# Main Challenges and Uncertainties for Oil Production from Turbidite Reservoirs in Deep Water Campos Basin, Brazil*

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Search and Discovery Article #10184 (2009)
Posted May 12, 2009

*Adapted from oral presentation at AAPG International Conference and Exhibition, Cape Town, South Africa, October 26-29, 2008

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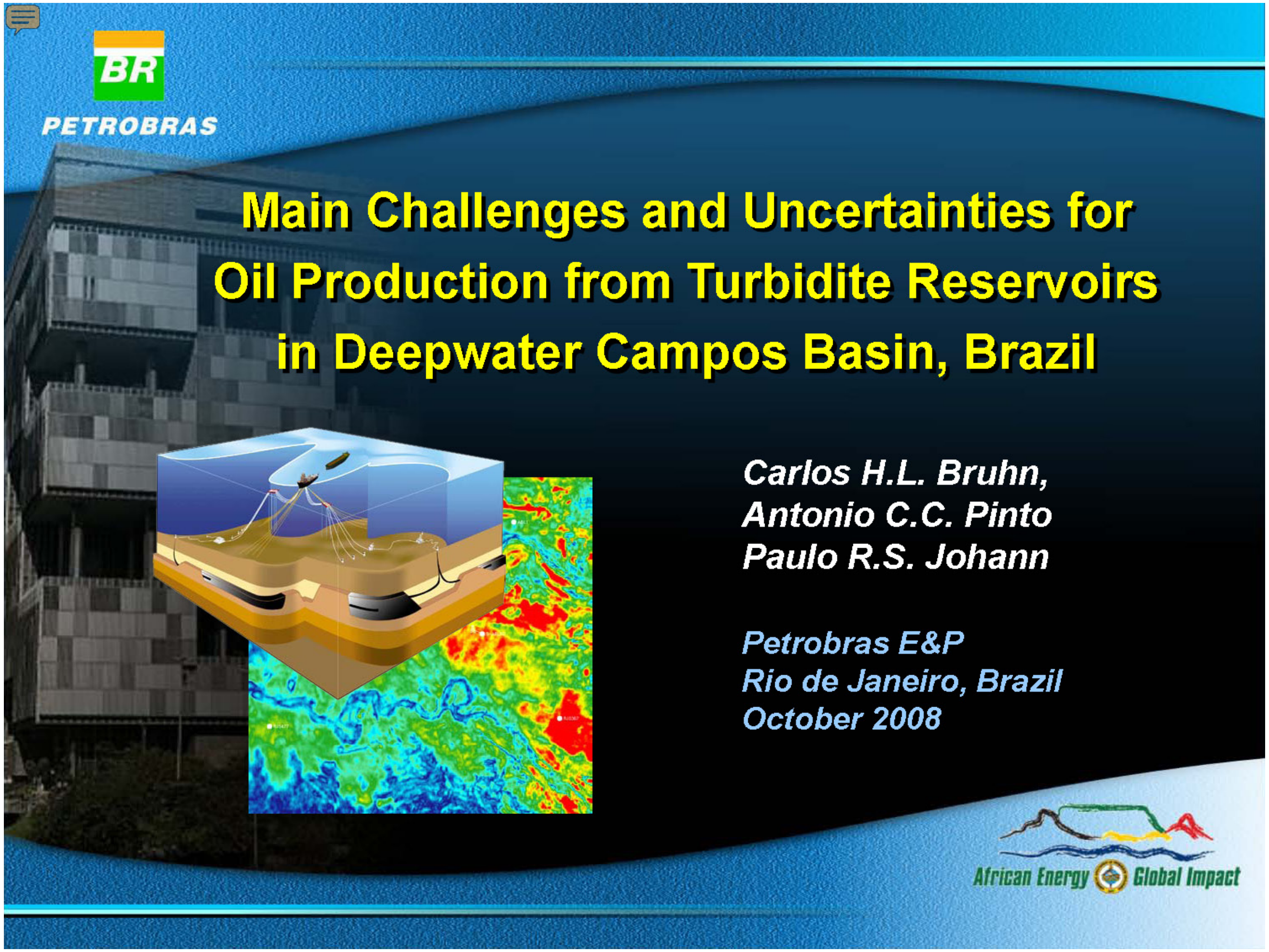
## Abstract

Deep and ultra-deep water giant fields were initially discovered in the Campos Basin in 1984. There was a succession of large discoveries, such as Albacora, Marlim, Albacora East, Marlim East, Marlim South, Barracuda, Caratinga, Roncador, Jubarte, and Papa Terra. The development of these fields has continuously provided new challenges for the reservoir characterization and management. These fields are developed with fewer horizontal and high angle wells drilled into poorly consolidated reservoirs. The extensive use of 3D seismic as a reservoir characterization tool has optimized well location and allowed the reduction of geological risks. Integration of high-resolution stratigraphic analysis with 3D seismic inversion, geostatistic simulation of reservoir properties constrained by seismic, well log and core data, and 3D visualization has guided the positioning of horizontal wells through thin (<10-15 m) reservoirs. Additionally, 4D seismic have provided a new tool for reservoir management, where seismic, well logs, cores, and pressure/production data are integrated into much more detailed and robust geological and fluid flow models.

The deepwater subsea wells must be designed to allow high production rates (typically >10,000-20,000 bopd). In order to assure high productivity, pressure maintenance must be efficient; if water injection is planned, the hydraulic connectivity between injector and producer wells must be guaranteed by high-quality 3D seismic, well log correlation, and observed pressure profiles. Detailed studies have been made in order to define the distribution and number of wells, since the number of wells strongly affects the net present value of deepwater projects. Wells with expected oil recovery of less than 10-20 million bbl are not drilled in the beginning of the projects and remain as future opportunities to increase oil production and recovery.




Notes by Presenter:
The first oil discovery in the Campos Basin, offshore Brazil, dates from 1974, and the oil production started in 1977. That was the beginning of a successful history that led Petrobras to become a world leader company in petroleum exploration and production in deep waters. It is my intention to present you today a brief overview of the
main technological challenges and uncertainties involved in the development of the important deepwater fields discovered in the Campos Basin, after the mid 1980's.

# Presentation Outline

1. Introduction: the importance of deepwater fields in Brazil
2. Main characteristics of turbidite reservoirs from deepwater Campos Basin
3. Major technological challenges for developing deepwater fields
4. Conclusions

