



Platform P-34 and the oil tanker, above, in the Campos basin

PETROLEUM INDUSTRY

Marine

Exploiting oil and gas beneath the sea's salt layer creates demand for knowledge and technology | MARCOS DE OLIVEIRA

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A SET OF ROOMS IN THE MECHANICAL ENGINEERING BUILDING OF THE POLITÉCNICA SCHOOL OF ENGINEERING OF THE UNIVERSITY OF SÃO PAULO (POLI/USP), IN THE SÃO PAULO STATE CAPITAL, is the source of some of the solutions that will enable the transportation of natural gas from the depths of the pre-salt layer in the Santos basin, the new oil reserves that Petrobras confirmed in late 2007. The team of professor Kazuo Nishimoto, coordinator of the Numeric Proofs Tank (NPT), a lab specializing in hydrodynamics and comprised of groups or clusters of computers, is developing systems that will simulate the future transportation of the natural gas from the platforms to the ships, one of the alternatives that Petrobras is considering to carry this type of mineral resource. The other alternative would be to lay large pipelines along the bottom of the sea, but this would be expensive and hard to do, requiring very large diameter pipes and a very long distance within a marine environment. The gas, which goes hand in hand with oil, will have to be converted into liquid right on the oil platform in order to make it easier to carry, in a ship specially adapted to carry liquid gas. This would be a system that would have to work properly out on the high seas, more than 300 kilometers away from the coast, in a hostile environment, in the midst of strong waves and winds, and at a depth, from the surface to the sea floor, of 2,200 to 3,000 meters, the so-called water sheet, an element that makes it difficult to anchor and to stabilize the *risers* (pipelines attached to equipment on the sea floor that carry oil and gas to the platform on the surface).

“Nowhere in the world is there a working system out at sea to turn the gas into a liquid. In this state, the LPG (liquefied petroleum gas) must be kept at a low temperature in a cryogenic and low pressure environment. The entire system

and pipeline for transferring the gas from the platform to the ship must be at a temperature of -120° to -160° Celsius (C). The tank must also be chilled. The problem is that metal, when it is very cold, can become fragile and crack,” says Nishimoto, from the Naval and Oceanic Engineering Department of Poli/USP. Yet another challenge is how to perform this transfer under critical circumstances, with the movement of the ocean and of the platforms, which may be semi-submersible or consist of an anchored tanker, know as FPSO units (for Floating, Production, Storage and Offloading) as well as the movement of the LPG ship, which will behave differently depending on whether its tanks are full or empty.

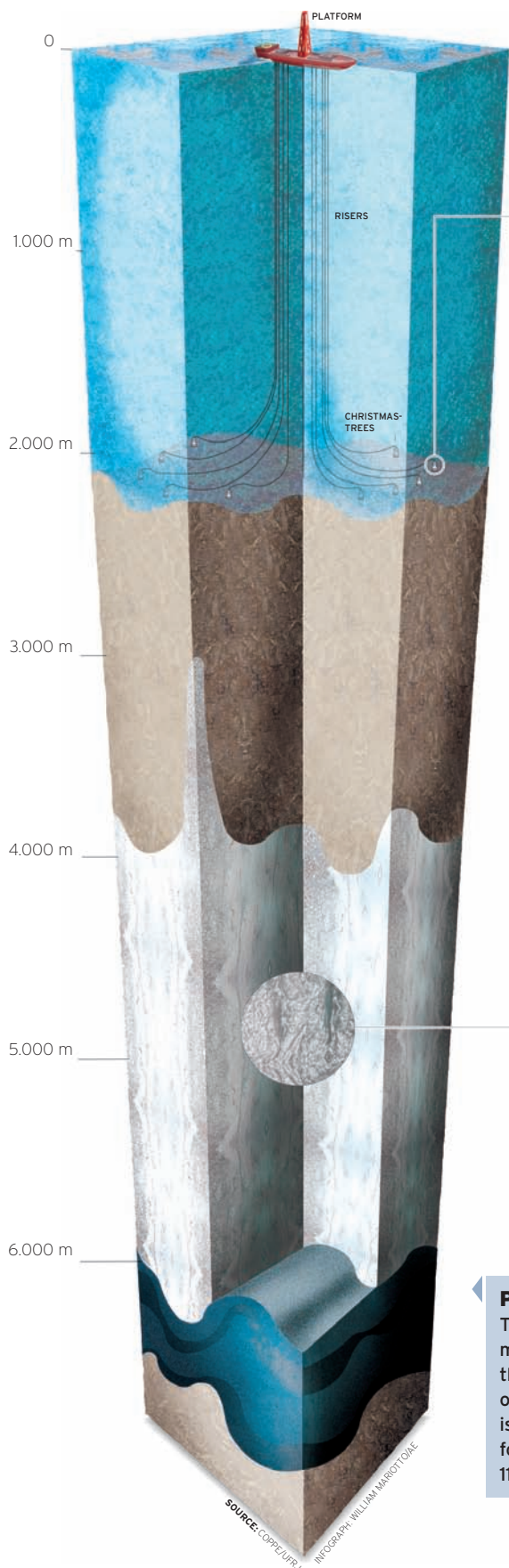
The NPT, which is part of the Petrobras systems development group, produces calculations and simulates situations about these future events, taking into account the marine environment and the equipment's several variables. It was set up in 2002 with funds from Petrobras and from Finep, the Studies and Project Financing Agency of the Ministry of Science and Technology. It also includes researchers from Coppe, the Coordination Center of Post-graduate Engineering Programs at the Federal University of Rio de Janeiro (UFRJ); from Tecgraf, the Technology and Graphic Computing Group of the Pontifical Catholic University

