TOTAL

CSTJF

EXCELLENCE IN TECHNOLOGY

EXPLORATION & PRODUCTION

+CSTJF

CENTRE SCIENTIFIQUE
ET TECHNIQUE JEAN FÉGER

ABOUT TOTAL

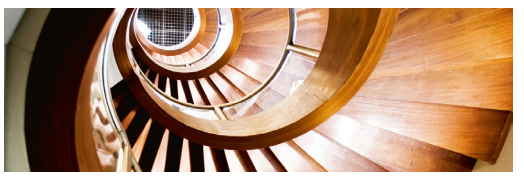
A top-tier international oil company, Total is also a global gas and petrochemical operator, and a refiner and marketer of petroleum-based products. Today, in response to soaring energy demand, we are stepping up our expansion into solar and biomass as well.

We are counting first and foremost on oil and gas, which are far from being depleted. Our activities in this sector range from exploration and production to refining, shipping and trading. To support our world-class refining and petrochemical operations, we are developing competitive, top-tier industrial platforms and strengthening our presence in the growth markets of Asia and the Middle East.
Total's Marketing & Services organization, whose activities notably include an extensive network of service stations, develops and markets a range of products mainly derived from petroleum, as well as all the related services.
We are also investing in renewable energies, opting to branch out into photovoltaic solar energy and biomass.
We have moved up our timeline for capital expenditure in those sectors, so that we can offer efficient, reliable solutions to partner fossil energies.
Total is also a world-class chemical manufacturer.
In addition to polymers, we are present in the specialty chemicals sector, which encompasses elastomer processing, adhesives and electroplating.
All over the world, our 96,000 employees produce the energy and products people need while putting into practice the four cornerstone behaviors of the Total Attitude: boldness, mutual support, listening, and cross-functionality.

CENTRE SCIENTIFIQUE ET TECHNIQUE JEAN FÉGER

EXCELLENCE IN TECHNOLOGY

EXPLORATION &
PRODUCTION

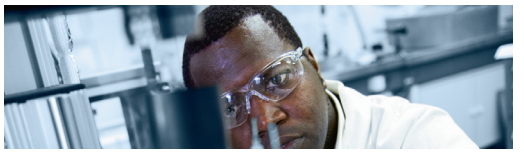


The CSTJF is a crucible of expertise and a melting pot of cultures, located in southwestern France. Everyone here shares a common purpose: to produce more oil and gas, more efficiently.

Ranking foremost among the complex challenges the imperatives of human safety and environmental preservation are increasingly in the public eye. Upholding these priorities is the only way to ensure responsible, sustainable production.

Their job is to get rock and fluid samples to tell their tale and to coax out meaning from images generated by one of the world's most powerful computers.

Experts in rock mechanics, chemistry and data processing test, model and analyze the viability of well designs in extreme conditions.



The Center's teams develop tools designed to increase recovery and monitor the performance of oil and gas fields throughout the production period.

Technological innovation is the only means of unlocking access to new oil and gas provinces, by developing solutions for responsible, sustainable production.

“With sights set firmly on the future, the Centre Scientifique et Technique Jean Féger is paving the way to tomorrow’s energy resources.”

PREFACE

The Centre Scientifique et Technique Jean Féger (CSTJF) in Pau is a world-class hub of technological excellence and home to the scientific expertise and R&D capabilities of Total's Exploration & Production (E&P) branch. It boasts state-of-the-art laboratory infrastructure and a powerful new high-performance computing (HPC) center. With these impressive capabilities and a staff of nearly 2,500, the CSTJF is an industry-leading center of integrated know-how.

The Center exports its scientific and technical know-how to Total's E&P subsidiaries worldwide, providing ongoing assistance to support our strategic objectives: maximizing production from existing fields, bringing new projects on stream as quickly and cost-effectively as possible, and replacing our reserves.

With sights set firmly on the future, this extensive and highly international campus is where we show our capacity to be a responsible partner, equipped with the tools and know-how to pave the way to tomorrow's energy resources.

Partnering sustainable growth in heart of southwestern France, the CSTJF also plays a pivotal role in the economic and social development of its hinterland.

Yves-Louis Darricarrère
President Upstream, Total

CHAIN OF EXPERTISE

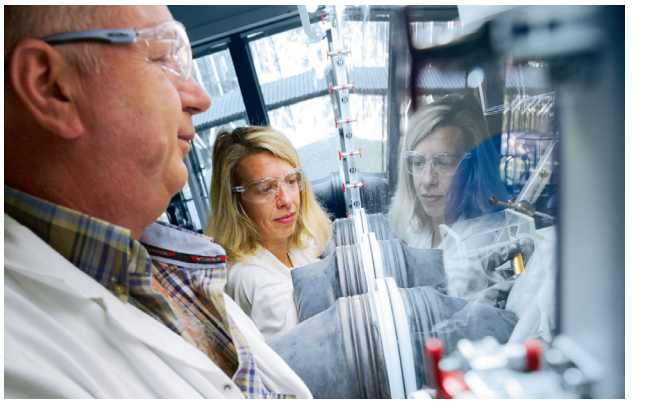
The CSTJF is home to experts in every discipline of the exploration and production value chain. The proximity facilitates interchange between geosciences, drilling and reservoir development specialists and ensures the integration of these diverse fields of expertise. A multidisciplinary approach is vital to redefining feasibility in the oil and gas industry.

A CRUCIBLE OF EXCELLENCE

The CSTJF is a crucible of expertise and a melting pot of cultures. Everyone here shares a common purpose: to produce more oil and gas, more efficiently. Located in the heart of the Béarn region (southwestern France), the birthplace of the French natural gas industry, the Center is dedicated to innovation in cost-effective, environmentally responsible technologies.

GLOBAL REACH

Providing technical support to Total's E&P subsidiaries is one of the R&D center's key roles: CSTJF's vocation is to deploy the full weight of its innovative capabilities in the field, worldwide.



2,500
employees
representing every discipline of the
Exploration & Production value chain.

IN 1951, exploratory drilling led to the discovery of the giant Lacq natural gas field. This and ensuing discoveries met up to 90% of France's natural gas demand and helped shape the economic and industrial destiny of this region of southwestern France.
With the establishment of the CSTJF and many of Total's partners and contractors in Pau, the city and the region have emerged as a hub for the oil, gas and related industries. Between its oil, gas and chemicals operations, Total accounts for more than 4,000 direct jobs at its facilities in Pau and Lacq. In addition to the CSTJF, the Mont-Lacq site is home to the R&D activities of Total Petrochemicals. Now known as the Pôle d'Etudes et de Recherche de Lacq (PERL), this R&D hub recently became a part of Total's Exploration & Production R&D organization.
As the founder of a major chemicals hub, Total has been acting on a commitment made in the mid-1970s to prepare for the "post-gas" industrial redeployment of Lacq, as the reservoir nears depletion.
By promoting the establishment of fine chemicals companies through Société Béarnaise de Gestion Industrielle (SOBEGI, set up by Total in 1975), and supporting small business startups (via Total Développement Régional, a spin-off of SOFREA, initially set up by Elf in Pau in 1978), Total has already helped to create or maintain nearly 7,900 jobs in the Lacq region through the support provided to more than 320 businesses.

Through its diversified R&D activities, the CSTJF is a prominent partner of the scientific community of southwestern France. The Pau metropolitan area has become a pillar of petroleum research thanks to IFP Energies Nouvelles (IFPEN) and the laboratories of a local school, Université de Pau et des Pays de l'Adour. These organizations collaborate within the framework of IPRA, a multidisciplinary institute of applied research in oil and gas engineering.

At the national level, the CSTJF is involved in some sixty R&D contracts with researchers at universities in Bordeaux, Marseille, Montpellier, Pau, Provence, and Toulon; at top engineering schools; and at various institutes and laboratories. In addition, Total is funding two entities based at the Université de Pau et des Pays de l'Adour that have introduced a new type of collaboration between the CSTJF and academic research. Founded in 2002, the Organisme Pétrolier de Recherche Appliquée en Géophysique (OPERA) specializes in new processing algorithms for seismic imaging, while the Centre Huile Lourde Ouvert et Expérimental (CHLOE), set up in 2007, focuses on evaluating and improving various processes to recover extra-heavy oil.

With a reach extending to the four corners of the Earth, the CSTJF also serves as a central point of contact

and a training center for employees of many different nationalities. Staff from partner national oil companies and representatives of Total's host countries for E&P projects also come to the Center for highly specialized training. Each year, the Center welcomes more than 50,000 business visitors and 70 delegations from around the world. A wide range of training and internship programs is available to meet the diverse needs of participants of all backgrounds. Most of these programs are targeted and short-term, but skills transfer can also take the form of customized programs lasting several months. Alternatively, it can be organized within the framework of two-year stints that provide on-the-job training in a mentoring format. Programs draw on the wealth of technological resources available at the Center. These span the full range of oil and gas industry expertise, such as petroleum exploration, appraisal of discoveries, design of complex borehole trajectories and deployment of innovative solutions to boost recovery factors and manage industrial impacts. They take advantage of the enormous computing power —with high-performance computers able to perform two million billion

operations per second!—that ranks the CSTJF among the world's leading scientific data processing centers. The Center also boasts an impressive platform of high-tech laboratories spread over 5,000 m² and —of course—an unmatched concentration of world-class skills.

The massive computing power installed at the CSTJF can be accessed by all of Total's E&P entities

via a private telecommunications network linking 1,250 locations worldwide. This highly strategic broadband network carries the communications that run constantly between the E&P subsidiaries and the Center in Pau. In addition to voice telephone traffic between the site and the rest of the world, the telecommunications infrastructure at the CSTJF handles video and audio communications from up to 37 videoconferences at a time, and transmits an abundant flow of digital data and email around the world.

These uninterrupted communications reflect the CSTJF's pivotal role in day-to-day activities in the field. Remote interactions are supplemented by frequent face-to-face encounters as the "globetrotters" of the CSTJF head off to meet with their operational counterparts based all around the world. Each month, they carry out

3,500 international assignments to provide on-site support at Total locations across the globe.

AN EXCEPTIONAL CAMPUS

The CSTJF complex in Pau was designed in the early 1980s by local architect André Grésy. On a site of about 30 hectares, its nearly 40 buildings feature elegant materials such as wood, glass and tile. Representing a total floor area of about 100,000 m², they offer 30,000 m² of offices and 5,000 m² of laboratory space in four dedicated buildings.

