CARBONATE GEOLOGY KNOW-HOW
Carbonate reservoirs account for about half of the world’s oil and gas reserves. These sedimentary reservoirs, a mixture of limestone and dolomite, include the diverse fossilized remains of the many living creatures and organisms that, in part, led to their formation. Subsequent chemical changes over millions of years has led to reservoirs of extreme variation in make-up that are more complex than their sandstone counterparts. Carbonate reservoirs are notoriously difficult to characterize and challenging to produce.
60% of the world's oil and 40% of its gas is found in carbonate reservoirs.

**Key figures**

- **1982**, Rospo Mare in Italy, Total drills world’s first commercial horizontal well developing offshore field.

**Challenges for both exploration and production**

Compared to sandstone reservoirs, carbonate reservoirs are extremely complex, due to an abundance of differing deposits, combined with specific post sedimentation (diagenetic*) phenomena such as karstification*, dolomitisation* & silicification*. The resulting formations are sensitive to fracturing and lead ultimately to reservoirs of varying porosity and permeability with complicated behavior in production.

- Seismic interpretation and reservoir characterization can be complex and may require full production cycle evaluation with careful planning to ensure that the most appropriate techniques are used. A significant challenge here is in understanding the impacts of the heterogeneous make up and diagenesis* on reservoir quality.
- The potential for acid gases, CO₂ & H₂S means that corrosion prediction and gas treatment or disposal are likely to be significant issues.
- Well optimization rooted in a good understanding of reservoir heterogeneities is essential to ensure acceptable recovery rates.
- The brittle structure of carbonates means that around 80% of carbonate reservoirs are fractured. The resulting fracture network must be evaluated and understood so as to:
  - Reduce the uncertainties on reserve estimates
  - Improve production and recovery factors
  - Improve drilling and well performance
  - Manage sour gas production.

*All chemical or physical processes leading to the transformation of the original rock, such as calcium carbonate dissolution and replacement by dolomite or silica.

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**Worth noting**

1982, Rospo Mare in Italy, Total drills world’s first commercial horizontal well developing offshore field.
Carbonate reservoirs, with their high geological complexity, provide great challenges to successful oil and gas production. At Total we have been meeting these challenges for more than 7 decades, and even today we are still developing better and more innovative solutions to enhance production and discover new resources.

Until recently our knowledge of carbonate sedimentology was focused mainly on classical marine carbonate deposits. Discoveries in the last couple of decades however have led to new research into “continental carbonates” that likely formed in the salt lakes along rift faults or in connection with volcanic activity. The associated deep hydrothermal fluids (gas and saline solutions) were an important factor influencing carbonate reservoir sedimentation and diagenesis. Whilst more evaluation will be required this new understanding is potentially ground breaking for exploration as such continental carbonates can be found at all latitudes wherever deep fault systems have occurred.
TOTAL has developed a suite of innovative 3D modelling tools to better understand carbonate heterogeneities and their impact on reservoir behaviour:

- **gOdiag™** is a geomodeling tool that identifies the effects of diagenesis (dissolution, cementation, dolomitisation, hydrothermal processes, fresh lens effects).
- **gOfrak™** models fracture networks and the dynamic relationship between matrix and fractures.
- **SEDLAKE** is a newly developed in-house tool for stratigraphical and diagenetic predictive modeling of continental carbonates.

**ALBION**

A LARGE-SCALE MULTI-DISCIPLINARY PROJECT

Characterization of heterogeneous reservoirs is one of the main challenges in carbonate understanding. One approach is by analogy with known carbonate systems, and then applying this knowledge to reservoir models. This allows 3D characterization at much greater scale than considering just the basic sediment structure.

The ALBION multi-scale and multi-disciplinary project near Orgon in France aims at achieving such 3D characterization of a carbonate formation. It is an analogue to some of the biggest carbonate reservoirs in the world. This multi-partner project uses several wells to establish correlations between physical observations and the relationships between early diagenetic events and current reservoir properties.

**CONSTANTLY ANTICIPATING AND INNOVATING**

- **Enhanced Oil Recovery (EOR).** Total has developed a bespoke methodology, **SWIM** (Smart Water Injection Method), to increase recovery by modifying the salinity and/or the ionic composition of injected water. Evaluation studies are ongoing at several locations including at Abu Al Bukhoosh & Umm Shaif in Abu Dhabi and Al Khalij in Qatar.
- **The acid gases CO2 and H2S** are present in most carbonate formations. Total patented solutions HySWEET and SPREX, developed at Lacq in France, remove these gases in a liquid form and enable direct reinjection avoiding atmospheric pollution or sulphur accumulation.
- **Understanding carbonate Rock Physics** has enabled Total to develop a new approach in correlating seismic response to rock structure. The EPAR (Equivalent Pore Aspect Ratio), integrates sedimentology, diagenesis and “rock physics”, enabling better interpretation of acoustic data.