challenges

Layers of water, soil and salt

Water sheet
It lies between the surface and the sea floor. It poses the first challenge that must be overcome. Today, Petrobras drills 1.8 km beneath the surface. In the Santos basin, the depth may be as much as 3 km

Saline crust
Formed approximately 113 million years ago, during a great evaporation of the ocean. It is solid and contains rocks called tachyrite, halite and carnalite.



The oil is at depths in excess of six kilometers. Teams of researchers from Petrobras, academia and suppliers study the difficulties involved in drilling and extracting gas and oil



Known as Christmas-trees, the valves that hold the tubes at the beginning of the well will have to be stronger

Post-salt layer
Sedimentary rocks formed from sediments such as calcareous rocks and sandstone from the column under the salt, more than 2 km long. In the Campos basin the oil is in this layer.

Saline danger
When drilling a well in this layer, there is a risk of it caving in. Therefore, the teams must put the lining in place very quickly

Pre-salt layer
The oil and gas are mixed within the pores of the carbonaceous rocks of which this column is comprised that were formed more than 115 million years ago

of Rio de Janeiro (PUC/USP); and from the State University of Campinas (Unicamp), the Federal University of Alagoas (Ufal) and the Technological Research Institute (IPT).

Making use of the natural gas is one of the technological challenges that Petrobras and the other companies involved in exploiting these reserves face, along with their partners in academia or suppliers. All are seeking solutions for the production, extraction and transportation of the oil and gas, under unprecedented circumstances, with oil fields beneath the salt layer, a set of solid rocks some two kilometers thick. The salt layer functions as a natural sealant for the oil and gas formed beneath it by the so-called carbonate rocks at a depth of five to seven thousand meters.