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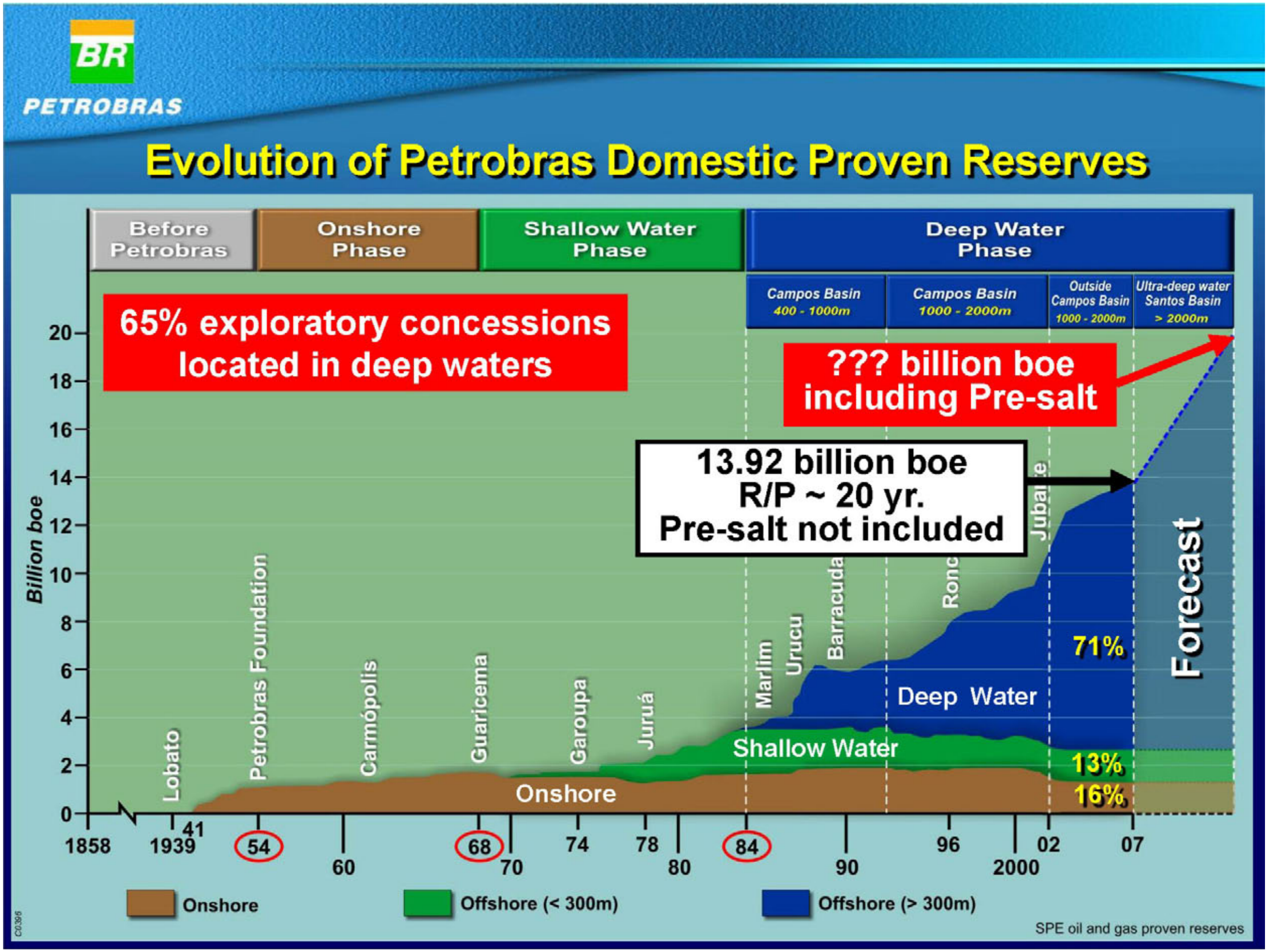
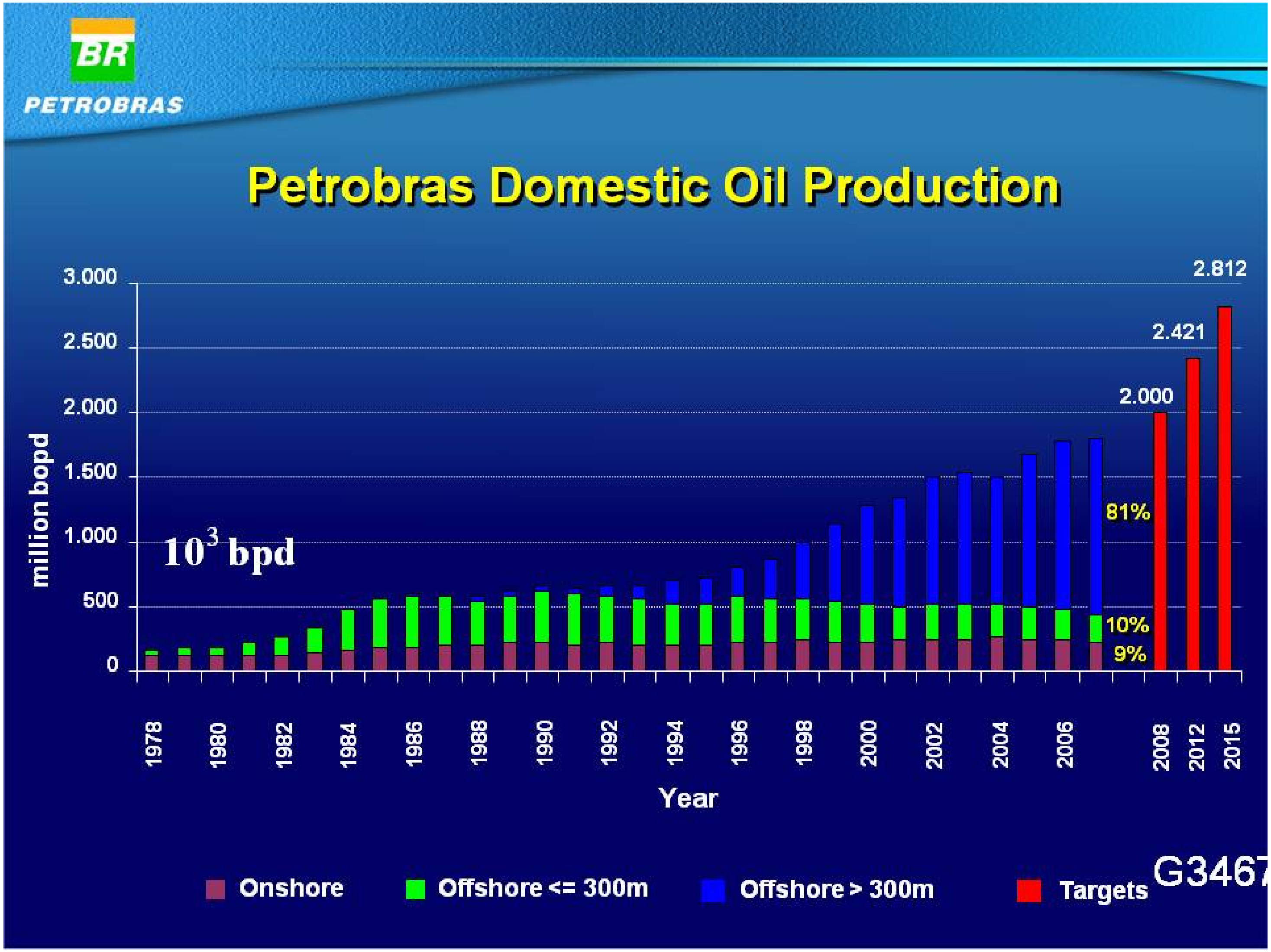



Notes by Presenter:

This diagram shows the evolution of the Petrobras domestic proven reserves. We can see in the last 20 years a remarkable increase in deepwater reserves, which comprise 71% of total proven reserves. In a near future they will be even more important because of recent pre-salt findings and because 65% of Petrobras exploratory areas are located in deep waters.




Notes by Presenter:

In terms of oil production, we can see similar trends, with deep water fields being responsible for 81% of the current Brazilian oil production of about 1.9 million bopd, which is expected to reach 2.8 million bopd by the year 2015.