A LANDSCAPED PARK

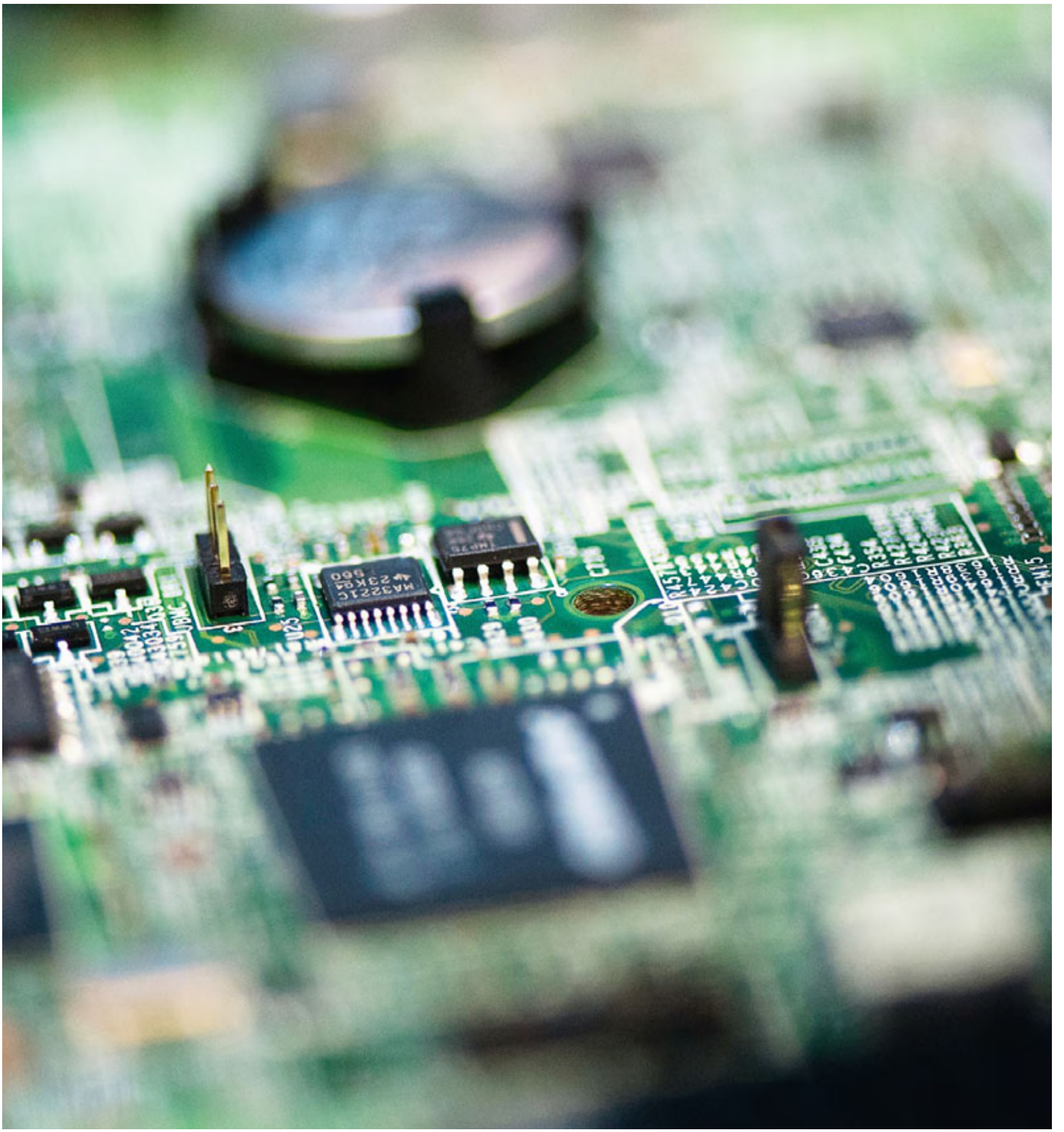
The Centre Scientifique et Technique Jean Féger (named after the engineer who discovered the Lacq natural gas field) is surrounded by extensive green areas planted with a thousand trees of diverse species (including oak, cork oak, mulberry and plane). Natural runoff from these well-maintained grounds is collected to supply a pond. The pond water is treated by aeration and ultrasound and is home to a number of native aquatic species (trout, ducks, moorhens).

Some
30 hectares
dedicated to engineering
and research.

MELTING POT

Thirty-five different nationalities are represented at the CSTJF, where each year more than 150 technicians, engineers and other professionals employed by Total's worldwide subsidiaries join the R&D teams for stints of three or more years. This is a strategic juncture in careers marked by geographic mobility on the scale of Total's international reach.


PETZL



60 GIGABITS PER SECOND

The Center's powerful telecommunications network is like a global superhighway. Every day, it enables teams around the world to stay in touch with this regional hub.

A MEMBER OF THE COMMUNITY

In addition to being a driving force in Pau's economy, Total plays an active part in community life through its cultural philanthropy, which includes support for the local orchestra and a local art cinema. Total also sponsors heritage conservation initiatives: nearly a dozen restoration programs have been supported by the Total Foundation to enhance the region's historic buildings and monuments, thanks to a partnership with the Heritage Foundation.

ON THE FIELD

Total is also a key sponsor of local sports as a partner to the Pau rugby team and its training center, the local basketball team Élan Béarnais, as well as auto racing with the Grand Prix de Pau.


ENTREPOSE
ENTREPOSE

COMMITMENT

Wherever we operate, we are fully aware of our responsibilities regarding safety and environmental preservation. Ensuring the safety of people working at Total sites is our priority. We also strive to minimize the environmental impacts of our operations as part of our active commitment to sustainable development.

HSE

HEALTH, SAFETY/SECURITY, SOCIETAL/ENVIRONMENT

Ranking foremost among the complex challenges overcome by Total's exploration and production teams, the imperatives of human safety and environmental preservation are increasingly in the public eye. Upholding these priorities is the only way to ensure responsible, sustainable production.

THINK SAFETY

Wearing appropriate personal protective equipment is mandatory for all laboratory personnel at the CSTJF.

OIL AND GAS production is a hazardous business. Ever present and multifaceted, the risks are proportional to the scale of Total's largest industrial projects. These can entail millions of man-hours of work by crews of thousands mobilized simultaneously on a single worksite for months at a time, or the installation of components and systems weighing hundreds of tons on the seafloor.

The goal of "zero accidents" drives the teams who design Total's E&P projects and work at its operating sites around the world. Engineers specializing in Health, Safety and Environment (HSE) provide support across the E&P value chain to minimize the negative impacts of our operations on people, the environment and local communities. Teams are committed to planning, acting and continually improving performance towards attaining Total's ambitious targets.

Environmental protection is an equally strong priority for the CSTJF and the focus of numerous research projects. It is also a dominant concern on all Total-operated production sites around the world. From the outset, every project is designed to limit the impacts of its operations on air, water and biodiversity, which is monitored especially closely. Total's Exploration & Production branch is assertively committed to curbing greenhouse gas emissions, a crucial component of the fight against climate change.

Water, a systematic by-product of oil and gas production, is managed sustainably through reinjection into the original formations whenever possible. Any produced water discharged into the natural environment is treated to comply with very stringent standards.

Through the combined efforts of experts at the CSTJF and in the subsidiaries, Total is able to reconcile production growth and profitability goals with the imperatives of human safety and environmental preservation.

These priorities are an integral part of the industry's responsibilities to current and future generations.

"Safety takes precedence over every other consideration, because lives are at stake."

Christophe de Margerie


TOTAL


FENZY

EMERGENCY DRILLS

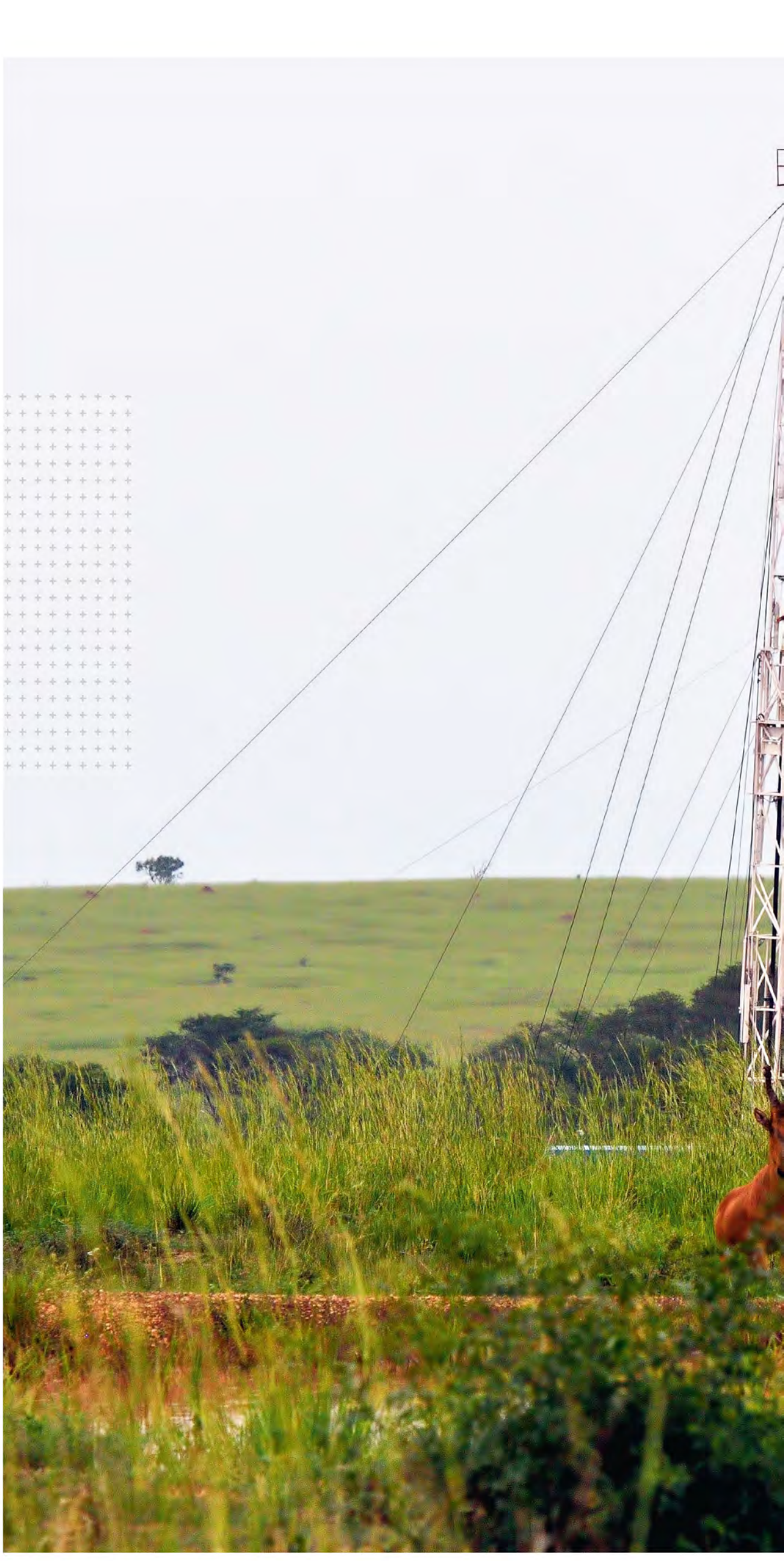
A safety exercise in cooperation with local firefighters serves to evaluate the effectiveness of the internal operations plan for Pau and the surrounding area. The firemen are wearing self-contained breathing apparatus in a drill simulating a gas leak and risks related to hydrogen sulfide (H_2S).