**REPRESENTATIVE MODELLING**

Over the last decade around 70% of global discoveries of more than 500 Mboe were found in carbonate reservoirs.

The unique Albion research facility, a network of abandoned military tunnels near Avignon in south eastern France.
At Total we strive continually to evolve and develop new and innovative techniques to extract from difficult and demanding carbonate fields. We are developing groundbreaking imaging techniques to map deep below ground where previously not deemed possible, and we are employing acid gas removal treatments, the result of years of dedicated research.

LACQ, FRANCE: A HOME TO INNOVATIVE DEVELOPMENT

Discovered in south western France in 1951, the Lacq gas field started producing in 1957, and by 1960 was supplying 60% of the country’s gas. However, the issue of sour gas (16% H2S & 10% CO2) from this giant gas field would need to be resolved. Total’s first sour gas sweetening unit, a diethanolamine (DEA) acid gas stripper, came into service in 1957, along with the development of a steel resistant to sulfide corrosion cracking, previously considered a show stopper for high H2S high pressure fields. For the next 60 years Lacq would be a hotbed for innovative development spawning modern technologies such as SPREX and HySWEET. Critically the lessons learned at Lacq would contribute to the economic production of more than 60 carbonate gas fields around the world, including flagship projects such as Elgin/Franklin (North Sea), South Pars (Iran), Bongkot (Thailand), Kharyaga (Russia), Sleipner (Norway) and some particularly sour gas reserves in Abu Dhabi. After a recovery rate of over 90%, conventional gas production for Total at Lacq finally ceased in 2013. However the field is still in service supplying local sulphur chemical works.
AL KHALIJ, QATAR: 4D SEISMIC TO UNDERSTAND WATER INFUX

Al Khalij has been one of Total’s most difficult carbonate reservoir operations. A major issue was the understanding of water influx as oil was extracted. Uncontrolled inflow could jeopardize successful production. 4D seismic monitoring was not yet proven in carbonate environments, and the preferential pathways created during diagenesis are difficult to image with classical 3D seismic techniques. However, using a phased approach to verify the detectability of a 4D signal linked to depletion effects and water sweeping, Total’s 4D specialist team was able to identify possible preferential water pathways and barriers. The pilot confirmed the understanding of fluid and dynamic connectivity of this naturally fractured carbonate reservoir. The increased understanding gained meant that in November 2015 Al Khalij produced its 200 millionth barrel of oil.

KHARYAGA, RUSSIA: SEISMIC INTERPRETATION AND DETAILED MODELLING

Inside the Russian Arctic Circle, the Kharyaga carbonate field produces light crude with a high H2S content. Complex fault and fracture systems coupled with extensive karstification (the creation of cavities affecting permeability) created the challenges for understanding the dynamic behavior of this field. 2D and 3D basin scale modeling conducted with the DIONISOS* software calibrated by well data allowed the simulation of scenarios to explain the evolution of the formation. Total’s in house gOdiag™ 3D stochastic simulator was used to model the karstification. The understanding gained has reduced the uncertainty in modelling such an elaborate network of cavities and irregular formations.

“At Total, we believe that our innovative and multi-disciplined approach to problem solving has been key to our successes in both the exploration and production of carbonate reservoirs.”

Emmanuelle Poli, Global Carbonates Project Manager

*DIONISOS Flow™  Beicip Geo-Technologies.

Advanced 4D seismic enables us to identify Preferential pathways in carbonate rock.

Understanding the Kharyaga field with three-dimensional modeling showing the platform edge (barrier zone), intersected by east-west faults, a basin, to the south, and a back barrier, to the north.
Total is a major energy player committed to supplying affordable energy to a growing population, addressing climate change and meeting new customer expectations. Those commitments guide what we do. With operations in more than 130 countries, we are a global integrated energy producer and provider, a leading international oil and gas company, and a major player in solar energy with Total Solar and our affiliate SunPower. We discover, produce, transform, market and distribute energy in a variety of forms, to serve the end customer.

Our 98,000 employees are committed to better energy that is safer, cleaner, more efficient, more innovative and accessible to as many people as possible. As a responsible corporate citizen, we focus on ensuring that our operations in more than 130 countries worldwide consistently deliver economic, social and environmental benefits. Our ambition is to become the responsible energy major.