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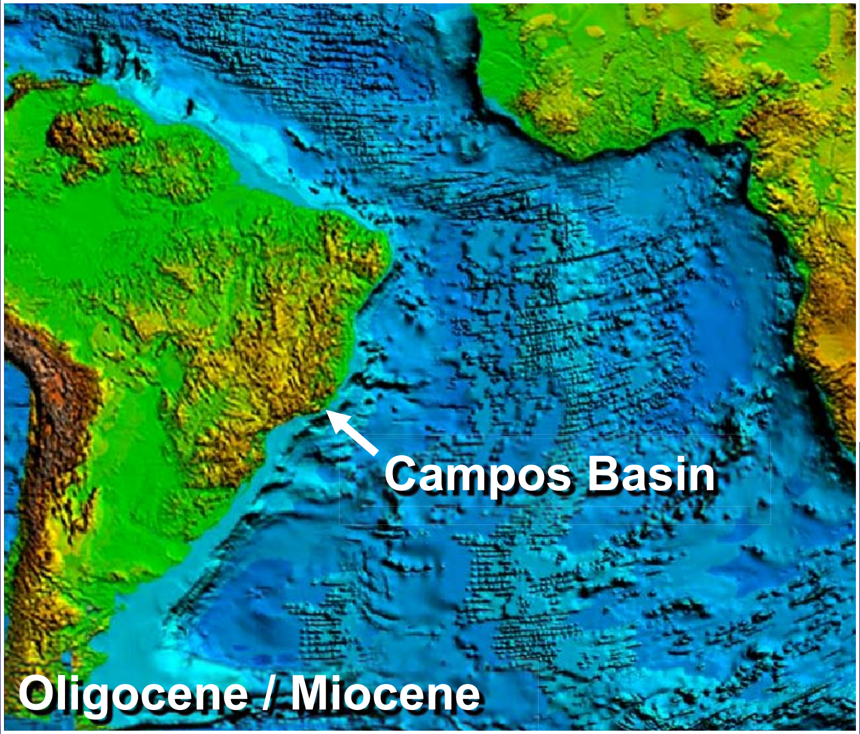
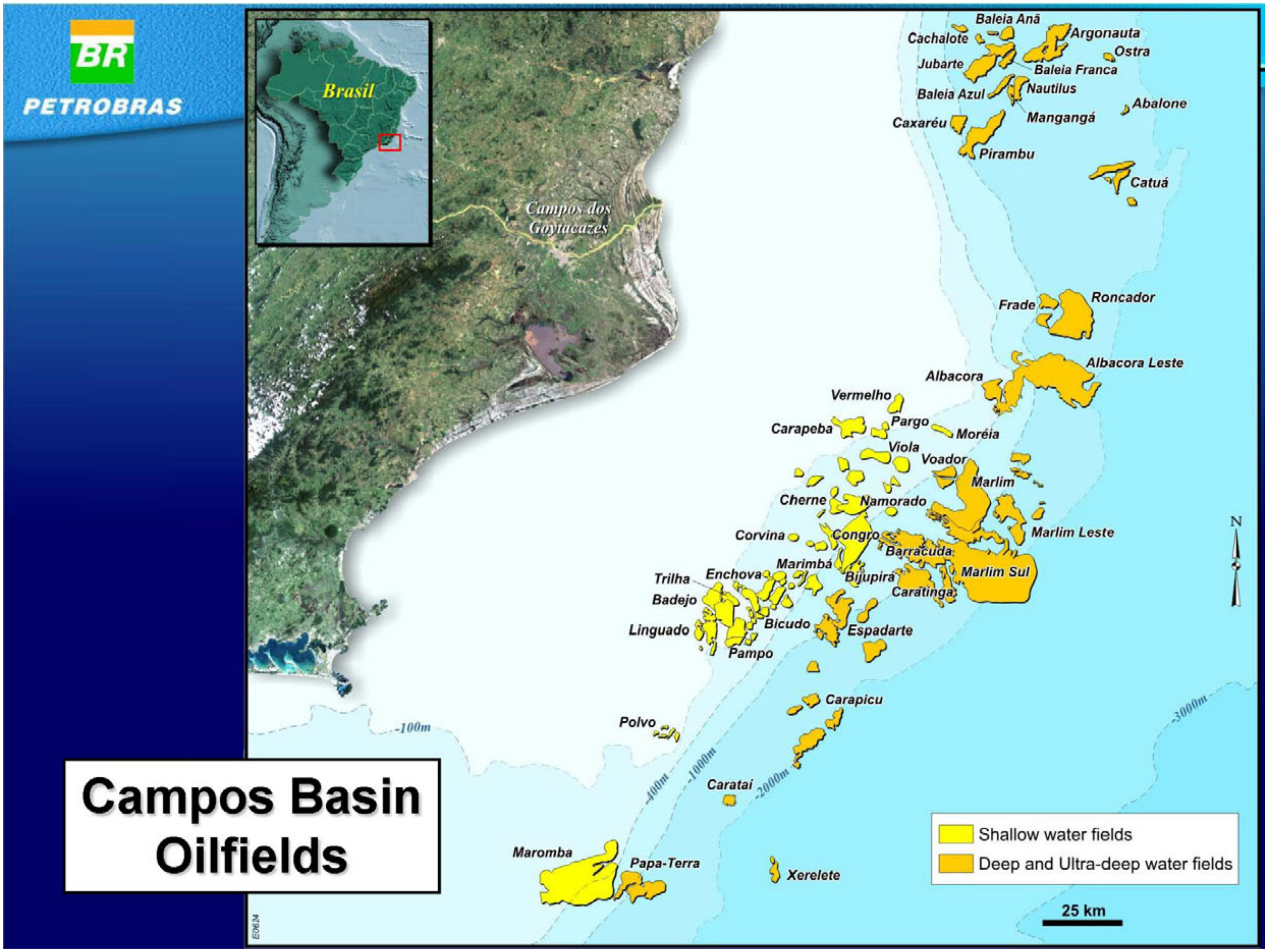
Notes by Presenter:
On the right we see a location map for the main Brazilian sedimentary basins. Those with petroleum-bearing turbidites are highlighted in dark yellow, including the Campos. The origin of the very prolific Campos Basin is related to the Neocomian breakup of Gondwana, the following separation between Brazil and Africa, and the opening of the South Atlantic Ocean. On the left we see the position of the Campos Basin during the Oligocene/Miocene, a period of time when giant turbidite reservoirs were developed.