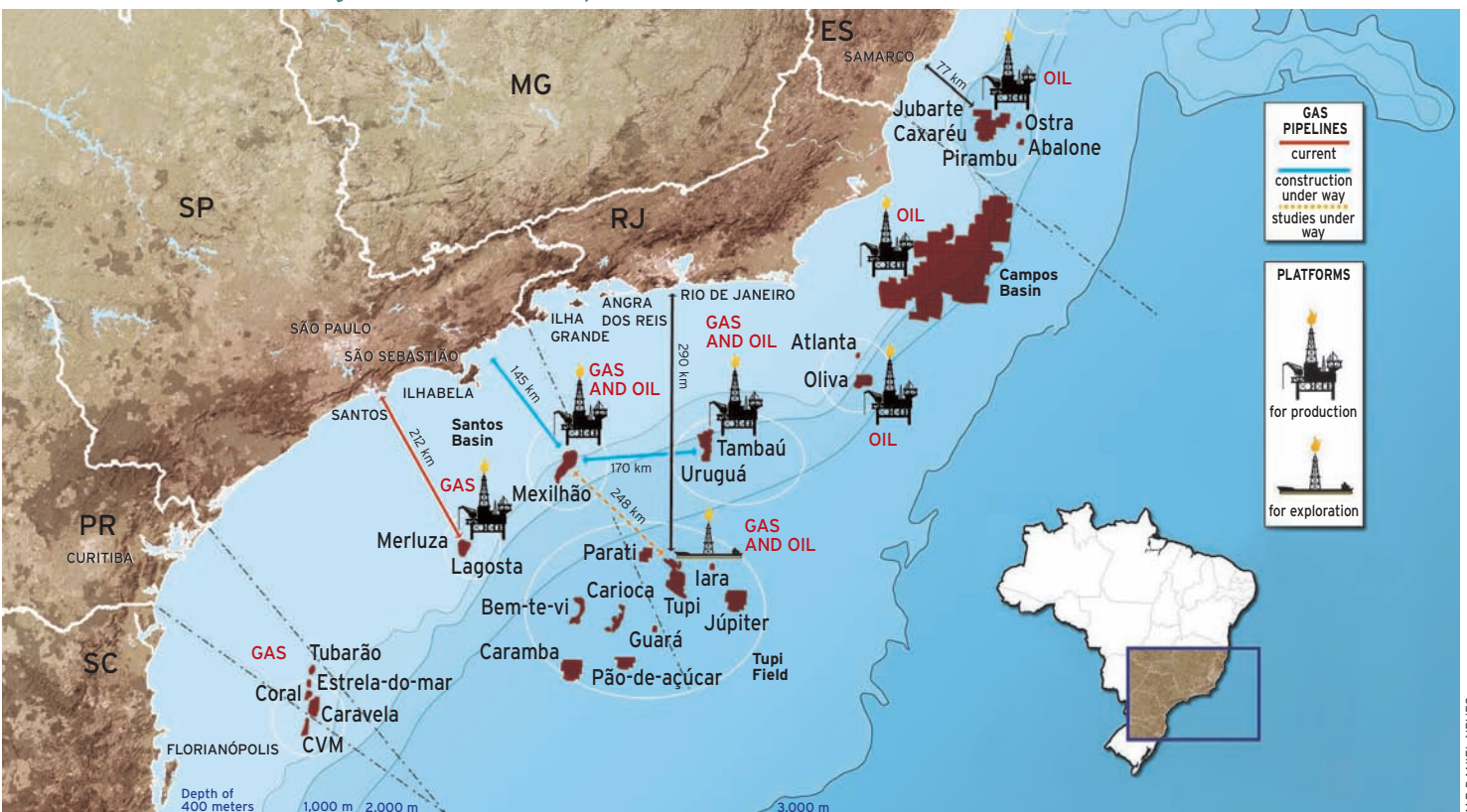
Though a leader of deep-sea oil exploitation, with commercial wells 1,800 meters below the surface of the water, Petrobras is checking the reserves of new wells and the volumes that will be

commercially viable in the region that extends from the coast of the state of Espírito Santo to the coast of the state of Santa Catarina. It is also checking on the technology required to extract gas and oil under extreme circumstances and to carry them to the refineries and gas distributors. To this end, it established Prosal, the Technological Program for the Development of the Production of the Pre-Salt Reserves. With 23 projects in different fields, such as well engineering, reservoir engineering, and gas and oil flow assurance, the company releases information that is veiled in secrecy. "Many details are still being kept under lock and key," says Osvalir Trevisan, the director of Cepetro, Unicamp's Petroleum Studies Center. "The company is defining the treatment, the standards and the parameters for engineering and production, but we estimate that there will be no major technological barriers facing the exploitation of the pre-salt layer," says Trevisan, formerly the exploration superintendent of ANP, Brazil's National Petroleum Agency.

The confidentiality that surrounds the more technical details, which even extends to the scientific community working with Petrobras, is probably connected to decisions about the paths that the exploration of the pre-salt reserves will take within the economic context, because the country may see a growth of its oil reserves from the current 14 billion barrels to 50 billion barrels or even more. Fields such as Tupi and Iara, in the Santos basin, have already yielded some 9 to 12 billion barrels in terms of reserves. The discoveries, whose initial indicators of excellent quality oil have been confirmed and which should be capable of providing a higher grade of petrochemical products, still need to be quantified more precisely. In any event, they may very well elevate Brazil to the level of one of the world's ten major oil producers. At present, it ranks 24th. The natural gas prospects that the company has announced just in connection with the Tupi field, in the Santos basin, in the pre-salt area, indicate the availability of some 176 billion to 256 billion cubic

The wells

The main oil and gas wells in the Campos and Santos basins



MAP DANIEL NEVES



LPG tanker: a possible solution for the Tupi field

PETROBRAS

strike a balance,” explained geologist Cristiano Sombra, the Prosal coordinator. Because of its many unprecedented aspects and the care required - all of which involves a lot of engineering studies, the coordination of Cenpes (Petrobras Research Center), and the exploration and perforation areas, both from the company - the cost of drilling the first well was US\$ 240 million. All in all, Petrobras has spent US\$ 1.7 billion on 15 wells. The next well perforations are expected to drop to US\$ 60 million. “In Campos, in the post-salt wells, the cost is US\$15 million at most,” says professor Bacoccoli.