VIGILANT TOGETHER

A safety briefing at the Okpo site in South Korea is attended jointly by Total teams and those of contractor DSME, during the construction of the Floating Production Storage and Offloading (FPSO) vessel destined for the Pazflor field in Angola *(previous page)*.

TARGETED MEASURES TO PROTECT THE ENVIRONMENT

In Murchison Falls National Park (Uganda), minimizing the impact of drilling operations on the park's particularly diverse wildlife is top priority. The use of small electric rigs has been recommended to limit the noise and visual disamenities associated with oil development.



22 mg/l

was the hydrocarbon concentration in produced water discharged by our offshore facilities in 2011, a strong performance and a significant improvement over 2010.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ADAPTING TO THE RIGORS OF THE ARCTIC

At Kharyaga, 60 km north of the Arctic Circle in Russia's Nenets region, Total has been producing this difficult oil field since 1999. The challenging environmental and climate conditions—sensitive tundra ecology, permafrost, extreme cold (down to -65°C with the wind chill factor)—dictate activities. Planning and preparation are crucial and all facilities must be winterized to protect them from the frost, wind and snow.

WATER CONSERVATION

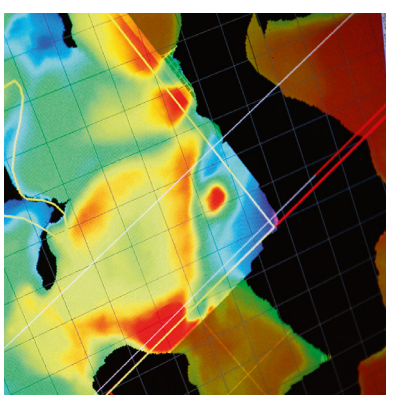
In the wings of Australia's Gladstone LNG (GLNG) project, which will convert coalbed methane into liquefied natural gas, Total is taking part in the Water Management program to reduce the impact of its operations on water resources. This Leucaena grass plantation is irrigated by water recycled from the Fairview gas extraction site in Roma, Queensland state.

THE RESERVOIR, UP CLOSE AND PERSONAL

Geomatics, geology (itself a broad field encompassing more than 20 disciplines), reservoir engineering and geophysics all share the same aims—to discover, understand and describe the specific features of petroleum reservoirs, complex geological structures that contain oil, gas and water. The ultimate goal is to generate detailed models showing a reservoir's architecture and internal structure and the behavior of fluids set in motion by the production process.

GEO-SCIENCES

The geosciences chain is made up of geoinformation or geomatics (GIS) engineers, geologists, reservoir engineers and geophysicists. Their job is to get rock and fluid samples to tell their tale and coax out meaning from images generated by one of the world's most powerful computers.



SEISMIC AND PETROPHYSICS

Reservoir quality is shown by seismic imaging: the warmer the color, the closer to the sandy trend; the colder the color, the closer to the shaly trend.

Revealing the invisible

using the seismic techniques of geophysics.

THE DISCOVERY and development of oil and gas resources depends on analyzing and interpreting petroleum data. Geomatics or "geoinformation science" (GIS) is the discipline that brings together specialists in petroleum data—the data that underpins the work of geologists, geophysicists and reservoir engineers. GIS engineers are involved throughout the life cycle of these data, from its capture, qualification and mapping to its processing, classification and storage. For there can be no future without a memory of the past.
Reservoir geologists focus on understanding and predicting the behavior of oil and gas basins over time and in space. Their job is to characterize the elements that form an oil system—the source rock, the reservoirs in which the oil is trapped, and the cap rock that seals the oil deep within the rock. The foundation of the oil and gas industry, geology is a broad discipline subdivided into some twenty fields of specialization. These include organic geochemistry (the study of source rocks), sedimentology (the study of sedimentary processes that form reservoirs), structural geology (to understand the structure of oil basins and reservoirs) and biostratigraphy (the study of the microorganisms found in sediment). Geological expertise is prevalent at every link in the exploration and production chain, from acquisition of the acreage to production of the reserves.

Based on this work, especially the sedimentary models of hydrocarbon traps that predict the volumes of oil and gas in place, reservoir engineers are able to estimate the productivity of the discoveries by modeling fluid movement during production. They can thus help reservoir architects optimize the development plan for individual fields. The combination of theoretical data, experience gained over the years, geological fieldwork, and characterization of the rock and fluid samples taken during drilling, contributes to numerical models made possible through the rapid growth in computing capacity.

Although samples provide valuable hard information when building these models, their size is extremely limited compared to the overall scale of the field under investigation. In fact, the challenge addressed daily by reservoir geologists and engineers is comparable in complexity to modeling the Eiffel Tower based on a sample the size of a pinhead.

The CSTJF receives samples for analysis from the around the world. Its extensive collection

of core samples taken during drilling is used to study the composition of reservoir rocks in minute detail. This geology laboratory is equipped with a CT scanner for three-dimensional imaging.

At the same time, the physical properties of reservoir rock and their ability to contain and permit the flow of oil or gas are analyzed in petrophysics laboratories. The fluids themselves are studied under reservoir temperature and pressure conditions. Experiments that can last up to several months predict the effectiveness of various production processes on a microscopic scale. The aim is to understand how the oil or gas will behave over the twenty-year (or longer) producing life of the reservoir.

The next link in the chain of geosciences expertise is geophysics, which has emerged as one of the CSTJF's areas of excellence.

By applying seismic technology, geophysics "reveals the invisible"—the reservoir—for the first time. Acoustic waves generated by vibrations on land or at sea are partially reflected by the various geological strata they encounter as they propagate through the subsurface. Logging the signals of these reflected waves at the surface yields an image of the geological layers. The data are then used to build a three-dimensional (3D) model of the contours and internal architecture of the oil traps.

Through ongoing dialogue, geophysicists in the E&P subsidiaries and specialists at the CSTJF can recommend the most appropriate acquisition systems for offshore and onshore operations. In addition, the Center's team helps to build the more complex seismic images using innovative processing algorithms that require the extensive computing power available at the CSTJF.

What do a supercomputer, a medical-type CT scanner and a small chamber pressurized to one metric ton

per square centimeter have in common? They are all part of the CSTJF's Geosciences platform. This hardware, along with other equipment, is used for studies conducted in Pau to assist the subsidiaries' efforts to discover and appraise new oil and gas reservoirs. Buried as far as 8,000 meters beneath the Earth's surface, lying in ultra-deep water, or trapped in the chaotic geology of mountain ranges, as-yet undiscovered oil and gas resources are spurring the industry to explore new and extreme frontiers, pushing technology to its furthest limits —then further still.

Exactly how deep is a reservoir? How big is it? Does this gigantic sequence of sedimentary layers contain oil or gas? In what quantity, and how much of that can be recovered? E&P subsidiaries turn to the CSTJF for answers to some of these questions. For the most complex scenarios, the full range of the Center's technological resources and advanced know-how is brought into play.

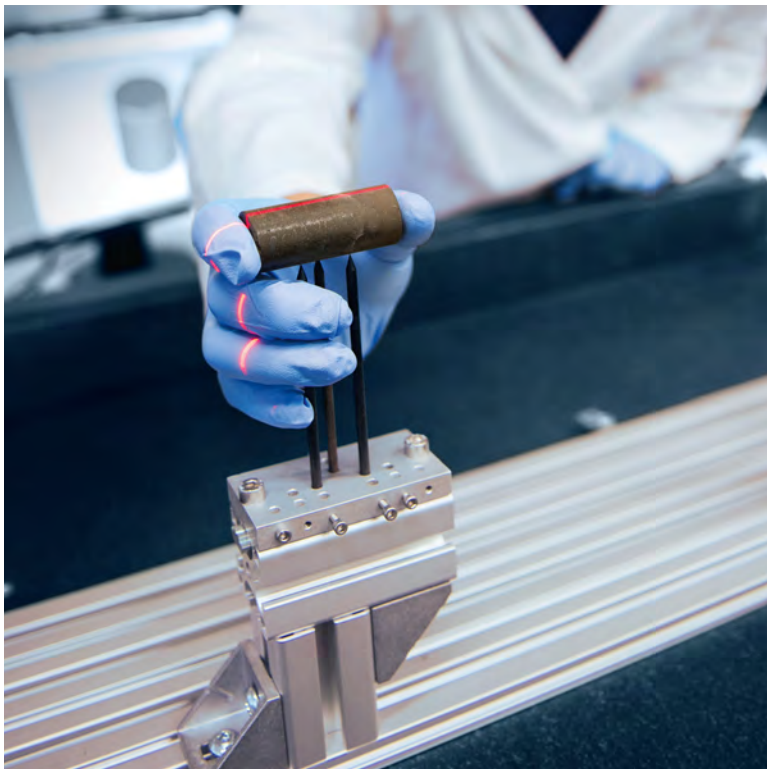
Coordination between the CSTJF and the subsidiaries is vital to obtaining reliable answers to these strategic questions.

CORE SAMPLES BY THE THOUSANDS

Core samples are cylinders of rock removed during drilling; they are the only visible elements of petroleum reservoirs. Every year, Total's subsidiaries ship more than a kilometer's worth of new cores to the CSTJF, where they are added to its large collection. The Center is equipped to extract a maximum amount of valuable data from these samples.

