-oceanic island arcs or continental magmatic arcs not associated with retro-arc thrust belts. Many back-arc basins are actually extensional rifts due to tensile stresses in the back of the magmatic arc arising from 'roll-back' (seaward retreat) of the subducting trench and slab. Back-arc basins are commonly



EQUATORIAL GUINEA MC3Ds

Multiple data volumes designed to map the distal hydrocarbon systems in this highly prospective region.

Geoex has available 7,900 km² of MC3D seismic data offshore Equatorial Guinea. The data has been acquired over the EG-02, EG-05, EG-16, EG-17 and EG-18 blocks, in partnership with Ministry of Mines and Hydrocarbons.

Available for viewing in our Epsom, UK offices. Book your visit via email enquiry@geoexltd.com or call +44 1372 742 170.

A Geoex Company

Learn more at www.geoexltd.com & www.mcg.no

found in the western Pacific; for example, Japan Sea. Back-arc basins formed on Sunda Shelf in South East Asia are significant hydrocarbon basins with high-heat flow.

Another type of continental sedimentary basin related to subduction that is an important habitat for petroleum is the **retro-arc foreland basin**. These basins form in front of a fold-and-thrust belt which develops as the old, cold continental crust is juxtaposed against the young, hot magmatic arc, and therefore underthrusts as a result of compression between the converging plates building up. The Cordilleras of North and South America formed in this manner, and the retro-art foreland basins associated with these mountains (the Rockies and Sub-Andean basins) are classic petroleum provinces.

Basins of Continental Collisions

As the intervening ocean between two converging continents completely subducts and closes, the two continents collide directly along a suture zone. If a part of the ocean on either side of the collided continent is not closed it is called a **remnant basin**, such as the Bay of Bengal on the east side of the Indian continental plate.

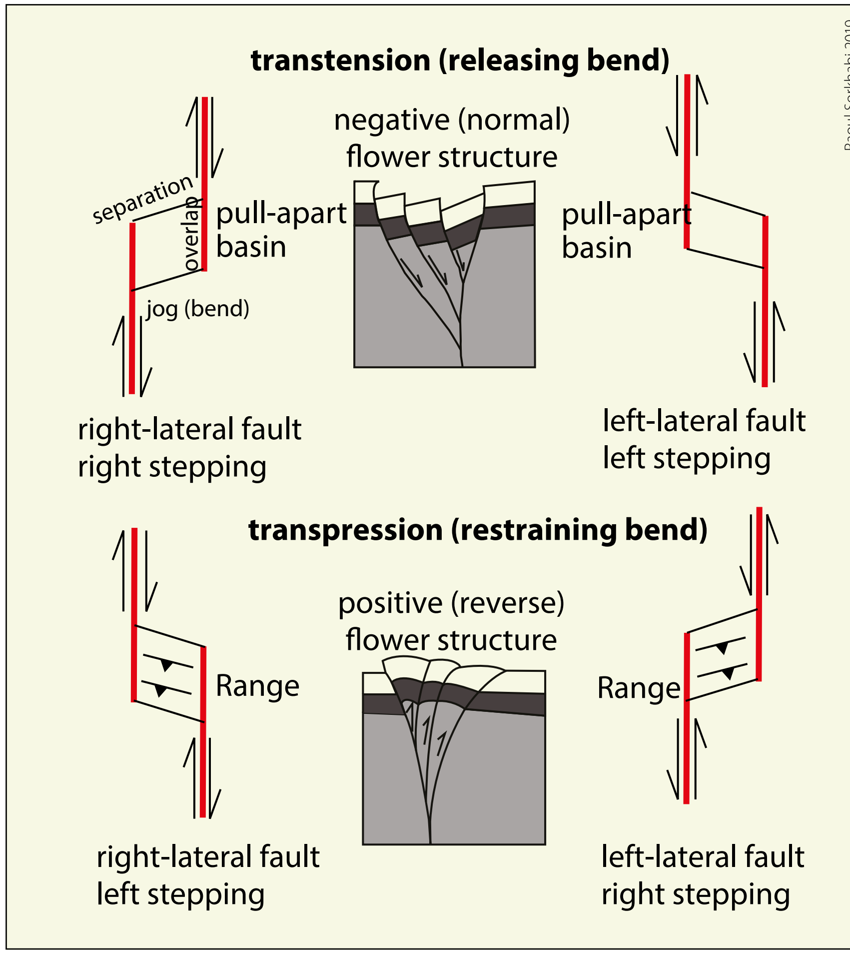
Continued tectonic compression between the continents shortens and thickens the crust and gives rise to mountain belts such as the Alps and the Himalaya. (Some geologists have called this 'A-type subduction' to distinguish it from the 'B-type subduction' of oceanic plate. However, continents, having low density, do not subduct into the mantle and it is better to use the term 'underthrusting' in continental collision.) Continental collision produces its own types of sedimentary basins. The largest is the **peripheral foreland basin** that develops in front of the rising mountain range and is filled with sediments shed from the range. The Zagros Basin is the world's most petroliferous foreland basin.

Collisional mountains form in a series of thrust sheets that sequentially move (younging) toward the foreland. Sedimentary basins may develop on top of the moving thrust sheets. Such basins are called **piggy-back** or **thrust-sheet-top basins**. An example is the Peshavar Basin in the Himalaya of Pakistan.

As the collided crust thickens over time, a rift basin perpendicular to the collision line may form. This is called **impactogen** and examples include the Rhine Graben in Europe, and north-south trending grabens in Tibet.

Basins of Transform Plate Boundaries

Transform or strike-slip faults displace the blocks horizontally (not vertically), and as such they do not create depressions (basins) or ranges. The San Andreas Fault in California is a textbook example of a strike-slip fault along which the North American and Pacific plates pass by each other. However, as can be observed along that fault, if the strike-slip fault steps sideways (jogs to right or left), localized stress will build up in the step-over or bend zones, and **transtensional** (**pull-apart**) **basins** or transpressional highs thus develop. The former shows a negative flower structure (normal faulting) and the latter a positive flower structure (reverse faulting) on seismic images. Pull-apart basins in California (for example, the Los Angeles Basin) although localized and relatively small in size, are nevertheless important petroleum-bearing basins.

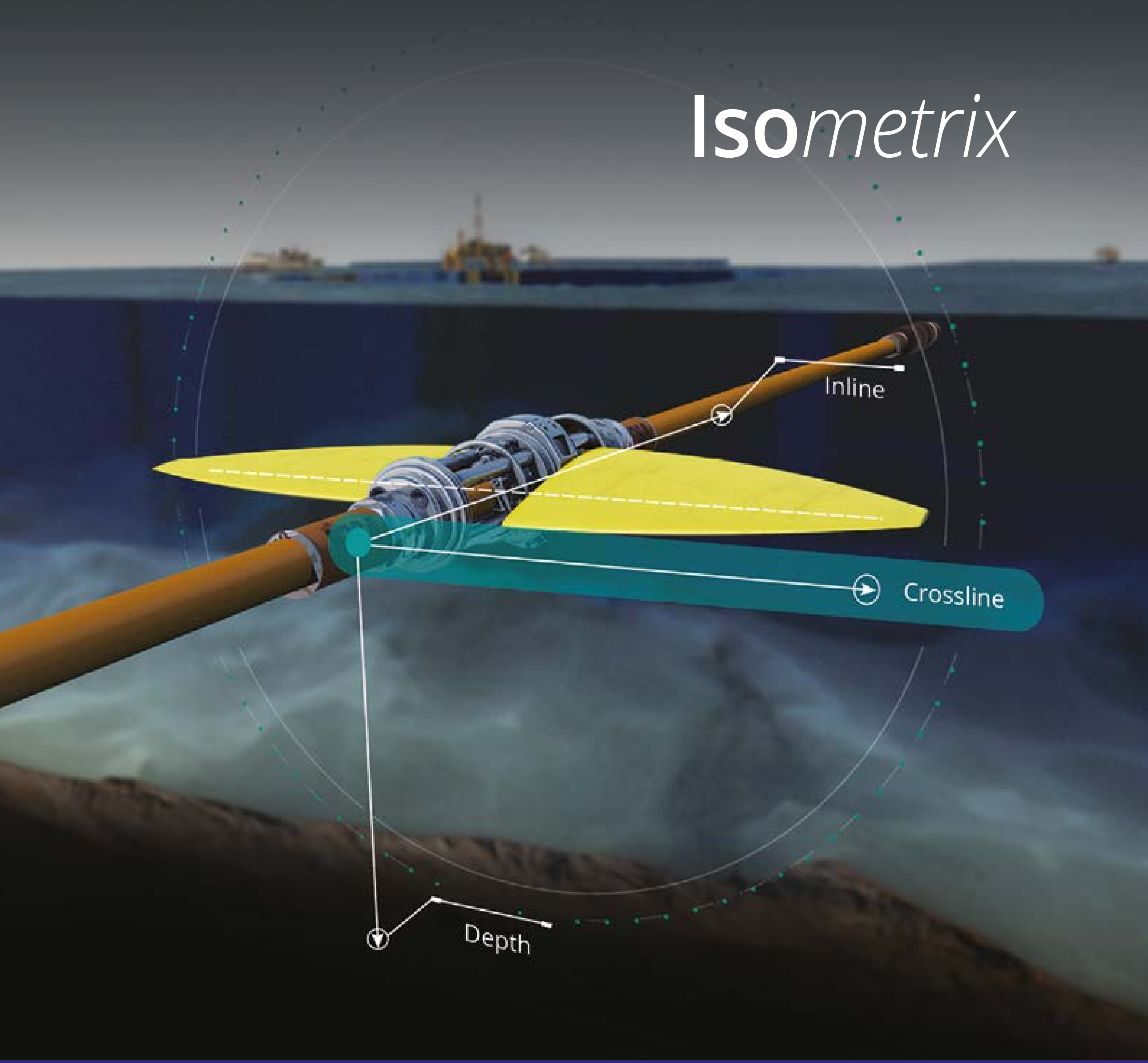


Basins of transform boundaries.

Basins and Petroleum: A Sum-up

With increased knowledge, basin classification schemes have improved. Petroleum exploration has contributed a wealth of subsurface imaging and well data to our understanding of sedimentary basins. Since the oceans cover 72% of the earth's surface, three-quarters of sedimentary basins have formed by tectonic extension. Moreover, 70% of sedimentary basins available for exploration formed during the Phanerozoic Eon (the past 540 million years) as the records of the Precambrian basins have been obliterated by erosion and tectonic activities. Of all the basins explored, rift basins and passive margins provide the largest reserves of oil and gas. Even the petroliferous Zagros Foreland Basin was superimposed on the passive margin of the colliding Arabian plate.

References available online. ■



Clearly Better Acquisition.

Iso*metrix* multi-component streamer technology enables true 3D deghosting and superior broadband data, by measuring the three dimensional wavefield over the full seismic bandwidth.

Revealing possibilities
shearwatergeo.com

SHEARWATER

From Arrhenius to CO_2 Storage

Part I: Blackbody Radiation and Milankovic Cycles

Growing concerns about climate change and emissions of carbon dioxide (CO_2) into the atmosphere are leading to changes in how the hydrocarbon industry operates. In a series of articles, we will discuss in simple terms some of the assumptions and basic physics behind these concerns and show how they might lead to new challenges and result in new ways to operate. We will discuss how CO_2 might be stored in the subsurface to mitigate or reduce the amount of it emitted to the atmosphere. Geoscience will probably play an important role in this mitigation process. But first, we digress to discuss some history and physics behind the topic.

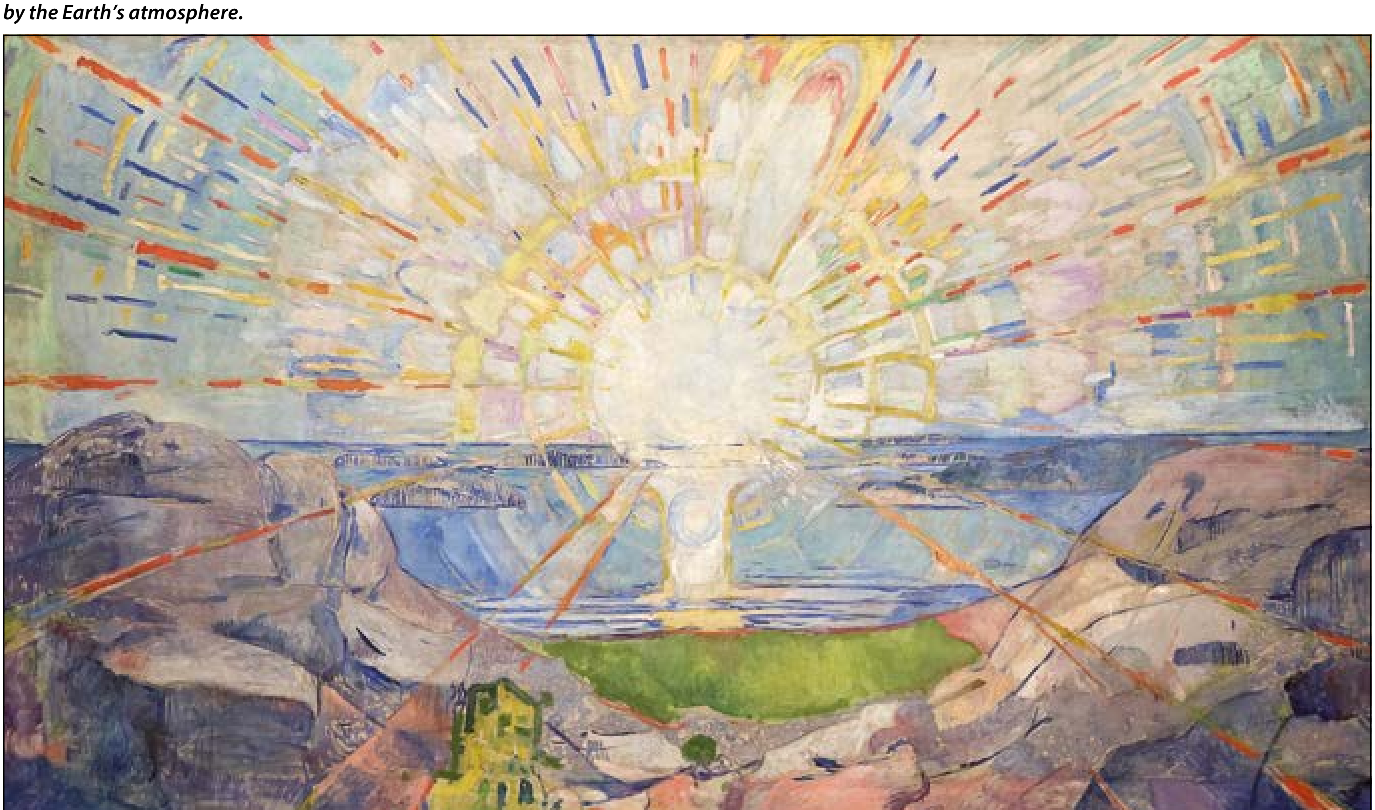
MARTIN LANDRØ and LASSE AMUNDSEN, NTNU/Bivrost Geo

"Available energy is the main object at stake in the struggle for existence and the evolution of the world."
Ludwig Eduard Boltzmann (1844–1906)

The Swedish physicist Svante Arrhenius (1859–1927) was among the first scientists to attempt to quantify the influence of CO_2 and water vapor on the Earth's temperature, in his quest to test a hypothesis that the ice ages were caused by a drop in CO_2. His paper on the topic was published in *The Philosophical Magazine and Journal of Science* in April 1896. In the first two articles in this series we will discuss basic principles and the ideas behind Arrhenius' work.

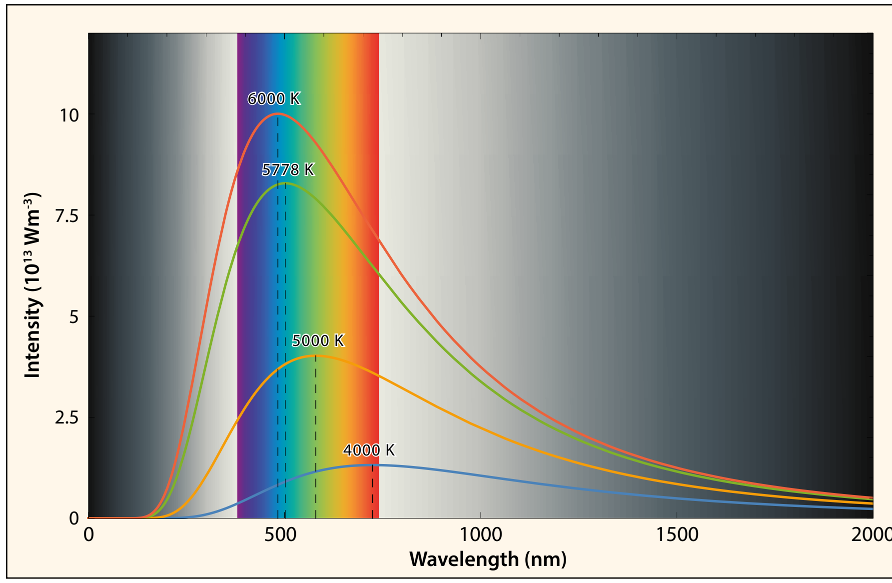
Arrhenius was very familiar with Stefan-Boltzmann's Law, stating that the total radiant heat energy emitted from a surface is proportional to the fourth power of its absolute temperature. The law applies to blackbodies, which are theoretical surfaces that absorb all

The Sun (1911) is one of several paintings by Edvard Munch that adorn the walls inside the Hall of Ceremonies at the University of Oslo. Inhuman itself, the sun provides Earth with the light and heat necessary to support life. The color of the sun is essentially all the colors mixed together, appearing to our eyes as white. At sunrise or sunset, the sun appears yellow, orange, or red, because its shorter-wavelength light colors (green, blue, purple) are scattered by the Earth's atmosphere.



incident heat radiation. A great puzzle at the turn of the century was to explain the shape of the blackbody curve. In an act of desperation, in 1900 Max Planck (1858–1947) found that he could fit the shape of the black body curve if he postulated that the radiant energy could be emitted only in finite amounts of energy. His idea introduced the quantum principle into physics: certain quantities in nature occur only in discrete intervals, and the size of these intervals is determined by Planck's constant, *h*.

Understanding blackbody radiation is one of the great triumphs of 20th century physics, since it led to the discovery of quantum theory. But blackbody radiation is manifest in the macroscopic world, and is determined by Planck's radiation law, which depends only on temperature and wavelength. No objects are perfect blackbodies, but everything radiates – you, the Earth, and the sun. The sun is close to being a blackbody, and it emits radiation in the visible range. The Earth and its atmosphere emit in the infrared. Another rather more obvious concept is that radiation encountering matter is either transmitted through matter, absorbed by matter, or scattered by matter. The sum of energy that is transmitted, absorbed and scattered must equal the amount of incoming energy.



Blackbody curves showing the intensity of light emitted at various wavelengths for four different blackbodies, each at a different temperature. Temperature is the only quantity that distinguishes one blackbody from another. Intensity is defined to be the amount of energy emitted each second per square meter of the body's surface. Blackbody spectra are important in physics because of their universality. Virtually any hot body emits electromagnetic radiation in the form of a blackbody spectrum. The object becomes visible as red, then yellow, and eventually a bluish-white as the temperature rises. When the object appears white, it is emitting a substantial fraction of its energy as ultraviolet radiation. The sun, with an effective temperature of 5,778 K, is an approximate blackbody with an emission spectrum peaked in the central part of the visible spectrum, but with significant power in the ultraviolet as well.