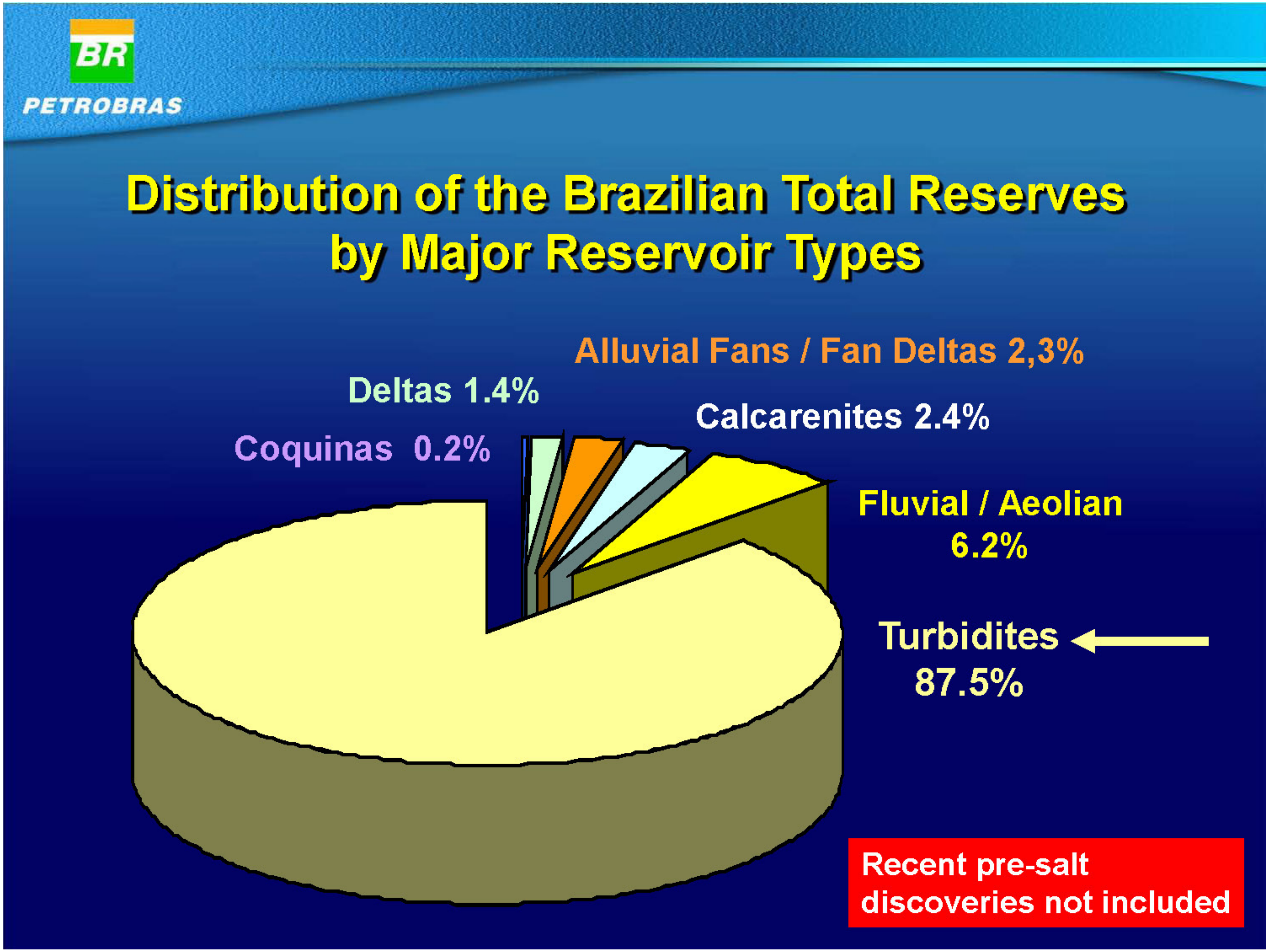




# Campos Basin Location




Notes by Presenter:

This is a location map for the Campos Basin oilfields. Fifty-eight oilfields were found between 50 and 140 km off the Brazilian coast, under water depths up to 2,400 m. These fields produce from a variety of reservoirs, including Neocomian fractured basalts, Barremian coquinas, early Albian calcarenites, and (mostly) late Albian to early Miocene siliciclastic turbidites. There are 28 deep water fields, which are highlighted in orange.




Notes by Presenter:
Here we see the distribution of the Brazilian total reserves, according to the major reservoir types. Turbidites are, by far, the most important reservoirs. They comprise reservoirs in 650 production zones, including those of giant fields such as Marlim and Roncador, which contain, individually, original oil reserves of over 3 billion bbl.

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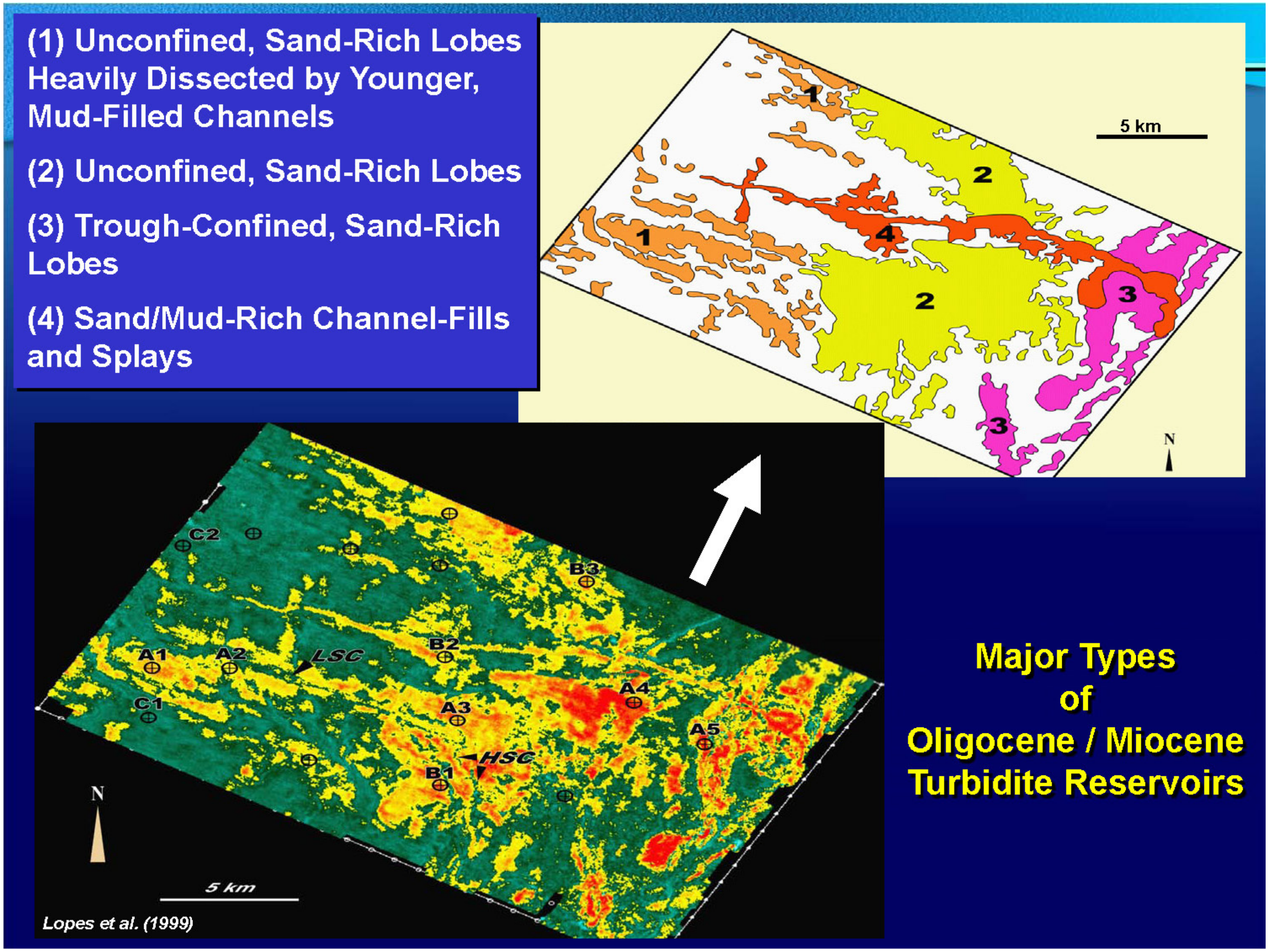
# Deepwater turbidite reservoirs comprise different types and can be very complex and heterogeneous ...