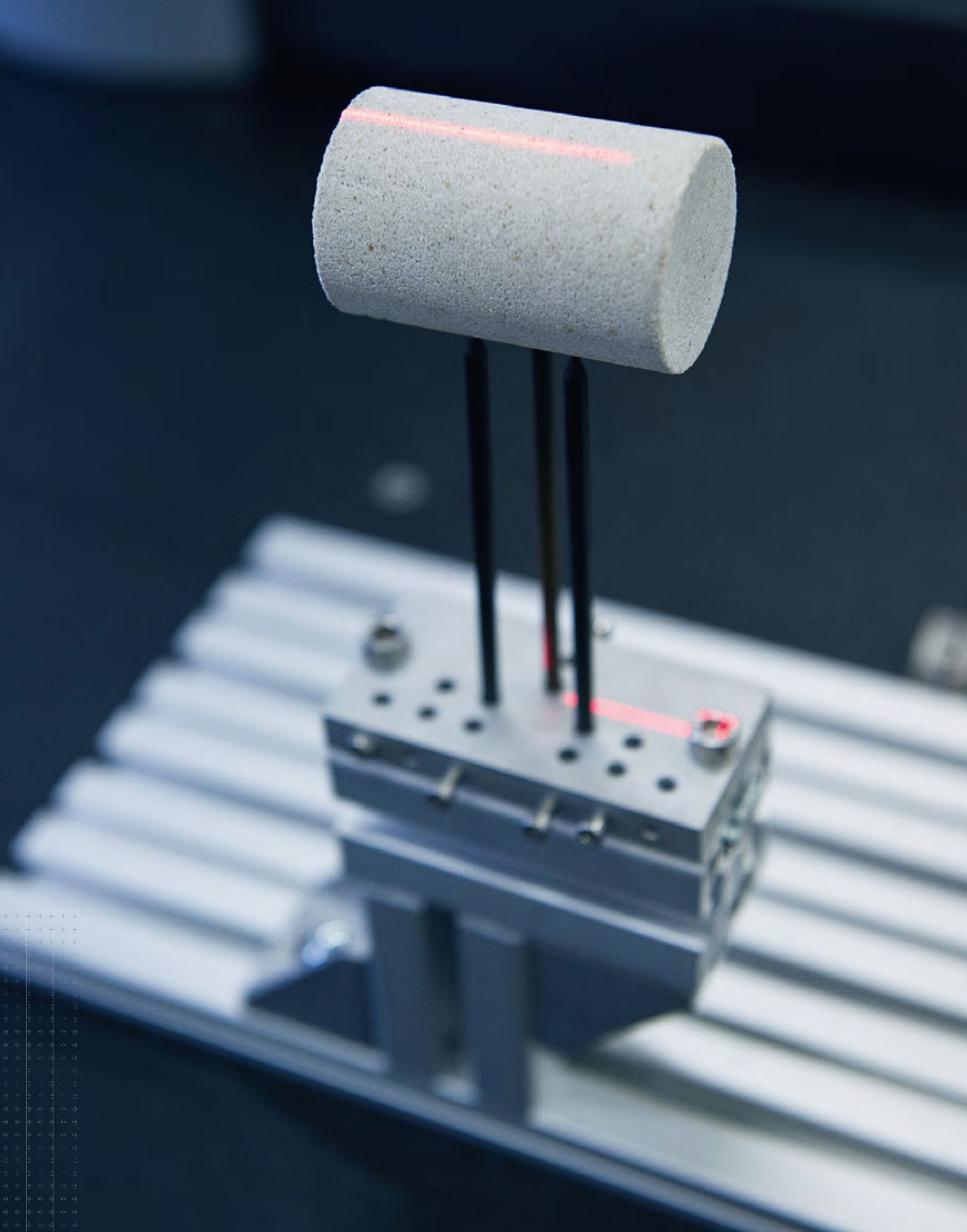
A CT SCANNER TO ANALYZE CORE SAMPLES

The CT scanner is just one of the high-tech instruments available at the CSTJF Geology Laboratory. Tomographic images of core samples are re-combined to yield three-dimensional images that highlight differences in density between the various components of the rock. This in turn gives a virtually direct indication of the volume of hydrocarbons contained in each sample, a key parameter of reservoir characterization.



SCANNING IN 3D

A rock sample is scanned using a portable laser to determine its total volume. The contours (or envelope) of the sample are registered and reconstructed to yield a highly accurate 3D model. Subtracting the actual rock volume from the total volume gives the volume of pores, or voids. This information will facilitate subsequent calculation of the porosity of the rock.

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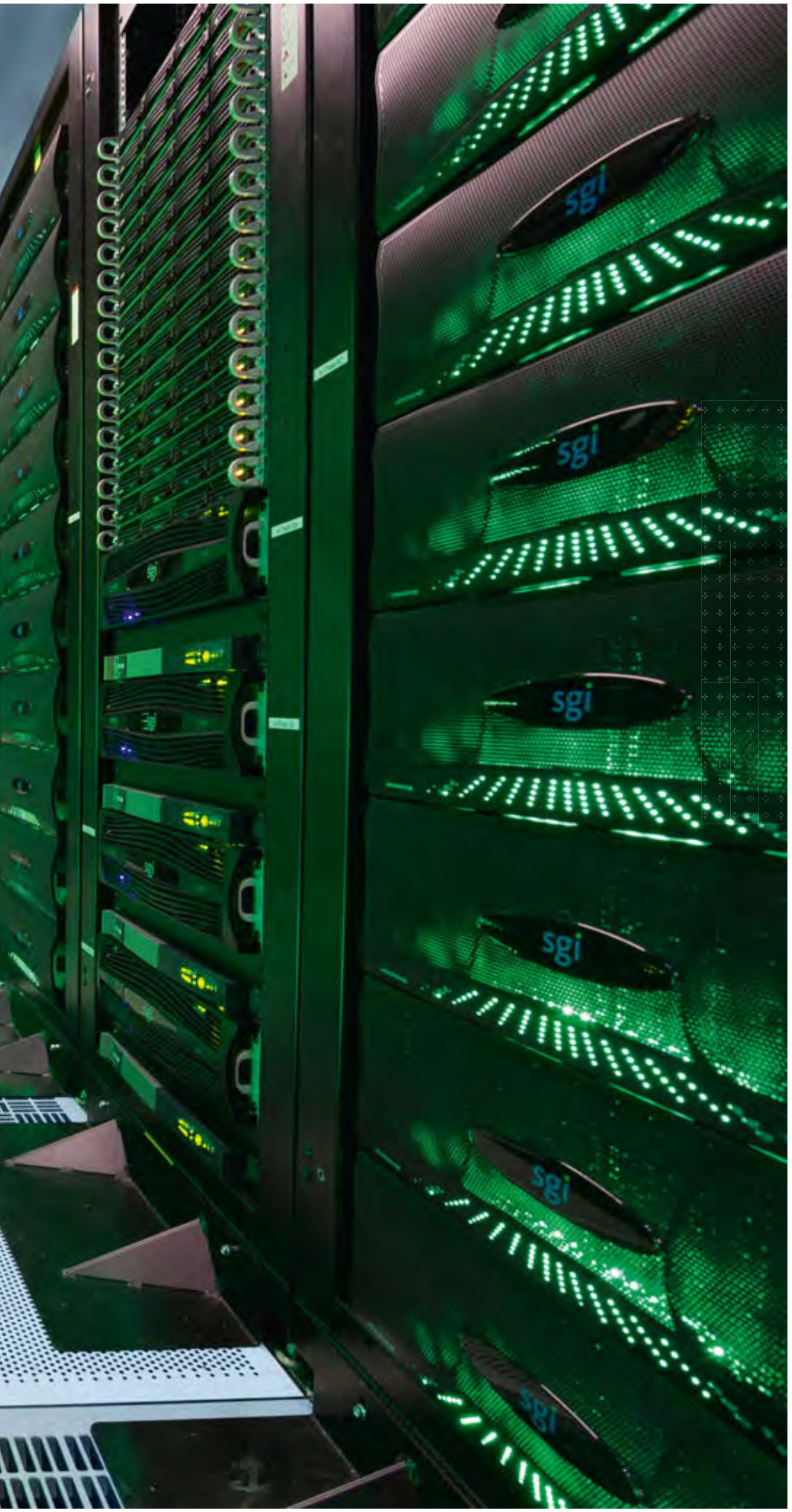
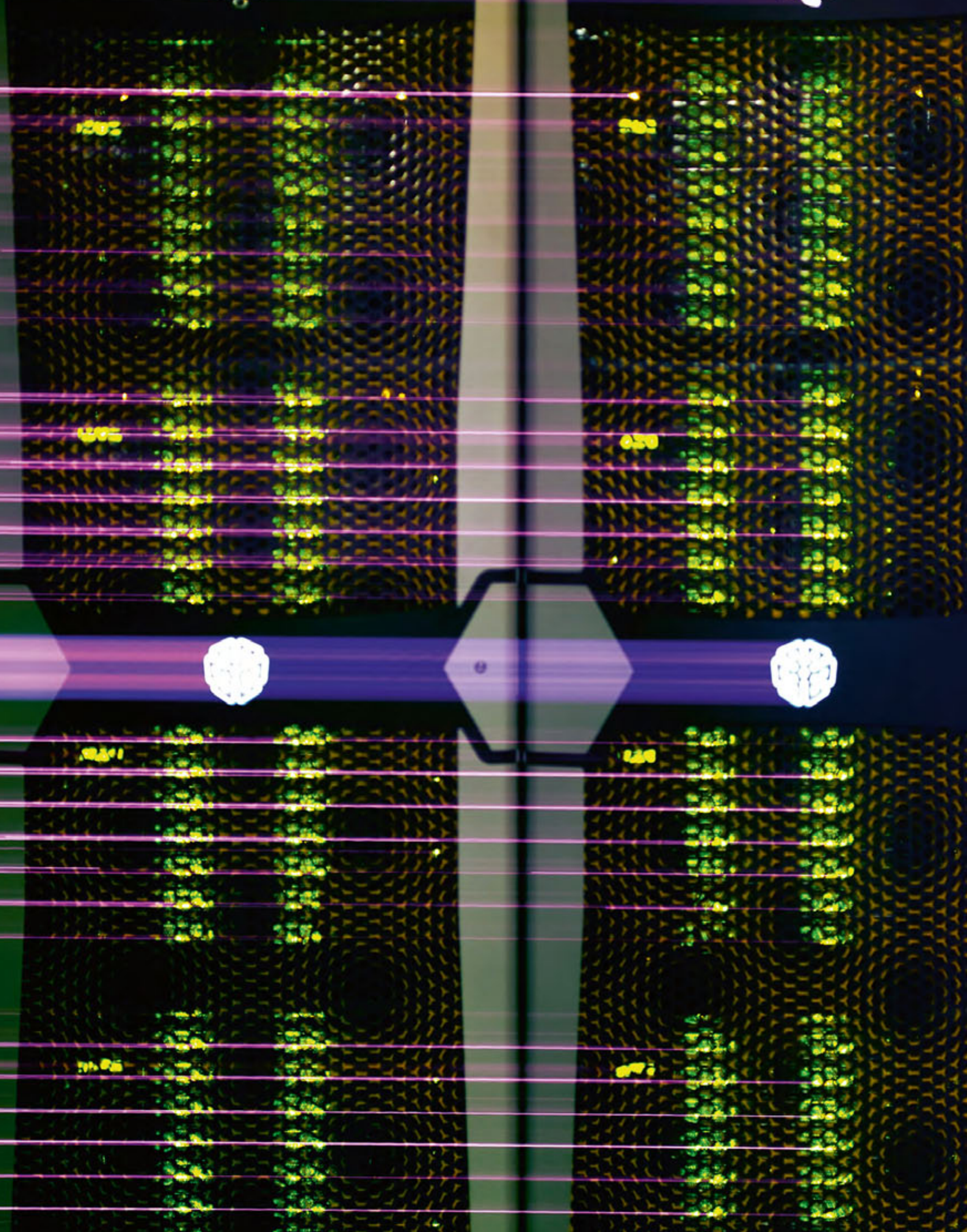


