TÉCNICO
LISBOA

Mapping technologies, in the value chain and supply chain for the oil exploration

Sónia Maria da Luz Coelho Romão

Thesis to obtain the Master of Science Degree in

Chemical Engineering

Supervisor: Dr. Joana Serra da Luz Mendonça

Examination Committee

Chairperson: Prof. Sebastião Manuel Santos Silva Alves

Supervisor: Dr. Joana Serra da Luz Mendonça

Members of the Committee: Eng. Artur Manuel Vieira dos Anjos Costa

05/2014

RESUMO

Na atual fase de maturidade tecnológica da exploração de petróleo, a produção de petróleo pré-sal abre uma nova fronteira tecnológica. Com este estudo, pretendemos contribuir para a identificação das tecnologias existentes para a exploração do pré- sal e os desafios da eficiência do processo bem como a adaptação às novas condições operacionais na camada pré-sal.

Para tal, desenvolveu-se um mapeamento tecnológico segundo a cadeia de valor e de fornecedores da indústria *offshore*. Em primeiro lugar, este estudo pretende mostrar a evolução histórica do desenvolvimento tecnológico na exploração *offshore* até à atualidade. Esta primeira fase será realizada com base nas trajetórias tecnológicas na exploração *offshore* em águas profundas, de três estudos de caso: Noruega, Reino Unido e Brasil. Além das diferenças contextuais entre eles, tornaram-se a partir da década de 1990 líderes na exploração de petróleo em águas profundas, ditando desde então as trajectórias tecnológicas na indústria *offshore*.

No final deste estudo, foram identificadas alguns dos desafios tecnológicos que a exploração pré-sal enfrenta, como perfurar em "rocha" tão instável, a elevadas profundidades, distâncias, temperaturas e pressões. Para ultrapassar estes desafios há desenvolvimentos principalmente nos segmentos da sísmica e reservatórios e na perfuração de poços, em áreas como nos materiais à escala nano, na robótica e no controlo remoto de máquinas. Na realidade estas são as áreas científicas que podem mudar a trajectória tecnológica na exploração de petróleo *offshore,* onde a robótica e o controlo remoto de máquinas em condições tão adversas podem mesmo constituir uma mudança radical naquela indústria.

Palavras-chave: Cadeia de valor de E&P, Cadeia de Fornecedores de E&P, Exploração Pré-sal, Tecnologias do Pré-sal.

ABSTRACT

In the current phase of technological maturity of oil exploration, the oil production in presalt opens a new technological frontier. With this research, we wish to contribute to the identification of the existing technological gaps for presalt exploration and the challenges facing the process efficiency and adaptation to new operating conditions in presalt layer.

To do so, a technology mapping was developed, in a value chain and supply chain matrix. Firstly, this study intends to show, the evolution of technological development until the present day in the offshore oil history. This mapping will be based on the technological trajectories in deep water oil exploration, from three case studies: Norway, UK and Brazil. Besides contextual differences between these countries, they became leaders particularly in high depth waters, since the 1990s, dictating important technological trajectories in that industry sector.

At the end of this study we are going to visualize some of the technological challenges presalt oil exploration face, like drilling at such unstable "rock", at so high depth under such hard conditions of temperature and pressure. To surpass those challenges the main technology developments are mostly in the seismic and reservoirs segment and in the drilling, in areas like materials in nano-scale, robotics and remote control. These are areas that can change the technology trajectory of oil offshore exploration and the robotics and machinery remote control in such hard conditions could be a radical change in offshore exploration industry.

Keywords: E&P Value chain, E&P supply chain, presalt exploration, presalt technologies.

ACKNOWLEDGES

This thesis represents a beginning of a new stage of my professional live in Innovation Management. Along this way I have to thank my supervisor, Dr.ª Joana Mendonça and Professor Sebastião Alves who turned this thesis possible. But first of all I must thank to my Rui, who endured my bad moods and always supported me not to give up. I also have to thank my parents, family and my friends for the understanding of the reason I didn't spend more time with them and for all the support they give me all the time.

Thank you all.

TABLE OF CONTENTS

LIST OF FIGURES

1 Introduction

In 1990 the industry of Exploration and Production (E&P) of oil and gas, was challenged with the discovery of vast reserves of hydrocarbons located beyond the continental shelves under thousands of meters of water. With these findings the experts in drilling and petroleum engineers were confronted with technological barriers that may be equivalent to the level of challenge of deep space exploration to aeronautics faced in the 1950s. Over time, the effort has become even more difficult with the discovery of huge reserves covered by layers of salt that would once again challenge the drilling technologies and practices known.

The Brazilian presalt discoveries, leads to a new technological frontier in the Petroleum and Gas sector (P&G). The location of this new exploratory frontier, at large distances from the coast (300 km) and at high depths (8000 meters), together with the magnitude of reserves and oil characteristics, create a new paradigm for the exploration and production segment of the oil, especially from the technological point of view (Araújo *et al.*, 2012).

Given this scenario the oil exploration industry is facing a possible technological trajectory change, creating a need for a debate and reflexion on the future challenges facing this technological breakthrough. This study aims to open the debate about technological trajectories changes in the oil deep-water exploration, looking to the past and to the present.

Taking into account the profile of the characteristically multisectorial actors that composes the value chain and the supply in E&P industry, this study intends to map the value chain and the supply chain into a matrix, fill it with developed and still in development technologies for presalt exploration needs.

It should be noted that, given the great complexity of P&G value chain (from exploration to delivery to the final consumer), this study will focus on the initial link in the chain, i.e., the link in the exploration and production, E&P or upstream oil industry sector. This focus is justified by the fact that of entire chain of P&G, the E&P phase is the main focus of investment and development of suppliers of goods and services (Bain, 2009).

In this study we will look at the history of the oil and gas exploration development in Norway, UK and Brazil. These three countries have a long and recognized history in deep water oil exploration, and they are models in many perspectives: technological, regulation, and innovation systems development. In the present study we are going to focus on the technological point of view since they are the source of important technological developments for deep water oil exploration that marked important technological trajectories changes in the sector. These cases are going to be the basis of the matrix construction for value chain and supply chain considering the most recent known technologies for deep water oil exploration.

At the end of this study we are going to visualize some of the technological challenges presalt oil exploration face, like drilling at such unstable “rock”, at so high depth under such hard conditions of temperature and pressure.

This study intends mostly, to open a debate for better clarification of requirements and technology offerings of the value of E&P chain. Trying to represent a technological matrix, it aims to be the starting point for more concrete discussion of the value chain of goods and services as well as E&P activities and technologies.

1.1 Motivation of this study

Environmental concerns have pulled the world in the last decade to an increasing investment in renewable energy worldwide. But the truth is that oil remains the world’s leading fuel, accounting for 33.1% of global energy consumption in 2012, and the statistics point for an increase of energy demand in the world (BP, 2013). According to the BP Outlook 2035, primary energy demand will increase by 41% between 2012 and 2035 (BP, 2014). The so called golden triangle of the Gulf of Mexico, Brazil and West Africa already identified for the high concentration of oil and gas in deep waters, will continue to have the highest concentration of capital investment in deep-water exploration with about 85% of the activity predicted in 2008 (Perez *et al.*, 2008).

So, when the oil price rises, the energy demand by the emerging countries and technology progress increases, it became a good opportunity to re-explore oil and gas reserves previously considered not economically viable. Given the presalt exploration scenario and a consequent possibility of technological trajectory change, it is important to understand how that industry interacts with other sectors of the economy, how offshore industry evolves over time until today and how the many actors are technological prepared for the challenges they face now with presalt oil exploration. This could be the starting point for a more concrete discussion for E&P industry and fundamentally directed toward the supply chain actors in this industry.

1.2 Methodology

This exploratory study was conducted in three essential phases. Because it is not possible to study a technology trajectory without studying his past history, the first one intended to understand the industry, through an overview of oil industry, in the development history and technology trajectories of deep water exploration focusing in three case-studies: Norway, UK and Brazil. Since we are talking about a possible technological change in oil exploration industry, an important basis for this understanding is to look for a conceptual background in academic literature for technological trajectories.

At a time when more and more companies resort to outsourcing their products/services, it becomes important to analyse the supply chain of goods and services in the industry. So the second phase led us to the value chain and supply chain mapping, focusing in the oil and gas deep-water industry. So it was listed the value chain phases for P&G first and then for just E&P link, the supply chain segmentation their main activities and technologies, based in a range of known and free information collected for deep water oil exploration industry today.

In the third phase and from the information gathered, a matrix was built, complementing the industrial sectors to which belong each segment and technologies already developed in the cases referred to E&P deep water exploration.

1.3 Thesis outline

The structure of this work is based on five different sections. The first topic, chapter 1 presents an overview of previous literature to better understand the context of presalt oil exploration, and includes the motivations for this study and the methodology employed.

In chapter 2, an overview of the oil and gas industry is presented, together with the identification of the presalt challenges and a conceptual background in technological trajectories. In this chapter we also present the technological trajectories for Norway, UK and Brazil. In this domain it will be a brief overview of offshore oil exploration in a historical point of view and technological trajectories for deep water exploration in those countries until today.

In chapter 3, the value chain and supply chain for E&P is presented, with a brief reference to the P&G value chain. Then it is listed according with E&P segmentation, the supply chain activities and technologies involved, as the type of supplier company for each segment.

The fourth chapter presents an array of technologies mapping, in a value chain and supply chain matrix for presalt oil E&P, pointing technologies developed or in development for presalt challenges.

Based on the previous sections, the last chapter opens the debate with some conclusions, pointing directions for future studies and important questions to be answered.

2 The Oil and Gas Industry

This chapter presents an overview and contextualization of the oil industry exploration under study. With this purpose it will be presented some oil consumption and production analysis, then look at the oil chemistry and geology, and some theoretical concepts used in this study.

2.1 Oil and gas industry overview

The pragmatic outlook is that the world will continue to consume energy and oil will continue to play a central role in the global energy mix, even when everyone acknowledges its important challenges. These challenges involve environmental aspects related to reducing global warming topic and to the increasing difficulty obtaining oil from conventional sources.

In 2011, the world consumed about 32 billion barrels of oil (crude oil and natural gas liquids), while oil proven reserves were about 1.3 trillion barrels. This means that those reserves should last more than 40 years. However, proven reserves are only a tiny slice of the overall supply of oil our planet hides (Maugeri, 2012).

On a global scale, the U.S. Geological Survey (USGS, 2000) estimated the remaining conventional oil resources on earth at about seven trillion to eight trillion barrels, out of eight-to-nine trillion barrels of Original Oil in Place. Part of this (about one trillion barrels in year 2000) has already been consumed by humankind. With today's technology and prices, only part of the OOP can be economically recovered[1] and thus be classified as a proven reserve (USGS, 2000).

World primary energy production grows from 2012 to 2035, matching consumption growth. Growth is concentrated in the non-OECD, which accounts for almost 80% of the volume increment. There is growth in all regions except Europe. Asia Pacific shows both the fastest rate of growth (2.1% p.a.[2]) and the largest increment, providing 47% of the increase in global energy production. The Middle East and North America are the next largest sources of growth, and North America remains the second largest regional energy producer (see Figure 1) (BP, 2014).

[1] The notion of recoverability is crucial to the oil industry. Given its complex nature, a hydrocarbon reservoir will always retain part of the oil and gas it holds, even after very long and intensive exploitation. Fields that no longer produce oil and are considered exhausted still contain ample volumes of hydrocarbons that cannot simply be economically recovered with existing technologies (Maugeri, 2012).

[2] From latin *per annum*.

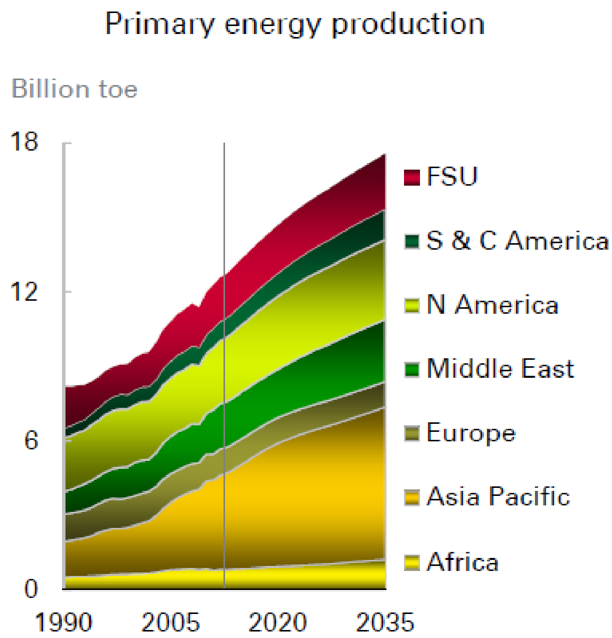

FIGURE 1 - ENERGY PRODUCTION BY REGION. (IMAGE SOURCE: BP ENERGY OUTLOOK 2014)

Oil is the most traded commodity commercialized in the world in terms of volume, value or capacity. During the last decade, the consumption of crude oil has risen largely by the growth of the world economy particularly in China and India, and the increasing use of motorized vehicles in emerging countries (UN, 2012).