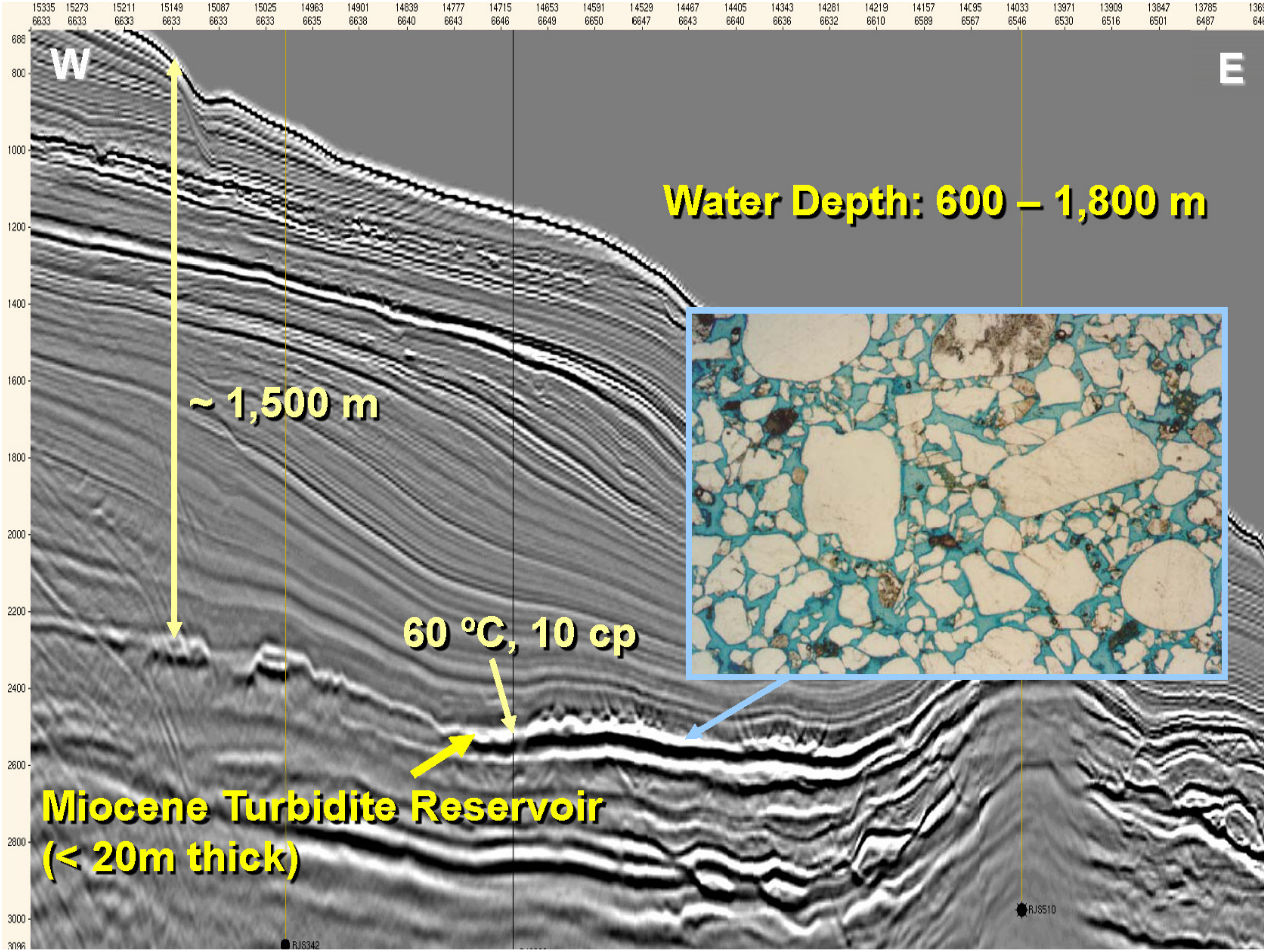
Notes by Presenter:

Detailed studies of the Campos Basin turbidites have been developed over the last 30 years. These studies have shown that deepwater turbidite reservoirs comprise different types and can be very complex and heterogeneous.

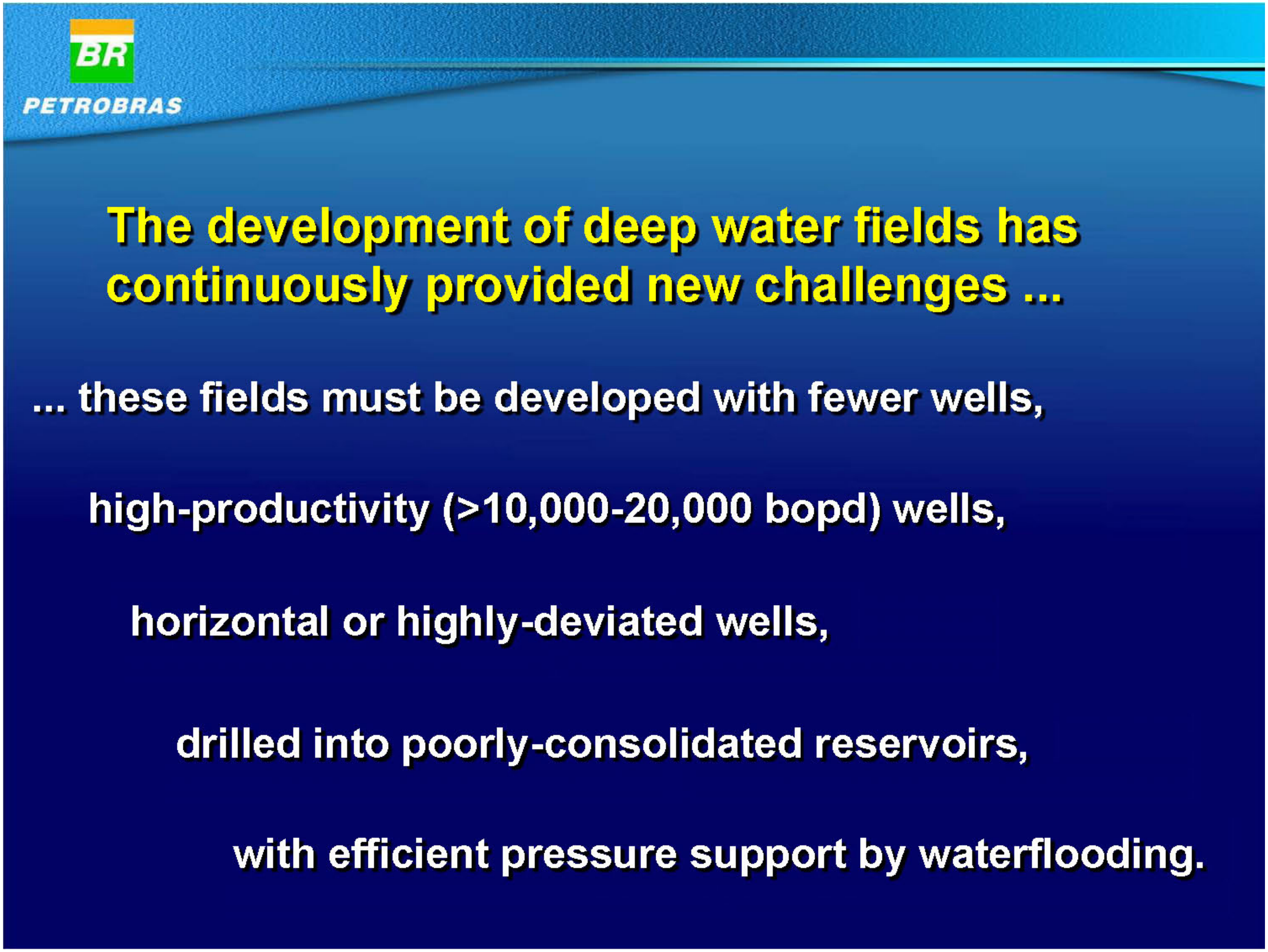



Notes by Presenter:

Here there is an example of the variability and complexity of the Campos Basin turbidite reservoirs. On the left we have the seismic amplitude map for some of the reservoirs from the Marlim Sul and Barracuda fields. Red and orange indicate thicker sandstone successions. Four major reservoir types are highlighted on the right: (1) unconfined, sand-rich lobes heavily dissected and compartmentalized by younger, mud-filled channels, (2) unconfined, sand-rich lobes, (3) trough-confined, sand-rich lobes, and (4) sand/mudrich channel-fills and splays.




Notes by Presenter:
This is typical seismic profile for deep water reservoirs. This white horizon represents a less than 20 m thick, Miocene turbidite reservoir. Deep water reservoirs may present a large variation in water depth, burial depth, temperature, and, therefore, oil quality. They are typically poorly-consolidated sandstones, how we see in this section, where grains appear in white, and porosity in blue.




Notes by Presenter:
The development of the deep water fields from the Campos Basin has continuously provided new challenges for the reservoir characterization and management in the Campos Basin, particularly because these fields must be developed with fewer wells, with high production rates to be economic (typically over 10,000 or 20,000 bopd), these wells are horizontal or highly-deviated, drilled into poorly consolidated reservoirs, which must have an efficient pressure support provided by waterflooding.

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# Major Technological Challenges for Developing Deepwater Fields

→ Seismic imaging of complex, thin (<10-20 m) reservoirs.

→ 4D seismic interpretation and integration with the fluid flow simulator.

→ Reservoir characterization and management under uncertainties.

→ Water management.

→ Improved recovery techniques for heavy and viscous oil.

Notes by Presenter:
Now, I am going to show you some of the main technological challenges faced by Petrobras to develop Campos Basin deepwater fields. The real list is much longer than this, but I sure we have here a quite representative set of technological challenges that have been at least partially solved over the years.