DIZZYING COMPUTING POWER

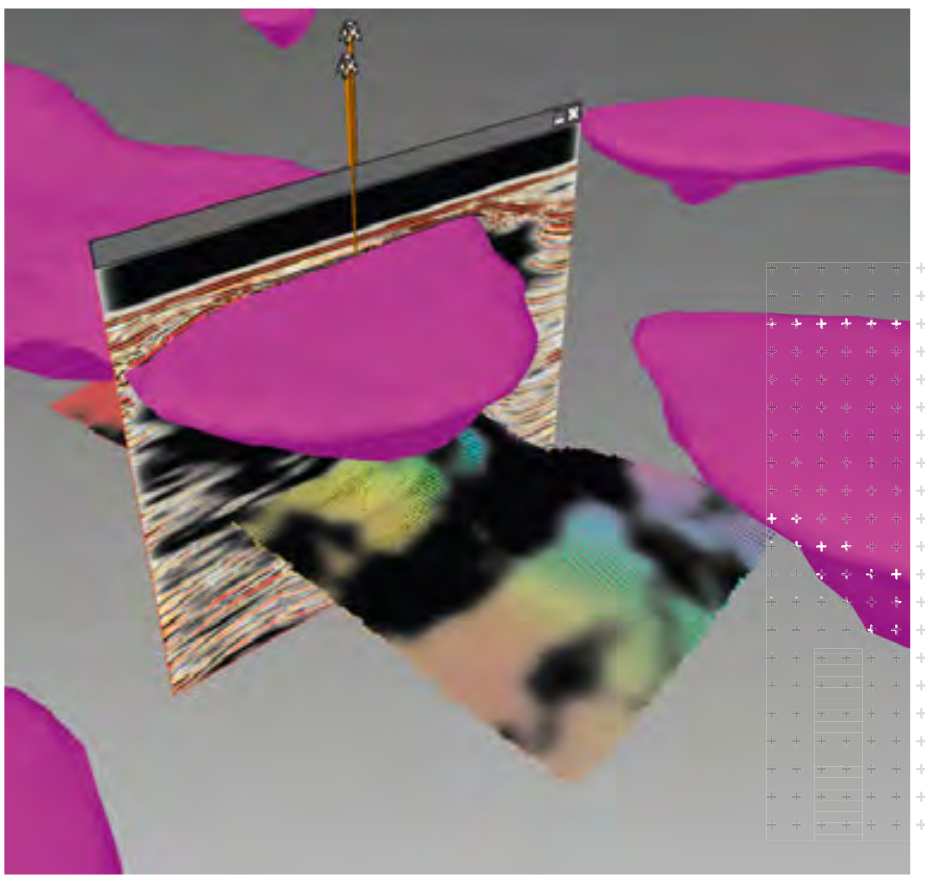
Boasting a record computing power of 2.3 petaflops—or 2.3 million billion (10^{15}) operations per second—the new high-performance computer acquired by the CSTJF *(this page and following page)* makes Total a global leader in scientific processing capacity. It is primarily used to process the complex calculation codes developed by the CSTJF to enhance the resolution and reliability of subsurface seismic images.

2.3 million billion
operations per second.



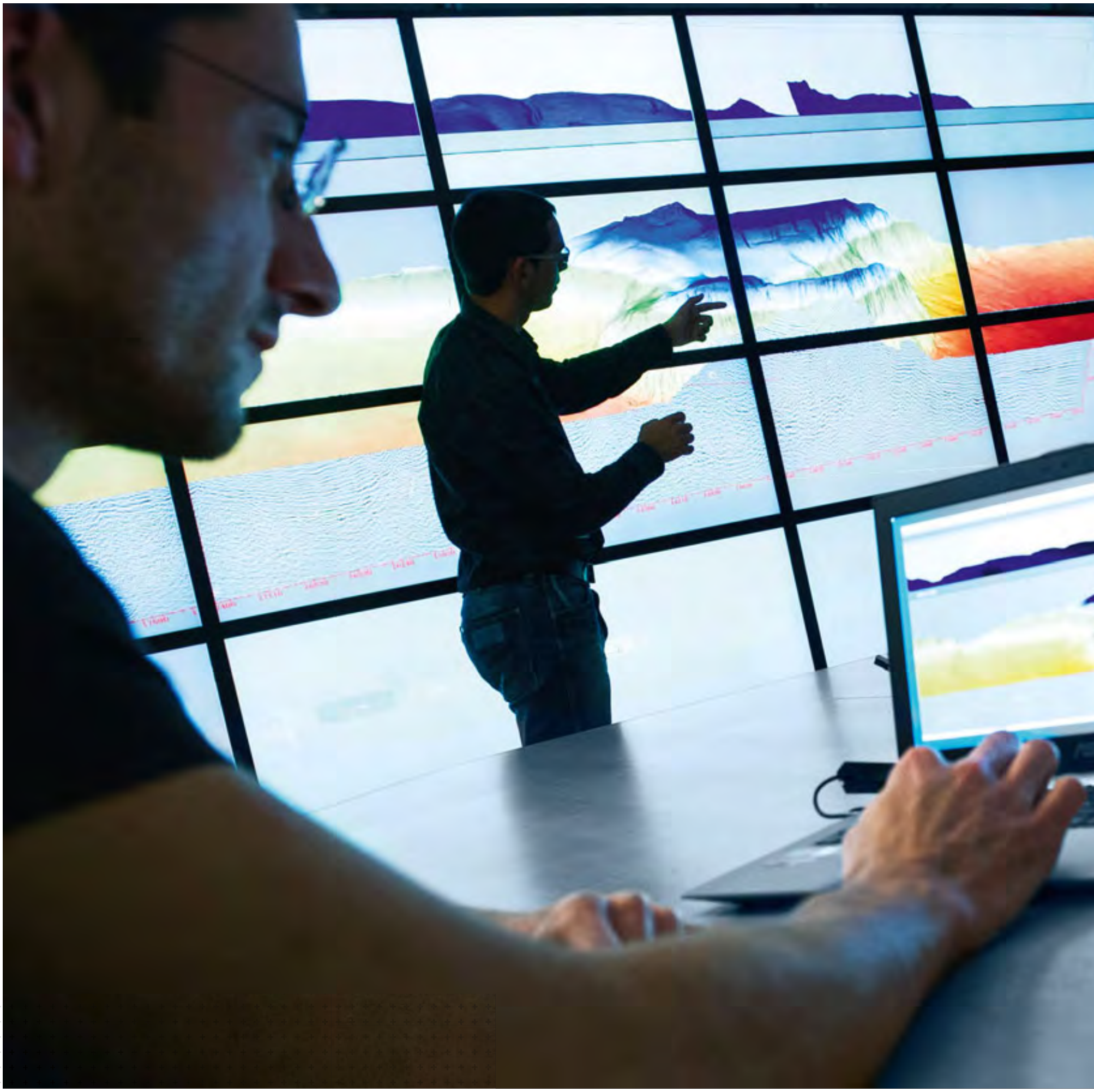
MASS STORAGE

Every day, the volume of digital data at the CSTJF swells with the addition of thousands of bytes of data from computation, design and modeling applications. Backing up these data is critical and relies on an internal storage capacity of 2.6 million billion bytes, equivalent to a five-kilometer-high stack of CD-ROMs. To ensure integrity and security in the event of a disaster or other critical incident on site, the data is transferred to an offsite storage vault every week.



GEOMODELING

With its new high-performance computer, CSTJF teams can generate higher-resolution seismic for more reliable, more detailed images of the subsurface.
This seismic image shows the cap rock in a complex sub-salt context.

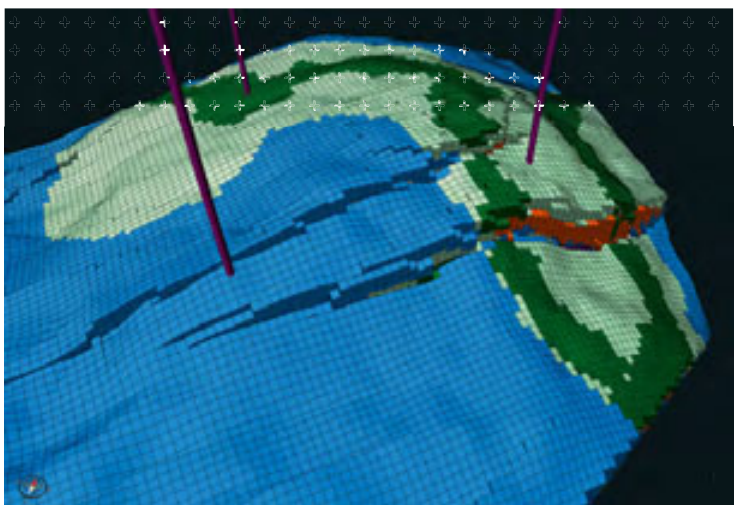


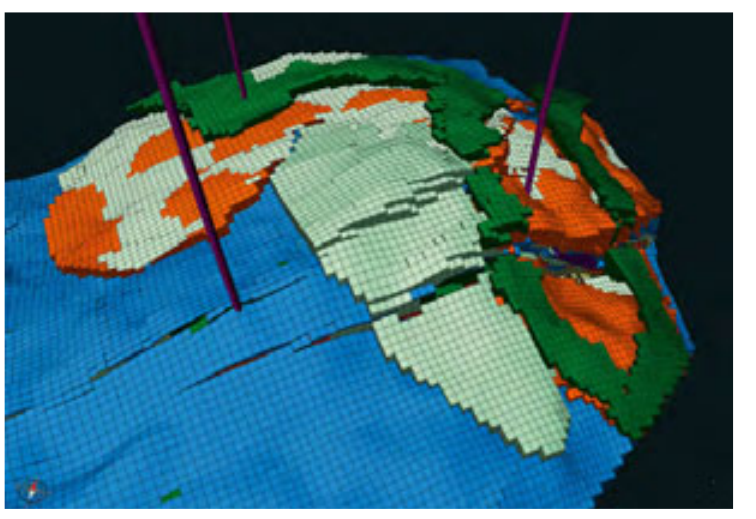
IMAGING TECHNOLOGY AND HUMAN INSIGHT

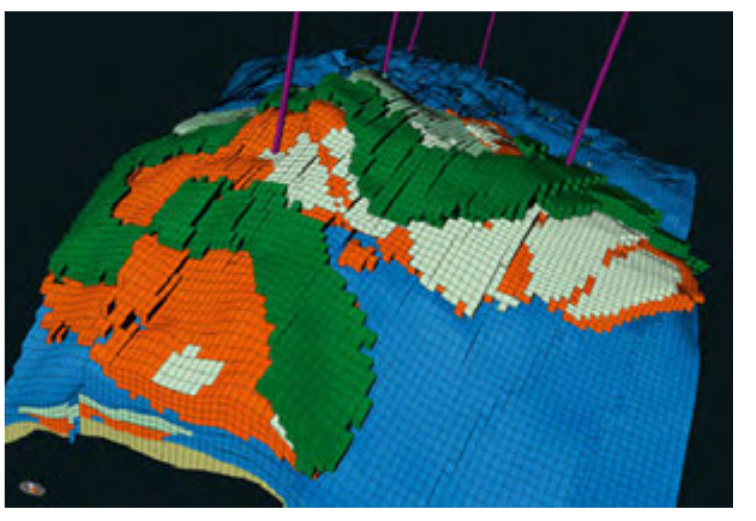
Satellite images give broad views of petroleum basins; seismic reflections reveal the chaotic contours and folds of the subsurface; 3D models depict reservoirs with their geological structures and fluids. All these images have much to tell geoscientists who know how to interpret them. For although calculations are one key to understanding and managing reservoirs, the art of interpretation is what makes them accessible.

INTERPRETING THE LAYERS

By correlating the interpretation of geologic layers revealed by seismic with sedimentary concepts of rock formation, experts can identify the zones that determine reservoir architecture and fluid flows.