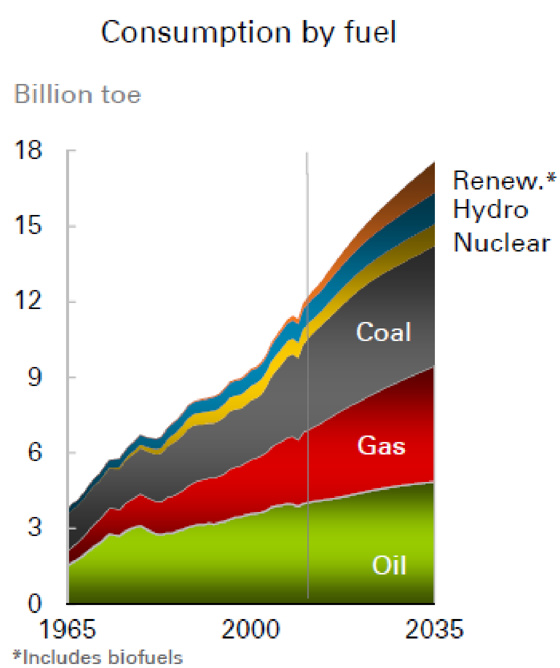

FIGURE 2 – ENERGY CONSUMPTION BY FUEL. (Image source: BP Energy Outlook 2014)

The projections of the International Energy Agency and the BP Outlook 2035 show that by 2035, demand for oil will grow by approximately 36% (see Figure 2) with demand from non-OECD countries, representing 93% of the increase in global energy demand (see Figure 3), despite measures taken by governments to promote efficiency energy and reduce greenhouse gas emissions associated with the use of crude oil emissions (IEA, 2010; BP, 2014).

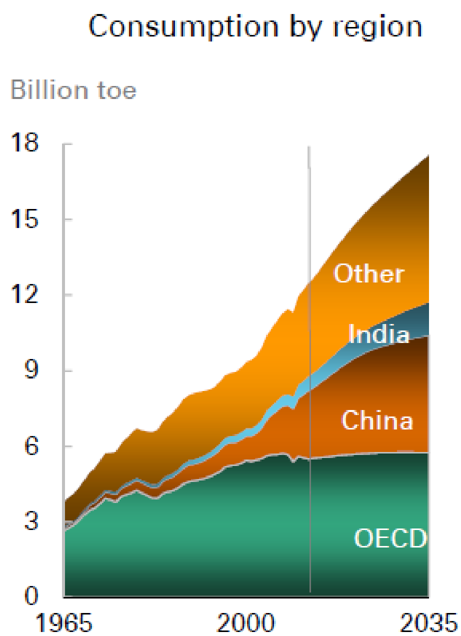

FIGURE 3 - ENERGY CONSUMPTION BY REGION. (Image source: BP Energy Outlook 2014)

By sector, industry remains the dominant source of growth for primary energy consumption, both directly and indirectly (in electricity form). Industry accounts for more than half of the growth of energy consumption 2012-35 and remains the dominant source of growth for primary energy consumption, both directly and indirectly. The next major component of growth is energy used in the 'other' sector (residential, services and agriculture), predominantly in electricity form. The transport sector continues to play a relatively small role in primary energy growth throughout the forecast, growing steadily but accounting for just 13% of total growth during 2012-35 (see Figure 4) (BP, 2014).

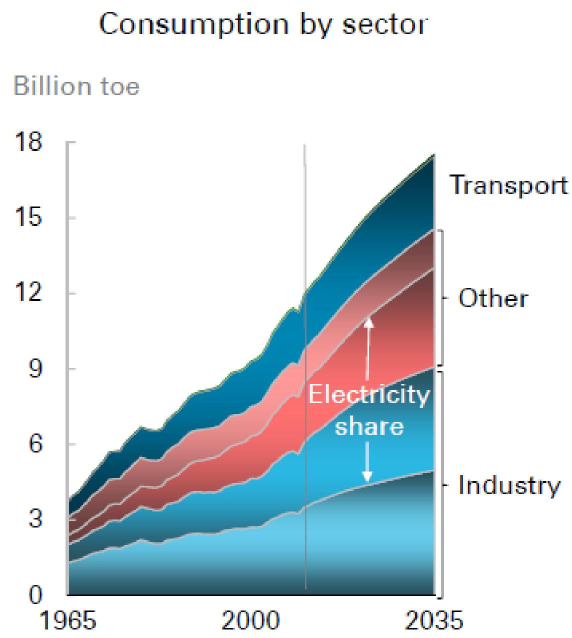

FIGURE 4 - ENERGY CONSUMPTION BY SECTOR. (Image source: BP Energy Outlook 2014)

Excessive price volatility in the oil market has the potential to inhibit demand and slow the speed of global economic recovery. Oil prices can also lead to significant changes in the distribution of wealth among different countries. For oil exporters, the recent high prices may improve the current account, generating revenue and increasing government spending. However, for oil importers and developing countries, rising oil prices and food prices led to high inflation and an increase in the tax burden. Thus, the oil price is an important variable in the evolution of other macroeconomic variables for each country (UN, 2012).

Furthermore, since oil is a finite resource, we must constantly seek new production areas, to counter the reserves that are consumed on a daily basis - even if the absolute volume presents low growth, there will be the need to add production from new fields (BP, 2011).

In this sense, it is clear that the realization of oil reserves on a large scale is an essential asset to meet future energy demand. Recent discoveries in presalt layer represent a great potential income for holders of these reserves countries (see Figure 5).

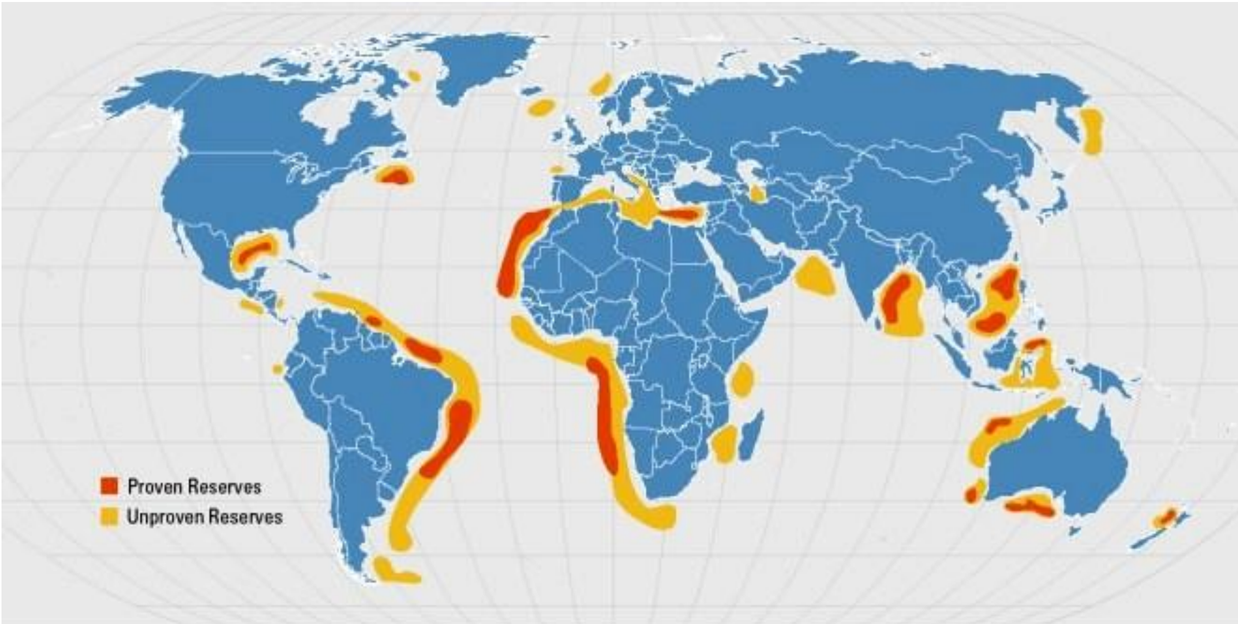

FIGURE 5 – DEEP WATER OIL RESERVES IN 2012. (Image source: Baker Hughes White Paper 2010)

The following steps to consolidate this potential involve a whole productive apparatus that gives continuity to innovation, enabling cycle of exploration, development and production of oil at competitive costs. This will need a supply chain of goods and services that contribute to overcome the technological, operational and logistical challenges (Bain, 2009).

As the industry pushes further from shore into ever-deeper water, costs and challenges have become even larger. In many regions, companies must now have a clear image, target and reach reservoirs below salt layers that are thousands of meters thick. These challenges place a premium on efficiency, technology and expertise that help reduce operators' uncertainty in deep water.

2.2 Oil's Chemistry and geology

Petroleum is a mixture of hydrocarbon molecules of varying sizes composed of carbon and hydrogen and volatile compounds (sulphur, oxygen and nitrogen), and therefore the type of oil found varies greatly. There are a variety of types of oil from the lighter less viscous and more viscous until the dark. Currently it is thought that there are hundreds of different types of oil to be sold, where each field produces one oil type. There are also many types of "Brent" which are formed from the mixture of oils from different sources. Oil is thus classified according to three key features (Hyne, 2001):

- Depending on the predominant types of hydrocarbons;

- Depending on the density of the oil, measured in API (American Petroleum Institute). In accordance with API grade oils may be classified as light, medium or heavy. The lighter oils are most valuable because they produce a greater amount of products of higher market value (LPG and gasoline) with relatively simpler and less costly refining technologies;

- Due to sulphur. Oils are thus classified as "sweet" (sweet) when they have a low sulphur content (less than 0.5% of its mass) or "acid" (sour). Oils with lower levels of sulphur are more valuable since sulphur is a very polluting element. The fatty oils thus have a higher cost of refining, particularly by passing it through elimination processes for producing sulphur derivatives according to the environmental specifications.

The oil is stored in solid rocks and occupies small pores or cracks in the rock. To produce oil a reservoir rock (or bedrock) should have enough porosity to store the oil molecules. In addition to proper porosity, it is important that the reservoir rock has sufficient permeability to allow the oil flow, that is, that the rock pores are interconnected. The permeability will influence the rate of oil production from a reserve. If the rock is highly permeable, oil contained therein can be extracted more easily (Hyne, 2001).

The reservoir rocks are formed by the migration of oil from source rocks. If not for this migration, the oil would be dispersed in slurry form in sedimentary basins, and their recovery uneconomical. However, once formed in source rocks, oil droplets tend to migrate to the surface as it is lighter than water. The migration path is determined by the type of soil and rocks that have to cross (Hyne, 2001).

The concentration of oil in a reservoir rock does not occur isolated. The oil is generally found along with water and gas. As the oil, water and gas are captured by the cap rock through the gravity effect, in general there is gas in the upper part of the reservoir rock, followed by oil in the intermediate part and water in the bottom. These fluids are stored under pressure. When the well is drilled to reservoir rock, those fluids tend to rise to the surface due to the pressure difference between the reservoir and the surface. The reservoir pressure is what determines the production of oil or gas (Hyne, 2001).

2.3 Presalt Oil

2.3.1 Oil characteristics

Since the discovery of presalt reservoirs, the targets in the strata above the salt are designated as postsalt or subsalt prospects (Beasley *et al*., 2010). Therefore, Brazil’s presalt trend differs significantly from the subsalt trend found in the Gulf of Mexico (Dribus *et al.*, 2008). According to Dribus *et al*., the reason why is that presalt wells are drilled into formations that were deposited prior to the emplacement of a layer of salt that remains at its original stratigraphic level (autochthonous layer). This original salt layer lies above older rocks and is in turn overlain by younger strata. By contrast, subsalt wells are drilled into formations lying beneath mobile masses of salt, fed by original autochthonous layer, that rise through overlying layers, and then spread laterally. In practice this results in significant different drilled depths as seen in Figure 6.

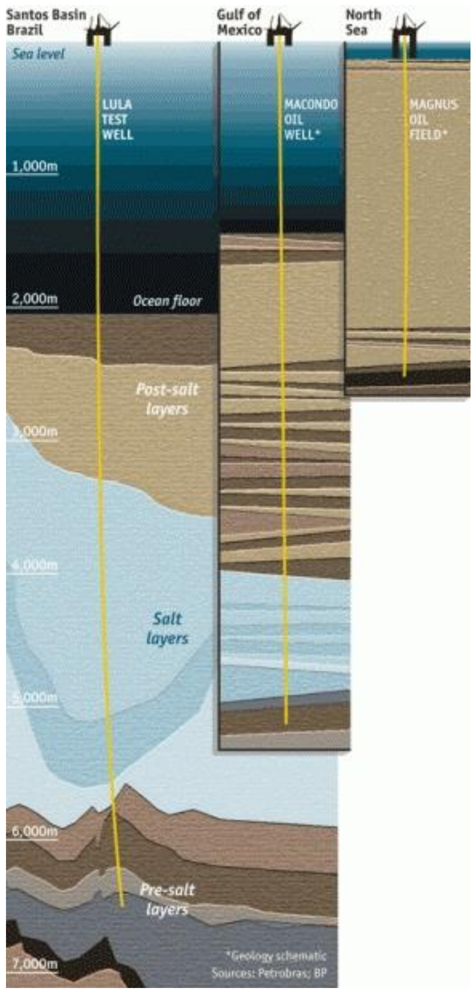

FIGURE 6 – GEOLOGY SCHEMATIC COMPARATION BETWEEN BRAZIL, GULF OF MEXICO AND NORTH SEA EXPLORATION (Image source: Petrobras; BP)

Thus, this older layer of salt (presalt) was deposited during the opening of the Atlantic Ocean after breaking the Gondwana Supercontinent (which theoretically sank forming the junction of American and African oceanic plates respectively). The breakup began with rifting in the south-ernmost part of what is now South America (Wilson, 1992).