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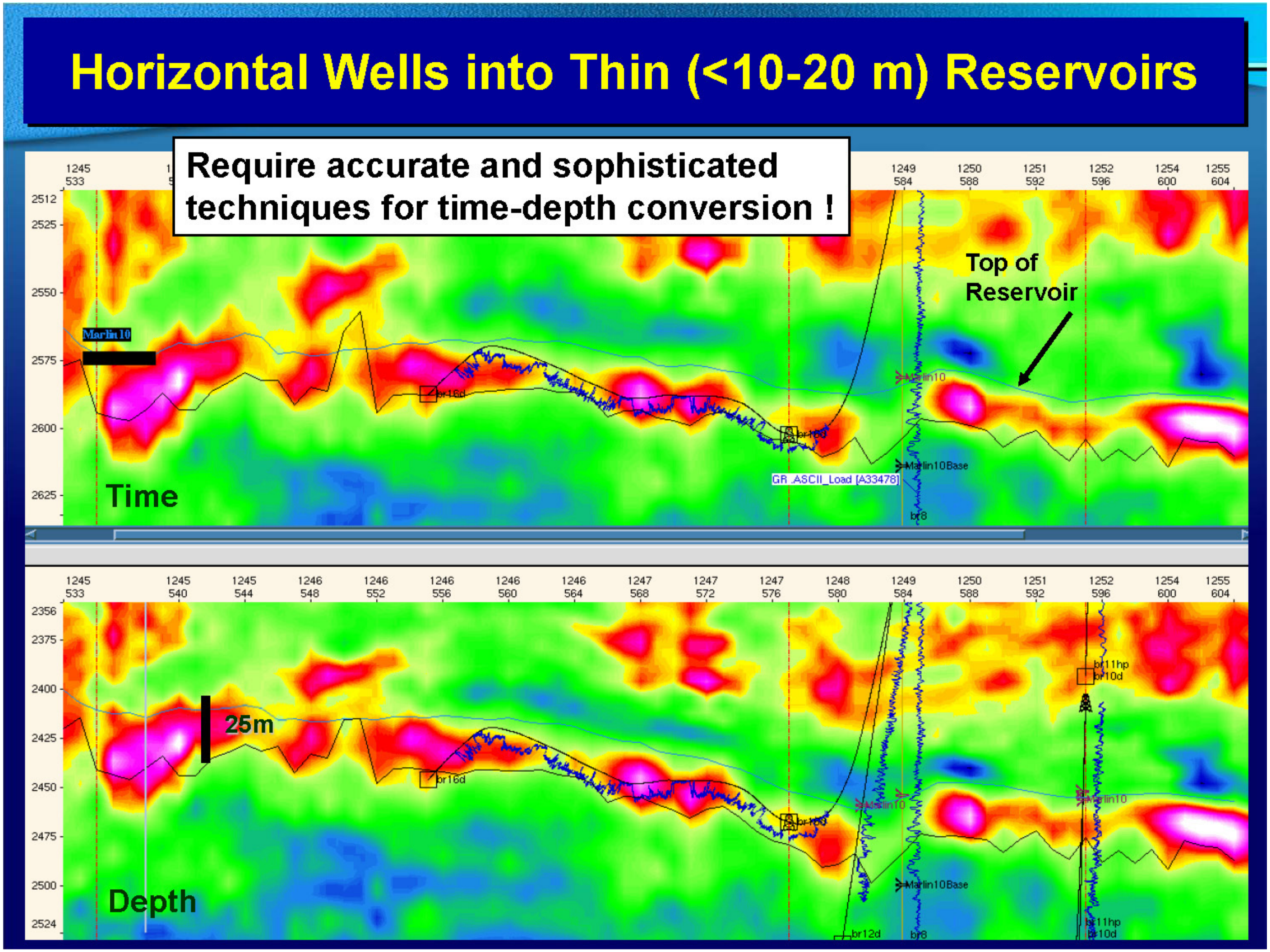


Notes by Presenter:
The extensive use of 3D seismic as a reservoir characterization tool has optimized well location and allowed the reduction of geological risks. Here we have seismic impedance sections, both in time and depth, for some of the reservoirs from the Barracuda Field. Purple and red indicate higher NTG ratio. The accurate time-depth conversion is essential to guide the drilling of long horizontal wells into sand-rich, but thin reservoirs (mostly under 10 m-thick).

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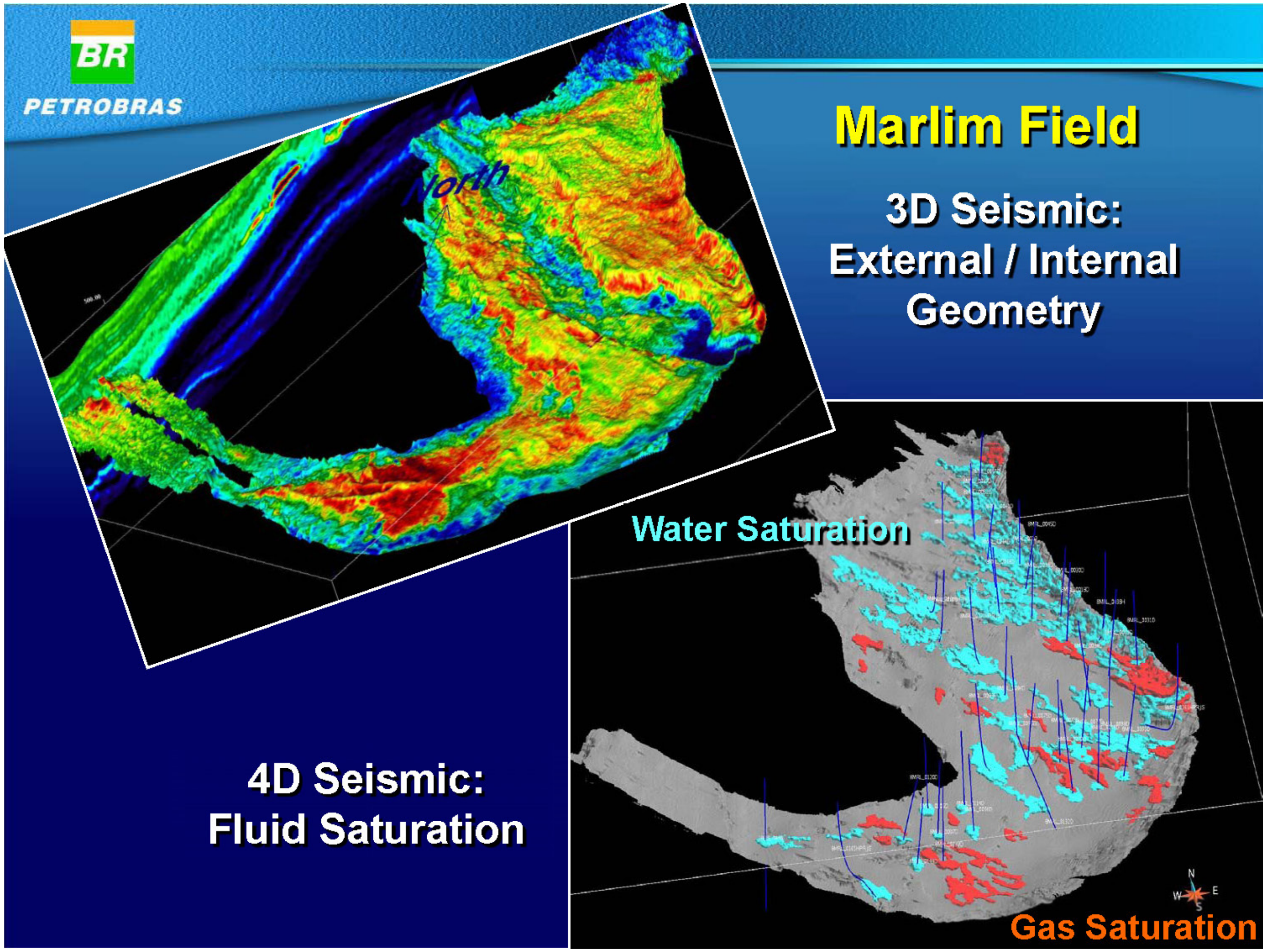


Notes by Presenter:
4D seismic is a very important tool for reservoir characterization and management, supporting several activities such as ...
location of undrained oil and gas,
monitoring of water and gas injection,
natural water influx, and gas cap formation,
mapping of reservoir heterogeneities and fault compartments,
location of new, infill drilling wells, and
improvement in the production history matching.