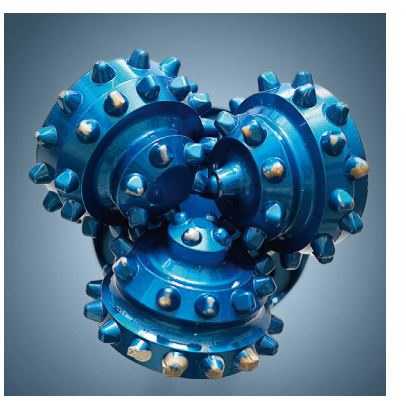

TOTAL

STATE-OF-THE-ART TECHNOLOGY

In the labs, experts in physics, chemistry and rock mechanics provide decisive input to prepare drilling programs. Although the basic principle of drilling is simple enough —bore a hole until it reaches oil or gas—drilling programs are industrial exploits that can last several years. Realizing them is a challenge that demands state-of-the-art technology.

DRILLING AND WELLS

Drilling is an adventure that begins in the laboratory, where experts in rock mechanics, chemistry and data processing test, model and analyze the viability of well designs under extreme conditions.



DRILLING TOOL

A prototype tricone roller bit attacks the rock by breaking and crushing action.

KIRKUK, 1927: Compagnie Française des Pétroles, the forerunner of today's Total and an early shareholder in the Iraq Petroleum Company (IPC), made its first oil strike in Iraq.
Tierra del Fuego, 1999: Total's Argentinean subsidiary completed a two-year drilling program here. One of the eleven wells drilled set a new world record for length, at 11,884 meters. Drilled from the shore, it descended more than 1,600 meters into the subsurface before continuing its horizontal trajectory to tap an offshore field lying more than 10 kilometers from the coast. Drilling is now a high-tech undertaking in which physics, chemistry, data processing, real-time analysis of downhole logging data (recorded during drilling) and sophisticated well-steering tools are all vital to managing today's increasingly complex well trajectories.

Drilling horizontal wells thousands of meters long that cross through one reservoir after another over their entire length is just one of the technological challenges facing Total's experts. And this challenge is of an entirely different magnitude when the fields are deeply buried. Take, for example, the Elgin and Franklin fields in the North Sea, where Total E&P UK had to work with high-temperature/high-pressure gas and condensate discovered under more than 5,500 meters of rock. At these depths, temperature hovers around 200°C and pressure exceeds 1,000 bar. One major difficulty lies in steering well trajectories without the help of downhole instrumentation, as electronic devices cannot operate under these physical conditions. Another is accessing the petroleum traps without triggering a blowout under pressure. In the Gulf of Guinea, Total's E&P

At these depths,
temperature hovers around 200°C
and pressure exceeds 1,000 bar.

subsidiaries in Angola, Nigeria and Congo are confronting the challenges of deepwater drilling (water depths from 1,000 to 2,500 meters). For this scenario, drilling rigs have evolved into floating vessels, their stability guaranteed by an ultra-sophisticated dynamic positioning system to centimeter-scale tolerance, even in rough seas.

Regardless of the context, efficiency and safety of operations are the watchwords when it comes

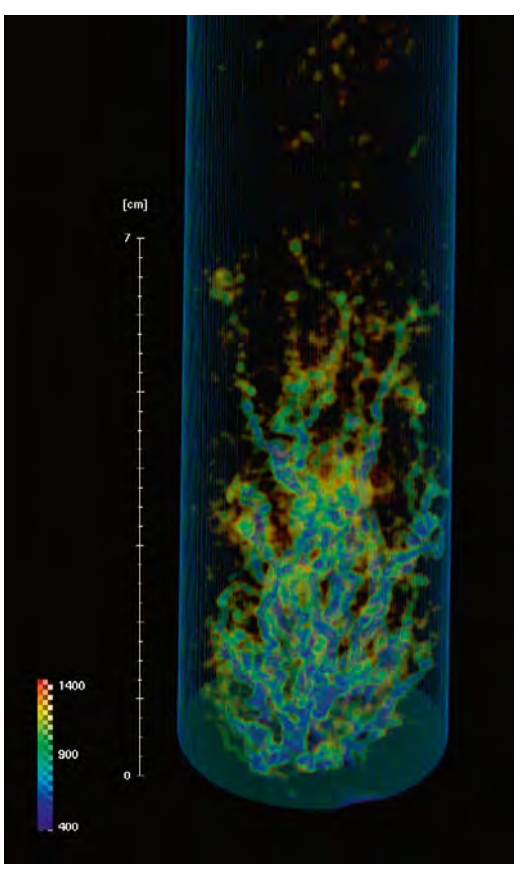
to minimizing the time it takes to drill wells, which can cost over a million dollars a day. Whether it lasts less than a month or requires a full year, every drilling assignment must juggle the need for speed and the imperative of risk management. An unstable wellbore or damage to the rock formation during drilling could jeopardize the well and its productivity. Thanks to its extensive engineering and testing expertise and skills, the CSTJF is the partner of choice when subsidiaries are confronted with challenging situations.
Borehole stability during drilling is a major topic of investigation at the Rock Mechanics Laboratory. There, strength tests are conducted on samples of the geological strata encountered in order to optimize the more complex well trajectories.
Commonly known as muds, drilling fluids play an essential role in borehole stability. Injected under pressure at the bottom of the hole, they circulate constantly, bringing the drill cuttings to the surface. Mud density is controlled to ensure balanced pressure between the hole and the formation. If the mud is too heavy, it could be forced into the rock, damaging the reservoir and potentially jeopardizing the stability of the borehole. If it is too light, it will not prevent fluid (either water or hydrocarbons) from seeping into the well bore from the surrounding formation.

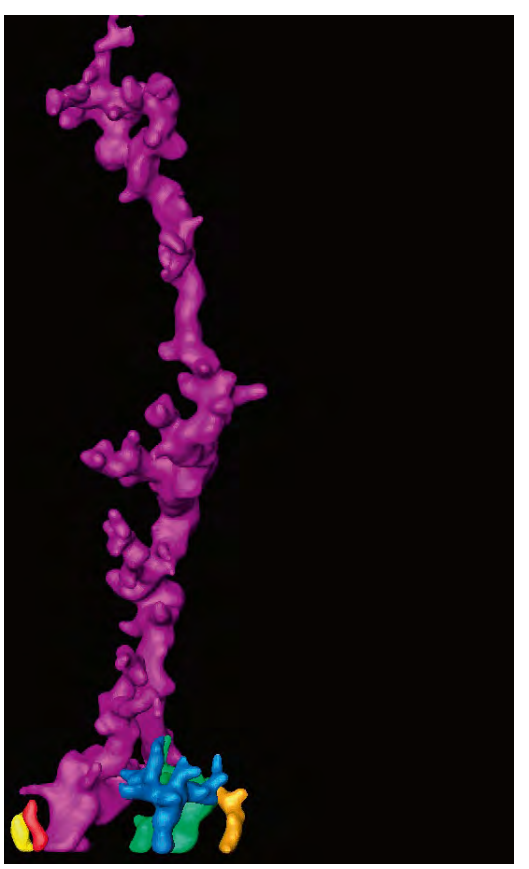
This is where the expertise of the chemists at the Fluids and Cements Laboratory comes into play. Their task is to find the right balance and most effective formulation for the drilling mud. For their part, the experts from the Productivity Laboratory will select specific additives to minimize damage or restore the productivity of reservoir zones, particularly the tiny networks of fractures that allow oil and gas to flow through the rock and into the well when it is brought on stream. Unlike the early Kirkuk project,

drilling is no longer a task for a single person. It requires the combined know-how of an integrated team of specialists.

Drilling costs for the most complex wells can exceed

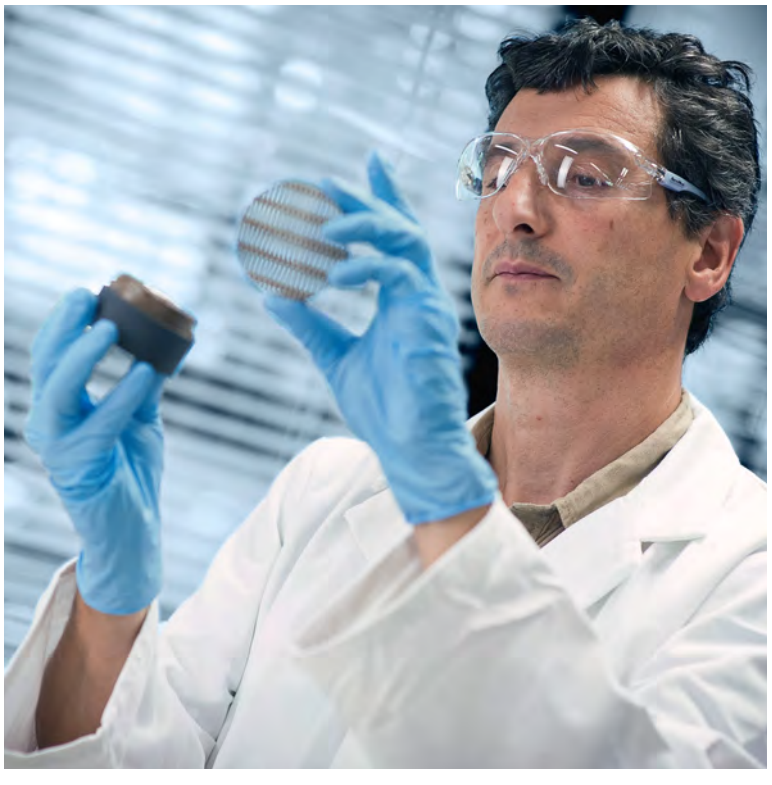
one million dollars a day.





ENGINEERING THE RESERVOIR/ WELLBORE INTERFACE

The reservoir/wellbore interface has strategic implications for well productivity. In certain configurations, this zone must be equipped with sand control systems to retain the sand produced along with the well fluids. Failing to do so could jeopardize productivity or damage equipment.
To stimulate productivity in carbonate formations, a concentrated acid solution is injected into the near-wellbore zone. The acid creates a network of wormholes that constitute conductive channels from the formation to the wellbore.