One of the challenges that seems to have been partially solved where exploration in ultra-deep waters is concerned are the *risers*, the flexible pipes that

carry oil and gas from the well to the platform. “The *risers* for operations at depths greater than 2,500 meters are in their final stages of development and approval,” says professor Celso Pesce, from the Mechanical Engineering Department of Poli/USP. “The new ones will be useful regardless of whether exploration is taking place in the pre-salt environment or not,” he says. Together with other researchers from Poli/USP, Pesce is studying the structural and mechanical behavior of the *risers*, in projects carried out in conjunction with Petrobras and the companies that manufacture these artifacts, with financing provided by FAPESP, Finep and CNPq (the National Scientific and Technological Development Council), including rise behavior at great depths. The studies involve the relation between the movement of the floating units that are subject to the effects of winds and waves, and the transmission of these stresses to the pipes, which vibrate with the current. How to keep these structures in operation, in waters more than three thousand meters deep and how to ensure they do not suffer mechanical fatigue are some of the factors being studied at Poli/USP.

Pesce indicates another challenge for the *risers* to be used in the pre-salt environment. “The temperature of the extracted oil will range from 60° C to 70° C, with very high internal pressure.

meters, almost equal to the current reserves of 330 billion cubic meters, most of which in wells that are yet to go into production. Brazil still imports 60 million cubic meters of gas, half of which comes from Bolivia.

The viability of commercial exploitation and the true reserves can only be established through long term trials, which, in connection with the Tupi reserves, should take a year and a half, starting in March 2009. Only then, in the second half of 2010, can the pilot production system go into action. Once everything has been proven and adjusted, one will get to the production stage, which should occur through new platforms that will be in operation around 2013 and 2014, each of which will initially produce 100 thousand barrels of oil a day and 5 million cubic meters of gas a day.

One of the challenges of exploiting the new fields is drilling the salt layer, because it can become deformed and cause the perforation column to collapse. “One must monitor it every hour,” says Nishimoto. “That is why each well must have an experimental numerical model made by computer programs reproducing the conditions of the sea and the soil, and calculating the dynamics of the ships and platforms.” This is one of the functions of the professionals from the perforation area of Petrobras, with the aid re-

search institutions such as IPT and USP. “The institutions often get e-mails from personnel on the drilling platforms in the Santos basin to prepare calculation forecasts.” Everything is done very carefully because the salt not only cracks easily, but it is also necessary preserve the well and make it permanent, ensuring the drill bits are not trapped. “Drilling through salt isn’t hard, the problem is the dislocation that can happen, blocking the well,” says professor Giuseppe Bacoccoli, from the CoppeUFRJ area of oil and gas and a former Petrobras employee. Containing the slide is a particularly difficult mission in a type of saline rock called tachydrite. Two other kinds are called halite and carnalite, both of which are stronger. Therefore, the exploration teams have to be quick about preserving the well and recovering the drill bits, which are often lost in the exploration of the pre-salt layer in the Santos basin.

Cement and steel - When drilling through a terrain it is necessary to line the well with steel and to fill in the space between this lining and the rock with a special type of cement. Despite these measures, the salt pressure can deform the steel. To avoid this, the company is studying the use of sturdier materials. “If the steel or the lining is too heavy, the drill’s capacity to lower these materials along the well may be harmed. One must

The tube's external layer, in contact with the water of the bottom of the sea, is far colder, with temperatures around 4° C. But loss of heat encourages the formation of paraffin that obstructs the duct. This also happens with wells in the post-salt environment. The solution currently used is to remove the paraffin from the inside of the tube with a piece of equipment called a pig, which works as an unblocker. "One must develop new concepts for the pipes, with thermal control or isolation that can avoid the formation of paraffin," says Pesce, who is involved with the Network of Submarine Structures, one of the 40 networks that Petrobras maintains with dozens of research institutions in Brazil.