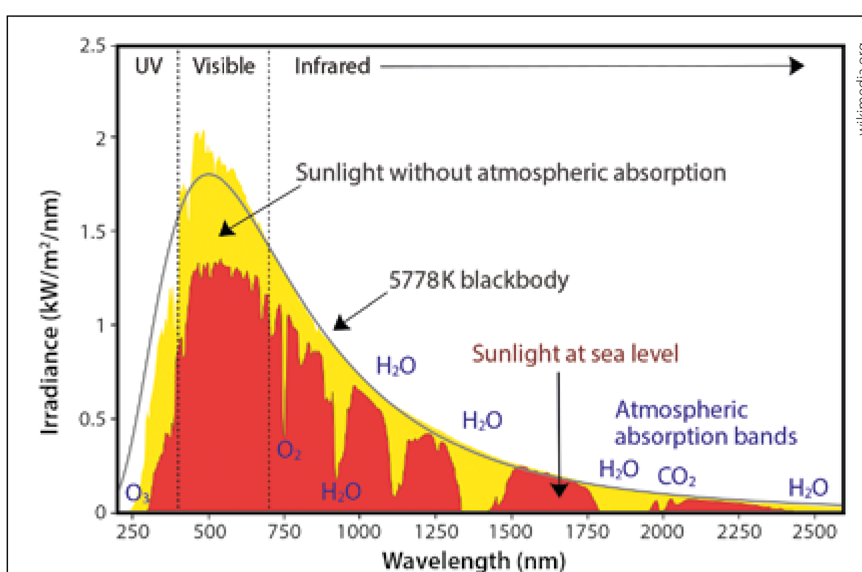
Blackbody Radiation

A blackbody is a body that completely absorbs all the electromagnetic radiation (light, X-rays, gamma rays, and thermal radiation) falling on it. A surface covered with lampblack will absorb about 97% of the incident light and, for most purposes, can be considered a blackbody. The opposite of a blackbody would be a 'whitebody' where all energy is perfectly reflected. The concept of the blackbody as a perfect absorber of energy is very useful in the study of radiation phenomena.

When a blackbody absorbs radiant energy falling on it, it heats up, and the way that a blackbody can maintain thermodynamic balance is to emit radiation in order to maintain a constant temperature. The prefix black is used because at room temperature the blackbody would emit almost no visible light, appearing black to an observer.

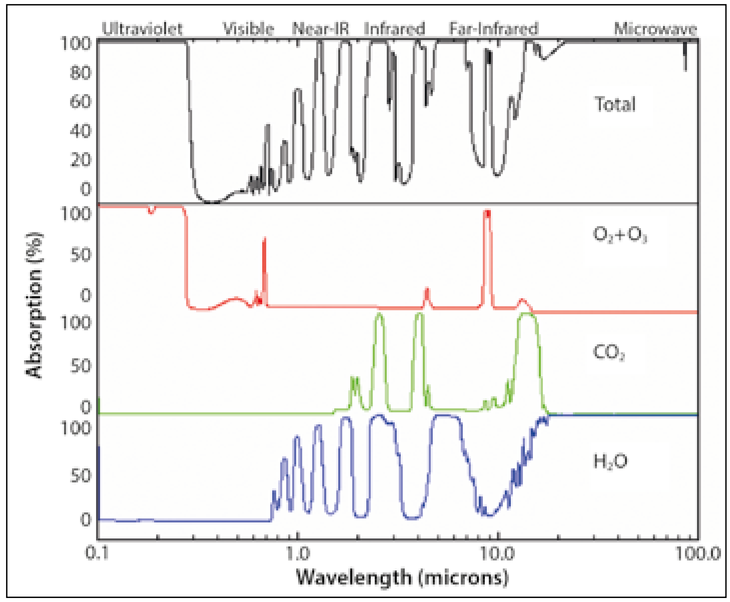
As discussed, Max Planck was the first to find the mathematical relation between the radiation

Solar radiation spectrum for direct light at both the top of the Earth's atmosphere (represented by yellow area) and at sea level (red area). The temperature of an ideal blackbody that would radiate energy at the same rate as the sun is 5,778 K (5,505°C), which is the sun's surface temperature. This effective temperature is obtained by setting the area under the intensity-wavelength curve for the sun's radiation equal to the area under the intensity-wavelength curve for the ideal blackbody, and solving for temperature. As light passes through the atmosphere, specific wavelength ranges are absorbed by carbon dioxide and water vapor. Oxygen and ozone absorb light in the UV spectrum on the left side of the graph, shielding plants from harmful radiation. Meanwhile, the atmosphere is relatively transparent to visible light from the sun. Additional light is redistributed by Raleigh scattering, which is responsible for the atmosphere's blue color. The curves are based on the American Society for Testing and Materials (ASTM) Terrestrial Reference Spectra.



emitted by a blackbody as a function of temperature and wavelength. His efforts laid the foundation of the quantum theory, for which he received the Nobel prize in 1918. The key observation is that blackbody radiation depends on only one parameter: the temperature of the blackbody. The radiation thus is independent of the shape and size and material of the blackbody.

Scientists study many real objects as ideal blackbodies. Examples are the Earth, non-terrestrial objects like the moon, the sun and stars, and humans and non-humans. We may use the blackbody radiation model to determine the temperature of our sun or to determine the body temperature at various locations on a horse or human.



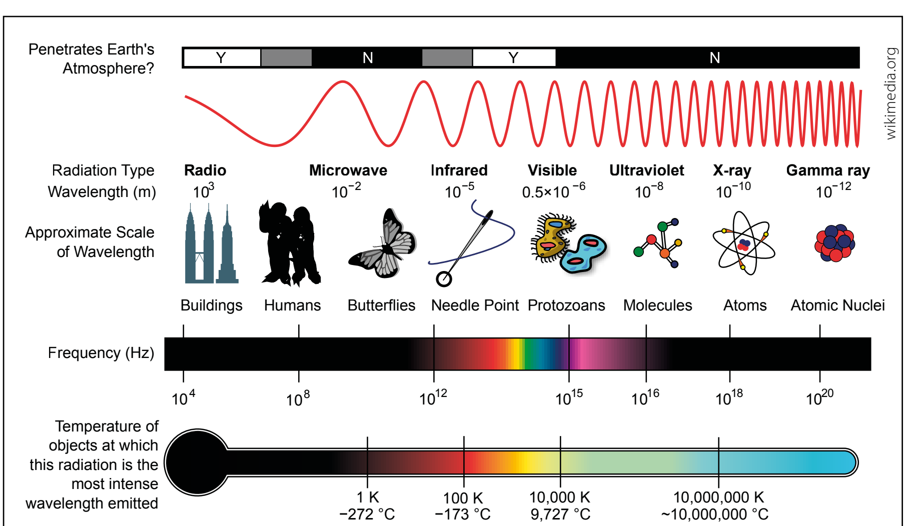
Absorption spectra of some atmospheric gases for wavelengths between 0.1 and 100 micrometers. Notice that water vapor has a wider 'blocking' spectrum compared to, for instance, CO_2. (Source: T.J. Nelson Cold Facts on Global Warming https://www.randombio.com/co2.html)

The Electromagnetic Spectrum

The entire range of light energy is called the electromagnetic spectrum. The light we can see with our eyes is within the optical spectrum, which ranges in color from red up to violet, with wavelengths from 380 nm to 740 nm. All objects in our universe absorb, reflect and emit electromagnetic radiation in their own distinctive ways. Light that is given off, or radiated from an object, is called radiation.

Frequency is related to wavelength by $\lambda=c/\nu$, where c is the speed of light. Temperature is related to wavelength by the Wien displacement law.

The energy of electromagnetic radiation is called radiant energy. It is measured in Joules (J). In many situations it is more interesting to consider the rate at which energy is transferred per time. The corresponding quantity is called power, which has dimensions J/s, or Watt (W). However, when talking about radiant power that is emitted by, passing through or incident on a surface, the term flux is more common. Therefore, the radiant energy emitted, reflected, transmitted or received, per unit time, is called radiant flux. Spectral flux is the radiant flux per unit frequency or wavelength (W/m). The term flux density refers to the spatial density of radiant flux; hence, radiant flux density is the radiant flux per unit area at a point on a surface, measured in W/m^2. If flux is leaving the surface due to emission or reflection, the radiant flux density is referred to as radiant exitance, while if the flux is arriving at the surface the radiant flux density is referred to as irradiance. Thus, irradiance is the amount of light power from one object hitting a square meter of a second object. Radiant exitance and irradiance are sometimes called 'intensity', since the SI-unit of intensity is also W/m^2. Spectral radiant exitance and spectral irradiance are the corresponding quantities per unit frequency or wavelength. For wavelengths, the SI-unit is W/m^3.



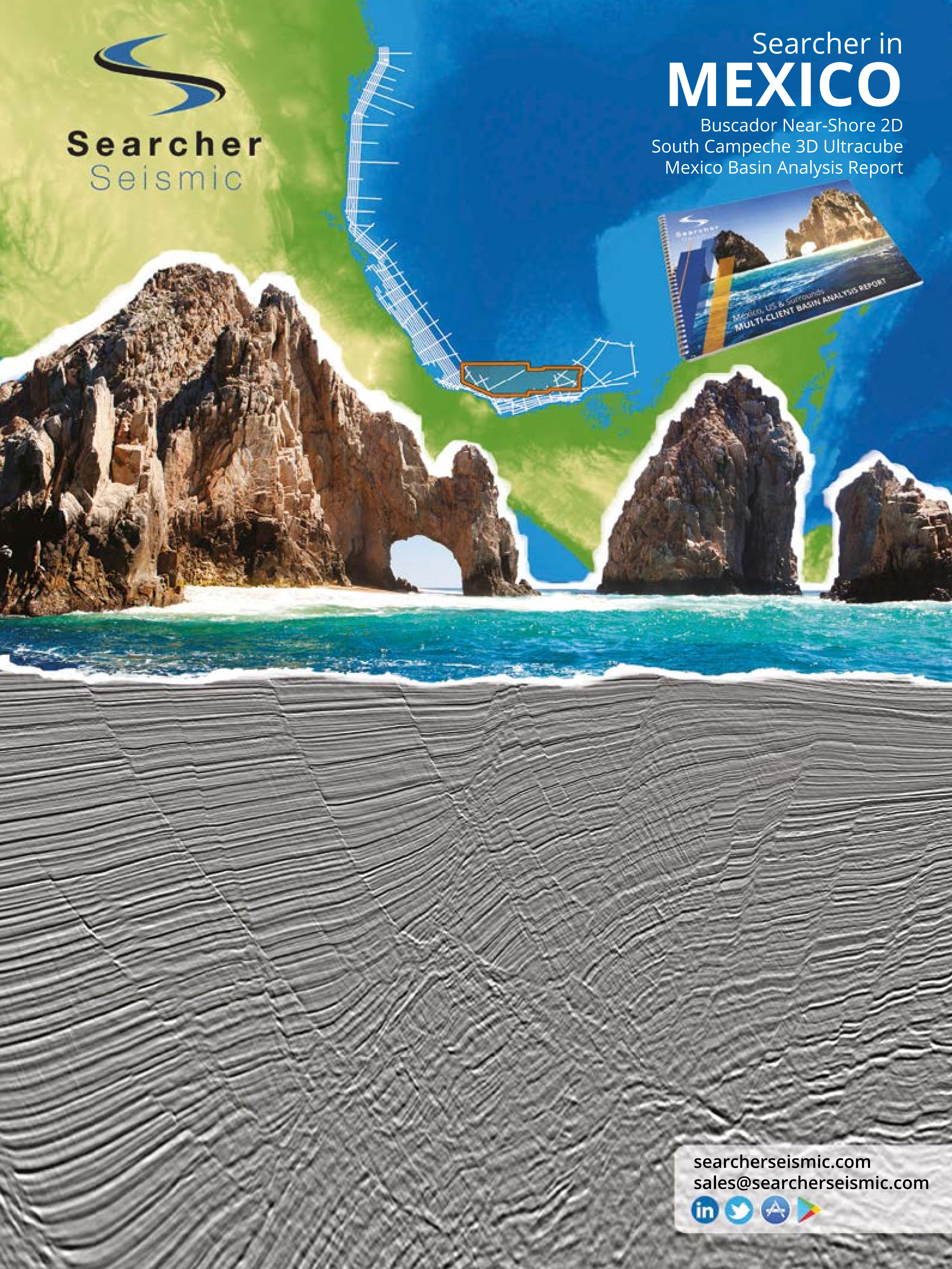
Sources of radiation are objects rather than point sources; each point of the surface of the object is characterized individually rather than the entire source. Radiance is the radiant flux emitted, reflected, transmitted or received by a surface, per unit solid angle per unit area. It is a directional quantity, measured in *W/(sr m^2)*. Unlike radiant flux density, the definition of radiance does not distinguish between flux arriving at or leaving a surface. Spectral radiance is radiance of a surface per unit frequency or wavelength, the latter measured in *W/(sr m^3)*.

The radiance B and irradiance U are related by:

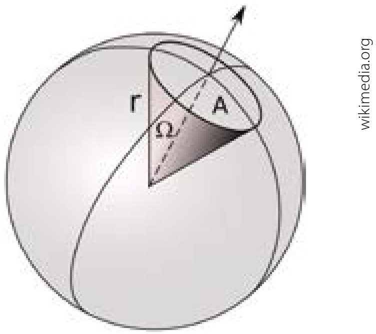
$$B = \frac{dU}{\cos\theta \, d\Omega}$$

where $d\Omega$ represents the differential of solid angle and θ is the angle between a beam of radiation and the direction normal to the surface (usually horizontal) on which the radiance is measured. Radiation whose radiance is independent of direction is called isotropic radiation. In this case the equation can be integrated to yield:

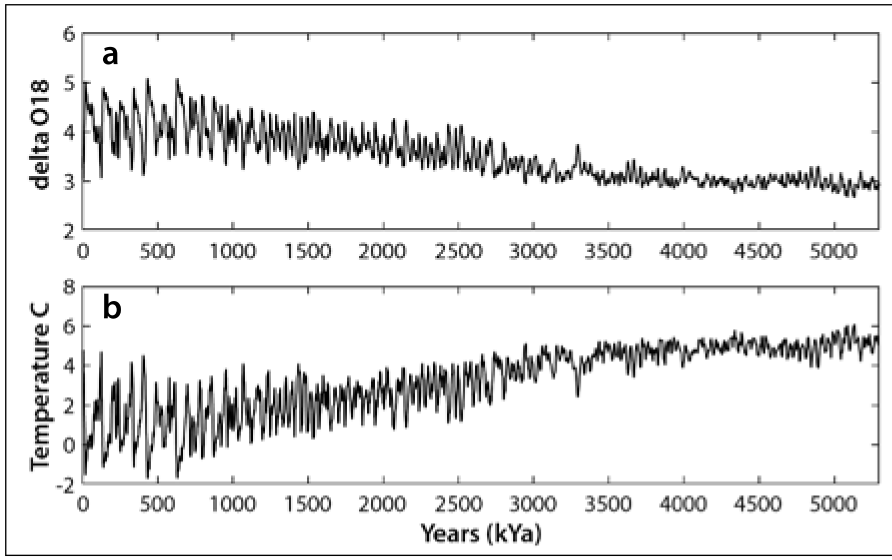
$$U = \pi B$$



Searcher
Seismic
Searcher in
MEXICO
Buscador Near-Shore 2D
South Campeche 3D Ultracube
Mexico Basin Analysis Report
Mexico, US & Surrounds
MULTI-CLIENT BASIN ANALYSIS REPORT
searcherseismic.com
sales@searcherseismic.com



A solid angle Ω is equal to the ratio of the viewed surface area A divided by the square of the viewed distance r; whence, $\Omega = A/r^2$ sr. (Solid angle is expressed in the SI unit steradian (sr)). When the area is $A = r^2$, then the solid angle is $\Omega = 1$ sr. A steradian 'cuts out' an area of a sphere equal to r^2, in the same way that a radian 'cuts out' a length of a circle's circumference equal to the radius. There are 2π radians along a circle and 4π steradians over a sphere.



a) Benthic sedimentary record composed of 57 globally distributed sites of measured $\delta^{18}O$ and b) the corresponding temperature estimate. Notice the gradual colder climate from three million years ago to present, and also that the magnitude of the temperature oscillations is larger towards present time.

Absorption Spectra of Earth's Atmosphere

As observed above, the Earth (and the moon) emits blackbody radiation mainly within the infrared band, peaking around 17 micrometers. This outgoing radiation from the Earth is absorbed by various gases in the atmosphere, and the figure top of page 42 shows for which wavelengths this absorption effect is most effective. For CO_2, we observe that there are three relatively thin bands: one around 2.5 micrometers, the next around 4 micrometers and a wider band ranging from 12–18 micrometers. Water vapor has several bands, and acts as a blocker for wavelengths above 15–20 micrometers. It is evident from this figure that if we increase the amount of some of these gases, then less terrestrial blackbody radiation will escape, leading to global warming. In most climate models there are complex coupling between an increase in CO_2 leading to a corresponding increase in water vapor and so on, often referred to as positive feedback.

Benthic $\delta^{18}O$ Records and Milankovic Cycles

When Arrhenius published his 1896 paper on CO_2 and temperature (to be discussed further in Part II), the famous work of the Serbian scientist Milutin Milankovic (1879–1958) was not known. Milankovic suggested in 1920 that the Earth's eccentricity, the tilt of its axis and the precession will cause systematic variations in how much energy the Earth receives from the sun, and hence, such variations might cause climate changes. One way to establish a link between this theory and observations is to use benthic sedimentary records obtained from deep sea drilling experiments (see Lisiecki and Raymo (2005) for a comprehensive discussion). By measuring the variation in $\delta^{18}O$ (the relative difference of the O^{18} to O^{16} ratio measured in parts per thousand) it is possible to link this ratio to the temperature. Epstein et al. (1953) suggested the following empirical relation between $\delta^{18}O$ and temperature:

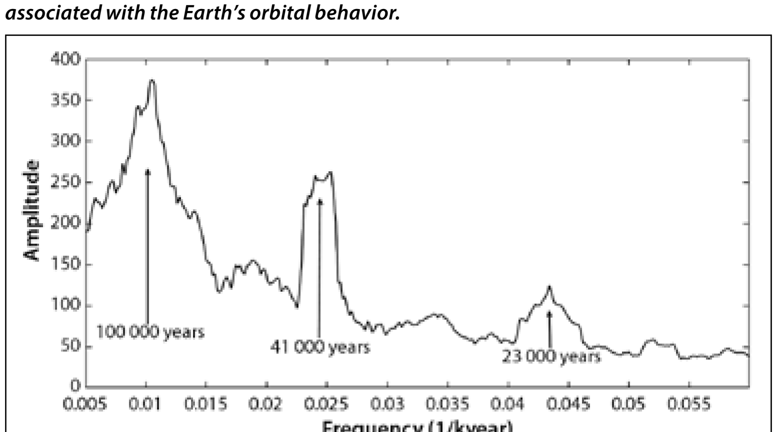
$$T(°C) = 16.5 - 4.3\,\delta + 0.14\,\delta^2$$

The figure above shows just such a comprehensive record (using Lisiecki and Raymo's data) and the corresponding temperature estimate using this equation.

The figure below shows the amplitude spectrum of the temperature curve (Fourier spectrum), and we can clearly observe three distinct maxima in the spectrum: one corresponding to a cycle of approximately 100,000 years (coupled to the eccentricity of the Earth's orbit), another cycle peaking at approximately 41,000 years (corresponding to the tilt of the Earth's axis) and a third cycle of approximately 23,000 years (corresponding to the precession of the Earth orbit). Today, Milankovic models are accepted as a cornerstone in our understanding of climate variations in the past. However, this does not exclude other effects like variations in atmospheric gases, and in 1896 Arrhenius suggested that CO_2 could actually be a cause for ice ages.

References available online. ■

Amplitude spectrum of the temperature series obtained from sedimentary measurements of delta O^{18}. The three peaks shown here actually fit nicely with Milankovic's model for various cycles associated with the Earth's orbital behavior.