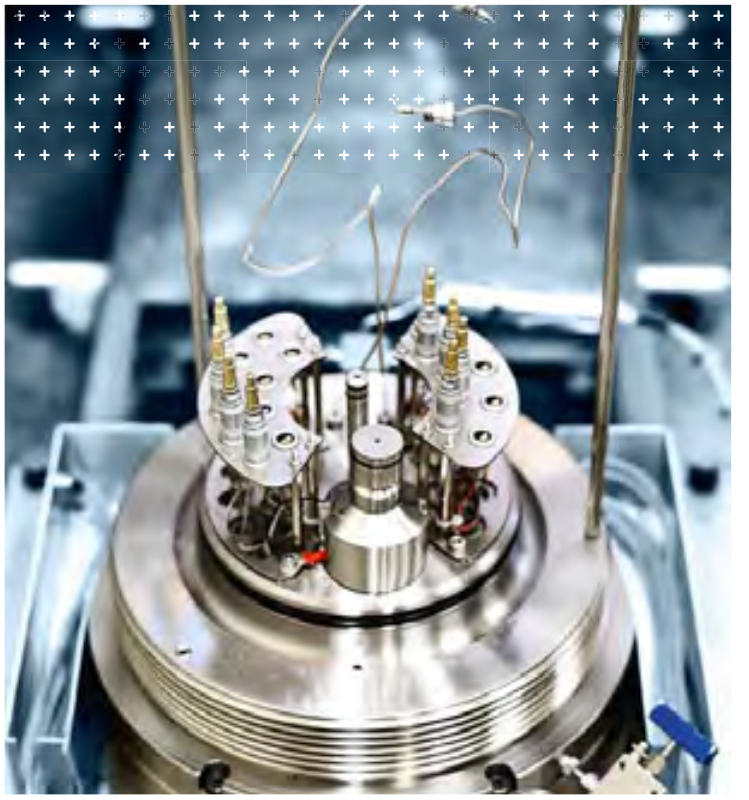


PRODUCTIVITY

Laboratory studies guide the choice of the most appropriate "filter" device based on the type and quantity of sand produced with the well fluids.

IN PURSUIT OF PERFECTION

To limit the ever-increasing costs of drilling as much as possible, perfection is the key—and the secret to optimizing drilling efficiency. Attaining this high standard requires in-depth knowledge of the rock encountered and its “response” to the drilling. This is one of the fundamental missions of the Rock Mechanics Laboratory.



CUSTOMIZED CEMENTS AND MUDS

Despite the similarities between the subsurface layers drilled, the mud formulation, essential to smooth drilling operations, is tailored to each case.


V3

MORE THAN 1,000 BAR

In the U.K. sector of the North Sea, Total drilled one of the very first stepout wells in a high-pressure/high temperature environment. The 7,300-meter-long Glenelg well reached its target 5,600 meters beneath the seabed, with a reservoir temperature of 200°C and pressure of 1,150 bar. This feat was made possible by the complex studies performed at the CSTJF's laboratories. Here, the Pressure Volume Temperature (PVT) lab.

1,500 bar and 200°C

These extreme pressure and temperature conditions are a regular focus of investigation in the CSTJF laboratories.

DECADES

Producing a reservoir is a complex, dynamic process lasting many years, in which enormous volumes of fluids of varying viscosity and corrosiveness are set in motion using a variety of technologies. Oilfield operations engineers focus on key themes such as forestalling the decline in production, preventing the deterioration of production facilities and adapting extraction processes to the physical and chemical changes that well fluids undergo over the producing life of the field.

PRODUCTION TECHNIQUES

Innumerable parameters affect the volume of hydrocarbons that can be produced from a reservoir. The teams at the CSTJF have developed an arsenal of tools designed to increase this recovery factor and monitor field performance throughout the production period.

"STRESS TESTS"

These measurements serve to analyze the compressibility of fluid samples.

AN OIL ACCUMULATION is not an underground lake that can simply be pumped to bring its contents to the surface. In fact, oil and natural gas are trapped in porous, permeable rock formations called reservoirs. Producing the resources thus involves draining the pores. Only a small percentage of the oil or gas in place (10 to 35% for crude oil) can feasibly be extracted. The exact amount depends on the rock's properties and on the fluid's ability to flow through it. Enhancing this recovery factor by even a few percentage points has tremendous implications for reserve replacement and is a core challenge for all the disciplines involved in oil and gas production.

It takes several years to bring a field into production after it is discovered. That period is put to good use identifying the most appropriate production technologies and systems. At the CSTJF, scientists and engineers focus on determining the most effective recovery mechanism for the reservoirs, calculating the well trajectories that will optimize drainage and estimating the quantities of oil, gas and water that the field will yield over its lifetime. These analyses are coordinated with a simultaneous effort by other experts who apply their ingenuity—aided by physical-chemical analyses—to predict how the hydrocarbons will behave during production, especially their ability to flow to the well. They carefully evaluate and mitigate all factors liable to hinder production, such as pipe clogging or corrosion. In addition to the long list of factors that will guide the definition of the production plan, risks relating to seismic activity, the ocean environment and meteorological conditions must be assessed and taken into account.

Defying time

to forestall oilfield decline.

All oil companies are now producing more water than oil, and the water cut inevitably rises as a field matures. Some—but not all—of this water can be reinjected into the reservoir for pressure maintenance. For the remainder, increasingly stringent international regulations governing produced water discharge into the marine environment call for another solution. Ideally, a greater proportion of it could be returned to the formation. To do so, produced water must undergo fine filtration to mitigate the risk of formation damage or plugging of wells. Given the scale of an oilfield, the chosen technology must be both highly efficient and economical.

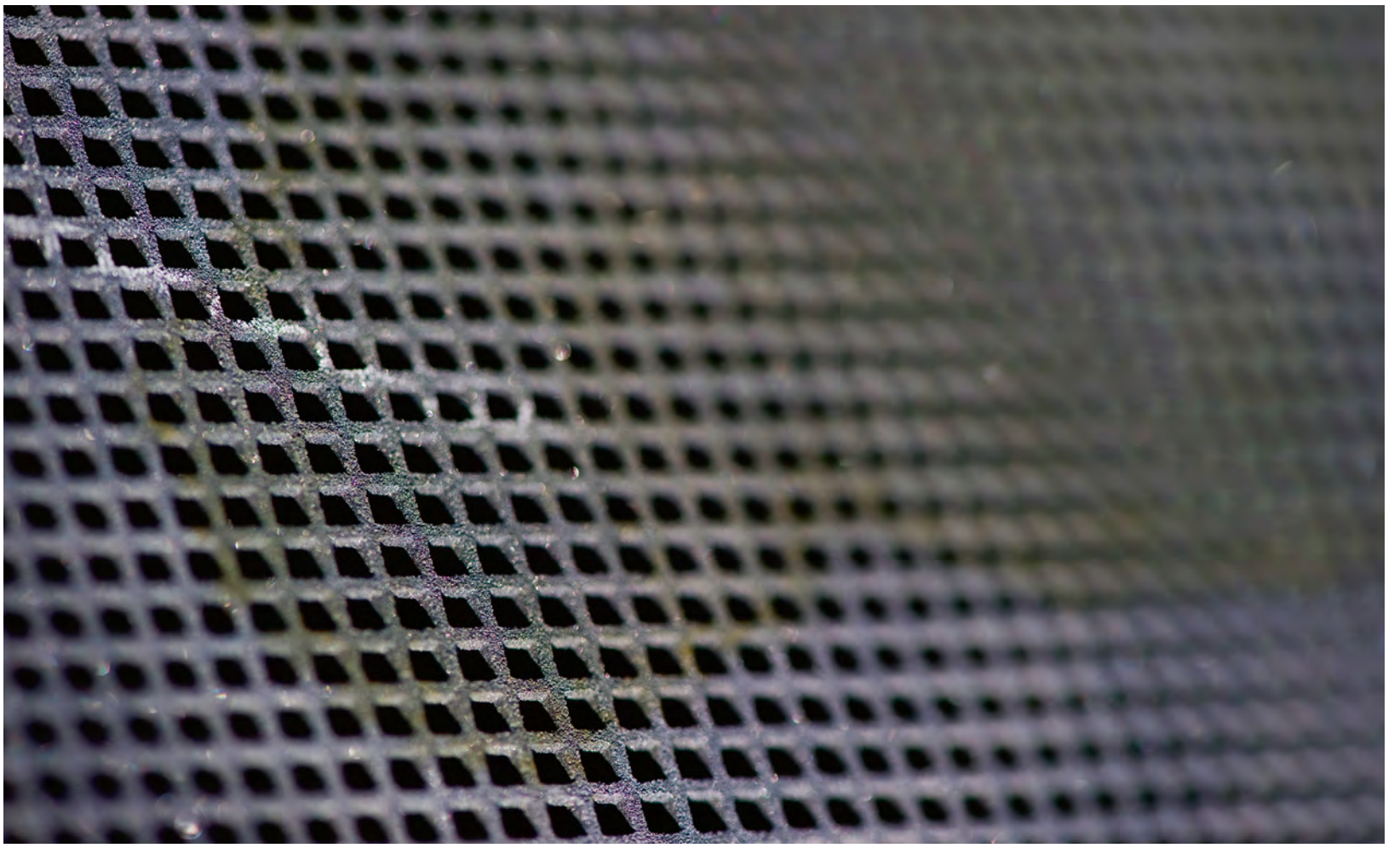
The engineers at the CSTJF are meeting the challenge with a ceramic membrane ultrafiltration process, an innovative technology that offers superior performance compared to conventional systems. It removes suspended solids as tiny as a few hundredths of a micron, as well as droplets of non-soluble hydrocarbons. This is the first time the technique is being applied to oilfield produced water—a new “first” for Total and a new milestone for the E&P industry in general.

Throughout the decades-long life of a field, the CSTJF helps Total’s operating entities optimize and sustain the productivity of their fields, extending their producing life down to the last drop. Expert analyses of rock samples and well fluids guide the development of processes to restore productivity in reservoir layers that may have deteriorated over the production period.

A wide array of leading-edge technologies can also be deployed to boost output by "forcing" the oil and gas to flow to the wells. Conventionally, water and gas are injected to "sweep" the maximum possible amount of hydrocarbons in the right direction, but more sophisticated techniques are also available. Analytical chemistry makes it possible to formulate additives tailored to the properties of individual reservoirs. These can be mixed with the water or gas being injected to displace the crude oil from the rock more effectively. The CSTJF is also examining the feasibility of injecting polymer, air, steam, foam or solvent (hydrocarbons and/or carbon dioxide) in an effort to devise new solutions and raise the final recovery factors significantly. In the drive to improve the productivity of Total's assets, the CSTJF has the resources it takes to invent new tools that will benefit Total's E&P subsidiaries. For example, new software applications have been developed to pinpoint possible causes of production losses, in real time. These innovations inaugurate a new era of remote monitoring of field performance, with data accessible in subsidiary offices as well as at the CSTJF.

These innovations all target the same goal: pushing recovery factors ever higher.

Improving
oil recovery factors,
a test of expertise.



CERAMIC MEMBRANE ULTRAFILTRATION

In a world first, our R&D tested ceramic membrane ultrafiltration on produced water. This technology successfully removed suspended solids down to a hundredth of a micron (versus 5 microns in conventional technologies).

HYDRATE LOOP

Resembling ice plugs, hydrates form in hydrocarbons in the presence of water and gas under specific pressure and temperature conditions. They constitute a serious physicochemical risk.
The CSTJF's hydrate loop, where hydrocarbons flow at controlled temperature and pressure, is used to study and quantify the specific risks for each field, then to test preventive solutions.