Corrosion is another issue that the engineers will have to face in order to drill wells six or seven meters below the surface. "The tubes and valves on the sea floor, the so-called Christmas trees, will have to be stronger because in that environment there's a lot of carbon dioxide (CO₂) and sulfur," says professor Nishimoto. "These components, coupled with the chemical aggressiveness and structural instability of the salt are unusual for Petrobras," says professor Trevisan, from Unicamp.

Positions available - The multiple challenges will most likely require a lot of personnel. The figures are still unclear, but the areas are already defined. "Professionals will be needed in the metal-mechanical industry area, in the petroleum chemistry area, and in logistics and services, for instance," says Trevisan. The universities' and the research institutions' recent graduates will continue to be sought after. "During the course of more than 20 years, Cepetro has produced more than 300 Masters and PhDs who went to work for Petrobras." Equally significant figures appear at the Federal University of Rio Grande do Sul, at UFRJ, at USP and at Paulista State University (Unesp), where the building of Unespetro has started in the Rio Claro campus. This will be a teaching and research complex focusing on the oil industry, in particular on geology and the environment. The initial investment in construction plus equipment purchase is R\$ 5 million, entirely shouldered by Petrobras. In a

building of 1,600 sq. m there will be a Sedimentary Geology Center (CGS) and a Center of Excellence for Organic Petrology (Nopec). "Petrobras contacted Unesp in May 2007 after deciding to establish in Brazil a center of research into carbonaceous rocks, those that are found in the pre-salt layer and that hold the newly discovered oil and gas," explains professor Dimas Dias Brito, from the Department of Applied Geology of the Institute of Geosciences and Exact Sciences and the man in charge of the Unespetro project. "The Rio Claro geology course is almost 40 years old and

several of our faculty members, myself included, have worked for Petrobras," tells us Dias Brito. Petrobras investments have already enabled 18 geologists from the company to hold a six-month course at Unesp, this year, about carbonaceous rocks. "At the center, we will study all types of calcareous rocks from the Brazilian Atlantic coast, from the pre-salt to the post-salt layers. The geological challenges are huge and spectacular. At present, Brazilian geologists, represented by their Petrobras colleagues, are experiencing a magical moment," concludes Dias Brito. ■

Old history

An interesting combination of geological and climate factors formed, by sheer accident, the oil and gas found beneath the sea, under a layer of salt in the south-southeast coast, covered by deep waters and far away from the coast. The reserves are held within carbonaceous rocks formed by Cyanobacteria (blue-green algae) millions of years ago. When the super-continent of Gondwana broke apart, resulting in South America and Africa, lakes were formed there between 145 million and 113 million year ago. Soon thereafter an invasion of sea water occurred. The bacteria then started to interact and to grow within the shallow newly-formed carbonaceous ecosystem, which had a high temperature and high salt content. This microbial action generated calcareous packages, which later became the 'hosts' of the oil created by the transformation of the organic matter from plankton, a type of microorganism that lives in water and that had accumulated in the former lakes. Thus, during the course of millions of year, the progressive covering of the lacustrine rocks heated and put pressure on this matter, which turned into hydrocarbons (gas and oil), later expelled toward the carbonaceous rocks, in which they were trapped.

"The thick layer of salt rock, which is impermeable and hundreds of meters deep and which worked as a

shield and kept the oil from migrating to the post-salt rocks, was formed during a short geological period of only about 500 thousand years, possibly between 113 and 112 million years ago, when a great evaporation of the primitive young ocean took place," explains professor Dimas Dias Brito from Unesp. The layer of salt can also be found in other regions, and even on land, for instance, in the town of Carmópolis, in the state of Sergipe, where Petrobras pumps oil from several wells. "Even the oil of the Campos basin (which has been pumped since the 1970s) originated in the pre-salt layers. It consists of hydrocarbons that escaped into higher ground, calcareous rocks and sandstone, through gaps in the salt layer, in areas in which the sea was shallower, where the layer is thinner. Thus, most of Brazil's oil comes from the former lakes that preceded the South Atlantic." He recalls that the pre-salt carbonaceous reserves, like the others, are not huge cavities filled with oil. Both the oil and the gas are within rock layers that have interconnected pores.

Although he lacks further details about the new oil fields, Dias Brito reminds us that these carbonaceous formations with cyanobacteria are unique in the world, because the other calcareous formation that exist, though also associated with oil, had different origins.