Finding Petroleum

EVENTS IN LONDON 2019

FINDING NEW SOLUTIONS TO INDUSTRY PROBLEMS

Finding Oil and Gas in South Africa
London, 24 May 2019
Building on the February Total discovery in Outeniqua Basin

Finding Petroleum Opportunities In The Middle East
London, 11 June 2019
Changing business landscape available to investors and small / medium oil and gas companies

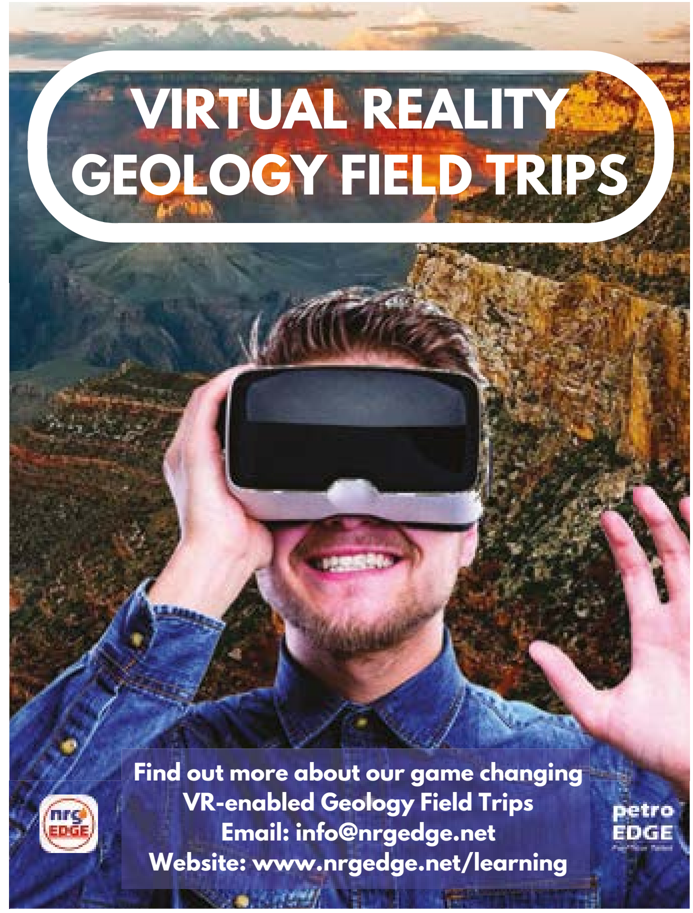
Opportunities in Mature Provinces and Super Basins
London, 25 June 2019
New ideas to develop small pools, get more production from large reservoirs, reduce cost of producing

Opportunities in the Eastern Mediterranean
London, 19 Sep 2019
Discoveries offshore Egypt, big interest in Cyprus and developments in Israel and Lebanon

Finding Oil in Central & South America
London, 28 Oct 2019
Brazil, Mexico, Colombia, Argentina

Solving E&P problems with digitalisation
London, 13 Nov 2019
Are 'digital' people as disruptive as they claim to be? How can the status quo be changed?

www.findingpetroleum.com



DEVEX 2019

7 & 8 MAY, AECC, ABERDEEN

LEGACY & SUSTAINABILITY: 50+ YEARS OF UKCS HISTORY & LESSONS FOR THE FUTURE

BOOKINGS NOW OPEN!

MEDIA PARTNER

GEOExPro

DEVEX is now in its 16th year and is the only technical conference of its size which is focused on the full cycle of reservoir discovery, evaluation, development and recovery in the UK and provides excellent opportunities for engineers and geoscientists to come together and share knowledge.

FIELD TRIP - 9TH MAY

The trip will take place at the Old Red Sandstone and Highland Border Complex of Kincardineshire. Limited places available - don't miss out!

SPONSORSHIP AND EXHIBITION

If you'd like to raise your profile, take advantage of the sponsorship opportunities available. Exhibition space is also available at just £950 which includes a free delegate pass.

WHY ATTEND?

- Opportunity to learn from the experts and share knowledge
- Strong technical programme with parallel sessions
- Expert-led Masterclasses
- Excellent networking opportunity with over 700 delegates
- High volume of Operators present
- Core displays
- Young Professionals Event
- Field Trip

FOR MORE INFORMATION:

www.devex-conference.org
devex@mearns-gill.com
01224 646311

DEVEX 2019 ORGANISERS

SPE International Aberdeen Section

AFES Aberdeen Formation Evaluation Society

PESGB

Data, the Cloud and Me
A Geoscientist's Perspective

**How can cloud technologies help me as a geoscientist?
Here we offer a demystifying guide and provide the answers to some of your questions.**

RHIAN BURRELL, CHARLES JONES, JOSEPH NICHOLSON and JAMES SELVAGE; Osokey

Within geoscience, the technical workflow is well established. There are clear ways to utilize the geoscientist's knowledge and domain expertise to deliver subsurface evaluations. From time to time a new method may be incorporated, but overall the workflow remains relatively constant. Compare that to the rate of change of technology across all industries. What if we could harness some of these exciting new technologies and apply them to our workflows? With cloud technology, that possibility starts to become a reality.

Why do I care where my data is stored?

Do you know where every single seismic line that your company owns and licenses is located? Can you find that data and be looking at it in under a minute? If the answer is no, then cloud technology can help you with this.

By storing all your data in the cloud (including all your archived data), you can save both money and, more importantly, time. The cloud enables you to access any seismic line within seconds. This means that your time can be spent looking at the data rather than looking for the data.

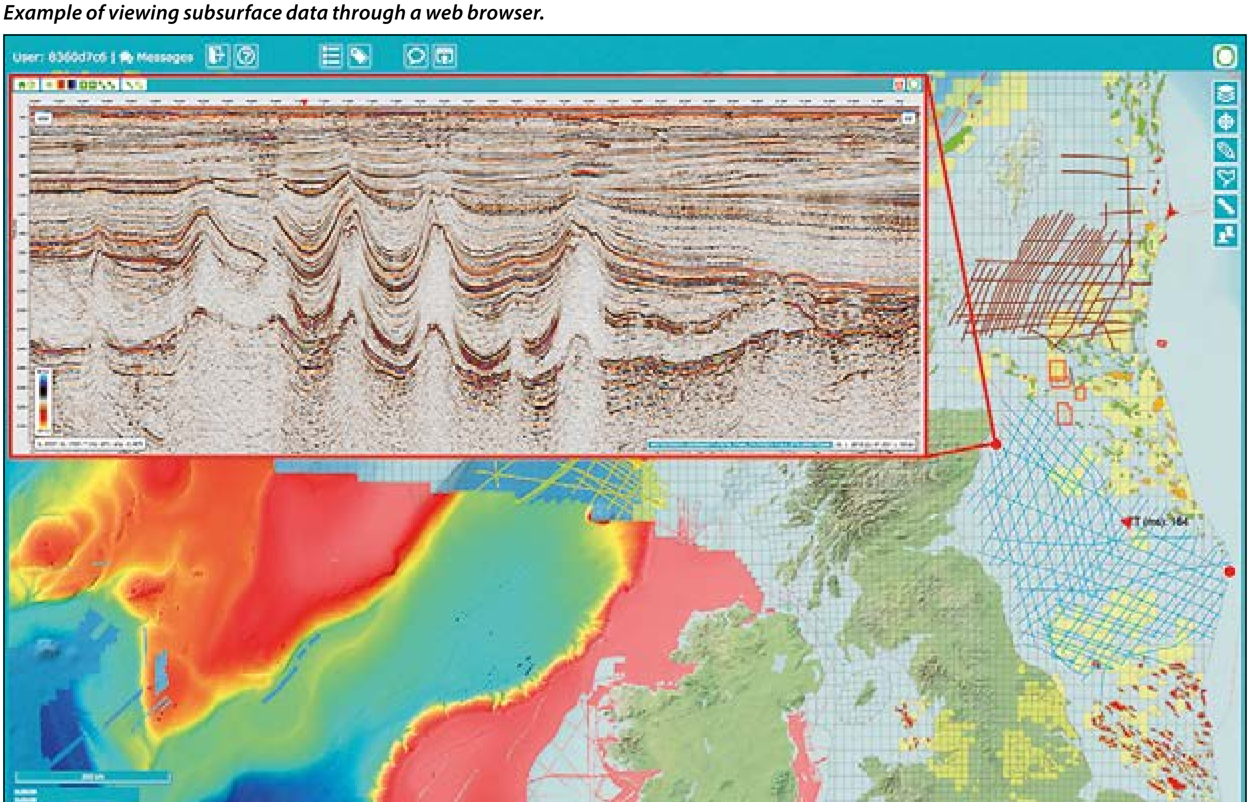
OK, my data is stored in the cloud. Now what?

There are two clear paths that you can go down. Firstly, there is the 'lift and shift' option. You move your data and your workflows into the cloud and you keep doing what you have been doing. It may save you a bit of money and a bit of time. However, to do that is to ignore the key opportunities associated with the cloud and ignore the technologies that have been created because of cloud computing.

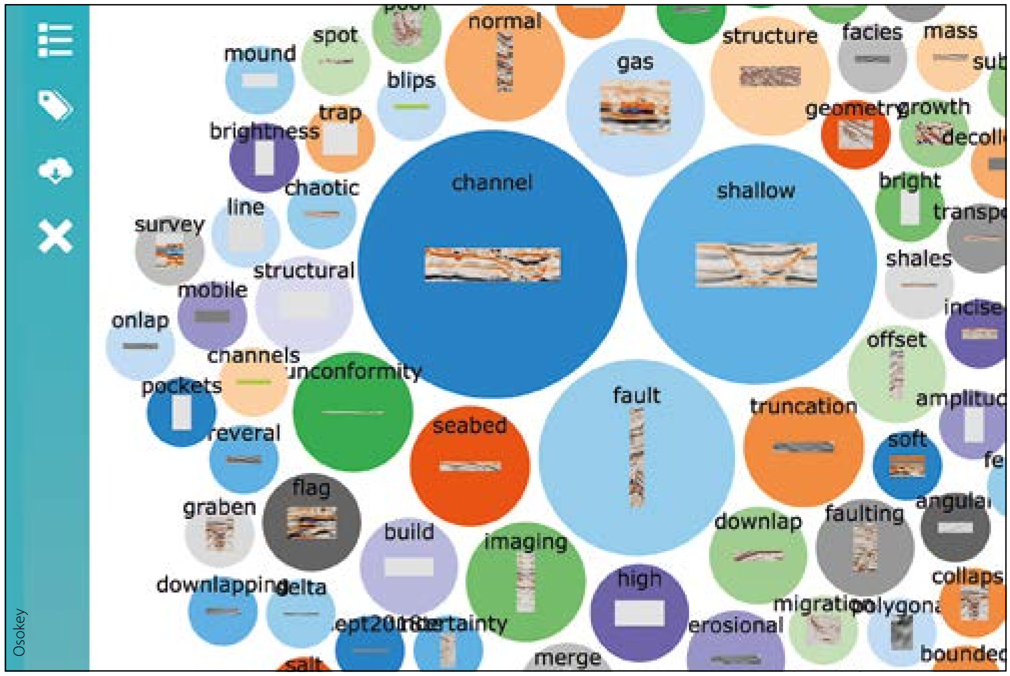
What is cloud computing?

Cloud computing provides global, on-demand services including compute power, storage and databases, all via the internet. Technology companies like Amazon, Microsoft and Google all provide cloud services platforms. It represents a paradigm shift in the way that functionality can be provided to your desktop. The scale of these cloud services platforms

Example of viewing subsurface data through a web browser.



is mind-boggling. The total outlay on cloud infrastructure in 2018 exceeded US$80 billion (Canalys, 2019). This investment is necessary to support the increasing adoption of cloud computing by a diverse range of customers. For example, in 2016 one AWS (Amazon Web Services) customer, DigitalGlobe, moved 100 petabytes of data to the cloud. This level of adoption leads to economies of scale that can result in price reductions that all cloud customers, including geoscientists, can benefit from.



Example of seismic in the cloud being used to build global analog feature collections for future machine learning.

So how can the cloud help me?

There are numerous benefits to using the cloud.

From an IT perspective, the benefits include reducing investment in, maintenance of, and deployment time of IT resources, coupled with scalability to meet changing workload and user demands. In addition, you only pay for the resources that you use.

For a geoscientist, the key opportunities are the scalability and connectability of the cloud, as well as its near-limitless compute power.

Tell me more about the scalability of the cloud.

The cloud can scale up and down depending on what you are trying to do. That means that you can test an attribute on a single seismic line, but it also means that you can quickly scale up and run that same attribute over your entire seismic repository. Operations can run in parallel, meaning that even if you have 100 times the amount of data it will not take 100 times as long to get the results. This has exciting potential for data screening and large-scale portfolio evaluations.

How can the near-limitless compute of the cloud help me?

What would you do with your data if you had unlimited compute power? Seismic data is often large and unwieldy. It requires large amounts of compute to do things with the data, and this, in the past, has been a limiting factor. Project durations are often dominated by critical path computation. The current geoscience workflows have been developed around this limitation; however, once your data is in the cloud, that limitation no longer exists. To not think about what you would do differently risks missing the opportunity that the cloud provides. It also means that any lift and shift strategy is only a short-term solution because your current workflows and applications were developed before the cloud.

So, take a moment to think about "What would you do with near-limitless compute?"

What about: standardized processing over your entire portfolio to allow for direct comparisons between seismic volumes? Reprocessing older data using the latest technologies? Compressing your geoscience workflow timeframe? Or you could run machine learning algorithms to identify new opportunities; or augment the knowledge of geoscientists with techniques to remove human bias?

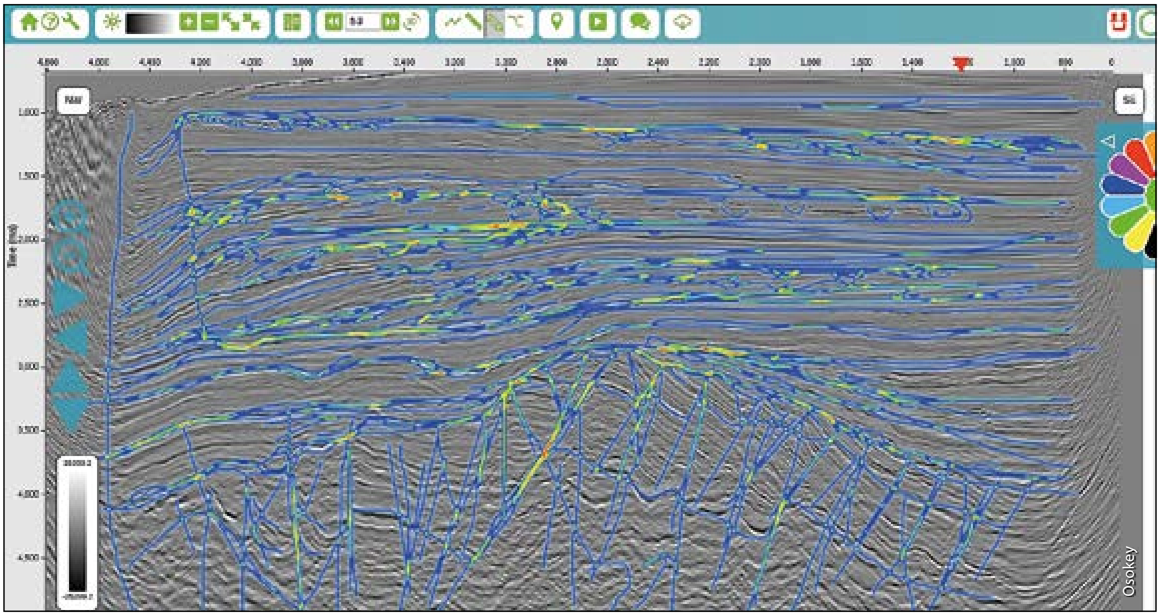
The near-limitless compute of the cloud opens up new possibilities and allows you to ask new questions about your data in a way that was previously not possible.

What do you mean by the connectability of the cloud?

The connectability of the cloud provides you with the option to securely share data with third parties. This allows you to improve your collaboration with both joint venture and academic partnerships to share understandings and develop new insights into your data. The connectability of the cloud can also be utilized internally to enhance the geoscience workflow. Data can be shared globally and viewed within seconds to deliver crowd-sourced interpretations and multiple perspectives on the same data. This helps open your eyes to the diverse range of potential concepts, resulting in a better understanding of the full potential – and also the challenges – associated with a particular asset.

Once your data is in the cloud, you also have the potential to rapidly connect to the latest innovations across multiple industries, which will help to deliver a unique competitive advantage for your business. Data can be transformed ready for use by data scientists and also by deep learning algorithms. You can combine your knowledge and domain expertise with the latest technologies to redefine the existing geoscience workflows, gain new insights and identify new opportunities.

Example of an interpretation heat map generated from crowdsourced interpretation.



This sounds like a lot of effort.
It isn't the easy route and there are challenges. The hardest thing is often just getting started. It is an adventure into the unknown and that is what makes it exciting. Geoscientists are known for exploring, being curious and finding meaning amongst the uncertainty. In the end, you should be able to ask more and different questions of your data to gain new insights.

Seismic data is complex and uncertain. The geoscientists are the experts and therefore play a vital role in shaping what geoscience in the cloud could and should look like.

Will this take a long time?
It is actually very quick and easy to get started with the cloud. It is now possible to go from initially opening a cloud account to securely storing, viewing and collaborating on your data in less than one hour.

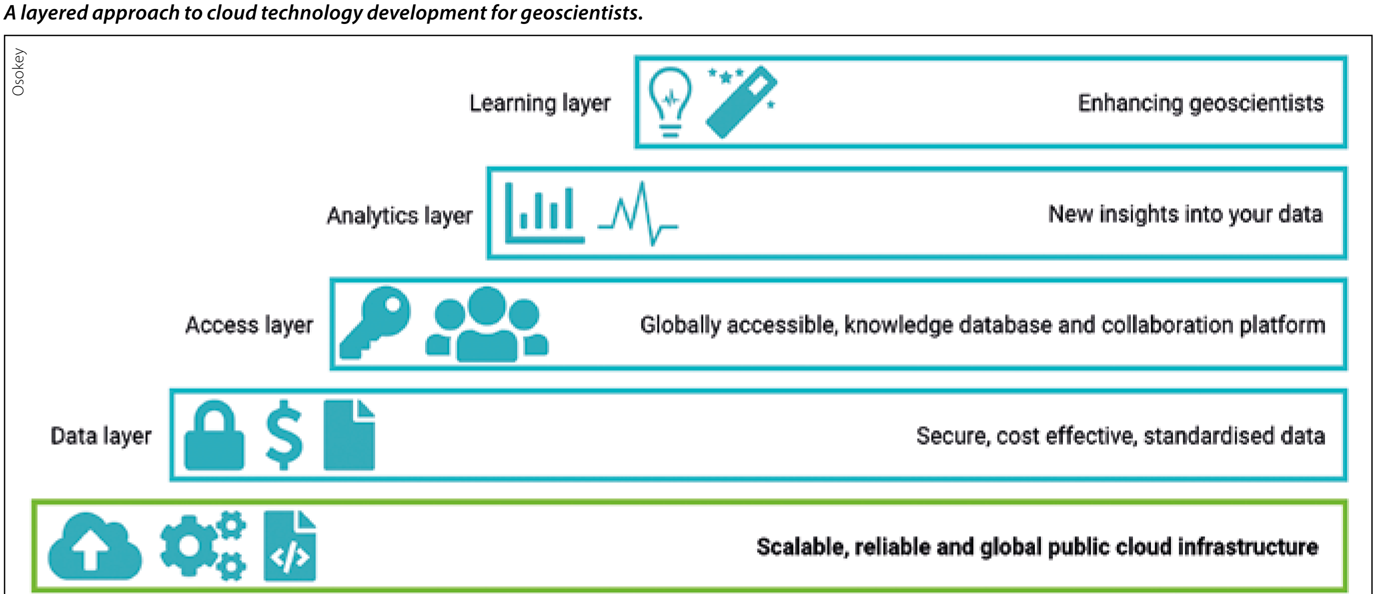
Geoscience data in the cloud can be integrated with existing geoscience applications to ensure business as usual is maintained as you explore and develop your workflows in the cloud. The technologies and scale of the cloud deliver performance whilst using industry standard data formats such as SEG-Y data. This reduces the complexity of data management by removing the need to create copies of the datasets in multiple data formats for different applications.

OK, I'm interested to know more, where should I start?
Our experience has been that a layered approach to development has helped people to get started.

Start by putting some data into the cloud and then you can learn as you go. Cloud services are on-demand services which means that you only pay for them when you use them, allowing you to explore cloud technologies with no upfront costs.

Explore, learn and investigate to see what the cloud can do for you. ■

A layered approach to cloud technology development for geoscientists.



DR. JAMES REILLY,
DIRECTOR OF THE U.S. GEOLOGICAL SURVEY,
ANNOUNCED AS KEYNOTE SPEAKER

The Evolution of Unconventional Play Analysis at the USGS

Registration Now Open

Dr. Reilly is responsible for leading the nation's largest water, earth, biological science, and civilian mapping agency. Previously as an astronaut at NASA, he had a distinguished 13-year career where he flew three spaceflight missions and conducted five spacewalks totaling more than 856 hours in space.

We received thousands of abstracts and are preparing a hot technical program that you won't want to miss! New topics include Distributed Acoustic Sensing, Emerging Technologies, and Induced Seismicity, with a special emphasis on Latin America.