Salt basin development occurred gradually, as rifting between South America and West Africa gradually evolved into a full-fledged drift. According to Platt *et al.* (1993) *and* Lausaire *et al*. (2009), approximately 150 million years ago, extensional faulting and subsidence were active in the Gondwanan supercontinent.

Further stretching and extension during the Early Cretaceous led to the formation of large-scale rifts along the future western African and eastern Brazilian margins. By Aptian[3] times, continued subsidence and a rise in global sea level permitted incursion by the sea. At first, this was intermittent, with the alternately entering and evaporating form the basins, creating thick evaporate deposits. The area later became completely submerged as continental breakup of Gondwana led to a separation, or drift, of South America from Africa. Whereas the basins had previously been linked on one continental plate, they became separated by a growing expanse of ocean, as injection of new crust at midoceanic[4] ridge caused the Atlantic to open (Platt *et al*., 1993; Lausaire *et al*., 2009).

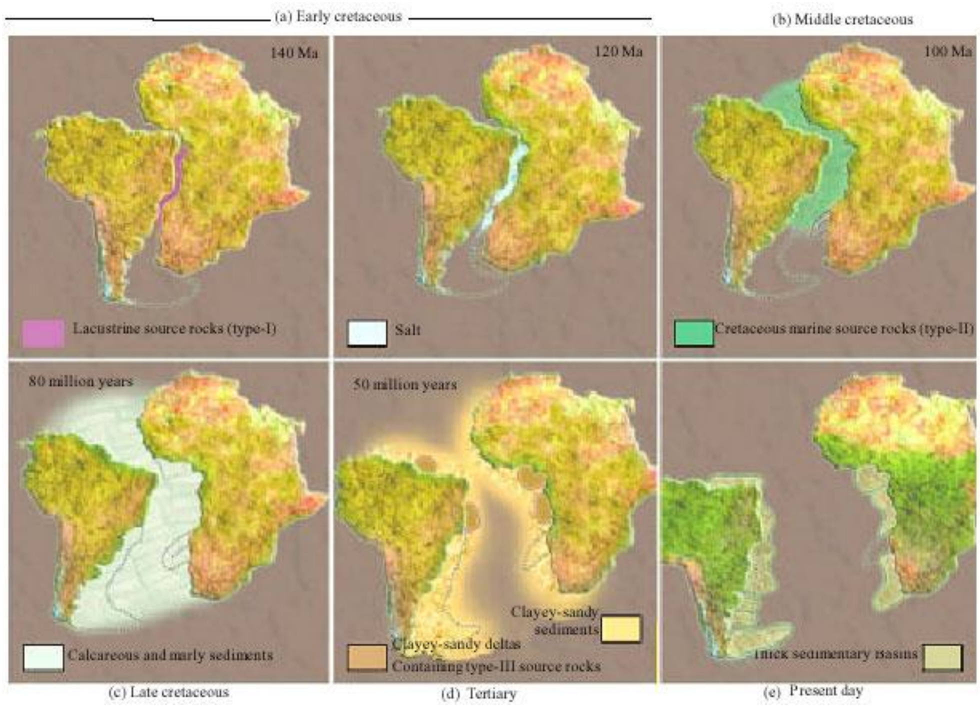

FIGURE 7 - SCHEMATIC EVOLUTION OF COASTAL BASIN (Image source: LAUSAIRE *et al*., 2009)

It is also important to notice that this oil is considered high and medium quality according to the API scale. This corresponds to a classification of lighter petroleum and thus more valuable because they can give rise to oil products with higher market value as gasoline and liquefied petroleum gases such as propane and butane (LPG).

2.3.2 Exploration and production challenges

[3] Aptian Stage, fifth of six main divisions (in ascending order) in the Lower Cretaceous Series, representing rocks deposited worldwide during the Aptian Age, which occurred 125 million to 113 million years ago during the Cretaceous Period (Source: *Encyclopaedia Britannica*).

[4] A mid-ocean ridge or mid-oceanic ridge is an underwater mountain range, formed by plate tectonics (Source: *Science Daily*).

The organic rich lake deposits formed after a series of events, presalt layers, lies at a depth 1,000 to 2,000 meters of water depth and between 4,000 and 6,000 meters deep underground. Thus, the total depth, the distance between the sea surface and the reservoirs below the salt layer (sub-salt layer) can reach 8,000 meters (see Figure 8). Adding to this there is the 300 Km distance from the oil reserve untill the coast line.

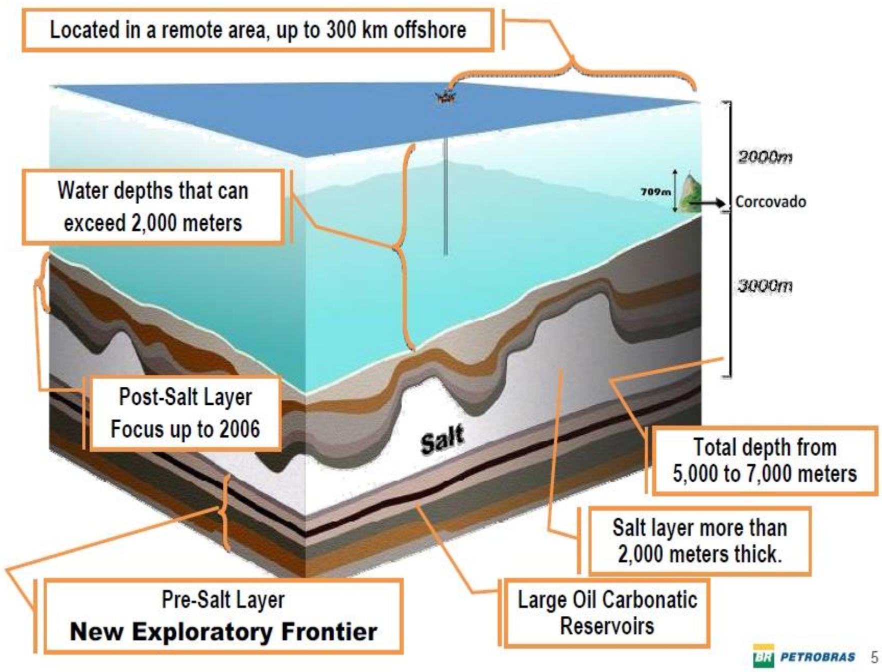

FIGURE 8 – LOCALIZATION OF PRESALT LAYER. (Image source: Petrobras)

The Santos basin initial site of presalt discoveries in Brazil (see Figure 9), presents numerous E&P challenges implicit in a setting where ultra-deep waters cover a deep carbonate reservoir masked by a thick layer of salt (Beltrão, *et al*., 2009). That's why there is no doubt that presalt frontier includes additional obstacles directly related to the geology of these reserves. All these obstacles can be exacerbated by meteorological and oceanographic conditions, which can range from moderate to severe (Beltrão *et al.*, 2009).

FIGURE 9 – LOCATION OF OIL RESERVES IN BRAZIL (Image source: Financial Times)

In these waters E&P teams are confronted with difficulties in imaging beneath salt because of its composition and geology, which consequently turns processing data also more complicated. The high contrast in seismic velocity between the salt and sediments causes problems when using conventional techniques. Although among the more daunting challenges is wellbore construction. Immediately above the target reservoir lie as much as 2.000 m of evaporates[5], which its varying composition interval can be especially difficult to drill (Beasley *et al*., 2010; Perez *et al*., 2008).

Furthermore, the presalt reservoirs consist of heterogeneous, layered carbonates, which can adversely affect drilling progress. Drilling through salt requires special attention to drilling fluids. Potential problems include sections of borehole enlargement and weakened borehole walls as a result of salt leaching (Perez *et al*., 2008). In fact, drilling in the salt layer is complex due to the fluidity and instability of the geological *stratum* and the problems can be further increased when it has to be applied horizontal drilling. This technique tends to facilitate appropriate access to the reservoir rock and contribute to increase the recovery factor of oil contained in the reservoir. Moreover, horizontal drilling requires a greater amount of drilled meters from the vertical drilling, and therefore more costly (Viegas, 2011).

That is the reason why there are areas were challenges are more significant in presalt exploration, like in materials to face problems like exert tension of the salt layer and consequent closing of the wells. Other important technological area to pursuit is temperature adjustment. The oil comes out of the hot rock and can form precipitation when entering in the flexible lines that are in contact with the sea ice (Viegas, 2011).

[5] Evaporite is any variety of individual minerals found in the sedimentary deposit of soluble salts that results from the evaporation of water. Typically, evaporite deposits occur in closed marine basins where evaporation exceeds inflow. The most important minerals and the sequence in which they form include calcite, gypsum, anhydrite, halite, polyhalite, and lastly potassium and magnesium salts such as sylvite, carnallite, kainite, and kieserite; anhydrite and halite dominate (Source: *Encyclopaedia Britannica)*.

To address these exploratory environment constraints, technological innovation has been playing a major role in reducing uncertainties in both phases of operation such as oil production, increasing the odds of success and creating economic viability of new deposits (Viegas, 2011).

Therefore, because of oil geological characteristics, exploration in presalt layer marks a brand new exploratory model and the beginning of a new technological trajectory in E&P industry. That's why it is important to understand some concepts some oil exploration history background before exploring the technological trajectories of the three chosen case-studies. Next figure resumes some of presalt oil exploration drilling challenges.

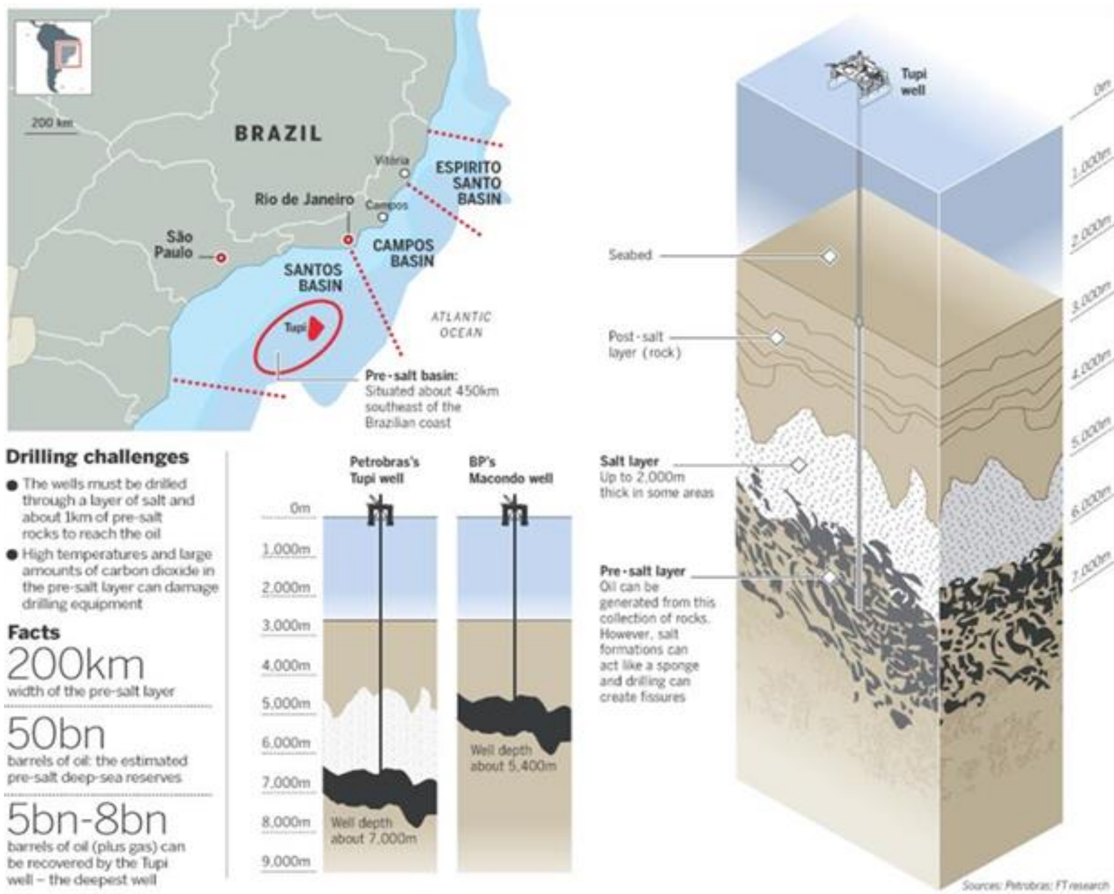

FIGURE 10 – BRAZILIAN PRESALT DRILLING QUEST. (Image source: Financial Times)

3 Technological evolution in oil exploration

Since the first discoveries of oil reserves that its exploitation is a very complex activity due to the characteristics of oil in nature. The offshore oil exploration and production are recent activities which begun in the last century, around the 1950's, in the Gulf of Mexico, United States (Viegas, 2011). These exploration activities were developed from equipment and techniques adaptation for onshore exploration. In fact, it was transferred to offshore the same technological standards used in onshore segment (Neto and Shima, 2008).

Only with the extension of deeper oil findings, the consequent increase in the operating difficulties and more distant from coast, procedures and new technologies were developed. Since then, a search for new technological trajectories was initiated to make offshore exploration in open sea feasible (Neto and Shima, 2008).