We have here one example from Marlim Field: on the left, 3D seismic used for mapping the external geometry, and, at some extent, the internal geometry of this reservoir, which was partially eroded by a younger turbidite channel; on the right, 4D seismic used for mapping water and gas saturation. Blue areas indicate more efficient waterflooding, and red areas show the development of secondary gas caps.

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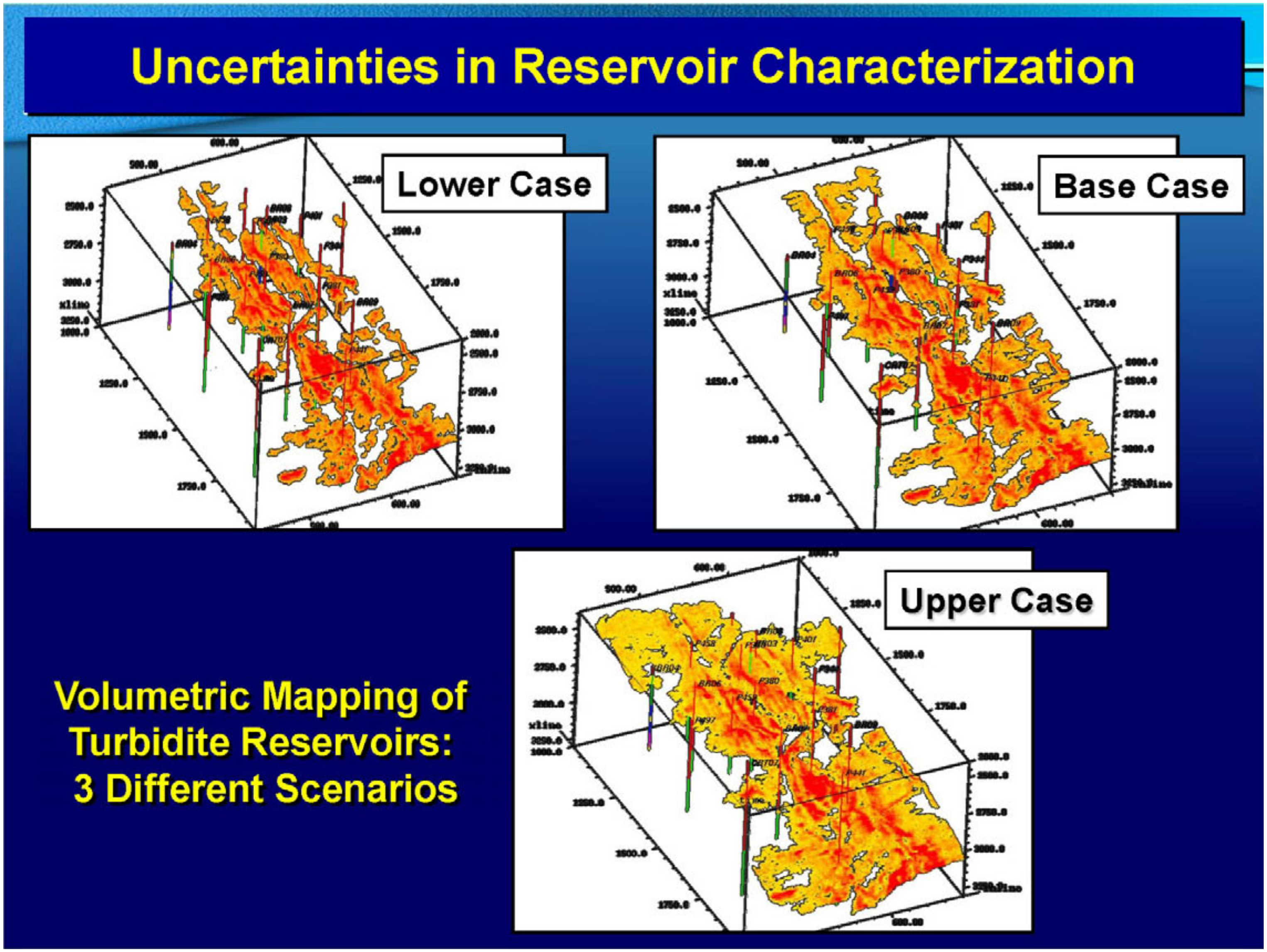


Notes by Presenter:

Data gathering in deep water fields can be much more difficult and expensive than in shallow water fields. Very often, important decisions have to be taken with the support of very little amount of data; therefore, all sources of uncertainties must be identified and quantified, and, for each reservoir, different scenarios must be presented to the decision makers.

Here we have one example of volumetric mapping of turbidite reservoirs, using seismic data, where three different scenarios are provided.

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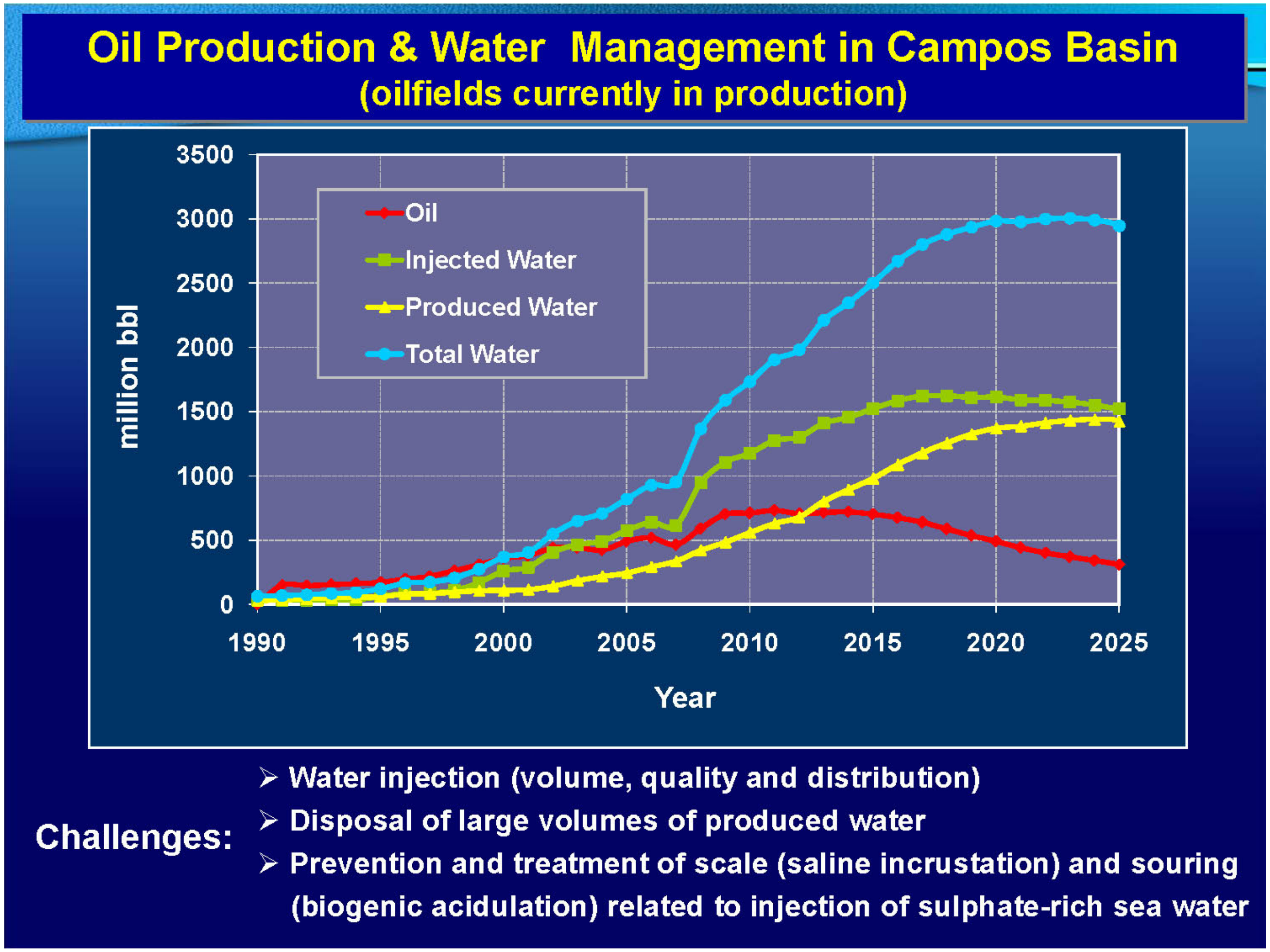