Register by 30 July and save!
seg.org/am

#SEG19

SEG19
SAN ANTONIO, TX
15-20 SEP 2019
INTERNATIONAL EXPOSITION
89TH ANNUAL MEETING

What Lies Beneath:

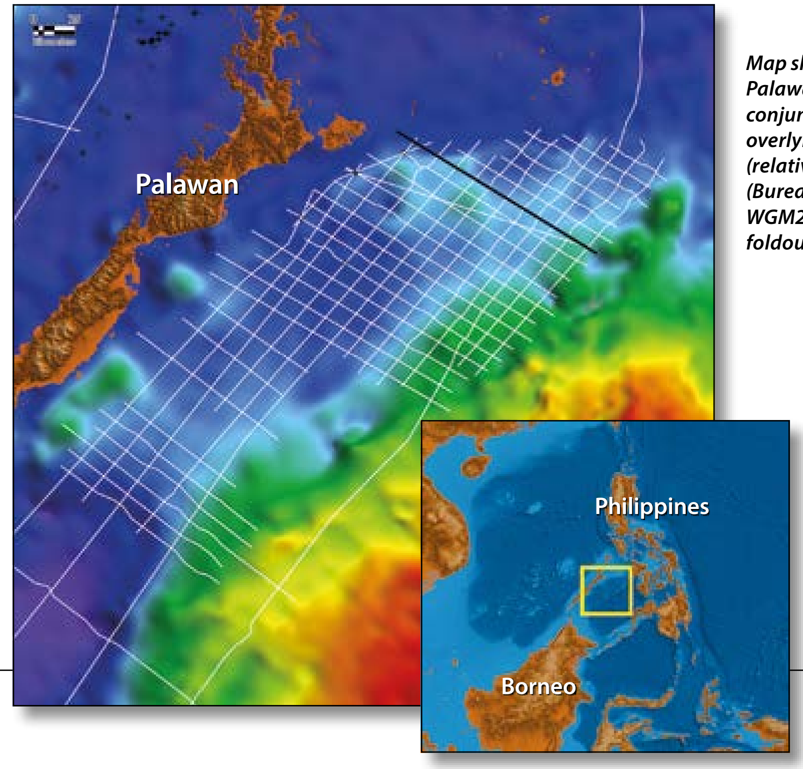
Unraveling the potential of the East Palawan Basin, Philippines

The Philippines has had some significant petroleum discoveries to date, with several important producing fields in the Northwest Palawan Basin. Just around the corner lies its sibling, the East Palawan Basin, which is devoid of any hydrocarbon discoveries or producing fields. This does not make sense as the East Palawan Basin has shared much of the same sediment provenance as the Northwest Palawan Basin through time.

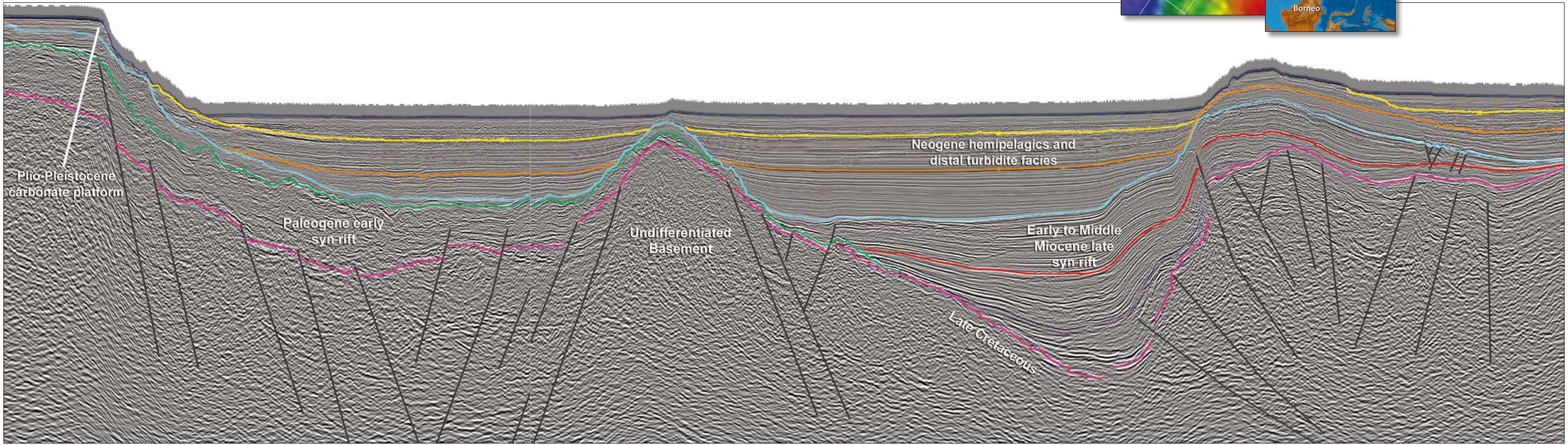
Searcher Seismic, in cooperation with the Philippine Department of Energy (DOE), has acquired over 8,500 km of long-offset, PSDM processed 2D seismic data in the East Palawan Basin. The interpreted line below is oriented north-west to south-east and highlights thicker sedimentary sections than the producing Northwest Palawan Basin, as well as previously unidentified sub-basins in the area (e.g. the Mialara Sub-basin).

With the approaching Philippine Conventional Energy Contracting Program (PCECP) bid round, these datasets are revealing new hydrocarbon potential and highlighting the prospectivity of the East Palawan Basin, which makes for an exciting future for exploration in the Philippines.

Searcher Seismic



Map showing the location of the East Palawan data (white), acquired in conjunction with the DOE, TGS and Seabird, overlying the free-air gravity anomaly (relative highs in whites/reds, lows in blue) (Bureau Gravimétrique International, WGM2012 Model). The location of the foldout line is highlighted in black.



The Underexplored East Palawan Basin

Insights from the only five wells drilled to date, together with modern seismic data, reveal that there is still much to be unraveled in the East Palawan Basin.

ANDREW WELLER, Searcher Seismic Pty Ltd, and **KRISTA DAVIES**, Discover Geoscience Pty Ltd

Much of the Philippines is characterized by mobile arcs, accretionary terrains and spreading centers. However, the western Philippines is underlain by Sundaland continental crust (Metcalfe, 2017). Palawan and its surrounding basins rifted and separated from southern China during the opening of the South China Sea in the Oligocene and Early Miocene. It is this period that much of the exploration efforts have been focused on; i.e. Oligo-Miocene carbonate plays such as the Malampaya Field.

In 2014, Searcher Seismic acquired the Mialara 2D seismic survey to provide long-offset, high resolution seismic data over the East Palawan Basin to help identify prospective stratigraphic and structural trends, as well as tie the wells and the previously acquired Pala-Sulu 2D seismic survey (see map on main foldout page). The Mialara data addresses multiple issues with the vintage data in the area by using a 10 km streamer with improved frequency response, a larger source array for improved signal penetration, and a broadband anisotropic PSDM processing workflow.

Only Five Wells

The East Palawan Basin, when compared to its producing sibling the Northwest Palawan Basin, remains an enigma, as it is devoid of any hydrocarbon discoveries or producing fields. With only five wells drilled in the area, as shown on the map (right), the basin remains underexplored.

The majority of the wells in the East Palawan Basin were drilled in the 1970s and early 1980s, in general chasing Miocene objectives, although most resulted in dry holes. Perhaps the most intriguing of them is Dumaran-1 (1979, Citco Philippines Petroleum Corporation) as this flowed gas to surface and revealed traces of dead oil at depth. This suggests that up-dip migration from the deeper parts of the basin could be feasible. Dumaran-1 ultimately terminated in pre-Cretaceous ultramafic basement rocks.

The most recent well was drilled by Shell in 2010 (Silangan-1). The well was chasing a turbidite flat spot objective, but post-drill analysis showed limited reservoir development. The flat spot was interpreted as a slump and the well, which terminated in the Middle Miocene, was plugged and abandoned as a dry hole.

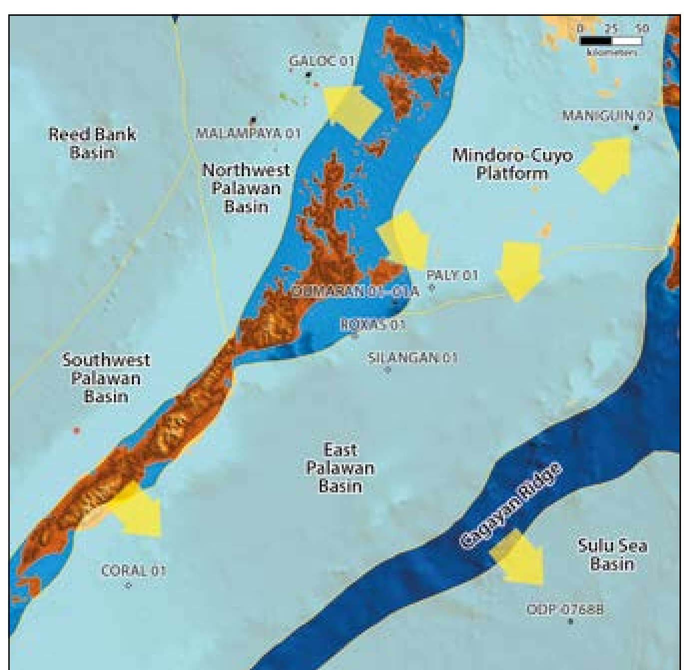
Several Plays

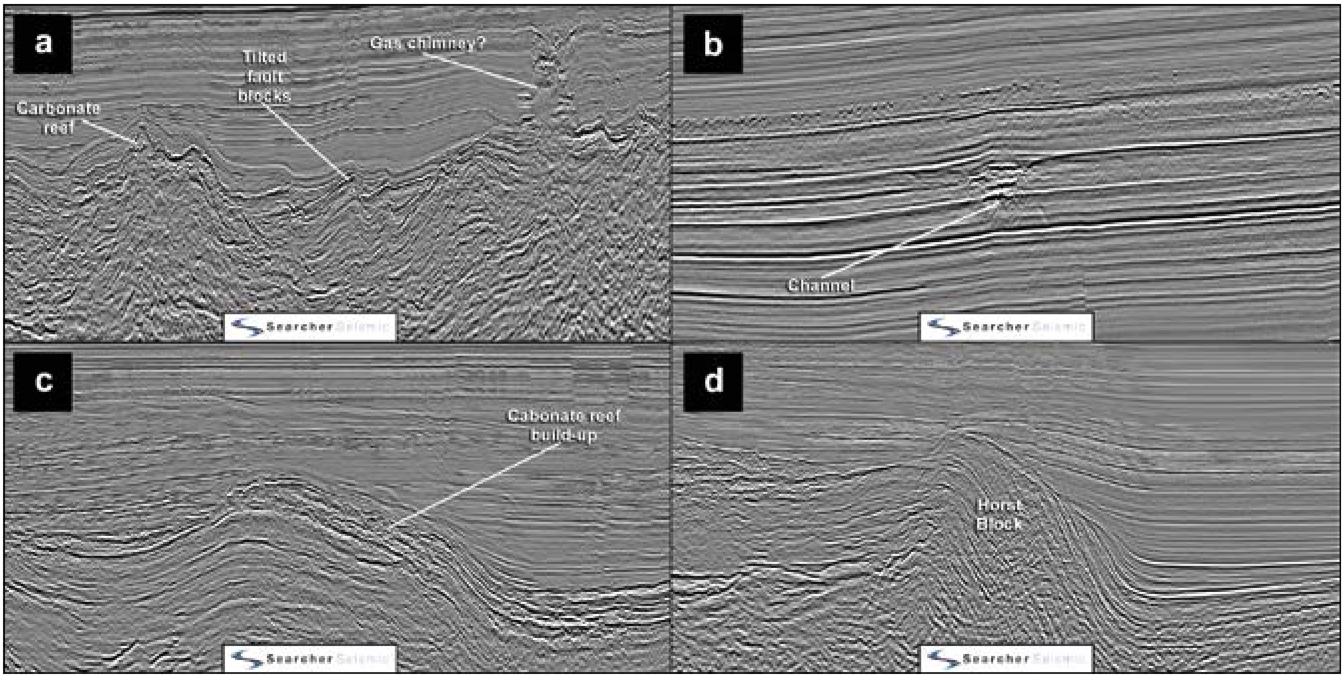
Sandwiched between the Northwest and East Palawan Basins lies the Mindoro-Cuyo Platform. The platform contains several rift-related grabens that appear to have a similar late Paleogene history to the Northwest Palawan Basin and its known oil and gas producing areas (Ballesteros and Robinson, 2012). During the Neogene, their development changes and is analogous to the depocenter associated with the Maniguin oil discovery.

The only available data are from the four old wells on the basin margin. Excluding Silangan-1 (Shell, 2010) which is in a more basinal location and terminated in the Middle Miocene, the wells in the Mindoro-Cuyo Platform arguably provide the closest useful data. The Maniguin-2 well was drilled in 1994 by PNOC on the eastern flank of the Mindoro-Cuyo Platform and flowed 300 bopd of waxy oil from a Lower Miocene sandstone reservoir (the Semirara Formation). Post-well analysis suggests that the Miocene source rocks and reservoirs were deposited under paralic to shallow marine conditions (Forbes, 2002). Lower to Middle Miocene sandstones in adjacent wells (Semirara-1 and Maniguin A-1X) also have high porosities (9–31%) and permeabilities (<1,070 mD). Is it feasible that this source-reservoir interval exists towards the Mindoro-Cuyo Platform's southern margin (and the East Palawan Basin)?

Distributary channel facies are observed in the

Structural elements of the Palawan area (from the DOE) with the location of key exploration and ODP wells. Yellow arrows indicate possible Miocene continental (quartz-rich) sediment transport and subsequent reservoir potential in the deeper parts of the basins (e.g. the reservoir of the Galoc Field, the Galoc Sand, a Miocene turbidite).





Insights into the stratigraphic and structural trends present in the Mialara data that warrant further investigation. a: tilted fault blocks, carbonate reef and gas chimney with potential hydrocarbon related diagenetic zone; b: channel feature with differential compaction suggesting coarse clastic fill; c: Upper Miocene carbonate reef; and d: Pre-Miocene horst block.

Neogene section throughout the Mialara data, including channels with differential compaction evidencing coarse clastic channel fill (see b above). This suggests that Miocene sandstones like those encountered in Maniguin-2 have been delivered into the East Palawan Basin from the Mindoro-Cuyo Platform and Palawan areas.

The Mialara data allows mapping of several rift-related grabens across the East Palawan Basin, some of which reach up to 7 km of burial which is likely to be buried to sufficient depths for the generation of hydrocarbons. Some grabens appear to be filled primarily with Paleogene early syn-rift sediments, while others are predominantly filled with late syn-rift Neogene fill. The Dumaran-1A well recovered gas to surface and encountered common traces of glutinous black tar with bright yellow cut fluorescence only, suggesting a working petroleum system in the area.

Calibrating the heat flow and thermal history data from Maniguin-2, Searcher Seismic has produced a burial history model for the Mialara Sub-basin. This puts the Lower Miocene source in the late oil-gas window in the deepest part of the basin, which provides an encouraging benchmark for the other (deeper) parts of the basin.

The area has also demonstrated good quality reservoir characteristics. The Roxas-1 well was drilled in 1979 by Citco Philippines Petroleum Corporation and encountered porous Middle Miocene sands (from 823 to 1,220m). ODP wells drilled as part of Leg 124 encountered Middle Miocene quartz-rich, continental-affinity turbidites, demonstrating that long distance transport during this period is feasible, the source of the sediments most likely being the Cagayan Ridge to the west.

Additionally, undrilled Miocene carbonate reef facies, analogous to the Nido Limestone targeted in fields across Northwest Palawan, are observed on the Mialara data and may provide targets with excellent potential reservoir quality (see a and c above).

Potential Leads

An analysis of the Mialara data uncovers several stratigraphic and structural trends. As well as the Neogene section with the potential for source intervals that are thicker and more extensive than in the proven areas of Northwest Palawan (see foldout), significant Paleogene (and older) potential also appears to be present at depths conducive to hydrocarbon generation. Potential leads include channels with differential compaction suggesting coarse clastic fill, Pre-Miocene horst blocks, Upper Miocene carbonate reefs (possibly Malampaya analogs?) and tilted fault blocks. Additionally, gas chimneys identified on the Mialara data provide Direct Hydrocarbon Indications (DHIs). The figure above highlights several of these features that we believe warrant further investigation.

The Future

Exploration success relies on high quality seismic data for the delineation of prospects. The Mialara data unequivocally provides a clearer image of the structural and stratigraphic framework and challenges the perceptions of limited prospectivity and the existence of a viable petroleum system in the lightly explored East Palawan Basin. Imaging of the deeper Paleogene and older strata, as well as better Neogene definition, enables the de-risking of the likely generative system in the area.

With the approaching PCECP bid round, the future is exciting for exploration in the Philippines. Coupled with Searcher Seismic's modern 2D seismic data, the true play potential of the region is beginning to be unraveled.
References available online. ■

Under the Patronage of
His Royal Highness
Prince Khalifa bin Salman Al Khalifa
Prime Minister of the Kingdom of Bahrain

CALL FOR ABSTRACTS IS OPEN
SUBMISSION DEADINE
20 JUNE 2019

4 DAYS.
ONE SHOW.
INFINITE OPPORTUNITIES.

GEO 2020
14th Middle East Geosciences Conference and Exhibition

CONFERENCE:
16– 19 March 2020
EXHIBITION:
17– 19 March 2020

BAHRAIN INTERNATIONAL EXHIBITION & CONVENTION CENTRE

geo-expo.com

CONFERENCE THEME:
Geosciences in the Digital World: 2020 and Beyond

HOSTED BY
الهيئة الوطنية للنفط والغاز
National Oil & Gas Authority

SUPPORTED BY
EDB ECONOMIC DEVELOPMENT BOARD BAHRAIN
تمكين
Tamkeen

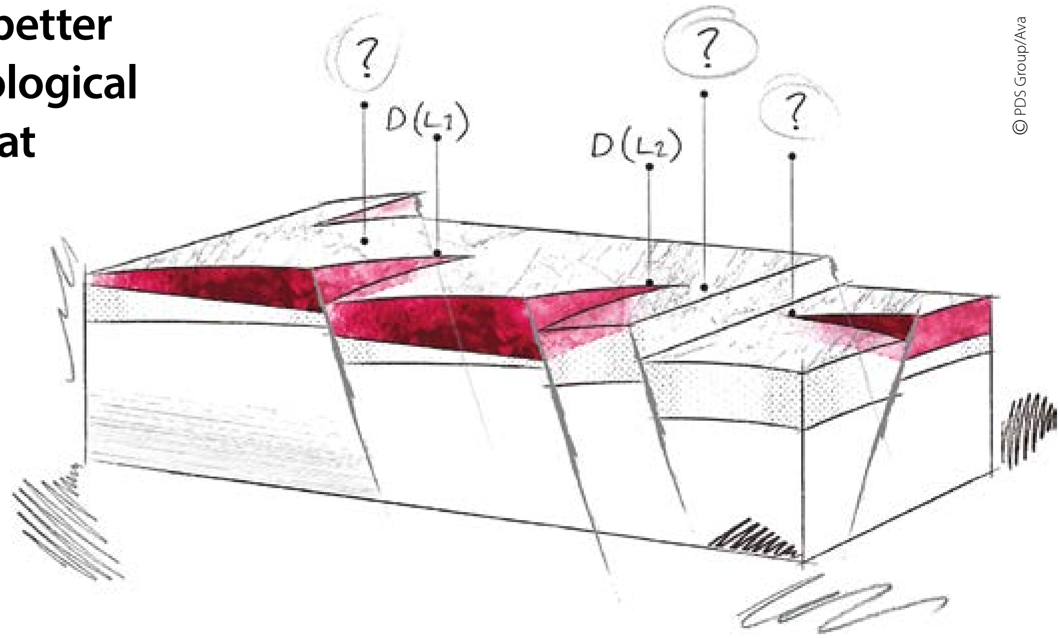
CONFERENCE ORGANISERS
AAPG
EAGE EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS
SEG SOCIETY OF EXPLORATION GEOPHYSICISTS

EXHIBITION ORGANISERS
UBM
AEM

Counting the Cost

Are we getting better at assessing geological uncertainties that underpin our economic decisions?