With the many advances in Research and Development (R&D) in several convergent areas of knowledge, it is possible to reach ultra-deep fields (over 1,500 meters) in the 1990s. Such advances occurred in three major technology areas: seismic, drilling and platforms with their equipment (Miles, 2005; Austin *et al*. 2004).

The significant discovery of presalt reserves opens a new set of technological challenges which can lead to a new trajectory in the oil industry. This was preceded by a paradigm change in oil industry: offshore oil exploration (Neto and Shima, 2008).

Technological paradigm and trajectory concepts

The idea of technological paradigms is closely related to the perspective originally proposed by Schumpeter in Business Cycles (1939), which emphasized the discontinuities associated with the introduction of radical technologies and the disruptive effects that these may have on the dynamics of the whole economy. According to Dosi (1982), a technological paradigm can be defined as a model and pattern of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies. Historically, the emergence and diffusion of new technological paradigms have been closely associated with the rise of interrelated and pervasive radical innovations which had the potential to be used in many sectors of the economy and to drive their long-run performance for several decades (Freeman *et al*., 1982; Freeman and Louçã, 2001).

Thus, the concept of technological paradigm does not simply describe a set of structural techno-economic features in a static sense, but is inherently related to the dynamic behaviour of the system, i.e. the growth potential that any given set of interrelated and pervasive radical technologies entails. The exploitation of such technological and economic potential proceeds along well-established directions, the technological trajectories (Castellacci, 2008). So technological trajectory is defined as the set of evolutionary and cumulative characteristics that influences development and changes, experienced by technology diffusion when are used in production and services (OECD, 1992).

Technological change can also be conceptualized as a socio-cultural evolutionary process of variation, selection, and retention (Anderson and Tushman, 1990). Variation is driven by technological discontinuities as the core technology of an industry evolves through long periods of incremental change punctuated by times when radical, new superior technologies displace old, inferior ones (Tushman and Anderson, 1986).

Clark (1985) points out that "radical" technological change will be associated with a movement up the design hierarchy, i.e. when existing core concepts are challenged. Along the same lines, the notions of technological paradigms and guideposts are easily associated with the well-known concept of technological discontinuities (Foster, 1986; Utterback and Kim, 1986).

So, old technologies can be substitute by new ones or improved with incremental changes, suggesting that each technology have a life cycle. Thus, technological trajectories have their own characteristics, such as the fact that they cross certain evolutionary stages (Furtado, 1996).

Technology life cycles

Progress is slow in the early stages of development as the industry struggles with basic uncertainties, faster as these early knowledge are broken and slow again as the natural limits of the technology are reached (Dosi, 1982; Sahal, 1985). The oil and gas industry exhibits time-to-market characteristics that are consistent with other heavy industries, such as mining, steel production, and power generation (Neal *et al.*, 2007).

According to the study made by Mckinsey for Shell, whereas consumer goods might progress from drawing board to store shelves in less than two years, oilfield technologies consistently require 15 to 20 years to complete the same maturation cycle. While this is advantageous to the producers of established technologies, it makes the sector unattractive to investors and limits the industry's ability to react to changing environments and to enter new domains (Mckinsey, 2001).

However at the initial stage of a life cycle usually there are several competing technological systems, each of one having potential to become dominant. There are several possible ways, each of one represents a particular set of inter-related technologies. In the offshore industry evolution that was no exception and its early stage, the offshore technology was adapted to great depth sea exploration, where technological trajectory has a wide spectrum of possibilities (Furtado, 1996).

The point at which a dominant design is introduced in the industry is expected to be followed by a rather sharp decline in the total number of participants until the curve of total participants reaches the stable condition with a few firms sharing the market. A major technological discontinuity would start a whole new cycle again (Utterback and Suarez, 1993).

A dominant design is the outcome resulting from a series of technical decisions about the product constrained by prior technical choices and by the evolution of customer preferences. A dominant design often does not represent radical change, but the creative synthesis of the available technology and the existing knowledge about customer's preferences (Utterback and Suarez, 1993).

A parallel and closely related research suggests that technological cycles shape the form and level of competition, the attractiveness of entry, and industry structures. Accordingly, it is argued that the historical-structural relationships among organizations that are shaped by ecological and industrial dynamics are actually a reflection of underlying technological changes (Baum, Korn and Kotha, 1995).

It is the subsequent work of Abernathy, Utterback and later Clark that synthesizes a clearer picture of the product life cycle (PLC) and addresses the factors that drive it (Utterback and Abernathy, 1975; Abernathy and Utterback, 1978; Abernathy, 1978; Utterback, 1979; Clark, 1985). Like Mueller and Tilton (1969), they do not advance a formal model but hypothesize about how variations over time in uncertainty and technological change shape the PLC (Mueller and Tilton, 1969).

In fact, in the actual stage of offshore oil exploration, there are some uncertainties about the feasibility and success of some of the new technological development for presalt challenges. Presalt technology life cycle is in the early stage where the opportunities for radical innovations offered by the presalt are very attractive and the uncertainties involved to break through technological boundaries are very high (Oliveira and Roa, 2012).

Although as important as the concepts understanding is industry technology history. To better predict the future it is important to understand the past until the present. So the history of a technology is contextual to the history of the industrial structures associated with that technology (Dosi, 1982).

3.1 Technology's history in offshore oil industry

It is impossible to talk about the new technological trajectory that presalt could represent without making a past economic and technological overview of offshore oil exploration. The development, sophistication and even maintaining a paradigm will be "driven" by technological trajectories performed within this. The technological trajectory will be the direction of technological progress within the paradigm, which will be directly influenced by technological and economic variables (Neto and Costa, 2007). According with

Giovanni Dosi (1988), a technological trajectory is the activity of technological progress between trade-off of the economy and technology, both defined by a paradigm (Dosi, 1988). Thus, some of the factors that can influence a trajectory can be economical, social and technological (Neto and Costa, 2007).

That is why often the competition of technologies is a competition between countries whose governments support their national business groups, through multiple mechanisms such as the promotion of industrial R&D and funding of the first production series. But the big multinational companies, even without the support of their respective governments, establish fierce competitions among themselves to enforce their own technological system worldwide (Furtado, 1996). Norway, UK and Brazil became technological oil exploration leaders particularly in high depth waters, since the 1990s, dictating important technologic trajectories in that industry sector (Neto and Costa, 2007; Neto and Shima, 2008). That was the main reason they were selected to case-studies in this thesis, to better understand the technological trajectories evolution in deep water oil exploration.

3.1.1 Offshore history overview

In spite of the initial landmark quite rudimentary offshore production, occurred in Santa Barbara County, California/USA, in 1896, this event it is not assumed as the beginning of a new technological paradigm. The first well had a depth of almost 6 feet and stood at a distance of 15 meters from the beach, operated by the transfer and adaptation of onshore technology to water conditions. But it was in the Gulf of Mexico that an offshore innovative dynamics was established. It is from this region that the starting point of a new paradigm was established, with dedicated technological trajectories, and consequently, the global offshore production on a commercial scale (Neto and Shima, 2008).

Even with some important technological developments like in seismic and offshore platforms, a new alternative would arise only in a selection environment whose conditions would be totally different. It is the discovery of under sea oil fields in the North Sea, and the nonlinear geology of European basin in fields in waters more deep near the coast that a new production system would be necessary, better suited to larger water depths. The North Sea moved almost one-third of industrial investments in the UK and Norway in the 1990s (Neto and Shima, 2008).

Through one of the largest investments made by European industry, the North Sea became one of the largest petroleum provinces of the world (Beynon, 2006). Parallel to this, the oil companies and other national companies became major players in offshore oil exploration worldwide (Neto and Shima, 2008).

As oil and gas industry is among the most technology intensive and high globalized industries, a comparison of Stavanger (Norway) and Aberdeen (UK) according to Hatakenaka *et al* (2006), affords a valuable analytical opportunity as the circumstances under which the two regions developed into oil capitals are strikingly similar. The two regions developed over the same period, interacted initially with the same group of global oil companies, faced similar market conditions and geological and technological challenges.

3.1.2 North Sea Oil Exploration – Norway and UK

Norwegian oil industry has become a model of development for others oil country producers, in administrative, political and technological ways. Scotland's oil industry has accompanied that development at the same time as Norway's industry, but the evolution of local technological and industrial capabilities in the two regions has followed very different paths (Hatakenaka *et al.*, 2006).

Government policies in these two regions differed in three important ways: i) in managing the speed of depletion (by deciding what to license); ii) in the emphasis on domestic capacity building; and iii) in localization decisions (Hatakenaka *et al.*, 2006). According to Noreng (1980), this difference in approach was at least partly dictated by differences in the two countries' macroeconomic circumstances.

From the earliest days, the Norwegians saw oil as a national asset to be managed carefully. The national, regional and local authorities made concerted efforts to develop local capabilities in the oil and gas industry, and to concentrate industry-related institutions in Stavanger (Hatakenaka *et al.*, 2006). Norway had close to full employment and generally healthy macroeconomic conditions. Indeed, there were real concerns that if the development of the oil industry was left to market forces, the relatively small Norwegian economy might be overwhelmed, it was sensible for them to move slowly if only to avoid inflation (Noreng, 1980).

Environmental concerns and co-habitation with fisheries were other issues. Concessionary procedures were used as an instrument to force the international companies to engage in technology transfer and local content development (Hatakenaka *et al.*, 2006).

On the other hand, the British government was preoccupied with a crippling balance of payments crisis, and therefore needed a rapid scale-up of oil production (Noreng, 1980). In contrast with Norway, the British government moved quickly to adopt a fast depletion policy, prompting a larger number of foreign companies to move in (Cameron, 1986; Cook, 1983).

At the outset of the North Sea oil era, both Norway and UK confronted the problem that they had virtually no local capabilities in the oil and gas industry. Even though the UK was at an advantage, given the broad experience of BP and Shell, the extraction and production of oil required a range of supply industry functions. Efforts to promote local industrial development in the UK started later than in Norway, changed over time and did not go as far. Nevertheless, the industry in Aberdeen grew despite a lack of consistent support from the national and local authorities (Crabtree, Bower and Keogh, 1997; Hatakenaka *et al.*, 2006).

For the oil and gas industry in general, collaboration and interaction between three types of companies are critical for innovation: i) oil exploration and production companies (also known in the industry as operators), who have the rights to explore oilfields and without whose participation new technologies cannot be tested in the oilfields; ii) integrated service providers, large global companies capable of providing most exploration and production-related services to oil companies; and iii) small specialized suppliers/service companies, which are often the pioneers in developing new technologies (Hatakenaka *et al.*, 2006).

Stavanger and Aberdeen are also characterized by very different local innovation systems. Stavanger has developed a reputation for technology-driven innovations, while Aberdeen is known for its operational innovations. Such reputations are consistent with industry benchmarking data and Norway is seen as "*a test-bed for new technology*" (Duncan, 2001). Stavanger is generally characterized by high levels of both industry and industry-government coordination and collaboration, while the prevailing ethos in Aberdeen appears to be market coordination and competition (Neto and Shima, 2008).

To strengthen offshore activity, the British government, as the Norwegian, created a fund to stimulate research where benefited institutions like the Institute of Geological Sciences, the Institute of Oceanographic Sciences, among many other laboratories, such as the National Science and Engineering and Engineering Research Council (Freitas, 1993). These institutions have shown great importance to the advancement of technological and economic feasibility of oil exploration in waters in the North Sea (Neto and Shima, 2008).

Norwegian technological trajectory

Production in the North Sea began in 1969 with the discovery of the giant field (2.5 billion barrels) of *Ekofisk*, located at 70 meters depth. But activity on a commercial scale started in 1971, through a fixed self-elevating platform.

The Norwegian state-owned company, Statoil, had a fast and intense process of training for offshore technologies, which already in 1976 along with their suppliers, was able to develop and install in the field *Tommeliten*, the first subsea system on the Norwegian coast. It was an important achievement in terms of technological development, even for the traditional companies dominated and operated such technologies in the U.S. particularly in the Gulf of Mexico. From this initial venture, Statoil became the second largest operator of subsea equipment, following Petrobras (Keilen, 2005).

In this training process, the Statoil Company increased the use of fixed platforms jack - up type (auto - lift) with a concrete base (pneumatic box). This concrete base, reaching 50 meters height, was designed to be filled with ballast (lighter) air or water, facilitating the platform transportation by boats (Lappegaard *et al.*, 1991). The choice on this type of platform follows obviously the easy movement but also because of the type of Norwegian fields, which are large and thick. Thus, the new structure prevented the platform to sink into the sand, like the Shell platforms in 1969. The deepest of these platforms were installed in *Gulfaks* at 220 meters deep (Norwegian, 2006).

FIGURE 11 – FIXED PLATFORM. (Image source: Maritime Connector site)

Some of the resources of the Norwegian fund created by the government in 1986 were meant for Statoil and was used to develop the offshore industry greatest innovation: the technology of horizontal drilling. This technology was developed to enable the exploration of some fields of *Ekofisk* area (Neto and Shima, 2008), previously not viable, due to its large amplitude horizontal. This technology was completed in 1991 and was rapidly introduced across all the industry, as in *Roncador* field (Brazil) in 1996 (Keilen, 2005).

Another important innovation started in the 90s by Norwegian companies, was in 4D seismic technology, which allows, for example, the visualization of the underground oil flow, optimizing drilling locations in giant fields such as *Troll* Field, with 450 Km^2 (Keilen, 2005).