Notes by Presenter:
Water injection has been widely used both in shallow- and deepwater fields. The large lateral continuity of most reservoirs, the little amount of gas, and the favorable characteristics of the relative permeability curves, make seawater injection as the most feasible method for pressure maintenance and increase in oil recovery.

This diagram shows the large volumes of water to be handled in the Campos Basin in the next few years. During the year of 2010, for example, oil production is expected to reach 700 million bbl, but in the same time water injection will reach about 1.2 billion bbl, and water production will reach about 500 million bbl. This give us an idea of the challenges related to (1) the volume, quality and distribution of injected water, (2) the disposal of large volumes of produced water without causing damages to the environment, and (3) to the prevention and treatment of scale and souring related to the injection of sulphate-rich sea water.

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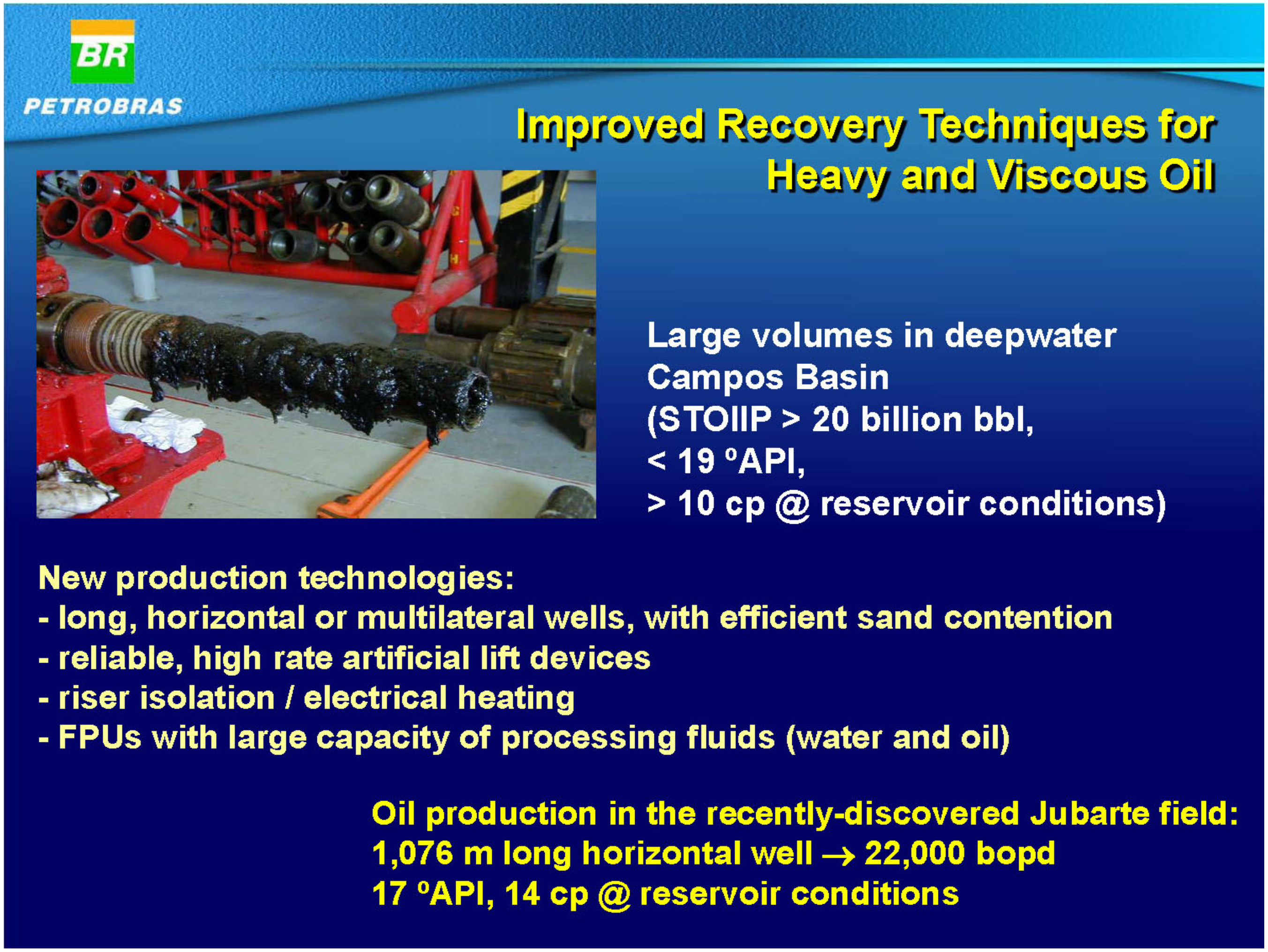


Notes by Presenter:
Large volumes of heavy (< 19ºAPI) and high viscosity (> 10 cp at the reservoir conditions) oil have been found in the deep water Campos Basin.

The economic production from these accumulations relies on a group of new production technologies, which mainly include: (1) long horizontal wells or multilateral wells, with efficient sand contention (2) reliable, high rate artificial lift devices to compensate the decrease in productivity caused by the high oil viscosity), (3) efficient heat management systems, and (4) FPUs with large capacity of processing fluids.

A successful experience in producing heavy oil from a deep water field is taking place in the recently-discovered Jubarte field, where production rates as high as 22,000 bopd are being obtained from over 1,000 m-long horizontal wells.

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# Conclusions (1/2)

→ Since 1968, when offshore exploration started, Petrobras continuously moved to aggressive exploration and production in deep waters.

→ Deep water reservoirs are responsible for
81% production (1.7 million boepd),
71% proven reserves (9.7 billion boe),
65% exploratory portfolio (90,000 km$^2$).
Their importance will keep growing ...

→ Deepwater turbidite reservoirs (Albian to Miocene) comprise different types and can be very complex and heterogeneous.

→ Data gathering can be difficult and very expensive in deepwater fields. Most expensive decisions should be taken only after extended well tests and/or pilot production projects.

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# Conclusions (2/2)

→ The development of deepwater fields has continuously provided new challenges for reservoir characterization and management:
- few, horizontal or highly-deviated wells
- high-productivity (> 10,000 – 20,000 bopd) wells,
- wells drilled into poorly consolidated reservoirs,
- efficient pressure support in the reservoir by waterflooding.

→ Several technological challenges, related to reservoir characterization and management, had to be overcome to make possible oil production from deepwater Campos Basin.

→ Despite the recent, large pre-salt discoveries, siliciclastic turbidite reservoirs should be continuously studied, since new turbidite discoveries are still occurring, and turbidite reservoirs will be responsible for most of the Brazilian production for many years.

# Thank You !