LAURA ROBERTS and VIKI O'CONNOR; PDS Group/Ava



© PDS Group/Ava

What impact does fault compartmentalization uncertainty have on development costs?

It is a common misconception that inherent subsurface geological complexity prevents us from accurately estimating key reservoir parameters. The understanding developed over many decades of research combined with extensive operational experience means that general reservoir geology is no longer a mystery. The real challenges are our lack of understanding and data coverage and quality for a given target reservoir interval.

What Happens Today?

Current technologies support the generation of suites of three-dimensional (3D) models; this has become best practice for simulating the physical properties of oil and gas fields. They are a fundamental part of the reservoir characterization workflow, used to forecast field production, and are the basis for assessing economic viability and the associated risks.

Uncertainty is present in all aspects of the reservoir modeling workflow, from obtaining the raw data, to data processing and interpretations, through to model creation. As we cannot peer into the subsurface directly, our non-unique geological interpretations are based on expert knowledge/assumptions combined with a mixture of locally available hard and soft data.

Multiple versions of the same model are often built. There are a variety of approaches to generate these model suites, but regardless of the approach, multiple models can help geoscientists identify, assess and evaluate the geological uncertainties, as well as quantify their cumulative economic impact.

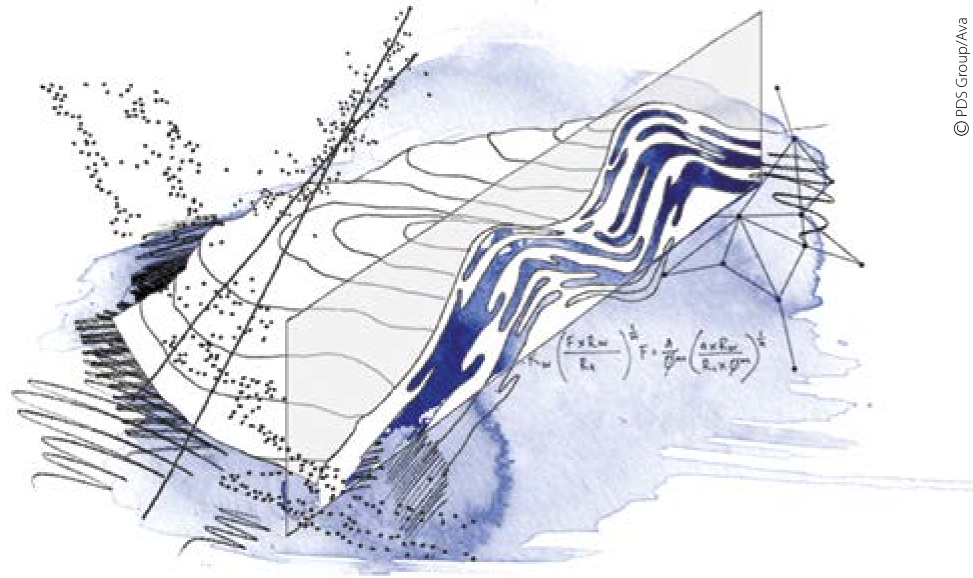
Emerging data collection and analysis approaches, combined with the scalability offered by cloud architectures, provide opportunities to increase complexity in our model representations. However, generation of larger and more complex models without appropriate geological constraints is not valuable. This potential for misdirected effort is unacceptable, especially when many teams are currently understaffed. Geoscientists are often left without the time or the technology to generate either multiple plausible scenarios for a single reservoir and/or multiple models for individual aspects of their simulations, such as facies, petrophysical and structural models. The representations of these three areas of uncertainty are susceptible to ambiguous data and subjective interpretation.

The State of Play for Structural Modeling

Geoscientists recognize that in the vast majority of geological settings, a reasonably accurate and plausible structural model is crucial in terms of estimating the gross value and development cost of an oil or gas field. They also recognize that anchoring any subsequent uncertainty workflows on a single structural scenario is undesirable, but often challenging to realize, given time and technology constraints.

The number, location and connectivity of faults throughout the reservoir are the primary factors that determine the number and size of reservoir compartments, impacting reservoir efficiency, sweep patterns and ultimate recoverable volumes. Failure to express the potential for structural compartmentalization is risky and is the subject of many after-action well reviews.

To fully characterize structural uncertainty in a reservoir, objective assessment of fault interpretation quality is needed, testing it with basic structural geology rules. A detailed understanding of the fault network and connectivity allows geoscientists to develop and probe plausible alternative structural models that are representative of the range of uncertainty, and its impact on the number and size of reservoir compartments. Importantly, they can act as proxies to development cost.



Not exploring multiple saturation models and scenarios can have important economic implications.

© PDS Group/Ava

Links Between Structural and Saturation Modeling?

Increased confidence in investment decisions can result from understanding structural uncertainty in detail, in particular its interplay with saturation modeling.

Unfortunately, the derivation and then application of a saturation height function to a reservoir model with multiple fault blocks can be a time-consuming, arduous process. This is because building a saturation model involves many calculation steps, the inputs to which have their own specific uncertainties (e.g. porosity depends on the logging tool, calculation method and input parameters).

Frequently, a single saturation height function is applied to the reservoir model with uncertainties relating to the calculation method and its impact on reservoir volumes not considered due to a lack of time. The relationship between permeability distribution and saturations is often a single scenario and uncertainties in free water level depth are not always considered when deriving a saturation-height function.

However, not exploring multiple scenarios can have a significant impact on the distribution and volume of hydrocarbons in a reservoir, which can in turn have important economic implications.

How About Facies Modeling?

In terms of facies distributions in the inter-well space, although it's possible to investigate aspects of potential depositional settings through experimental equivalents in the lab and numerical simulations, the processes cannot be replicated to scale. To fill this knowledge gap, we have to rely on other information to augment our understanding.

Previously, geological and expert knowledge of similar assets would be relied upon to define facies properties in the inter-well space. Though valuable and still necessary, there are inherent shortcomings to this approach: it is subjective and lacks the rigor of evidence-based decision-making. Ample data acquisition efforts now mean that incorporating analogs in reservoir modeling workflows is considered best-practice. However, it remains a time-consuming process that is still somewhat subjective and highly variable, often depending on available domain expertise.

To fill some of these gaps there is a requirement for high quality sedimentological databases, which encapsulate scientific rigor in the data collection stage and which incorporate a breadth of information from both modern and ancient successions. They must have the potential to represent analogs to present-day hydrocarbon reservoirs by including quantitative analog data distributions, which can be used to inform workflows such as facies modeling.

By incorporating appropriate analog information, an improved and defensible distribution of reservoir facies through the model can be achieved. Crucially, effective investigation of depositional uncertainties is enabled by the selection of suitable analog datasets to define a range of contrasting, but geologically realistic, scenarios.

An Uncertain Future?

The multifaceted nature of geological uncertainty in 3D modeling makes its appropriate characterization one of the biggest challenges that the oil and gas industry faces. Despite the difficulties in defining reasonable ranges for these key parameters, the economic costs of not doing so are significant. As the industry is forced to adapt to the ongoing demographic transformation and the exploitation of resources in increasingly marginal geological environments, the benefits of dedicating more to the appropriate assessment of uncertainty in 3D models far outweigh the costs.

There are many exciting new technologies coming into the market that help assess these key geological parameters. The integration of established approaches, such as databasing, with more recent innovations such as the application of machine learning, create new opportunities for geoscientists to explore the financial impact of critical geological variables on the economics of their asset, in an efficient, rigorous and repeatable way. ■

NVENTURES

Global Bid for Successful Rounds

What makes for a successful bid round – and what are the pitfalls to avoid?

PETER ELLIOTT, NVentures

A momentary peak in oil price in late 2018, hitting $80, spurred amongst other things a rash of bid rounds designed to take advantage of renewed exploration confidence. Exploration investment remains low, however, with an all-time hiatus in multi-well drilling campaigns. The role of license and bidding rounds is due some scrutiny, as some of those launched late 2018 have stalled or failed. Whilst the major trend is towards more established petroleum plays, some countries (Mexico and Argentina, for example) are starting to add unconventional into the conventional oil and gas mix.

Expectations for a typical bid round start high, and remain high, based on the level of organization, promotion and favorable geological prognosis. The latter risk is the most difficult to manage, and authorities need to engage in the bid round process only when expectations below ground are robust. Frontier exploration can always be promoted, but competitive bidding and prescriptive licensing rules can – and do – put off major investors. On the other hand, a well organized and well promoted exploration sector (with good data availability) will always compete to attract exploration dollars for higher risk acreage. Recent successes and failures highlight this simple dichotomy.

Mature Areas Winning

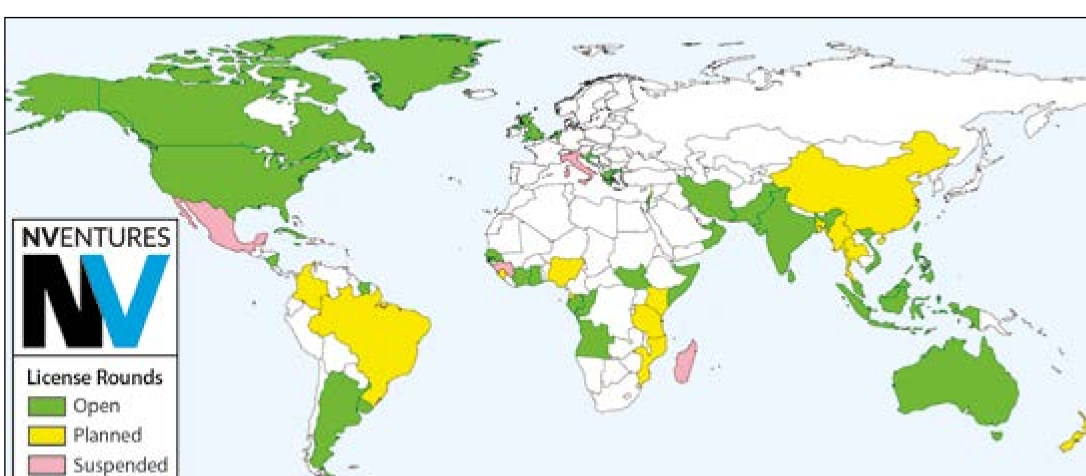
The most successful bid rounds of the last 12 months have been in areas of proven and often mature exploration and production. There are thought to be over 60 active bid rounds globally at the moment, with those in the Americas appearing to attract the greatest investment. Newfoundland and Labrador held three Call for Bids in 2018, attracting over $1.4bn in bids, mainly from BHP. In the US onshore, bidding on the Permian Basin in 2018 topped $972m, twice the amount recorded in 2008, while the offshore Gulf of Mexico Lease Sale 252 attracted $284m in bids for 257 licenses (see page 8).

Moving south, a number of governments (Mexico, Brazil and Argentina, for example) have seen a renaissance in licensing strategies designed to re-engage with weary IOCs. Mexico launched successful bid rounds for a number of terrains, with the shallow water Round 3 First Bid Process probably the most successful. The Sureste Basin was the highlight of that round (the Zama discovery, for example), reminiscent of the early years of the Lower Congo salt basin bids of the 1990s. Brazil is likewise bringing order to their licensing strategy, with nine rounds in total, as well as various sub-rounds for exploration concessions versus pre-salt PSCs; Rounds 16 and 6 are currently underway. Elsewhere, successful rounds have been associated with proven or recent hotspot basins, such as Cyprus, Congo, Australia and Egypt.

A number of bid rounds are reaching their culmination. Great interest is being shown in the Tano Basin offshore Ghana, as well as shallow and deepwater Gabon. Croatia, driven like a lot of EU countries to re-organize the E&P sector and promote participation and structure the licensing process, have two onshore rounds that are expected to attract reasonable investment. Argentina will announce the results of Round 1 soon and are planning a second one.

Open Doors Open Frontiers

In some recent examples, however, the competitive bid round has either stalled or been abandoned. Good organization of an open door policy, with regular acreage releases, well prepared and affordable data packages, national repositories and strong communication routes (online access, for example) are often more attractive for IOCs to understand the potential of frontier, higher-risk acreage. Sierra Leone, Kenya, Madagascar, Tanzania and Albania are amongst a few that have witnessed stalled or re-scheduled rounds. Uruguay took the high road and went from a bid round system to a well organised open door policy, and hopes to reap the rewards soon. ■



THE WORLD IS ATTENDING ICE 2019

ATTEND ICE 2019 AND OPEN THE DOOR TO A WORLD OF NEW OPPORTUNITIES.

- Hundreds of oral and poster presentations allow you to design the perfect learning experience, giving you the knowledge and skills necessary to overcome your greatest exploration and production challenges.
- Meet with key governmental and industry leaders in the International Pavilion, where you can discuss opportunities, overcome obstacles, and make deals that create new paths to profit.
- Take the opportunity to meet with a broad section of Latin America experts and officials all under one roof.
- Get the best deals on the latest technology by visiting the exhibition and dealing with motivated sellers face-to-face.
- Take advantage of the amazing city of Buenos Aires to develop relationships with key contacts in hundreds of amazing restaurants, pubs, and clubs.

For information on large group pricing contact
Wade Huntsman
Promotions and Sales Manager
whuntsman@aapg.org

LIMITED EXHIBIT SPACE IS AVAILABLE BOOK NOW TO RESERVE YOUR BOOTH.

If you plan to successfully market in the Latin American E&P space during the 2020's, ICE is a key building block to achieving that goal. Be there in person to establish the relationships that turn calls into sales. You can also take advantage of sponsorship opportunities to make your brand first in mind when buying decisions are made.

INTERNATIONAL PAVILION SALES:
GINA GODFREY
Tel: +1 303.618.6595
gina.godfrey@petroweb.com

EXHIBIT SALES
TRACY THOMPSON
Tel: +1 918.560.9414
tthompson@aapg.org

REGISTRATION NOW OPEN
Visit ICEevent.org

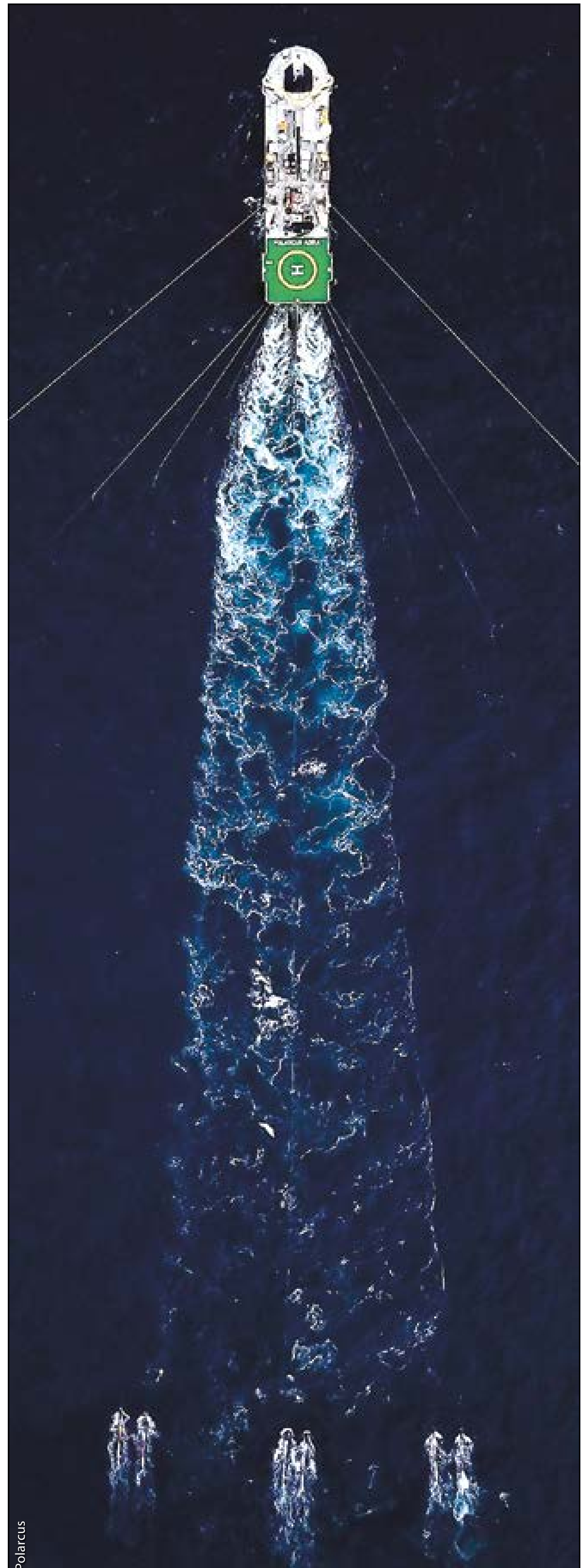
ICEevent.org

Pie in the Sky?

Some thoughts on the future of marine towed streamer seismic.

ED HAGAR, Polarcus

Polarcus XArray™ Triple source acquisition.



Seismic acquisition and exploration technology have been in an arms race since day one. Equipment manufacturers have taken us from low channel analog recording systems to high-channel count digital systems with low-noise streamers. Processing houses have taken us from NMO stack to DMO and post-stack migration to pre-stack time migration and depth migrations and now full waveform inversion (FWI). In each case, one can argue that each step forward is countered by an alternative competing solution – for example, low-noise solid streamer countered by high-end de-noise workflows and similarly for broadband solutions. For processing and imaging, the driver behind new and competing algorithms tends to be access to cheaper and faster compute capacity. In each case, any advance, and hence commercial advantage, is quickly commoditized by an alternative, through either acquisition or processing or a combination of both. A true step change in seismic quality is difficult to see right now; high-end acquisition systems may well produce demonstrably better results, but not always where they are useful to the geologist – and they carry significant R&D costs.

So how are we going to progress given truly novel and useful innovation is a way off? In part, it will be the application of known science in new ways or just different ways of looking at the problem; knowing the problem and providing the simplest practical solution.

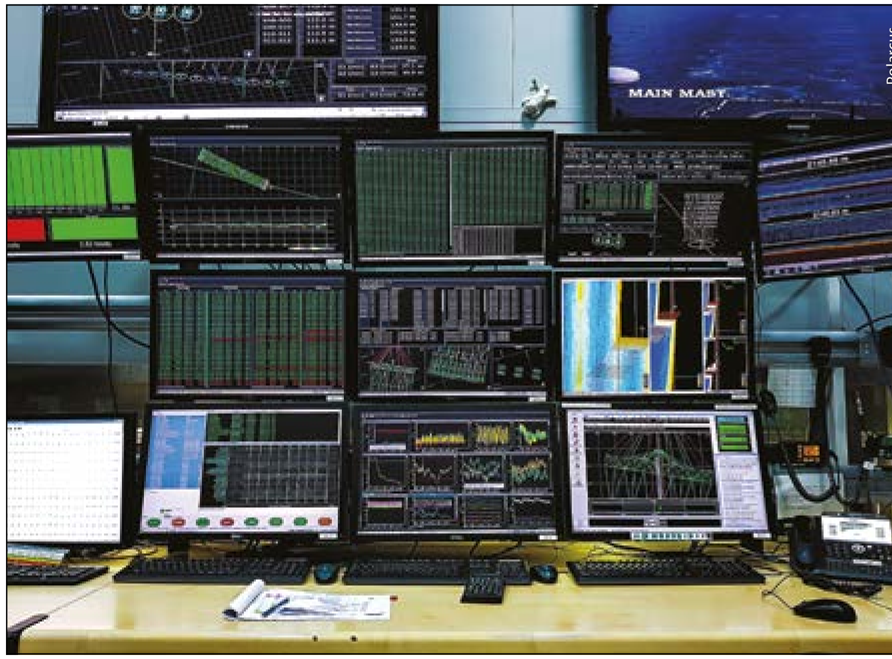
For example, as part of their drive on costs during the downturn, exploration companies have shortened the exploration cycle time – and here the 'cloud' offers solutions. For environmental factors, the humble near-field hydrophone gives new options if we understand how the seismic source works. For quality, 4D repeats can be improved in simple ways that decrease the risk. All-in-all the future is about flexibility and adaptability to help de-risk the project, be it a large exploration survey or the smallest 4D repeat.

We discuss some interesting, and maybe unexpected, solutions in this article.

Cloud Solutions

By getting seismic data in the cloud – i.e. uploaded to a data center somewhere – we decouple the data location from where it is generated to where it is used. Simple, but the implications are wide ranging.