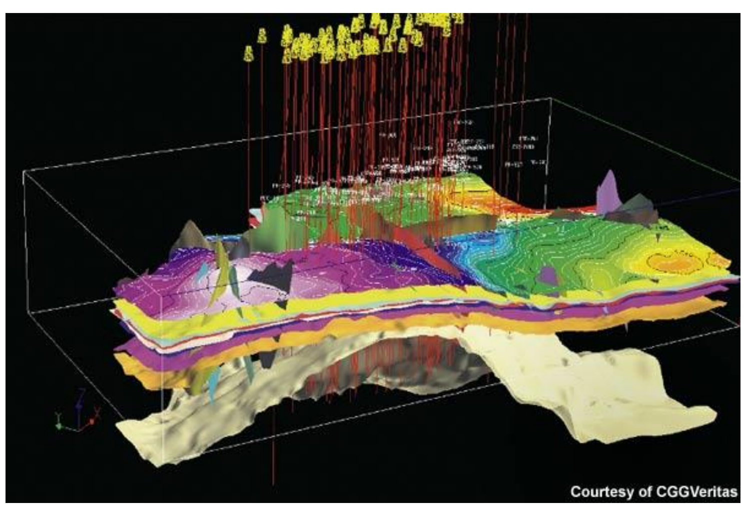

FIGURE 12 – 4D SEISMIC IMAGE OF OIL EXPLORATION. (Image source: Offshore Technology site)

Summarizing, the contribution of the Norwegian offshore segment is primarily related to seismic technology and drilling. However, many of the companies created to support R&D in the region were essential for the development of new types of platforms or new technological trajectories, developed in the southern part of the North Sea.

British technological trajectory

The Argyll Field served as starting point for the floating production system (FPS), in which was installed the first semi-submersible production platform (SS-FPU) with an Early Production System (EPS) in 1975. This platform, in reality, was a drilling vessel adapted to also serve as a production unit. But before its triangular design and unique production function and non-transport (offshoring), the vessel was considered a platform, not a boat. The Field of Argyll ceased trading in 1992 becoming economical unviable, after producing about 100 million barrels of oil, but returned to work again in 2003 (Neto e Shima, 2008).

FIGURE 13 - SEMI-SUBMERSIBLE PLATFORM. (Image source: Maritime Connector site)

This platform was a major technological progress, since it was the first, no other floating platform was installed and maintained in the North Sea until the mid-80s. But companies sited in British region continued to search for a more efficient technological model than fixed platforms, for the reason that there was an interest in expanding the exploitation depth. Thus, in 1984, the British oil company Conoco initiated the FPS when installed the Tension Leg Platform (TLP) at Hutton Field, at 148 meters deep. This type of platform has become one of the most widespread worldwide (Neto and Shima, 2008).

FIGURE 14 - TENSION LEG PLATFORMS (TLP). (Image source: Maritime Connector site)

The TLP is characterized by a floats system (buoyants), similar to the floating platform, and a flexible support structure, not rigid like in fixed platforms, which does not permit dynamic positioning as much of the floating platforms. This is therefore a hybrid platform model. The supporting structure is the most outstanding and complex feature of this new model. Usually it has four large columns, where the floats are installed and each of these columns has entwined set of cables (tendons or strained legs) and tied[6] in templates[7] on the seabed (Neto and Shima, 2008).

The templates where tendons were tied have strain gauges connected to computers on the platform. Besides to these meter equipment, another 200 sensors were placed on the tendons, allowing host platform computer to control each cable tension. Thus, the stability of the platform would be ensured by the constant traction or cables relaxation, depending on the hydrostatic buoyancy of water on the platform, even in situations of severe storms and hurricanes. It was a technology that established the beginning of a new trend in terms of concept which was to make the platform track, even though in restricted limits, the sea motion (Jardine and Potts, 1988).

Apparently the Hutton TLP was well succeed, formed the basis of knowledge for other companies to develop their own TLPs. The progress was moving further toward the new trajectory of floating drilling system (Adrezin and Benaroya, 1999).

The installation of the Hutton TLP was the basis of experiments and investigations for Conoco. After three years testing and studying, Conoco installed its first TLP in the Julliet field in Gulf of Mexico, at 536

[6] In the maritime industry, the term mooring is used to designate the whole connection procedure, welding and other situations of interconnection equipment and parts.
[7] The template is a base metal installed on the seabed, where they are installed or fixed equipment, parts and cables used in exploration and production operations. In the case of TLP, templates serve as the basis for the equipment, and also as support for the anchoring.

meters depth, becoming the leader worldwide technology. Given the success, the model presented at the Offshore Technology Conference in 1988 became widespread in offshore industry. With the beginning of the use of TLP in the Gulf was possible to achieve greater levels of depth. Including Shell was the company with the largest number of records in prospecting depth advance (Albaugh, 2005).

3.1.3 Brazilian oil industry

It is not possible to look at the Brazilian Oil Industry, without considering Petrobras' evolution. Petrobras is the Brazilian state controlled oil company and a major player in the international offshore oil industry, particularly in deep and ultra-deep water operations. Petrobras was created in 1954 to impose state monopoly on oil exploration, production, refining and bulk transport but not distribution and it became the main player in the emerging Brazilian oil industry (Dantas, 1999; Furtado, 1995).

The Brazilian debt crisis in the early 1980s added urgency to the need to increase oil production in the deep water basins and it became clear that because of its institutional role, Petrobras could not wait for the major oil companies and international suppliers to develop the necessary technologies in their own time. This led the company to make considerable efforts to catch up technologically and subsequently to forge ahead with the development of deep water technologies (Dantas and Bell, 2009).

But before becoming a producer of offshore technology, the company had to use imported technology, which was adapted to local production conditions, through a process of incremental innovations. So before starting the bulky programs in technological development, proved consistent with the principle of seeking first the knowledge through external acquisition with improvements (Neto and Costa, 2007).

Having an average depth wells higher than 1000 meters, the need to develop new technologies was the only option to Brazil so he could compete with technology development in the North Sea in the 1980's. After making the decision, Petrobras began an original technological trajectory. Given the absence of scientific knowledge necessary for such undertaking, the country had to fill that space on international experience, which even in a still embryonic way, there was some know how in offshore technology (Neto and Costa, 2007).

Brazilian technological trajectory

From 1973, with environmental condition changes such the first oil shock and the consequent price increasing, Petrobras started its spending on R&D more targeted in exploration and production activities. The main action of the Petrobras Research Center (Cenpes) was to approve the development of its own projects of the rigid system of production platforms. The efforts resulted in three different draft fixed platforms with different sizes and number of devices. These became known as the 1st, 2nd and 3rd

platforms families (Neto and Shima, 2008), representing the first example of endogenous formation of knowledge in offshore oil exploration in Petrobras. However, despite this example, the R&D was still lock-in and, consequently, path dependent, only opened to imported technologies, without its own dynamic site of innovations.

An attempt to change this scenario was the creation of the national Superintendent of Exploration and Production (Supep), with the purpose of monitoring new technologies developed abroad and, with the aid of Cenpes, developed an efficient system of import/unpacking technologies when they were interesting to use in the Brazilian operation. The main action of Supep was to identify the Early Production System (EPS) with the Floating Production System, established in the North Sea in 1975, as solutions to the high cost of production in Brazil, and to facilitate the exploration of distant and deep fields (Freitas, 1993).

The EPS constitute the temporarily use of boats or floating drilling rigs, with the purpose of recognizing the reservoir and anticipate revenue through production with the drilling and operation of a pilot well. The early phase or pilot, permits anticipating the production as the same time relevant data of the reservoir in question is acquired. Thus, the collection of information collected, indicated the economic viability of the oil field, reducing the risk of exploring a field without prospecting trading conditions. Thus, one can characterize the EPS as the anticipated output production by pilot systems and development of the field by steps (Petrobras, 2005).

The EPS has been used in Brazil still in its embryonic state, it was the second time that was being used in oil exploration history. His pioneering use was in 1977, in *Campo Enchova* (Basin *Campos/Rio de Janeiro*), located 120 meters water depth, through a drilling platform. For the permanent stage of production, a drilling platform was installed and converted to production. *A priori*, the permanent phase of the EPS should be operated by a fixed platform, but as the field was located more than 100 km from the coast, making much more difficult the installation of a fixed platform, the option was the floating platform (Furtado, 1996; Petrobras, 2005).

The EPS brought cost reduction, increase in the volume of oil production in Brazil and the beginning of the use of Floating Production System across semi-submersible drilling platforms converted to production. The transformation of platforms to act as producers and not only as drilling was conducted by the Petrobras Department of Basic Projects, which has become one of the largest in the world, of semi-submersible platforms projects (Barbosa, 2004; Petrobras, 2005). Since, it was initiated the use and involvement of other important actors of the national economy directed to a technological design relatively complex, and since it established itself as a new selected trajectory by Petrobras/Cenpes, it is clear that all these arose the strong foundations of a Sectoral Innovation System in the Brazilian offshore industry.

However, the possibility of trajectories breakage usually arises from the unexpected events that create relatively more profitable technological opportunities. More specifically, what happen are changes in market opportunity that alter other conditions of environment (Neto and Shima, 2008). With the discovery of giant fields of *Albacora* (1984), *Marlim* (1985) and *Albacora* Leste (1986), with over 1.5 billion barrels of equivalent petroleum (BEP) and all with over 400 feet deep, has made the beginning of the a new trajectory in offshore deepwater oil exploration. In other words, the new oil discoveries made possible the sustained break of a previous technological trajectory based in imported technologies (fixed structures) and made possible the development on local bases for a new technological trajectory (Neto and Shima, 2008).

Nevertheless, as the trajectories oppose and resist each other, was not at that time that the company surpassed its routine of using existing technologies, and use R&D instead for new knowledge required for the new type of exploitation. At that time there was a whole institutionalized conduct and serious operational difficulties to overcome. An external factor that definitely forced the company to change their behaviour in favour of innovations endogenization occurred only with the Saudi Arabia countershock in 1986. The countershock did reduce the price of an oil barrel, requiring an immediate reduction in production costs of Petrobras, adding to the need for increased domestic production. Otherwise, the option could discourage imports by local production is offshore production costs were not reduced (Neto and Shima, 2008).

This represented a new phase in the company life, since left only accumulate knowledge of operational experience in the use of imported technologies, to gain knowledge aimed in innovations endogenization. Thus, given the need to develop the frontiers of knowledge on the production activity of deepwater oil, Petrobras started Procap[8], based on the Floating Production System. This program, in more than 20 years of existence and three phases, became the main Petrobras coordinator in the function of providing the advance in oil exploration in ever increasing water depths and increasingly adverse conditions as to national self-sufficiency (Neto and Shima, 2008).

[8] Technological training program for deepwater oil exploration created in Brazil in 1986.

4 P&G VALUE CHAIN AND SUPPLY CHAIN

The value chain of Petroleum and Gas, known as P&G, consists of several links to primary and secondary activities. This study will be focused only in the first link of this chain: Exploration and Production (E&P). Firstly, the value chain of the oil exploration and production and their main activities will be presented. Next, we will explore the segmentation of goods and services suppliers (supply chain) that links to the E&P value chain, their main activities and technologies. Following a company's classification that interacts in each supply segment will be also framed.

In the case of offshore E&P segment, technical, technological and existing security demand require the development of highly complex goods and services. Therefore, their activities reveal, in general, a greater potential for value addition and technological density than in other segments of the value chain of the sector (Araújo *et al*, 2012).

The sector of oil exploration is an industry dominated by vertical integration, where large oil companies can cover almost all parts of the value chain. However, the outsourcing industry is a given trend that can bring innovation to a complex sector with many technological challenges. The global investment in oil E&P companies had a weighted annual rate between 1980-2002 average growth of about 3% and between 2002 and 2007 of 22% (Bain, 2009). According to industry analysts, this increase is due to a combination of various factors due to oil production versus demand and costs optimization. The first group of factors are:

- consistent increase in world oil demand since 1980, that does not explain by itself the change seen in investments since 1995 with increasing Asian rate demand of 3% per year (BP, 2008)
- increased need to replace the production of fields that have reached or are reaching maturity (Bain, 2009).

The second level of factors concerning to costs optimization are (Bain, 2009):

- Redefinition and focus on the core business of oil operators: these increasingly directing their attention and effort in the management of reserves and production, hiring vendors to perform numerous activities;
- Optimizing the use of capital by the oil operators: they reduce the need for capital to be immobilized in assets;
- Benefits of sharing costs and investments: service providers and equipment vendors can better promote their cost structures and investments, and sharing this increasingly relevant investment

with the need for development of advanced technologies in particular for smaller industries and neediest national oil operators technology.

4.1 P&G Value chain

The value chain of Oil and Gas (P&G) in a very general form consists of three levels of performance throughout the process: upstream, midstream and downstream. The upstream level corresponds to the initial phase of exploration, development and production of petroleum (E&P). The phase midstream only refers to the movement of oil before being refined and processed gas before. The last step of the process, the downstream concerns the petroleum refining and subsequent distribution of resulting products.

However, the value chain according to the model shown in the figure proposed by Bain (2009), divided into primary and secondary activities or support activities for the implementation of primary. Primary activities are: E&P, Refining, Sales and Marketing. Activities to support this chain are: Services, Transportation and Storage of Energy Trade.