PYROLYSIS

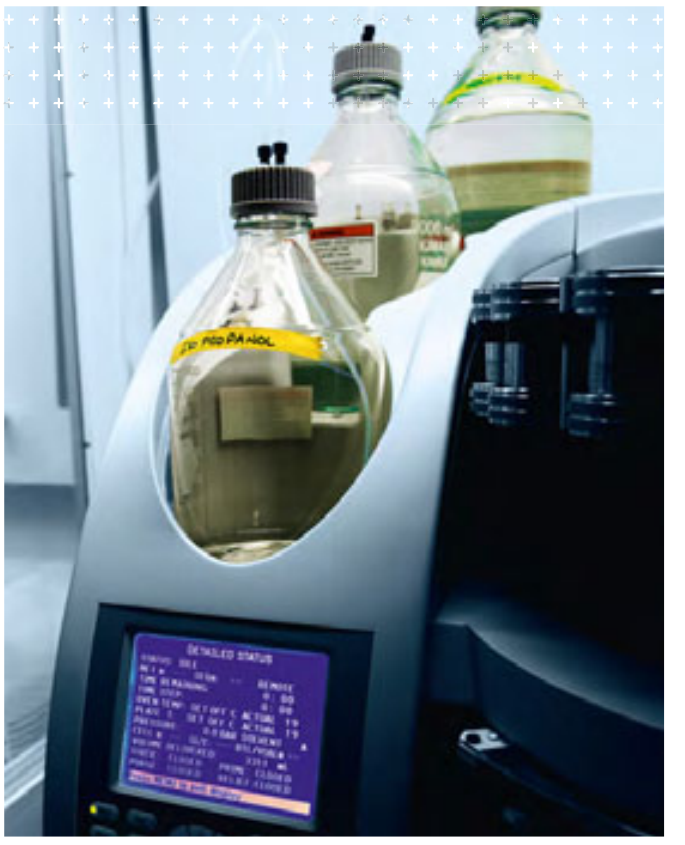
The Fluids and Organic Geochemistry Laboratory simulates hydrocarbon generation by heating metal tubes that contain rock samples in an inert atmosphere to very high temperature. The resulting hydrocarbons are then analyzed.

NUCLEAR MAGNETIC RESONANCE

This laboratory measures the petrophysical properties of rock samples. Using specific acquisition sequences, nuclear magnetic resonance reveals the rock's porosity and pore network structure as well as the nature and quantity of the fluids it contains, in both laboratory and reservoir conditions.

MEASURING POROSITY AND PERMEABILITY

Here, core samples are cleaned to remove all organic matter using either a small quantity of boiling solvent or pressure. Permeability and porosity are then measured on the cleaned rock samples.




CELLULE 2
Cellule ISOTROPE
PS: 600 Bar
VT 0.5 L ;TS = 20 C
Liquides groupe:2

STEP DECAY METHOD

This laboratory recently put in place by Total is equipped to perform high-precision permeability measurements on dense, low-permeability rock samples taken mainly from formations that contain unconventional resources (*e.g.,* shale gas, tight gas).

MICRODISTILLATION

The aim of microdistillation is to separate small samples of oil into their component fractions, according to boiling point. In addition to identifying the precise composition of the oil, microdistillation can be used to evaluate its commercial value.

FROM THE LAB TO THE FIELD

As the main R&D hub for Total's E&P branch, the CSTJF's vocation also includes overcoming the technological hurdles that hinder access to frontier resources. This R&D strategy attests to Total's impressive innovative capabilities. We have operations in the world's major sedimentary basins.

RESEARCH AND APPLICATIONS

Technological innovation is the only means of gaining access to new oil and gas provinces, through the development of new solutions for responsible, sustainable production. When it comes to the future of energy, only innovation has the power to stretch the realm of feasibility.

CHROMATOGRAPHY

The chemical components of a sample (oil, rock or mud) are examined and analyzed in the Chromatography Lab. Here, oil samples are bottled and kept in cold storage.

MOST OF THE R&D supporting Total's Exploration & Production operations is concentrated in France, at the CSTJF. Here, nearly 700 R&D engineers and technicians are dedicated to improving the tools already available to exploration teams. They also strive to develop innovations that will enable profitable production of frontier resources. Additional research priorities include optimizing production techniques to increase reserves on conventional fields, and developing new technologies to preserve the environment (especially air and water) and ensure the safety of people and facilities. The CSTJF is the nerve center for more than 30 research projects in the areas of deepwater development, extra-heavy oils and oil sands, acid gases, carbonate reservoirs, deeply-buried reservoirs and unconventional gas.

Total's E&P research is driven by six other centers as well, five of which are outside France.

This network gives Total access to expertise available in other parts of the world concerning themes decisive for our growth (*in situ* mining of oil sands, deep offshore, carbonate reservoirs, environment and geosciences). Two of the centers are in North America (Canada and the United States), three in Europe (France, UK and Norway) and one in the Middle East (Qatar). The Lacq-based R&D hub Pôle d'Études et de Recherche de Lacq (PERL), recently joined Total's E&P research organization. Its 80 scientists specializing in physical chemistry, gas treatment and environmental science now take part in research on enhanced oil recovery and dispersants for pollution prevention in the context of the deep offshore.

The international scope of Total's R&D is further reflected in the more than 700 active partnerships with university research, national and international oil companies and other firms of varying sizes. With innovation being a driver of growth in Total's Exploration & Production activities, the Intellectual Property department is part of the R&D organization and dedicated to securing patent protection for Total's innovations. This portfolio, which has grown steadily since 2006, showcases the technological advances that Total has achieved and enhances our image of technological excellence.

Shale gas and coalbed methane are termed unconventional gas due to the atypical geographic locations

of the plays or the atypical geological characteristics of the reservoir rock. Producing these resources demands a specific set of stimulation and recovery techniques. Unconventional gas has game-changing potential for the replacement of global gas reserves. So after a decade of involvement in the development of tight gas reserves, Total recently invested in the production of shale gas and coalbed methane by forging alliances with companies having proven expertise in this field. Through one such partnership in Argentina, Total now holds interests in several permits to appraise shale gas potential. Drilling began in 2012.

Total is meeting the challenges of deepwater oil and gas production. Our facilities have been recovering

reserves under more than 1,500 meters of water for more than a decade. These bold operations are set to become even more complex going forward, as oil and gas will have to be transported over long subsea distances—in some cases, more than 100 kilometers. R&D teams are developing new architectures centered on subsea processing technology. In other words, the facilities for water treatment and injection, chemical storage and pumping, will be installed on the seabed. Also ahead is a shift to “all-electric” systems to replace hydraulic controls. These innovations will be the key to descending even deeper below the surface—to water depths of 3,500 meters—and producing even the most difficult fluids.

A further priority of R&D is Enhanced Oil Recovery (EOR), an umbrella term that encompasses several families of techniques aimed at improving recovery factors. Chemical EOR research is being carried out by Total’s Exploration & Production teams, including the Lacq-based R&D hub (PERL) and our subsidiary Total E&P Angola. This collaboration led to the development of the first polymer-viscosified water injection system designed to improve oil recovery factors in the deep offshore. Deploying the project on Angola’s deepwater Dalia field would increase its reserves by 3% over ten years.

Oil and gas will have to be

transported over long subsea distances—in some cases, more than 100 kilometers.

Meanwhile, other teams at the CSTJF have developed a solution for tapping many of the gas discoveries in Europe, Russia and the Middle East, most of which contain acid gases such as carbon dioxide and hydrogen sulfide as well as other sulfur-containing compounds (*i.e.,* mercaptans and carbon oxysulfide). HySWEET® technology, the fruit of several years of development, meets the challenges of simultaneously removing mercaptans and acid gases (including hydrogen sulfide); limiting co-absorption of hydrocarbons, and achieving energy gains compared to conventional sweetening technologies. HySWEET®, based on the use of a hybrid solvent, has been in industrial operation at Lacq (France) since 2008.

Another topic with significant implications for the future is CO_2 capture and geological storage. How can we limit our emissions of greenhouse gases, particularly carbon dioxide? Once we have separated the acid gas CO_2 from the natural gas (methane) stream, how can we dispose of it without simply venting it to the atmosphere? Moreover, with combustion being an indispensable part of oil production, how can we avoid emitting tons of additional CO_2 each year? These are compelling questions for the future of our planet.

One of the most promising solutions lies in capturing the CO_2 and storing it underground in geological formations. Once again, the CSTJF is on board: as early as 2007, its R&D teams began developing a pilot project unmatched in Europe at an industrial plant not far from the Lacq complex. The purpose of this project is to demonstrate the industrial feasibility of an end-to-end chain of CO_2 capture, transport and injection into a depleted underground natural gas reservoir.

CO_2 CAPTURE

An end-to-end CO_2 capture and storage chain equipped with a 30 thermal megawatt (MWth) oxyfuel combustion boiler was tested at Lacq in Europe's first integrated trial of this technology.

DISRUPTIVE TECHNOLOGY

All gas produced at Total's Lacq plant is now being treated using the HySWEET® process for acid gas sweetening. This technology combines the chemical action of an amine compound with the physical properties of a co-solvent to allow simultaneous absorption of CO_2, H_2S and other sulfur compounds (*e.g.,* mercaptans and carbon oxysulfide). HySWEET® also shows energy gains of 10 to 20% compared to conventional techniques. The first commercial license for this game-changing innovation was issued in 2010 for a unit due to come on stream in 2013. This will allow pursuit of the thiochemicals (sulfur-based chemicals) business in the Lacq region.

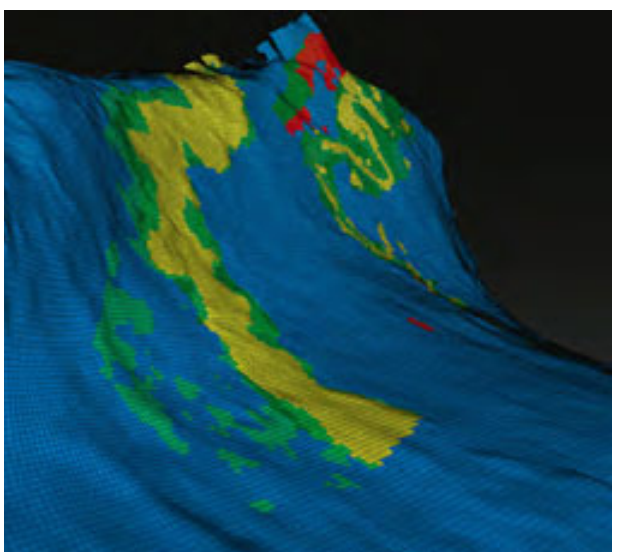

VD29

EXTRA-HEAVY OIL

The gigantic PetroCedeño project is the fruit of the CSTJF's research on the recovery and upgrading of extra-heavy oil. Large-scale production of these unconventional oils and conversion to a light synthetic crude began in Venezuela in 2002. R&D teams at the CSTJF and the Lacq-based R&D hub (PERL) are currently developing an enhanced oil recovery technique based on injecting water and polymer into the reservoir; this could potentially double the recovery factor of the PetroCedeño field.

DALIA

The Dalia field is the site of the world's first pilot study of deepwater polymer injection (polymer-viscosified water) aimed at improving recovery factors.



ONGOING INNOVATION

Advances in seismic imaging now allow geophysicists to "see" things that were invisible barely a decade ago. For example, the CSTJF developed new calculation codes for seismic depth imaging that have shed light on salt structures impervious to more conventional imaging. Here, a reservoir grid deformed by salt movements.

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