The simple aspect is that by uploading the data, we eliminate the time and possible delays it takes from getting the physical tapes from the vessel to the processing house and provide access to anyone and anywhere.



Seismic operations room onboard a Polarcus vessel.

In addition to the acquisition-QC displays already sent off the vessel, access to additional data such as streamer separations, gun timings, currents and bathymetry, cloud seismic allows for more detailed analysis of the actual data. This means that onboard representative staff can be reduced and theoretically eliminated (OK, that is pie in the sky!), offering a reduction in both HSE risk and costs whilst increasing the ability of onshore experts to evaluate and monitor quality from anywhere.

Fast-track Processing: Frankenstein's Monster

Maybe a harsh comparison to make but, like the original

Acquisition project planning onboard.

Frankenstein's monster, fast-track imaging can be sometimes terrible and sometimes a life-saver; for example, initial amplitude scans and initial well-prognosis can both be concerns.

Fast-tracking suffers from three issues. The first is experience in the field; the second is supervison in the field; and third is compute resources.

So, if we can upload seismic data from the vessel directly to the cloud it allows access to unrestricted compute resources: more time for testing as processing stages can be run much faster than onboard, enabling higher-end flows such as depth migrations and FWI. The processing center can be nywhere – a big screen and an internet connection are all that is needed – so oversight is easier to manage. Even without local processing, just being able to interactively examine the tests properly will help, including bringing in additional experts regardless of their location. What we will end up with then is super-fast slow-tracks where the interpreters can get going in just a few weeks after the last shot, reducing the cycle time.

A real advantage of seismic in the cloud is the ability to use the final processing center to QC the acquisition; whilst onboard data QC is sophisticated, it will not match the baseline processing in the onshore processing center. The processing contractor can then sign off on the acquisition, which will reduce the risk. Of course, having the data available and a known processing flow means having 4D results in no time – with a caveat.

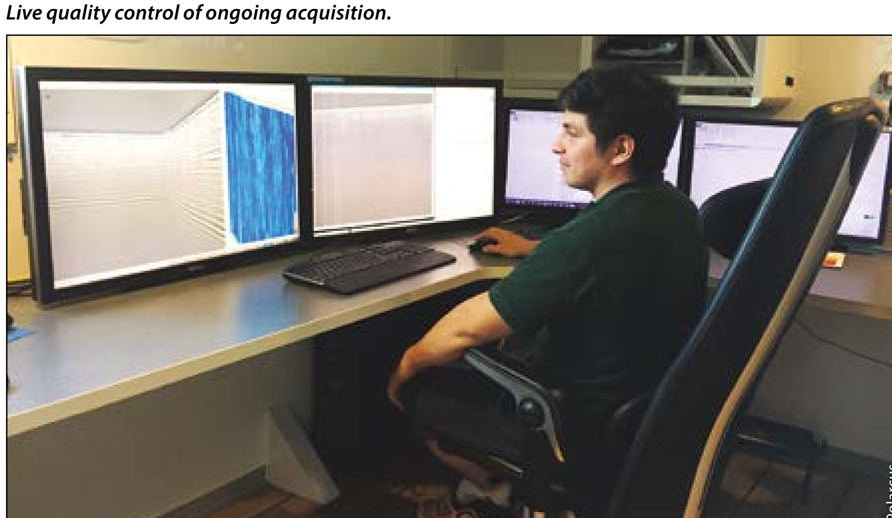
Uploading to the cloud off the vessel has been accomplished, and the satellite links are stable enough. However, the satellite network is still limited by the rate of data transmission. To get around this, we must compress the seismic data. In the past compression has resulted in information being lost, but now technology is available that allows virtually loss-less compression. How do we define loss-less? When we difference compressed and uncompressed data, we can see that the 'loss' is 60 dB down. More importantly, the spectrum of the difference is perfectly flat, indicating white noise containing no information or signal. For 4D the differences may be borderline, but compression levels can be varied to suit to eliminate risk.

Big is Beautiful?

Another trend that is building within the industry is for smaller but more sources. Triple source acquisition has become ubiquitous since the reboot by Polarcus a few years ago. Implicit in this is the reduction in source volumes, as seismic vessels generally have six sub-arrays which can be used – and with the triple source, we go from three sub-arrays per source to two. Given the amount of data acquired with this design, there does not appear to be any concerns with the smaller output.

This can be explained by the decreased ambient noise

Live quality control of ongoing acquisition.



recorded with solid streamers and better algorithms for removing the remaining noise, coupled with high-dynamic range recording systems. If we go for still smaller sources, we will start to lose the airgun tuning that drove up source sizes in the first place: the reduction of the 'bubble' rather than the increase in overall acoustic energy. The solution is to use the near-field hydrophone (NFH) to create shot-by-shot estimates of the source signature, which allows for accurate de-bubble in particular. With this, metrics such as the peak-to-bubble ratio become obsolete. Concerns over ambient noise will always be there but can be mitigated by increasing the shot sampling to more than compensate. In many cases, the 'noise' is, in fact, shot generated and therefore relative to it, as in the example of multiples. Tests have already been run with single cluster sources with some success, showing that smaller sources can be viable.

Back-deck streamer deployment.

Smaller sources would reduce any adverse environmental effects, at least due to the peak sound level (SPL), but if we fire the airguns more frequently, which we would then need to do, the downside is little, if any, reduction in the sound exposure level, which reflects the level of background noise; for comparison, a motorcycle that backfires has a high peak sound level, while the background traffic noise is like the sound exposure level. However, like safety, reducing outputs to a minimum should be an essential ambition, and one that will be forced on the seismic industry at some point anyway.

We can use more sources to help our acquisition designs and increase quality. By using wide streamer spreads we gain efficiency but can create problems in the demultiple process with the lack of near offsets. The simple solution is to spread out the sources – wide-tow sources – to create a mix of near-trace offsets so that demultiple processes like SRME can work better and regularization can fill any holes (if any) to improve the near-surface imaging. This is an example of the 'arms race', where different software and hardware solutions have been developed in the past to deal with the poor near-offsets of wide spreads. Wide-tow sources offer an alternative, which, like many good solutions, is the simplest – and also removes proprietary acquisition and processing not so beloved by operators, especially their procurement departments!

4D monitor surveys can also be helped by the smaller, but measured sources. We can create source geometries that simultaneously replicate the baseline 4D geometry whilst also increasing the resolution and fold. With NFH data we can compensate for the different source signatures. We can even verify this through use of the cloud: upload data, run de-noise and de-signature, then compare. This would test not only that source characteristics match but also the compression, source-receiver position-matching and any other effects, known or unknown, that might affect the 4D response.

Hybrid Surveys

There are advantages to the notion of combining streamers and nodes in that we take the benefit of the near offset density of streamers so we can increase the node spacing. Challenges will be there for the combination of such different datasets, but maybe that is not so important. Streamers will give access to data via the cloud very quickly and enable the velocity modeling to begin sooner, whether it be manual, tomography or FWI. Once node data is retrieved, shipped and loaded, it can be used to complete the velocity model building with long-offsets.

If the node separation is small enough then we can create an image dataset for the deeper section. Given that nodes can provide deep velocity control, then streamer lengths can also be reduced, depending on the node geometry and project objectives. Ideally, streamer and node data would be combined, but that will depend on many factors, driven one way or the other by the geology.

A Possible Future?

The cloud clearly offers some great options for the future, especially in the 4D world where even the smallest deviations could ruin the result. The concept of uploading data comes with a risk of what might be lost during compression – but this can be checked and quantified as required, and even if something slips through, the affected shots can be simply replaced at the processing stage. Or if the reservoir level interpretation (inversion) is particularly challenging, rerunning lines over the target area will just be a CPU burn and will remove any doubt. What fits in well with data compression is the multi-source style of acquisition where more sources do not increase the data volumes for compression, as the shots overlap, but more streamers do. Increasing source numbers and hence smaller volumes are enabled by accurate de-signature through NFH data.

So, the future will be driven by the humble near-field hydrophone. Who would have thought of that? ■

Big Data Crowns a Career

Having risen through the ranks in ExxonMobil, from working offshore Nigeria to senior managerial roles, Tolulope Ewherido is now Vice President, Technical-Geoscience, where she is able to satisfy her passion for technology and her interest in Big Data, while steering the company towards the most efficient use of new digital tools. She is also the first black female Vice President in any ExxonMobil upstream company, and the first Nigerian Vice President in the ExxonMobil Corporation.

JANE WHALEY

The routes into a career in geoscience are many and varied – but rarely involve architecture, the subject that Tolu Ewherido initially intended studying. "I'm an accidental geologist," she laughs. "I started studying architecture at the University of Ibadan, in Nigeria, and I am still interested in the subject, but after my first year, the funding for the course was pulled, so I had to find something else. In school I had always enjoyed geography and anything to do with the formation of the earth, so I transferred to geology and soon found I loved it. I also discovered I had a natural affinity for the subject, because despite missing the whole of the first year I graduated first in my class."

While at university Tolu undertook an internship with Mobil, working in an asset team, and this confirmed for her that oil and gas was the path she wanted to travel. "In Nigeria, all graduates must do a year's internship," she explains, "so I did that with Mobil and then in 1991 I applied for and got a job with the company. I was an operations geologist, and on my first trip offshore I was the only woman, with seven guys. The 'company man' ended up giving me his bathroom – the only single one – in those days they just weren't prepared for women on the rigs. But I have to say, the men on the rigs were always absolute gentlemen. That surprised me a bit, because from the way people talk you get the impression that they would be rough, but for me it was actually a really nice experience and everyone went out of their way to help."

Maximizing Productivity and Value

After a couple of years in the asset team working on the Mobil Producing Nigeria development and appraisal drilling programs, Tolu transferred to the production geoscience team. Overall, she reckons that about a third of her career has been spent in exploration and the rest in the production arena.

"I have to admit, I'm a production geologist at heart," she continues. "I really like the part of the value chain post-discovery when you are evaluating the field and working out the concepts that will deliver maximum productivity, recovery and profitability and then executing that over the life of the field."

Tolu initially worked on the development planning and start-up of the Oso field, the only condensate development project in Nigeria, and also on the Usari field, where the complex shallow marine fan stratigraphy has resulted in more than 11 distinct reservoir compartments. Having helped bring these fields onto production, the asset team then needed to concentrate on optimizing recovery over the life cycle of these fields.

By 2000 Tolu was the Asset Team Leader for the Usari field. She was responsible for coordinating creation and implementation of asset business plans consistent with business outlook and the execution of activities focused on maximizing value through the asset lifecycle. "Our asset teams are cross-disciplinary, with facilities and production engineers as well as

AAPG

Tolu speaking at the at the panel session on 'Next Age Technology: Big Data, Big Success' during the AAPG International Conference and Exhibition in Capetown in 2018.

geologists. This was my first foray into cross-functional working, and I found I really loved it," Tolu continues. "At the end of the day, the value of these reservoirs comes through bringing together the best solutions cross-functionally and leveraging them across those functions. This suited me perfectly; I think I have a natural affinity for it but also, I love the way it brings together a range of expertise, some of which at the time I wasn't very familiar with, so it gave me a huge amount of growth. It also helped me understand how the business makes money and I really liked gaining a deeper understanding of that. You don't get such knowledge if you only do geoscience work, but having obtained it, I've found that having an understanding of 'where the money comes from' has been key to my career progression.

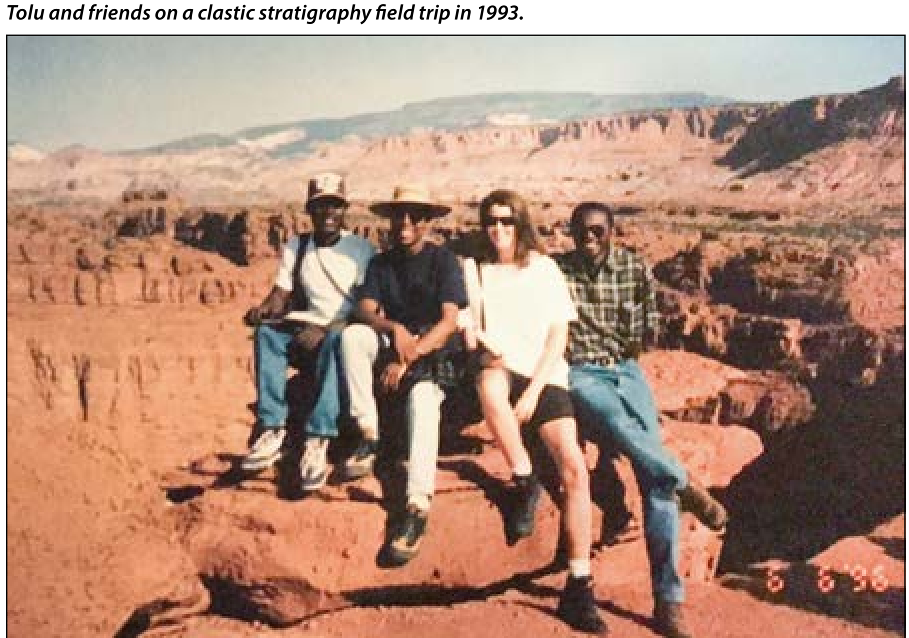
"I was quite young at this time, and I was lucky to be working with and learning from men who had 20 years' experience or more. However, as I was team leader, it also produced some interesting dynamics that I had to learn how to navigate. Nigeria's culture is both hierarchical and patriarchal; I recognized that though these older men worked for me, I had to show them that I valued and respected them to fully leverage their expertise and participation on the team. It was a fine balance; for example, I never used their first names which, even though acceptable in the business environment, is perceived as culturally disrespectful. I think that realizing I respected them culturally, they were more willing to respect me and my ideas professionally. It was excellent experience."

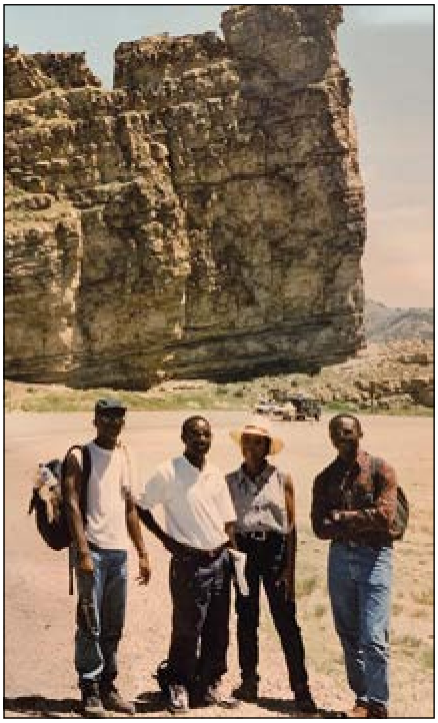
A Move to the US

In 1996 Tolu transferred to Mobil Technology Company, Dallas for three years, working on reservoir characterization and field simulation studies. Following the Exxon and Mobil merger in 2001, she moved to Houston to take up a very different role in the new company: that of Geoscience Functional Advisor, responsible for stewarding career development and training plans for about 60 ExxonMobil development and production geoscientists in Houston, New Orleans and Nigeria.

"In this new role I was responsible for training, career development and recommendations, working as an advisor to the production geoscientists. I talked to them about their current jobs and aspirations; if they needed mentoring, I connected them, or helped with training. I was working at a very close personal level with people in the early stages of their careers, some of whom have become close personal friends. It was very satisfying.

Tolu and friends on a clastic stratigraphy field trip in 1993.





Another field trip in 1993, this time on deepwater stratigraphy.

"Around this time, I took a career break of about a year, as I had just had twins, making four kids under five! The company has flexible career policies and is very supportive over career breaks, ensuring that when you return you will be able to continue on your career path. It's great to know you have the freedom to ask and you're not taking a risk; you know there will be a good job offered to you on your return. I have taken advantage of this opportunity on four occasions, taking breaks of between two months and a year. It has worked well and I would not have progressed my career to the extent I have without being afforded these flexibilities; I was able to take time out and be at home when I felt I needed it, and then when I returned, I was able to give myself 150% to the job. You can only be creative and at your best at work, or home, when your whole self is present."

She points out that her husband also works for ExxonMobil, which makes it easier to balance work requirements and home life; for example, they can ensure that at any one time they do not both have jobs at the same time that require traveling.

"When I came back after the twins I wanted to work part-time, so I was offered a role developing a training course that integrated geoscience and engineering together with economic analysis, so the experience I had gained previously proved very useful. I'm pretty proud of the fact that the concepts I developed on that course remained on the core curriculum for early career geoscientists until very recently," she adds.

Head of Technical Geoscience

She traveled back to Houston in 2012 and has remained in the US since then, working in different functional and cross-functional executive roles. "I could not have mapped my career path to get me to where I am now, but in retrospect I realize that as a global company, ExxonMobil is really good at identifying talent and helping people reach their potential in the countries where we do business," she explains.

In 2017 she was promoted to yet another exciting and rather different role: that of Vice President, Technical-Geoscience in ExxonMobil.

"This is a global role with probably the broadest scope of any I have had," Tolu explains. "My remit is to acquire seismic and well data on behalf of the business, so I am working with vendors and also using the expertise within the company. I have core technical experts within my group and we can deploy them wherever they are needed in ExxonMobil. My team must ensure that within the company we are applying the best technologies, whether sourced internally from our research group or externally from vendors, and that they are quickly embedded so our geoscientists can make full use of them. Sometimes we work with vendors or other researchers on ideas that we see benefit in developing but which we don't feel need to be proprietary. With the development of digital tools, the role of new technologies has become very significant.

"I am excited by the industry's use of big data and digitalization. I think we are all trying to use it to evolve machine learning techniques to reduce cycle time. The foundational element to begin that digital journey really is big data. The things we need to put in place in terms of the infrastructure need not be proprietary, and the fact that we are all doing it separately at the moment means that we are spending more money and we will all end up maintaining independent platforms at high cost for a long time. This is too expensive and not effective. We need to work on open data standards together so everything can be integrated, or we run the risk of producing individual, sub-optimal solutions.

"In ExxonMobil we have signed up to the Open Subsurface Data Universe, a consortium open to all operators and oilfield service companies. The idea is to come up with common standards. It's early days yet, but at least the conversation is progressing – it'll be interesting to see where it goes," she adds.

What Lies Ahead?

Tolu feels very grateful to ExxonMobil for the route her career has taken and has never felt stuck or in a dead end.

"I feel that the company's career development strategies allow you to have multiple careers in one. I've enjoyed each job, but always found the next one to be new, interesting, stimulating and different; I think we make a pretty good job of developing our workforce and allowing them to grow. My story is testament to that."

With such a varied career behind her, where would Tolu like her career to take her next?