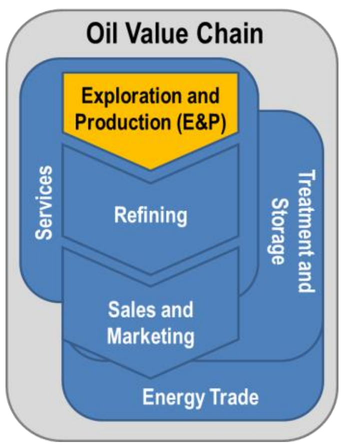

FIGURE 15 – OIL VALUE CHAIN. (Image source: translation from Bain, 2009)

4.2 E&P Value chain

As stated above this study will only focus on the yellow area of the previous figure, i.e., on the offshore exploration and production of oil (E&P). The value chain of processes for E&P in particular, bear a resemblance to a well life cycle in offshore environment, which can be split in a very simplified form, in three phases cycle as the model presented by ONIP[9]. In this model the objectives of each phase of the E&P chain are distinct and well defined, such as (Fernandez and Musso, 2011):

A. **Exploration:** search, identify and quantify new reserves of P&G;
B. **Development:** planning approach and define the resources needed to produce that maximize the profitability of a reservation. Includes all the preparation for the production stage;
C. **Production:** extract oil and gas from a reserve in order to maximize its lifetime.

To complete each stage of the value chain, there are a list of activities that characterizes each phase, such as (Fernandez and Musso, 2011):

Operation:

- guarantee access to reserves through negotiations with public or private entities;
- examine the geology of the subsoil;
- identify potential reservoirs of P&G;
- confirm the existence of the reservoir.

Development:

- evaluate with the aid of the extension wells, production potential and economic viability of reserves;
- investigate the characteristics of the subsurface that can affect production;
- assess possible production scenarios;
- plan the best way to explore, from where the holes should be made until the infrastructure should be used;
- implement the infrastructure for production.

Production:

- extract the oil and gas with various recovery techniques (primary, secondary and advanced);
- activities that maintain the production levels of the reservation optimized (workover);
- shut down its production (deactivation of infrastructure and treatment of toxic wastes).

FIGURE 16 – E&P VALUE CHAIN MODEL.

[9] Created on May 31, 1999, ONIP is a Brazilian non-governmental organization, private and nonprofit that brings together all segments operating in the oil and gas sector.

There are other models for the E&P value chain, for example Oil&Gas UK[10] from UK and INTSOK[11] from Norway but all can be blended into the model shown in the previous figure. From previous figure it is possible to withdraw some reference notes. Firstly, it is emphasized that the maintenance, shipping operation and logistics support are part of the set of necessary activities or secondary activities for the operation. Another point to highlight is that only in Norwegian model the phase of deactivation is part of the chain as a link, which shows the importance of the closing of value chain. In other models this phase is integrated in Production or Operations phase not being highlighted its true importance.

However, according to Onip, and in accordance with the model, that organization lists some of the main activities that say to be primary activities, in each stage of the chain. So, the phase of exploration refers to the following set of primary activities (Fernandez and Musso, 2011):

- Seismic - acquisition, processing and geological mapping;
- Exploration and Evaluation - drilling and evaluation of exploratory wells;
- Probes construction - design and construction of drilling rigs.

The Development and Production phases include the following activities:

- Construction of production facilities - design and construction of FPSO's, semi – submersible platforms and fixed platforms;
- Development of production - drilling of production wells, construction of storage systems and installation of subsea equipment;
- Construction of tankers and support vessels - construction of tugs, anchor handling vessels, supply ships, large tankers, processing units and systems development and management of oil and gas;
- Decommissioning of the well or abandonment of extraction activities.

The secondary but no less important activities comprise the Logistics Support and Maintenance, Modifications and Operations Shipping.

- Logistics Support - supply and support of offshore drilling and production, whether sea, air or land;
- Maintenance, Modifications and Operations Shipping - activities of operation and maintenance of surface.

This will appear in the matrix as the horizontal axis and the model simplified in three phases: Exploration, Development and Production.

[10] Oil & Gas UK is the leading representative body for the UK offshore oil and gas industry. It is a not-for-profit organisation, established in April 2007 but with a pedigree stretching back over 40 years.
[11] INTSOK - Norwegian Oil and Gas Partners - was established in 1997 by the Norwegian oil and gas industry and the Norwegian Government.

4.3 Supply chain segmentation

There are numerous ways to target the services sector and mining equipment and production of E&P. Was adopted for this study the segmentation based on the purpose of each of the services and equipment, which leads to the proposed eight segments (Bain, 2009):

- Reservoirs Information;
- Drilling contracts;
- Drilling services and related equipment;
- Coating and completion of wells;
- Infrastructure;
- Production and maintenance;
- Deactivation;
- Logistical support.

For each segment it is possible to list groups of activities, which helps to understand each supply chain link, such as (Bain, 2009):

- Reservoirs Information:
    - seismic data acquisition
    - seismic data processing
    - imaging of reservoirs
    - data management
    - data integration
    - geophysical services
- Drilling contracts:
    - onshore drilling rigs
    - offshore drilling platforms
    - workover rigs
- Drilling services and related equipment:
    - drill bits
    - Drilling mud
    - solids control
    - Pit Tools
    - rental tools
    - Fishing services
    - directional drilling

    - conventional logging
    - logging while drilling (LWD)
    - log sludge
- Coating and Completion of wells:
    - Steel Pipes
    - casing and tubing services
    - continuous flexible pipe
    - inspection and coating of pipe
    - pumping pressure
    - Coating equipment and cementing
    - completion equipment
    - production tests
- Infrastructure:
    - engineering and design
    - construction and installation of offshore infrastructure
    - Offshore facility infrastructure
    - processing equipment in the field
- Production and maintenance:
    - artificial extraction
    - subsea and surface
    - well servicing
    - Specialty chemicals
    - Compression Services
- Deactivation:
    - plugging and abandonment
    - cleaning services
    - treatment and disposal of wastewater
    - removal and disposal of offshore installations and onshore
    - Passive monitoring
- Logistical Support:
    - Air support
    - Maritime support.

Now that we have a group of main activities for each segment, it is important to know where to put each segment in the value chain. According with several other studies made by specialized institutions like

ONIP, BNDES[12], INTSOK and Oil&Gas UK, the most important is to know for each supply segment where its activities are more relevant in the value chain (Fernández and Musso, 2011; Araújo, 2012; INTSOK, 2005).

Because the equipment and services suppliers for oil exploration are a very high fragmented and complex industry, this means that, the matrix shows the position of each segment in the value chain according to their importance weight in the chain and where they focus their activities (Bain, 2009; Fernandez and Musso, 2011; SPEARS & ASSOCIATES, 2008).

For example, the reservoirs exploration it's the more important segment in the Exploration link chain and is present during the most of the time in that phase. The Drilling contracts are also very important in the Exploration phase but the effective drilling operation jumps to the Development phase as a crucial group of activities for the development phase of the upstream value chain.

The next figure shows the result of this thinking, in a simple matrix holding the main activities in the upstream value chain (in horizontal axis) and supply chain segmentation (in the vertical axis) in offshore oil exploration. It's important to notice that to this point forward the relative position of each segment in the value chain will be maintained, only the contend will change.

[12] Created in 1952, BNDES is the Brazilian Development Bank which is the main financing agent for development in Brazil.

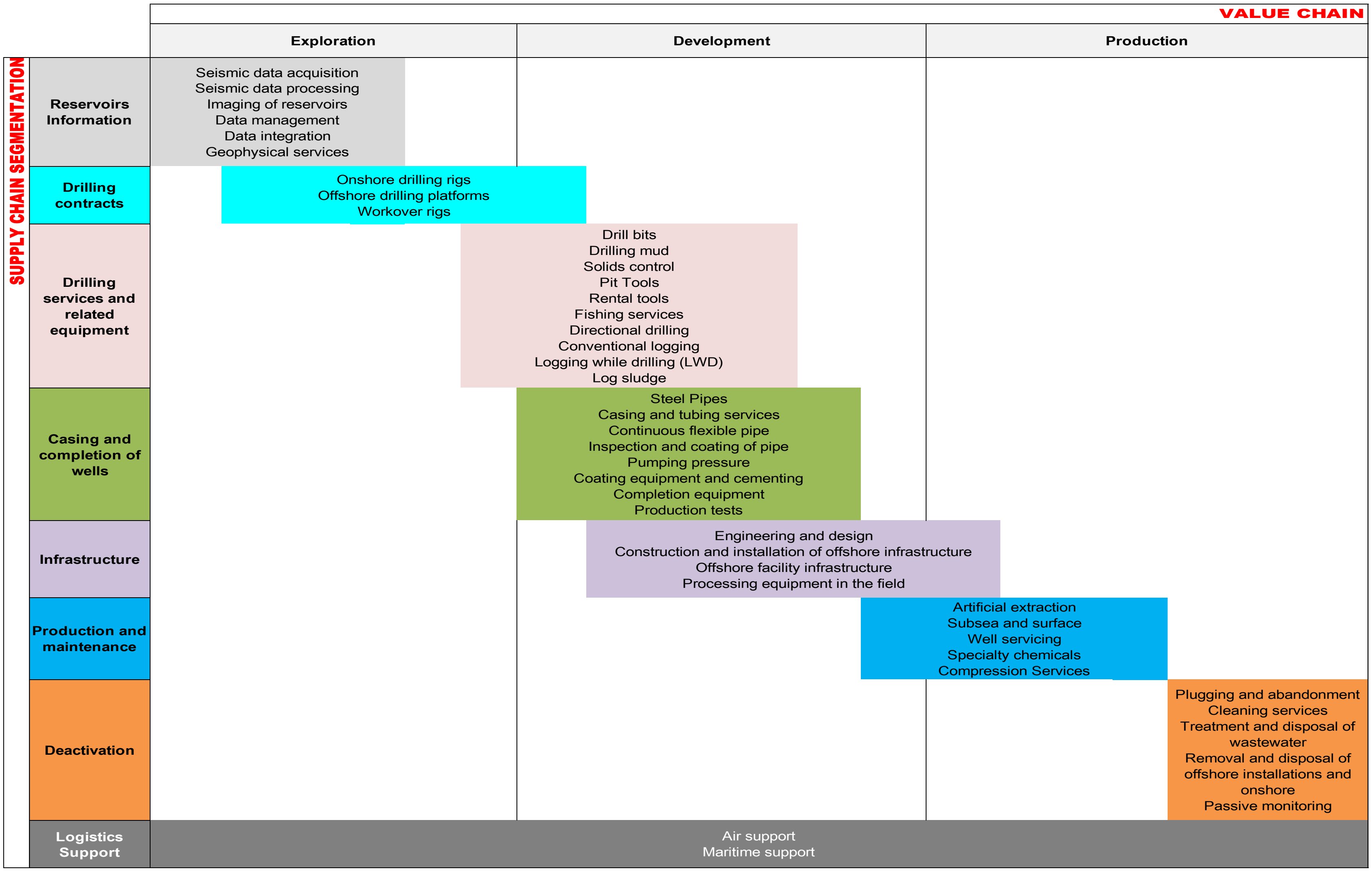

FIGURE 17 – ACTIVITIES IN THE UPSTREAM VALUE CHAIN AND SUPPLY CHAIN SEGMENTATION IN OFFSHORE OIL EXPLORATION.

4.4 Technology segmentation

Increasingly sophisticated methods and technologies have been developed that increase the odds of making a discovery in less obvious situations. This section covers some of those technologies and describes each segment importance in the history of how exploration well is evaluated and how it is carried out to surface.

4.4.1 Reservoirs Information

Information reservoirs can be considered the first group of activities of oil exploration. This segment aims to identify hydrocarbon reservoirs, estimating their characteristics using models and strategies to confirm these theoretical results. The techniques commonly used by geologists for this are three: gravimetric exploration, magnetic exploration and seismic exploration (Hyne, 2001).

The gravimetric exploration is a method in which the gravitational field sensors are used to measure anomalies caused by variations in density near the surface of bodies and can detect mainly calcareous salt domes and reefs. Magnetic exploration involves the use of magnetometers to identify variations of the geomagnetic field. This technique is used primarily to detect variations in the depth and composition of basement rocks (Bain, 2009). Several techniques can be used in the methodology of seismic exploration, but despite the differences in sophistication, all are based on the use of seismic waves, which are directed to the ground and have their reflections captured and analysed. The most common techniques are (Herrmann *et al.*, 2010):

- 2D – A single line of acquisition data is recorded, so meaning that an interpretation can only be made on a single slice of the earth. This is typically used for fast surveys of large areas in virgin territory.
- 3D – multiple parallel lines of data are acquired, so allowing a cube of interpreted data to be created, giving a 3D image of what is happening subsurface. 3D data is usually acquired when either 2D and/or exploration drilling throws up something interesting that needs to be investigated in greater detail, or when existing seismic data is of an older generation.
- 4D - this involves running the same seismic surveys again and again over time. The idea is the possibility to see how the fluids within a field move over time. In practice it has had limited success and is not a widely used application.
- Multi azimuth – The idea is to ‘illuminate’ more of the target subsurface geology than is possible with conventional 3D (below attenuating salt domes for example). This is achieved by using

more than one energy source location (i.e. there will be at least two vessels shooting air guns during the survey).

The seismic exploration allows the collection of information on the composition, fluid content and the extent and geometry of rock layers underground. The activities involved in the methodology of seismic exploration can be grouped into four steps: seismic data acquisition, processing of acquired data, imaging and reservoir interpretation technique (Bain, 2009; Araújo *et al*., 2012).

Three–dimensional seismic surveys have probably done more than any other modern technology to increase the likelihood of exploration drilling success (Alfaro *et al.*, 2007). Conventional marine 3D surveys acquire data from a vessel sailing in a series of adjacent parallel straight lines. The vessel is typically equipped with one or two airgun source arrays that generate seismic waves, sensors (hydrophones) and 8 to 10 streamers (see Figure 16). When the vessel reaches the edge of the defined survey area, it continues in a straight line for one-half the length of a streamer, and then turns around in a wide arc to position itself for another straight line in the opposite direction, as if following the course of a simple racetrack (Herrmann *et al.*, 2010).

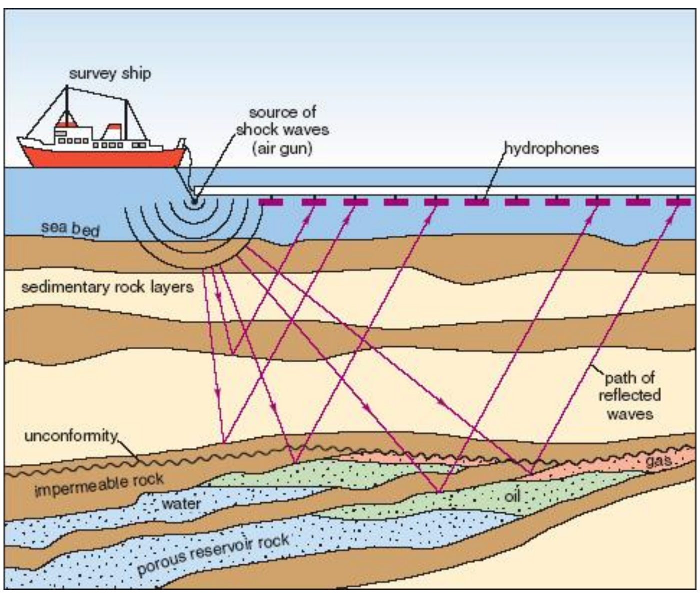

FIGURE 18 - MARINE SEISMIC ACQUISITION: pulses of sound energy penetrate the subsurface and are reflected back towards the hydrophones from rock interfaces. (Image source: Open University site)

The mathematical models developed in the processing stage are again treated by specific software in the imaging step, to graphical models, which allow the visualization of the different types of soil obtained. These graphical models are the basis of studies of data interpretation, which aims to infer the existence of hydrocarbon reservoirs in the study area step (Bain, 2009).

4.4.2 Drilling contracts

The drilling rig represents the culmination of an intensive exploration process. When seismic data highlight a suitable prospect, the next step is to drill into the reservoir in order to establish whether or not petroleum is trapped, and, if it is, to establish how large the accumulation might be. Only by drilling a well can a prospect be validated.

Oil companies usually hire a drilling company to drill their wells. The drilling contractor provides a drilling rig and crew (Varhaug, 2011). These rigs can be mounted on ground structures, onshore, maritime and offshore. The probe assembly of the offshore structure and aggregate equipment (for example, mud pumps) is known for drilling platform. According to site conditions and especially the depth of the water depth, are used distinct drilling rigs (Bain, 2009; Varhaug, 2011):

- Submersible: platforms in wetlands and bogs up to 85 feet (25 m), who's supporting structures that are supported in the bed. Have ferry, buoyancy format for easy transfer and fill with water to achieve the correct position;
- Jack-up platforms: with floating hull and retractable legs that are lowered to the seabed, raising the hull above the water level and reducing the effect of waves and currents. Operate at depths of up to 400-550 feet (120-170 m);
- Semi-submersible: platforms used at depths up to 10,000 feet (3,000 m) that have no support structure in contact with the bed. To ensure stability, makes use of submersible structures, mooring systems and dynamic positioning systems;
- Drill ships: the probe is installed on a ship that can operate in water depths up to 10,000 feet (3,000 m). These ships are equipped with dynamic positioning system and stability.

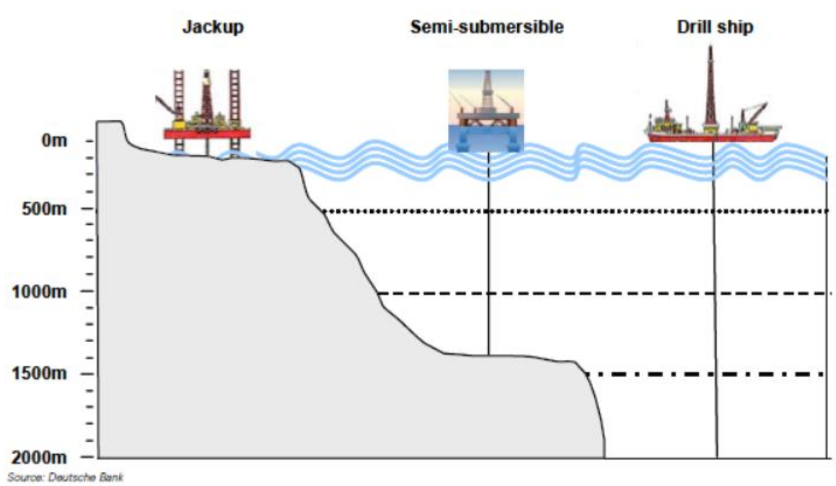

FIGURE 19 – OFFSHORE RIGS. (Image source: Investmentpedia site)

4.4.3 Drilling services and related equipment

Oil and gas reserves lie deep beneath the Earth's surface. Geologists and engineers cannot examine the rock formations in situ, so tools called sondes go there for them. Specialists lower these tools into a wellbore and obtain measurements of subsurface properties. The data are displayed as a series of measurements covering a depth range in a display called a well log. Often several tools are run simultaneously as a logging string and the combination of results is more informative than each individual measurement (Anderson, 2011). The activity of producing wells involves (Bain, 2009):

1. drilling sondes;
2. drilling platforms;
3. a series of aggregate equipment (e.g., mud pumps, cranes).

Besides these aggregate equipment, which is a constituent part of the platform, a number of other tools, known as equipment and supplies are essential for numerous drilling activity. Conventional logging is a work of analysing the characteristics of the rock, fluids and gases found in a well, and the added value of this activity focuses on the operation of the service equipment and the subsequent study, more than simply selling or making available instruments measuring needed. For a clearance of this segment it's important to separate consumables and less technological drilling tools from drilling services with high technological content. The first group of consumables are (Bain, 2009):

- Drill bits: The goal is the main supply of drill bits of all kinds, appropriate to the particular requirements of each application. For this, besides manufacturing drills, it is necessary the design, development and/or selection of the best solution for each case;
- Drilling mud[13]: The main purpose is the provision of drilling muds and fluids, tailored for each particular application, and the development and/or selection of the best alternative for each job is a service usually offered by companies operating here;
- Solids Control: The main objective is filtering and controlling sludge characteristics (e.g., density and viscosity), and perform final disposal of these. For this purpose, specific equipment is made available by sale or rent;
- Tools Pit: Aims at providing various equipment used in operations carried out in the well (as precursors, security seals);
- Tools renting and fishing service: The objective is the provision of well tools (e.g., enlargement tools) or recovery of lost objects or tools into the well (activity fishing). These equipment because of his specificity, usually they are not operators or drillers ownership.

The second group and technological drilling techniques are (Mantle, 2013/2014; Bain, 2009; Anderson, 2011):

[13] Drilling muds are pumped fluids through drill pipe and returned through the longing formed by this pipe and the well. The main functions of these fluids are cooling the drill bit reduce the corrosion of pipes and coating and lubricating chip removal, maintenance of a positive hydraulic pressure and the well.

- Directional Drilling: The ultimate goal is to drill wells in the different vertical perforations or requiring changes in directions[14]. Generally, providers offer the necessary equipment (such as drilling, stabilizers and measurement instrumentation engines during drilling) in conjunction with teams of specialized operation;
- Wireline logging: The goal of this sub-segment is the delivery of a number of geophysical information that allows inferring the presence of oil and/or gas reservoir with a potential determined precision. For this, the suppliers provide special equipment (e.g. measuring instruments) and operations teams and perform the analysis of the results;
- Logging while drilling: Allows real-time delivery of geophysical information along the drilling activity. To do so, it is used more robust measurement instruments that can be added to the drill string, thereby achieving measurements simultaneously;
- Registration of mud: The objective of this sub-segment is delivering information related to the chips, gases and fluids contained in sludge returning from the wells during drilling. Suppliers provide the specific equipment and teams to test samples.

Wireline logging today still uses the same basic technique – i.e. the lowering of instruments to the bottom of a well, then pulling them up slowly with a winch, whilst recording in high resolution (and with high depth accuracy) the information provided by the instruments. The main wireline devices ('tools') used today are the following (Bain, 2009; Anderson, 2011):

- SP (Spontaneous Potential) – helps detect water bearing reservoirs.
- Gamma Ray – indirectly detects the level of clay in the formation.
- Resistivity – indicates possible hydrocarbon zones.
- Micro resistivity – very shallow and high resolution resistivity – helps indicate permeability and detect thin beds.
- Calliper – measures the diameter of the well, in either 1 or 2 axis.
- Neutron and density – porosity and lithology (identifies sandstone, limestone, shale, carbonates, volcanic). Also helps discriminate between gas and oil.
- Sonic – porosity and gas indicator.
- Formation imaging – hundreds of micro-resistivity sensors combine to give a 360 degree, very high resolution resistivity image of the well wall. Useful for fracture detection and lithological analysis.

[14] Directional drilling is used, for example:
- When you need to reach the reservoir through multiple wells from a single production platform;
- When a horizontal well is the only solution to achieve acceptable production flow in a narrow shell;
- When offshore reservoirs must be attained from the coast;
- When the location of a drilling rig or platform of the wells is difficult;
- when it is necessary work around obstructions.

- Wellbore seismic – a 'quickshot' ties in the surface seismic to depth rather than just time. A full 'VSP' (vertical seismic profile) survey gives a single seismic column that can be overlaid with a surface seismic.
- Pressure and fluid sampling – reservoir pressure gradient measurements discriminate between oil, gas and water zones. Reservoir fluid samples can be brought to surface for further analysis.
- Sidewall cores – samples of down-hole rock from specific depths are brought to surface and then used for further analysis.
- Magnetic resonance logs – measure formation permeability.

The oil company will decide which combination of the above services are required for a particular well, but in general most exploration wells will have a combination or all of the above wireline services run.

4.4.4 Casing and completion of wells

After drilling the following required steps are casing and cement the well. The casing process which involves installing steel pipes and cementing the newly opened well prevents the collapse during oil extraction. More than ensuring the structural integrity of the well itself, it is necessary to perform a series of activities, call completion, such as installing pipe production, production and final preparation of casing tests. To those tasks accomplishment, a number of equipment and services are required and these may be organized into eight sub-segments (Bain, 2009):

- steel tubes for casing and production tubing (OCTG[15]);
- casing services and installation of production tubing (casing and tubing services);
- services of continuous coiled pipes (coiled tubing services);
- inspection and casing of pipes (inspection and casing);
- services pumping pressure (pressure pumping);
- Casing and cementing equipment (hardware casing);
- completion equipment (completion equipment);
- production tests (production testing).

The steel tubes for coating and production tubing (OCTG) is the second largest sub-segment coating and completion of wells and has as final products not only steel tubes themselves, but also related accessories (such as connections). The pipes and fittings are used in various applications, for example (Bain, 2009):

- columns drilling (drilling contracts);

[15] The acronym OCTG corresponds to the English term Oil Country Tubular Goods, used to designate the tubes and associated connections used for pipe casing and production of P&G.

- well casing;
- production tubing.

There is a huge variety of steel pipes and fittings, but a key difference is the presence or absence of joints on pipes. Continuous tubes are an end product of steelmaking processes while the manufacture of seamed pipes employs sheets and coils of rolled steel (PROMINP, 2008).

Wells are nearly always drilled in stages, and when the bottom of each stage is reached the freshly drilled hole, known as 'open-hole', is cased off using steel pipe and so becomes 'cased-hole'. The main reason is to prevent the well collapsing on top of the drill pipe (which might otherwise become stuck). This is called the casing process (Herrmann *et al*, 2010).

The pumping pressure services consist of pumping a fluid or viscous substance through the casing or production tubing at high pressure. These services have as their main purpose cementing and stimulation (Bain, 2009):

- Cementation: To 'set' the casing it is first lowered into the well, then the drill-pipe is lowered (without a drill bit on the end) down inside the casing to the bottom, and is used to pump cement up the annulus between the outside of the casing and the hole. This cement will set and bond the casing to the rock formation that has been drilled through. In this way then the casing and cement together should isolate different reservoirs from each other and from the surface;
- Stimulation: are techniques that use high pressures to increase production of a formation. There are various stimulation techniques, such as acidification and hydraulic fracturing.

Once a well has been drilled to total depth, evaluated, cased and cemented, engineers complete it by inserting equipment designed to optimized production into the well (Flatern, 2011/2012). Some of the equipment used is (Bain, 2009):

- Permanent or reusable sealant (retrievable and permanent packer) is an expansion cap, usually made of rubber, placed in a well to block the passage of fluid;
- Joint seal (bridge plug) is a set of seals with conical wedges and a glove rubber seal. It is placed in the well to isolate a production zone to test zone at a higher level;
- Casing support (liner hanger): these are mounted wedges with interchangeable teeth together and sealants, used to support a coating on the bottom section of the production casing column;
- Multilateral Completion (multilateral completions): are all kinds of equipment for multilateral completions (e.g., junctions, side entry modules, splitters);
- Intelligent completion system (intelligent completion system) is a set of equipment that allow you to monitor and control remotely and selectively supplies of oil, gas and different areas of well water;

- Expandable tubing (expandable tubulars) is a device that lets you expand the well casing through different techniques. The expansion of the coating is critical in very deep wells to prevent the progressive reduction of the diameter of this.