"I enjoy the diversity of roles that is available to me and love chances to expand my knowledge," she replies. "I do like to be in roles that are impactful and add value to ExxonMobil either in the business or in developing our pipeline of talent. I'm interested in anything that deals with diversity – not just physical difference, but in harnessing the diversity of thought, and integrating it into reaching better solutions. That really interests me, so who knows what roles lie ahead of me!" ■

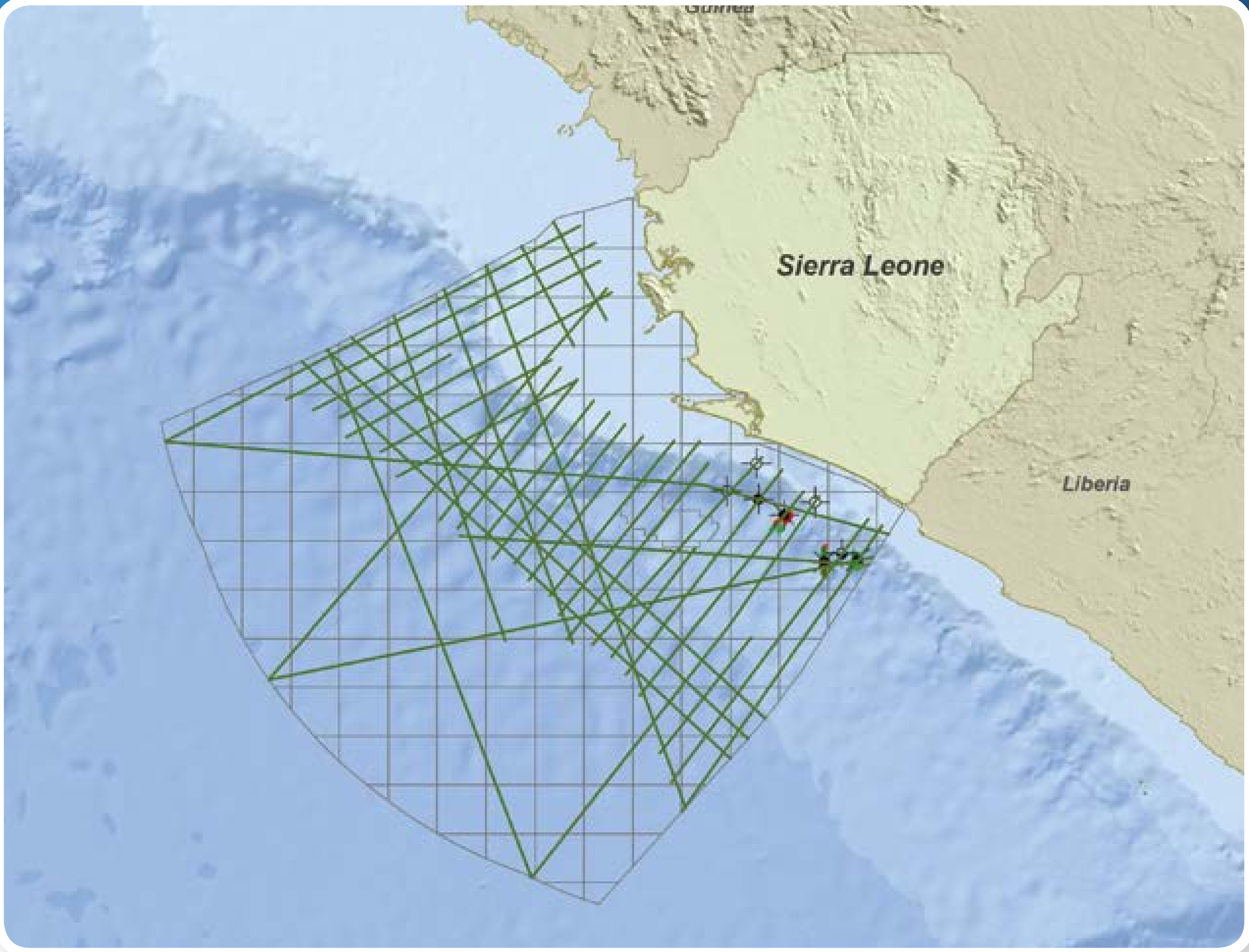
On the well site in 1992 – taking a much-needed mental break between multiple well operations!

NEW Multi-Client Seismic Africa • Offshore Sierra Leone

GeoPartners

Sierra Leone 2D 2019

First Announcement – New 2D Seismic Survey



GeoPartners, in partnership with the Petroleum Directorate of Sierra Leone, is pleased to announce a new 2D seismic survey offshore Sierra Leone to support the 4th Offshore Petroleum Licensing Round planned for later this year. The survey will comprise of over 9000km of new data and cover the full extent of the offshore area available in the Licence Round. Acquisition is planned to commence after completion of the necessary regulatory approvals and a subset of the data will be available for companies participating in the Licence Round.

The new survey is the first to cover the entire offshore area from shallow to ultra- deep water, providing ties to all existing wells and allowing a complete evaluation of the available acreage. Sierra Leone has proven oil discoveries and this new long offset survey will highlight the potential of this underexplored area.

For further information please contact Jim Gulland: jim.gulland@geopartnersltd.com
+44 (0) 20 3178 5334

An Introduction to Geomechanics

The study of how subsurface rocks deform or fail in response to changes of stress, pressure and temperature is known as geomechanics. It is becoming increasingly important in oil and gas exploration and production and in geothermal energy, especially for deep geothermal exploration and EGS systems.

JANE WHALEY

Geomechanics: the study of the way in which rocks stress, including how and when faults will develop.

Geomechanics is the theoretical and applied science of the mechanical behavior of geological material. It is used to reduce risks and optimize rewards related to the mechanical failure of the reservoir and surrounding formations resulting from oil and gas exploration and production activities, such as the drilling of oil and gas wells, hydraulic fracturing, water or gas flooding, and depletion. The aim is to predict when such failures will occur and thus reduce the risk.

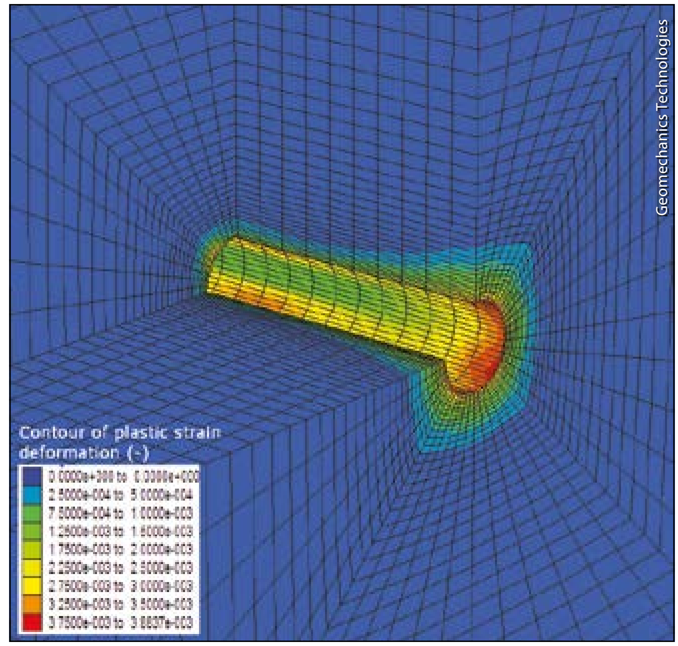
Each geological formation in the subsurface is subject to stresses caused by a variety of natural factors. These include deposition, which causes gravitational loading, tectonics, uplift, pressure inflation or deflation, stress relaxation and thermal effects. As a result, stresses in the subsurface are not static through time, nor can they be characterized in the same way everywhere at any one time. Similarly, a formation's strength properties are subject to changes throughout geological time, from deposition to present day.

A geological formation will fail when the stresses it is subjected to exceed its strength, and the role of geomechanics is to predict when and where that failure will occur as accurately as possible, assess the risks and opportunities and recommend mitigation plans. The pre-existing rock stresses before any human intervention are the dominant stresses that affect the performance of the reservoir. Any formation or reservoir geomechanical assessment therefore starts with analyzing the stresses, strength and pressure profiles of the rocks, so an understanding of the geological history of the formation of interest is crucial for its reliable geomechanical characterization.

Geomechanics applies right across the

E&P industry, from exploration to abandonment, and from microscale to the modeling of reservoirs, fields and basins. It is a relatively new discipline, but one that is becoming increasingly important, particularly since the advent of exploration in tight shales, in which understanding the variation of mechanical properties with orientation plays a vital role.

One of the first references to the topic of geomechanics was a paper by Hubbert and Willis on the mechanics of hydraulic fracturing in 1957. *Fundamentals of Rock Mechanics*, by Jaeger and Cook, was published in 1969, and in the 1979 *Journal of Energy Resources* one of the earliest studies in petroleum geomechanics looked at in-situ stress in an arbitrarily-oriented hole.



Contour of plastic strain deformation due to stress redistribution during drilling.

Geomechanics in the O&G Industry

Stresses and strengths in a subsurface formation are in an apparent state of equilibrium, except in seismically active areas. However, activities associated with exploration and production, such as drilling, fracturing, depletion and hot or cold fluid injection, can potentially alter this equilibrium. The role of geomechanics is to predict when and how this equilibrium will be altered, what the potential risks are and what possible impacts these could have on drilling and production.

Over the years, the role of geomechanics has become increasingly significant in the industry, as we explore deeper and in more complex and geologically challenging reservoirs. In addition, there is increasing pressure from regulators, NGOs and others to limit exploration and development activities in many areas due to the perceived negative impacts on the environment, so it is important that any such environmental outcome as a result of the rocks' response to drilling and production activities can be predicted early in the cycle.

The science of geomechanics is applied throughout the E&P cycle. In the pre-drill exploration stage, it is used to model in situ stresses and profile the rock properties, but it is equally important for ensuring borehole stability, predicting sand production, estimating and monitoring the effects of hydraulic fracturing and ensuring safe operating pressure and temperature envelopes for IOR and EOR developments.

Borehole Integrity

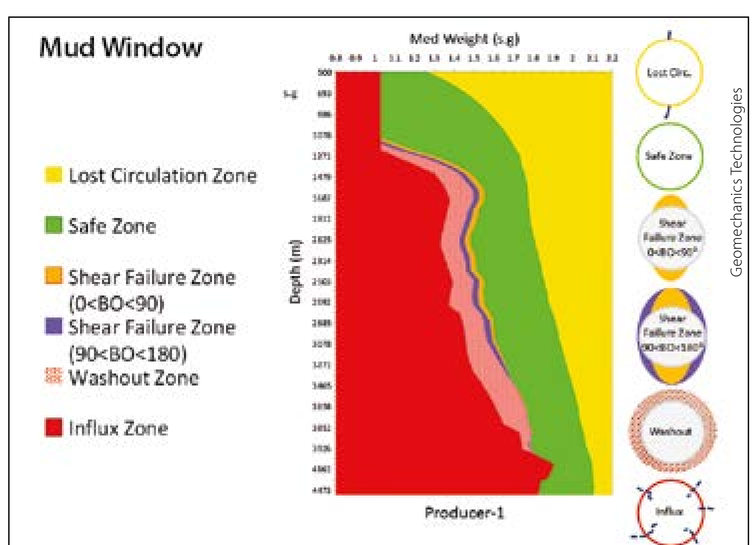
Downhole acoustic and density measurements and laboratory core analysis provide early input for geomechanical modeling and analysis of how drilling is affecting the surrounding rock. It helps the operator to understand how the drill bit removes rock in order to drill at the optimum rate given the natural stresses. Recent research in geomechanics has enabled us to gain more information about how a drill bit breaks the rock, which has has helped in the development of more efficient bits to use when drilling through different rock types.

Geomechanics can also help us understand issues with wellbore stability while drilling. The actual action of drilling produces external stresses on the rock, both from the wellbore itself and the drilling fluid, and there is a danger that the rock around the borehole may fail if the new stresses are greater than the rock strength. Similarly, if the mud pressure is too high the borehole wall may be stressed, or if it is too low there may be 'breakout' on opposing sides of the well. But if a geomechanical engineer has measured the stress changes around a planned well and generated a mud weight program for it, the chance of stuck pipe, lost circulation or other well failure issues happening can be reduced.

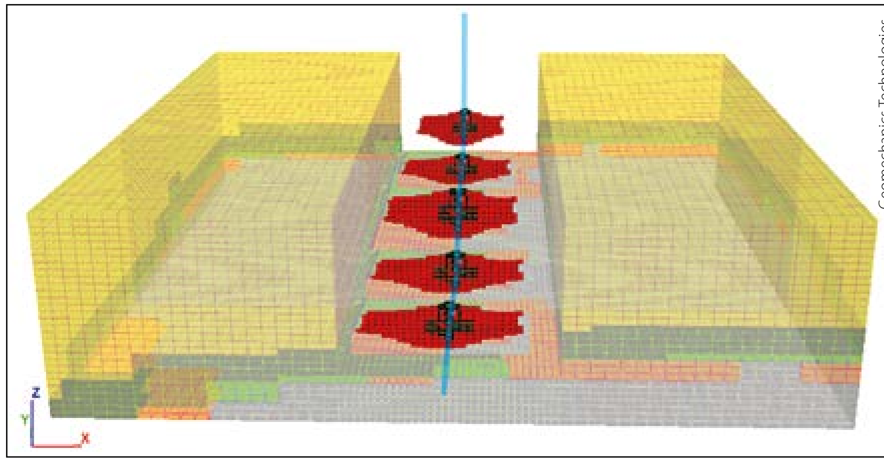
Geomechanical problems are still thought to be associated with a high percentage of drilling-related non-productive time, especially in deepwater and other challenging environments. Some issues that lead to well stability failure, such as unexpected faults or unstable bedding planes, cannot be predicted, so another aspect of the geomechanic's work is to monitor the well in real time using wireline logs, logging-while-drilling and sonic data. This data can also be extrapolated to planned wells.

Vital for Fracking Operations

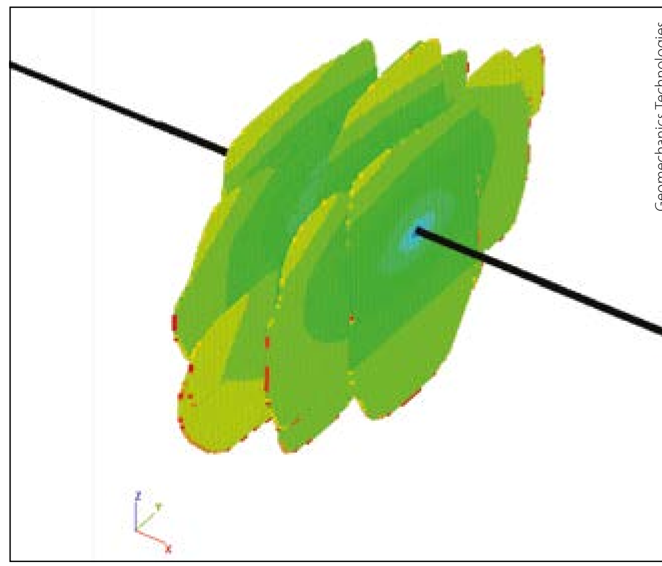
Unlocking complex shale reservoirs requires significant



geomechanical input, particularly when hydraulic fracturing is involved. Analysis of the evolving stress state in the reservoir and the surrounding formations and an understanding of the location and nature of the shale's natural fractures has a major impact on the eventual operational success and productivity of each well, as does an understanding of the relationship between matrix permeability, natural fracture permeability, and induced fracture permeability. In addition, comprehending the migration and maturation of the hydrocarbons contained in the shales will lead to improved understanding of how to place and design wells for maximum efficiency and stability. The understanding of fracture containment in the reservoir is an essential part of caprock integrity which can lead to environmental hazards if violated but can also efficiently reduce the amount of proppant needed for a stimulation process.



Multistage fracture dimensions.



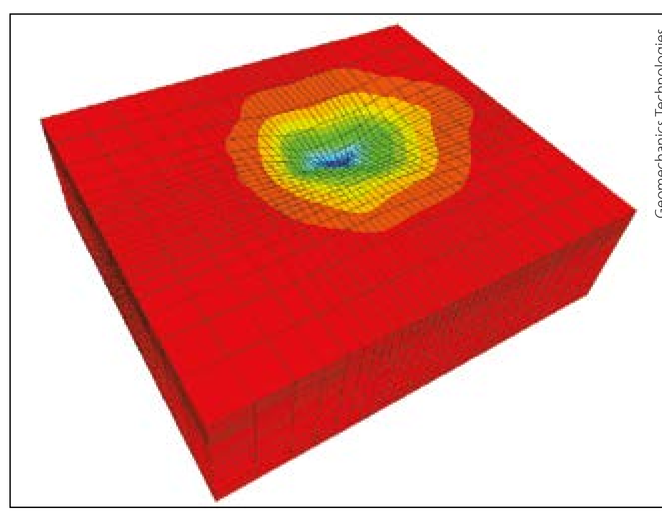
Pressure distribution in different clusters of a stage of a hydraulic fracture.

Geomechanics and Mature Fields

One of the most significant areas in which geomechanics is useful is in predicting and monitoring how a reservoir will change in the course of a field's life and how these changes will affect the surrounding area and the earth's surface. When fluid pressure is reduced by oil and gas production or in geothermal energy operations, more of the load is transferred to the rock matrix. This can result in formation compaction and subsidence, which can present severe field development and production challenges, including affecting completion stability and causing casing collapse and sanding across the field. The Ekofisk field is one of the best known examples of this subsidence (See *GEO ExPro* Vol. 14, No. 2).

Anticipating these effects through geomechanical modeling of the reservoirs in advance and updating the model as new wells are drilled will help mitigate the issue. Time-lapse, or 4D, geomechanical monitoring is therefore critical to understanding and predicting how reservoir properties will change throughout the life of the field.

As a field grows towards the end of its productive life, a number of techniques for increasing recovery may be used, usually involving the injection of fluids such as polymers, steam and gas, all of which affect reservoir stress re-distribution and re-orientation in the field. Geomechanical assessment of the reactions in the rocks during these processes plays an important role in ensuring that as much oil and gas as possible is recovered.



Subsidence due to field production.

Integrated Into the Workflow

Geomechanics has come a long way in recent years, and its application has become an important component in increasing efficiency and safety and driving down costs. It is increasingly being integrated into operators' workflows, and is now an integral part of the process of efficiently developing, producing, and ultimately abandoning reservoirs.

Acknowledgements:

The author would like to gratefully acknowledge help with this article from Latifa Qobi of Practical Geomechanics and Julia Diessl of Geomechanics Technologies.

References available online. ■


POLARCUS XARRAY™
The multiple source acquisition technique that is redefining exploration efficiency and data quality.
Polarcus®

Oil Wealth and the Osage Murders

RASOUL SORKHABI

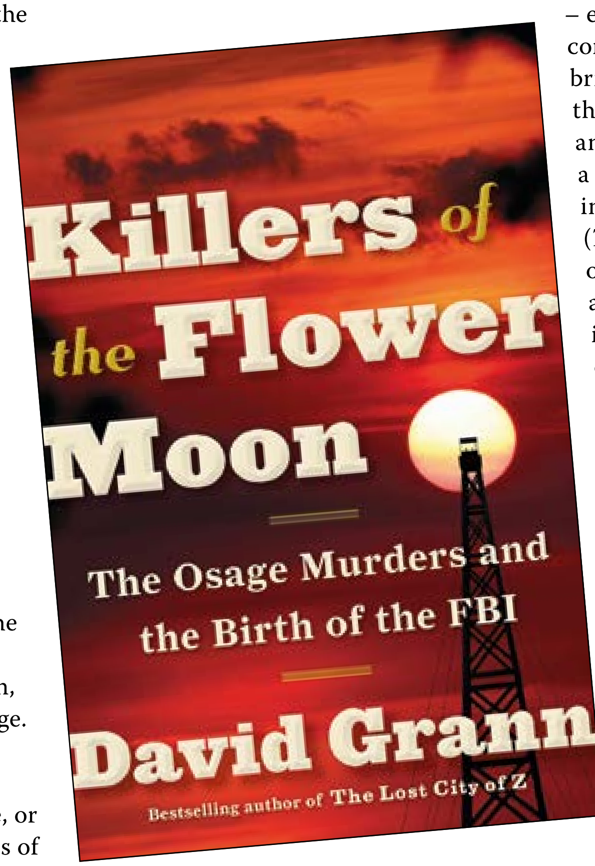
In the early 1870s, the Osage, a Native American tribe of the Great Plains, were forced by the US government to move out of Kansas as white settlers (including Laura Ingalls Wilder's family of the *Little House on the Prairie*) arrived in the region. The Osage moved to Oklahoma where, because they paid for their new lands, they kept the mineral rights.

The 1897 Bartlesville gusher put Oklahoma on the oil map and by 1907 the state was the largest US producer of oil, making the Osage "the richest nation in the world per capita", with each Osage receiving royalties from the oil revenue; in 1923 alone, the tribe earned $30 million – about $400 million today. But this was not to be without dire consequences for them. In 1921 the US Congress passed a law requiring that, because of "incompetence", each Osage member had a government-appointed paid "guardian" to manage his or her oil income. In the early 1920s a series of mysterious murders, using gunshot and poison, took the lives of dozens of the Osage. The murders were committed so the perpetrator could inherit the deceased's wealth or life insurance, or to eradicate evidence and witnesses of previous murders.

A Tragic Story

American journalist David Grann has devoted a whole book, *Killers of the Flower Moon: The Osage Murders and the Birth of the FBI*, to this tragic and mysterious piece of history – a far cry from the Wild West of the movies. Although related to oil, the book is primarily a story of human greed, corruption and brutality. The story is not new; as Grann acknowledges in the bibliography at the end of the book, several previous books (novels as well as non-fiction) have chronicled and exposed it. But it is not well known – I did not know about it before reading Grann's book. It is also a piece of history full of inconvenient truths and important lessons to reflect on.

Grann's writing is fascinating and the reader is given sufficient historical information in a well-written style to follow the murder cases. At its heart lie two families, or rather two people. The



first is Mollie Burkhart, whose sisters Minnie, Anna, Rita (together with her husband Bill) and mother Lizzie Que were all murdered; she was poisoned too, but saved. Mollie's life thus epitomizes the Osage victims. The second person is William Hale, a white cattleman and the self-styled 'King of the Osage Hills' who, together with his nephews Ernest Burkhart (Mollie's husband) and Bryan Burkhart (Anna's boyfriend), along with several outlaws and henchmen, masterminded some of the murders.

Part I of the book (*The Marked Woman*) chronicles the murder cases, while Part II (*The Evidence Man*) describes how the Osage Indian murders were the first major homicide project for the Federal Bureau of Intelligence (founded in 1908) under J. Edgar Hoover, although the actual investigations were carried out by Tom White and his undercover agents in Osage County. This part of the book reads like a Sherlock Holmes story – except that it is an actual history, complicated by the corruption and bribery of several local officials. After the highly publicized trial of Hale and his gang, the government passed a law prohibiting white people from inheriting Osage wealth. Part III (*The Reporter*) narrates Grann's own exploration of the history, as he traveled to Osage County, interviewed descendants and experts and studied thousands of pages of FBI archives on the story.

Flower-Killing Moon

Osage is the French version of the tribe's name and supposedly means warlike. The Osage call themselves "Wa-zha-zhe" which means "the people of middle waters." Today, they have a population of about 20,000, of whom nearly 7,000 reside in the tribe's jurisdictional land. In 2000 the Osage sued the US government over its failure to pay tribal members appropriate royalties, settling in 2011 for $380 million.

As for the title of the book: "flower-killing moon" is how the Osage refer to May, because in that month taller plants creep over the smaller ones and break their flowers. Anna was murdered in May, 1921.

A Hollywood movie based on the book is due in 2019. I cannot wait to watch it and see how it captures this fascinating history. ■

Killers of the Flower Moon: The Osage Murders and the Birth of the FBI
By David Grann
(Doubleday, 2017, hardcover; 2018 paperback)

To promote, for the public benefit, education in the scientific and technical aspects of petroleum exploration

Significantly discounted **member rates** to PETEX, PROSPEX, the Asia Pacific & Africa Conferences and various PESGB training courses - **you only need to attend ONE of these events to recover your membership fee!**

FULL MEMBERSHIP
Monthly Direct Debit
£60 per annum
Annual Direct Debit
£55 per annum
Annual Payment
£65 per annum

STUDENT MEMBERSHIP
Monthly Direct Debit
£30 per annum
Annual Direct Debit
£25 per annum
Annual Payment
£35 per annum

+ £5 admin (one-off) when first joining

pesgb.org.uk

ENERGISTICS
ADOPT > ADVANCE > ACCELERATE

CONNECT

Enrich Your Subsurface Models

Each reservoir is different, and the workflow leveraging the best technologies from static model to simulation often requires connecting different software applications.

Yet connections between different solutions remains primitive and inefficient.

Now the industry has a standard format for the exchange of subsurface models with a maximum retention of knowledge:

RESQML™

Compatible with cloud-based solutions, it gives geoscientists and engineers the freedom of choice while avoiding the headaches of bespoke connections.

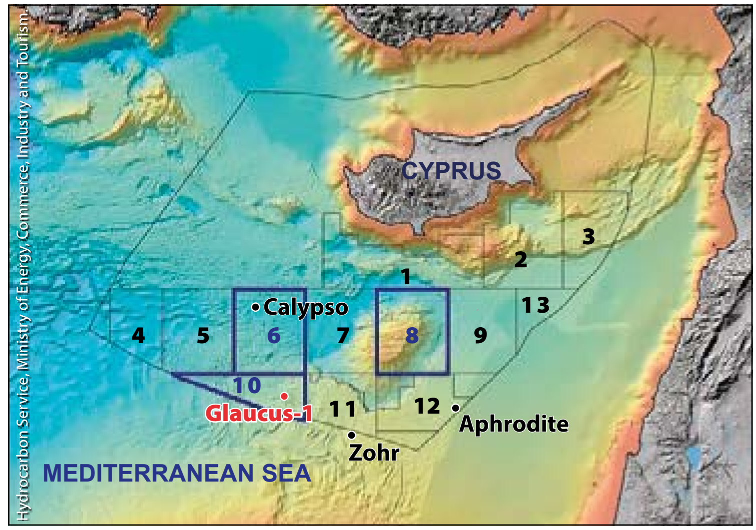
Find out how Energistics data standards can link disparate applications, enriching your subsurface models.

Better still, join the consortium and participate in the industry's digital future.

www.energistics.org

Cyprus: Giant Offshore Gas Field

The world's third-largest gas discovery in the last two years has been made in the Eastern Mediterranean, off the south-west coast of **Cyprus**. **ExxonMobil** announced in late February that its **Glaucus-1** well had found a 133m-thick gas-bearing reservoir and, based on a preliminary interpretation of the well data, the discovery could represent an in-place resource of between 5 and 8 Tcfg. The well, which reached a TD of 4,200m, lies in **Block 10** in waters over 2,000m deep, about 200 km south-west of Paphos. This discovery follows on from similar substantial finds offshore the south of Cyprus, including Calypso in Block 6, Aphrodite in Block 12 and Onesiphoros in Block 11, as well as the Zohr field just across the international boundary in Egypt.



Location of the Glaucus discovery and blocks offered in the third Cypriot license round.

At the moment Cyprus does not have an LNG facility, but hopes to access existing infrastructure in Egypt following a recent agreement to build a pipeline linking these significant gas resources with Egypt's LNG export facilities, so production from them could be delayed for many years. There are also fears that these discoveries may worsen the already fragile security situation between Cyprus and Turkey, the result of tension over boundary disputes.

Block 10 covers 2,572 km² and was assigned to ExxonMobil through a PSC in April 2017. The company is operator and holds 60% interest, with Qatar Petroleum holding the remaining 40%. ■

Angola: Play Opener

On March 13, 2019, **Eni** announced the discovery of a large oil field in deepwater **Angola**. The **Agogo-1** new field wildcat is located approximately 180 km from the coast and 350 km north-west of Luanda in **Block 15/06**, in water 1,636m deep. It found a single 203m oil column containing 120m net pay high quality oil (31° API), and indications are that the well could have a production capacity of more than 20,000 bopd.

This is the third commercial discovery on 15/06 since the launch of a new exploration campaign by the block consortium (Eni and Sonangol, both with 36.8%, and SSI Fifteen Ltd., 26.4%), which led to the discoveries of Kalimba and Afoxé last year. However, this latest find is a play opener for the block, since it is the first discovery in a subsalt diapir setting. The reservoir is reported to be a Lower Miocene sandstone with excellent petrophysical properties.

The discoveries on 15/06 are grouped into two areas, known as West and East Hub. Agogo-1 lies only about 20 km west of the N'Goma FPSO, which serves the West Hub. ■

Indonesia: Largest Gas Discovery for 18 Years

In February 2019 **Repsol** announced that its **Kali Berau Dalam--2X (KBD-2X)** well had found at least 2 Tcf of recoverable gas, making it the largest discovery in Indonesia for 18 years – since the Cepu discovery in 2001 – and one of the ten biggest finds in the world in the last 12 months. Prior to drilling, the prospect was estimated to hold in the region of 1.5 Tcfg, or over 250 MMboe. KBD-2X is in the 4.7 hectare **Sakakemang Block**, about 100 km north-west of Palembang on the southern part of the **Indonesian** island of **Sumatra**. The original well in the prospect, which targeted the pre-Tertiary fractured basement play, had well control issues and was re-entered earlier this year. It is hoped that this discovery will bring a much needed boost to Indonesia's energy supply situation, particularly as it lies only 25 km from the Grissik gas plant, which gathers and processes production primarily from ConocoPhilips-operated Corridor PSC, where supply is expected to start to decline from 2024.

As operator, Repsol holds a 45% stake in the permit. Its partners are Petronas, which farmed into 45% of the block in January 2019, and MOECO, with 10%. Repsol holds several licenses in Sumatra, both onshore and offshore, and plans to execute an intense drilling and seismic acquisition campaign during 2019 and 2020. ■

HOSTED & ORGANISED BY: frontier.

AFRICA E&P SUMMIT

YOUR UPSTREAM CONNECTIONS INTO AFRICA

Featuring the Africa E&P Summit & Exhibition, London Skyline Networking Reception & *Africa E&P Summit Gala Dinner

IET London: Savoy Place, 22 - 23 May 2019

REGISTER NOW

The Africa E&P Summit and Exhibition brings together Africa's upstream industry at a world-class venue in London for a unique event shaped for companies active in Africa's oil & gas game and provides unrivalled insight into the Continent's fast changing exploration horizon. Hear directly from key players and decision-makers from corporate players active in Africa through to fast-moving independents, finance, legal and service & supply companies and African governments and NOC's seeking investors.

** The Africa E&P Summit Gala Dinner is open to registered attendees of the Africa E&P Summit only and separately bookable.*

2019 Confirmed Sponsors & Exhibitors

Woodside | AfricaOil Corp. | ExxonMobil Energy lives here | TGS | KOSMOS ENERGY | stellar | rps | PGS | CNOOC

Event highlights

- Uncover the leading edge on Africa's E&P hot spots
- Enjoy the Africa E&P Summit Gala Dinner
- Attend the London Skyline Networking Reception
- Hear from Africa's leading E&P companies
- 50+ world class speakers over 2 days
- High-level C-Suite networking
- Africa Licensing Promotion & NOC Showcase
- Excellent Sponsorship & Exhibition opportunities
- Opportunities, outlook, risks & challenges

www.africaepsummit.com | Tel: +44 20 7193 8224 | email: info@frontier-communications.com

Time for a Hackathon!

As we move into the world of machine learning and artificial intelligence, it is increasingly important that geoscientists gain a better understanding of coding and how it can be used in the oil and gas industry. Jo Bagguley from the UK Oil and Gas Authority (OGA) tells us about an innovative approach to help improve this understanding: the coding 'hackathon'.

What is a hackathon?
A hackathon is an event where people come together to try and solve problems, usually in small teams. The OGA's hackathons have involved looking at solving subsurface problems using coding, but the approach can be applied to pretty much anything.

What gave you the idea to hold these?
It was actually my boss's idea! Since the OGA formed, we have been working towards making data more readily available to industry and academia, and to enable people to get the skills they need to apply data science and analytics to that data. We worked with Agile* to deliver free geocomputing training courses and they also helped us with the first two public subsurface hackathon events to be run in the UK.

Who are they aimed at?
The events are aimed at geoscientists and data scientists at any level of expertise in their field and attract complete beginners and those with much more experience in coding. The key is to bring the different abilities together to find ways of improving subsurface workflows or solving subsurface problems.

What do participants hope to gain from attendance?
Having attended a couple of these events as a complete coding novice, I certainly got an appreciation of the value to be obtained through bringing both the geoscience and data science skill sets together. From a geoscience perspective, participants can hope to gain an increased understanding of coding and how they can apply it in their day-to-day subsurface workflows. It is also a great place to meet like-minded people and form a network of people you can connect with for future learning and problem solving. The events are pretty intense in terms of working towards a solution within a short timeframe, but they are also a lot of fun.

What have you discovered as a result of holding these?
We've discovered that there is a huge network of subsurface professionals who are keen to build their own skills and embrace the change that data science can bring to the way we work, including gaining better insight from our data. The energy for this is enormous and it has a reasonable amount of momentum, thanks to the efforts of organizations like Agile. The key is to ensure that it's harnessed and applied to the benefit of our industry.

Will there be more in the future?
The OGA currently does not have any plans to host more events but we hope that individuals might use their new connections to keep the ball rolling and maybe even host their own events within their organizations.

**Agile Scientific are a data analytics and training company which specializes in subsurface machine learning and integrated subsurface interpretation.* ■


OGA

Jo Bagguley is a Principal Regional Geoscientist with the OGA.

THE LEADING PROVIDER OF OBN SEISMIC SOLUTIONS

BOOTH # 1040 - EAGE LONDON 3-6 JUNE

*Introducing **FlowBack**, our new back-page column by industry specialist **Nick Cottam**.*

A Balancing Act

If you happen to be in north-western France and you pick the right day you can see some superb displays of horsemanship at the Haras National du Pin, the French national stud. Among the highlights is the rider who enters the arena astride two horses; one person using all his or her skill to keep the two beasts together. A similar skill, you could argue, is being shown by the oil and gas supermajors as they seek to negotiate this protracted period of energy transition.

One horse is a company's traditional oil business, mature, sometimes prone to fatigue but a consistent generator of high profits and dividends over the years. Add in the gas element and you have a core business that will continue to deliver returns well beyond the 2040 date used, for example, in the latest BP Energy Outlook scenarios. The other horse, less predictable and still somewhat unreliable in a business sense, is the diversified energy company; also investing in renewables, power generation and a more consumer-focused downstream operation.

The BP Energy Outlook takes comfort in the 'trot-trot' staying power of the core business. Oil demand looks set to plateau or even start to fall in various scenarios with the growth of gas and renewables after 2020 but is carried along by rising energy demand in the developing world. Alongside this is the challenge, as BP's Bob Dudley notes in his introduction to the Outlook, of meeting this extra energy demand while also reducing carbon emissions. Small wonder then that in BP's 'evolving transition' scenario renewables are the fastest growing energy source (7.6% per annum between now and 2040), accounting for around two thirds of the increase in global power generation.

There lies the rub. Oil and gas majors must hedge their bets if they are to ride the transition conundrum. The obvious solution, notes Paul Bogenrieder, a Senior Energy Analyst with EY, is " – use your capital, expertise and brand to transform into the energy company of the future." Thus, ExxonMobil is targeting 10,000 barrels of biofuel a day, while Shell has taken itself into the energy retail business. Providing oil majors retain capital for exploration and continue to deliver the dividends demanded by shareholders, the diversification show must go on. In a world where it is predicted that over 60% of the global energy market will be in renewables by 2040, big oil (not to mention expanding gas) is working overtime to keep those two horses together. ■

An industry in transition: exploring the options with more horsepower.

Conversion Factors

Crude oil

1 m³ = 6.29 barrels

1 barrel = 0.159 m³

1 tonne = 7.49 barrels

Natural gas

1 m³ = 35.3 ft³

1 ft³ = 0.028 m³

Energy

1000 m³ gas = 1 m³ o.e

1 tonne NGL = 1.9 m³ o.e.

Numbers

Million = 1×10^6

Billion = 1×10^9

Trillion = 1×10^{12}

Supergiant field

Recoverable reserves > 5 billion barrels (800 million Sm³) of oil equivalents

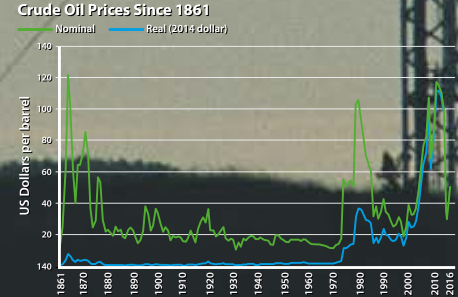
Giant field

Recoverable reserves > 500 million barrels (80 million Sm³) of oil equivalents

Major field

Recoverable reserves > 100 million barrels (16 million Sm³) of oil equivalents

Historic oil price



BGP – *Beyond the Belt and Road*

BGP is a leading geophysical contractor, providing geophysical services to our clients worldwide. BGP currently has 57 branches and offices, 6 vessels and 19 data processing and interpretation centers overseas. The key business activities of BGP include:

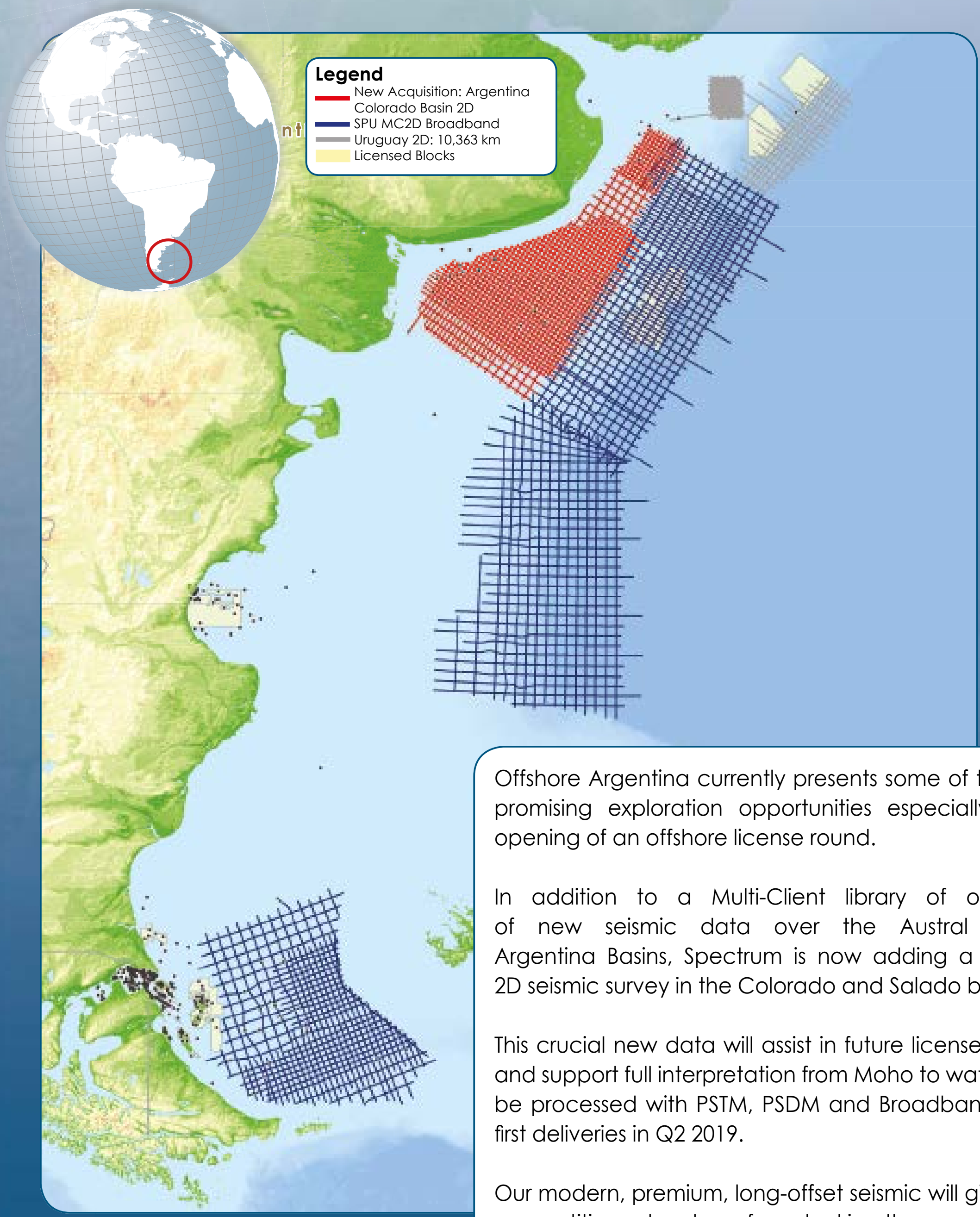
- Onshore, offshore, TZ seismic data acquisition;
- Seismic data processing and interpretation;
- Reservoir geophysics;
- Borehole seismic surveys and micro-seismic;
- IT services.
- Geophysical research and software development;
- GME and geo-chemical surveys;
- Geophysical equipment manufacturing;
- Multi-client services;

CNPC BGP **BGP Inc.** | E-mail: marketing@bgp.com.cn http://www.bgp.com.cn

multi-client seismic
ARGENTINA

Argentina Offshore

Essential Seismic Coverage For Current and Future Bid Rounds



Offshore Argentina currently presents some of the world's most promising exploration opportunities especially following the opening of an offshore license round.

In addition to a Multi-Client library of over 50,000 km of new seismic data over the Austral Malvinas and Argentina Basins, Spectrum is now adding a new 20,000 km 2D seismic survey in the Colorado and Salado basins.

This crucial new data will assist in future license block selection and support full interpretation from Moho to water bottom. It will be processed with PSTM, PSDM and Broadband products with first deliveries in Q2 2019.

Our modern, premium, long-offset seismic will give explorers the competitive advantage for unlocking these exciting new areas.

spectrumgeo.com
mc-us@spectrumgeo.com +1 281 647 0602

Spectrum