After a cementing operation has been performed and the cement has set, engineers frequently perform tests to confirm that the cement sheath integrity and performance meet the intended design criteria. Production tests also determine production rates from the well, before concluding with the casing activities and completion of the well. Operators rely on suppliers that provide equipment and specialist teams to carry out those various tests, such as (Bain, 2009; Nelson, 2012):

- Drill steam test: specific equipment is installed in the drill string and lowered into the well. Once isolated the area of interest, the flow of hydrocarbons is measured and recorded with such equipment;
- Surface production test: specific equipment is installed in drilling rigs aiming to control the pressure, measure the rate of production and the three separate fluids normally present in a well: oil, gas and water;
- Pressure test: Special instruments are installed in the drill string to measure the pressure for different production conditions in an area of interest previously isolated.

4.4.5 Infrastructure

Once the wells are completed, adequate infrastructure must be installed so that production can be initialized. Offshore infrastructure production involves not only the platform assembly itself, but all required equipment to connect to the well. There are many kinds of production platform and depth seabed is the main criteria for choosing between each. For application in shallow water, it becomes feasible to use fixed platforms, i.e. whose supporting structures are placed directly on the seabed. There are basically two types of fixed platform (Bain, 2009):

- Fixed Platforms: have rigid support structures (up to 450 m);
- Oscillating: feature star-shaped structures, trapped in a hanging card, allowing oscillatory movements (450-900 m).

In deeper waters, it is not possible to build a fixed platform and, therefore, is employed floating platforms. There are several types of floating platforms (Bain, 2009; Herrmann *et al*, 2010):

- TLP (Tension Leg Platform): floating structure anchored to the seabed by steel cables under high pressure, thus ensuring high stability (450 - 2150 m);
- Mini - TLP: follows the same concepts of TLP only on a smaller scale, enabling the production of smaller reserves (150 - 1100 m);

- SPAR: consists of a large cylinder with a deck mounted on its top in its location by anchoring. A platform type relatively inexpensive to build, but provides limited stability (600 - 3050 m);
- FPSS (Floating Production Semi - Submersible) superstructures supported by tanks that are partly filled with water, thus guaranteeing excellent stability in rough and deep waters. These are held in place by mooring systems and dynamic positioning systems (200 - 1,700 m);
- FPSO (Floating Production, Storage and Off-take vessels) or converted vessels built specifically for the production activity. Different systems are used to keep them in the correct position, ranging from simple to complex anchoring mechanisms of dynamic positioning. The use of the FPSO involves the use of subsea systems (60 - 2600 m).

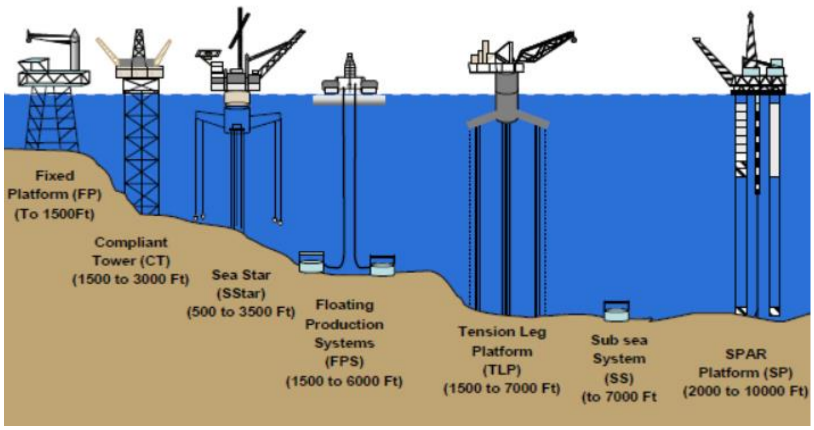

FIGURE 20 – DIFFERENT TYPES OF PRODUCTION PLATFORMS. (Image source: Deutsche Bank)

The first step is the construction of infrastructure engineering, whose ultimate goal is the design/detailed specification of the platform. Three groups of activities are included in engineering (Bain, 2009):

- Conceptual design: defining the technical and commercial feasibility of continuing the project;
- FEED (Front End Engineering Design): next step in the project design that seeks greater detail and accuracy in cost estimates. Final product is a technical document used in the bidding process;
- Detailed Engineering and complete detailed design specification for the beginning of actual construction.

4.4.6 Production and maintenance

A platform is all that can be seen from the surface for a typical offshore development, but on the seabed all the development wells (whether producers or injectors) need to be connected to gathering stations to the platform. This is usually done via small diameter rigid and flexible pipes that are installed by a specialist installation company and such hardware is collectively known as 'SURF' – subsea, umbilicals, risers and flow lines. Subsea units are production units that sit on the sea bed, feeding oil or gas from a well through a flow line to a manifold, which collects the hydrocarbons from numerous wells. Each manifold is connected to an umbilical and a riser. The former is a pipeline which carries hydraulic, power and communication cables, which enables the operator on the surface facility to control valves on the manifold. The latter is the piping through which oil or gas travels to reach the surface (Herrmann *et al*, 2010).

With installed and ready for production infrastructure, operators still rely on the supply of equipment and services directly related to the actual production and maintenance of infrastructure. The best way to explain what is included in this segment is simply describing their six sub-segments (Bain, 2009):

- Subsea equipment;
- Surface equipment;
- Artificial lift;
- Well servicing;
- Specialty chemicals;
- Contract compression services.

As the surface equipment, the purpose of subsea equipment is to control the flow of hydrocarbons from a well or several wells into production. Regardless of being an offshore well in shallow water or onshore, this equipment are positioned above the surface and connected by pipes to the wells. The main types of equipment are (Bain, 2009):

- Casing heads and tubing: structures that allow the connection of the drive pipe and the surface equipment, such as christmas - trees;
- Christmas - tree: system placed above the head or top of the casing/tubing, which controls the flow of oil/gas from the well;
- Safety shutdown systems: automatic closing systems of valves which ensure the safe operation of subsea production system;
- Gauges and flow control equipment: temporary system of valves, pipes and collectors necessary for the pressure injection or the sludge in the pit.

Intended for deep water production, they differ from surface equipment because most of the components of the complete system are positioned on the seabed. The main equipment that is included in this category is (Bain, 2009):

- Submerged Base (template): valve assembly mounted at the head of submerged well that is already in production;

- Christmas tree: fulfils the same function as the systems of production in the surface with the difference that here is submerged;
- Manifold: set submerged valves similar to those to load and unload a tanker ship (on deck) that serve to targeting the production of several wells;
- Umbilicals: wires and union hoses between the bell (or other equipment) and its unit release;
- Flexible or rigid pipe flow (flow lines): pipe which flows through the oil or gas produced.

In artificial extraction equipment is used to extract fluids out of the wells, particularly those whose natural upward pressure is not sufficient. In some cases, this same technique is used in order to accelerate the extraction. Various techniques are used, but basically can be grouped according to their most appropriate use in subsea production systems or surface (Shepler *et al.*, 2005). However, there are two techniques used in subsea systems:

- ESP or electric submersible pumps;
- lifting gas.

Four techniques are used in production of surface systems:

- Built-in pump (Rod lift);
- PCP or progressing-cavity pumps;
- Lift the plunger (plunger);
- Hydraulic pump (hydraulic lift).

Specific chemicals are consumables used for:

- Extend the life of equipment E&P;
- Improve the composition of oil or gas (for example, decrease the amount of water in the oil);
- Repair fluids that aid in the extraction of oil and in the reduction of losses, as in cementing and stimulation.

These products can be applied by the operator or by the specific chemical suppliers. The well servicing segment encompasses a multitude of maintenance and wells repair services. The range of services is so vast that there is no formal ratings market for them. Just as a reference, some of the services included are (SPEARS & ASSOCIATES, 2008):

- simple rod jobs;
- swabbing;
- water hauling;
- site preparation;
- roustabout services;

- hydraulic well control;
- snubbing;
- plugging;
- well abandonment;
- bottom-hole pump changes;
- well bore cleanouts of sand or fluids using coiled tubing;
- pressure testing and purging flow lines/pipelines/plant manifolds;
- well kick around to clean up for perforating or other well operations;
- kick start well;
- circulate free stuck drill pipe on drilling rigs;
- free down hole equipment through circulation of nitrogen;
- deepening;
- side-tracks;
- horizontal drilling.

All activity of compression applied before the pipeline (pipe through which the gas is sent from the platform to shore or infrastructure consolidation of production) is considered compression field. The main activities within this sub-segment are (Bain, 2009):

- Wellhead: gas compression is used to maintain or increase the pressure of the extraction operations. This activity is especially appropriate for mature wells so that its life cycle is extended;
- Gas capture: compression is necessary to combine the flows from several wells for subsequent injection into a line capture (gathering line);
- Processing: gas compression is required to combine the various capture stream lines with the purpose of processing/ final treatment and to increase the pressure before entering the pipeline system.

These activities can be performed by services providers (compression services or systemists) or by oil operators, who buy and operate such equipment (Bain, 2009).

4.4.7 Logistical support

To support all activities involved in the exploration and production of P&G, logistics services of various natures are used, divided into air support and maritime support (Herrmann *et al.,* 2010). For that purpose there is an entire industry that simply services the logistical needs of the offshore drilling industry. The offshore support services are of several types, such as (Bain, 2009):

- transporting people and light loads;
- transport of equipment and supplies for drilling and production platforms;
- towing of mobile drilling rigs and production, lacking own power;
- transport and positioning of anchors for drilling and production mobile platforms;
- support movement's drilling mooring and production mobile platforms.

Air support is focused on transporting people and light loads fundamentally between the coast and offshore structures or assets, transportation to onshore regions of difficult access and emergency support. These services mostly employ a few helicopters. Helicopters are divided by their ability to load: light, medium and heavy (Bain, 2009).

The boats used in maritime support are of various types, it is possible, according to the study by Pinto *et al*. (2006), classify them into three main groups:

- Tugs/Suppliers: vessels are medium sized (60 to 80 meters long) with towing capacity to supply drilling and production platforms, and the ability to transport and anchor handling;
- Suppliers: vessels are medium sized (60 to 80 meters long) whose main function is to transport supplies and equipment required by the operation and maintenance of production facilities and offshore drilling. Vessels of this group have the transport capacity of loose dry cargo in bulk or in containers (e.g., pipe, spare parts and food) and/or liquid cargo (such as drilling fluids and fuels). These ships do not have equipment to handle anchors and are not able to tow other vessels;
- Small vessels and Utilities: smaller vessels (20 to 40 meters long) used in various services, such as passenger and light cargo handling spies and supporting anchorage manoeuvres.

At the end of the life cycle of a field, wells should be abandoned and disabled production infrastructure, fulfilling a number of requirements set by the legislation of the country where they are located.

4.4.8 Deactivation

The processes of well abandonment and decommissioning of infrastructure vary from case to case according to current regulations, geographical conditions and characteristics of the premises concerned, thus requiring the development of a specific project. These processes involve a series of activities grouped into seven steps (Bain, 2009):

1. <u>Planning and obtaining deactivation permits</u>:

    - definition of disrupting operations of the field;

- pre - deactivation studies (geophysical, environmental, structural and process) that objectify obtaining information necessary to develop the best plan for decommissioning;
- analysis and selection of the best/most viable option for deactivation;
- structuring the decommissioning program of infrastructure and abandonment of wells;
- obtaining permits, approvals and other regulatory requirements;
- Basic and detailed engineering of deactivation;

2. <u>Abandonment of wells:</u>

- isolation of production areas of the wells by installing cement plugs;
- total or partial cutting and extraction of coatings and pipe production;

3. <u>Preparation of facilities for removal:</u>

- cleaning and removing any remnants of oil and hazardous substances (e.g. toxic, flammable) present in pipes and equipment on the premises;
- cutting connections between the production infrastructure and wells (as umbilicals, power cables and instrumentation cables);
- cutting the connections between the production platform and the shore or consolidation units of production (e.g., gas and oil pipelines, power and interconnect cables);

4. <u>Abandonment of pipelines:</u>

- cleaning and removing any remnants of oil and hazardous substances in pipelines;
- Cut the pipes into smaller sections for easy handling and transport provided;
- Lifting, conveying and storage of recoverable products;
- sinking sunk ducts;

5. <u>Removal, transportation, storage and/or sinking of structures:</u>

- cutting and removal of topside production platform;
- cutting and removing the support structure (jacket) of the production platform;
- transport and storage ashore or sinking of infrastructure (where permitted);

6. <u>Clean and check the website:</u>

- Final disposal of hazardous substances;
- Review and removal of debris on site;
- inspection of the seabed;

7. <u>Subsequent inspections to deactivation:</u>

- analysis of hydrocarbons;
- Analysis of heavy metals;
- Analysis of local biological activity.

At this point a most complete matrix is ready to be show, with the purpose of better visualising the value chain vs supply chain in more detail, with main known technologies. In this matrix it is represented the value chain phases, the supply chain segmentation, and for each cross point in the matrix there is a characterization by sub-segmentation of goods and services and by the main known technologies.

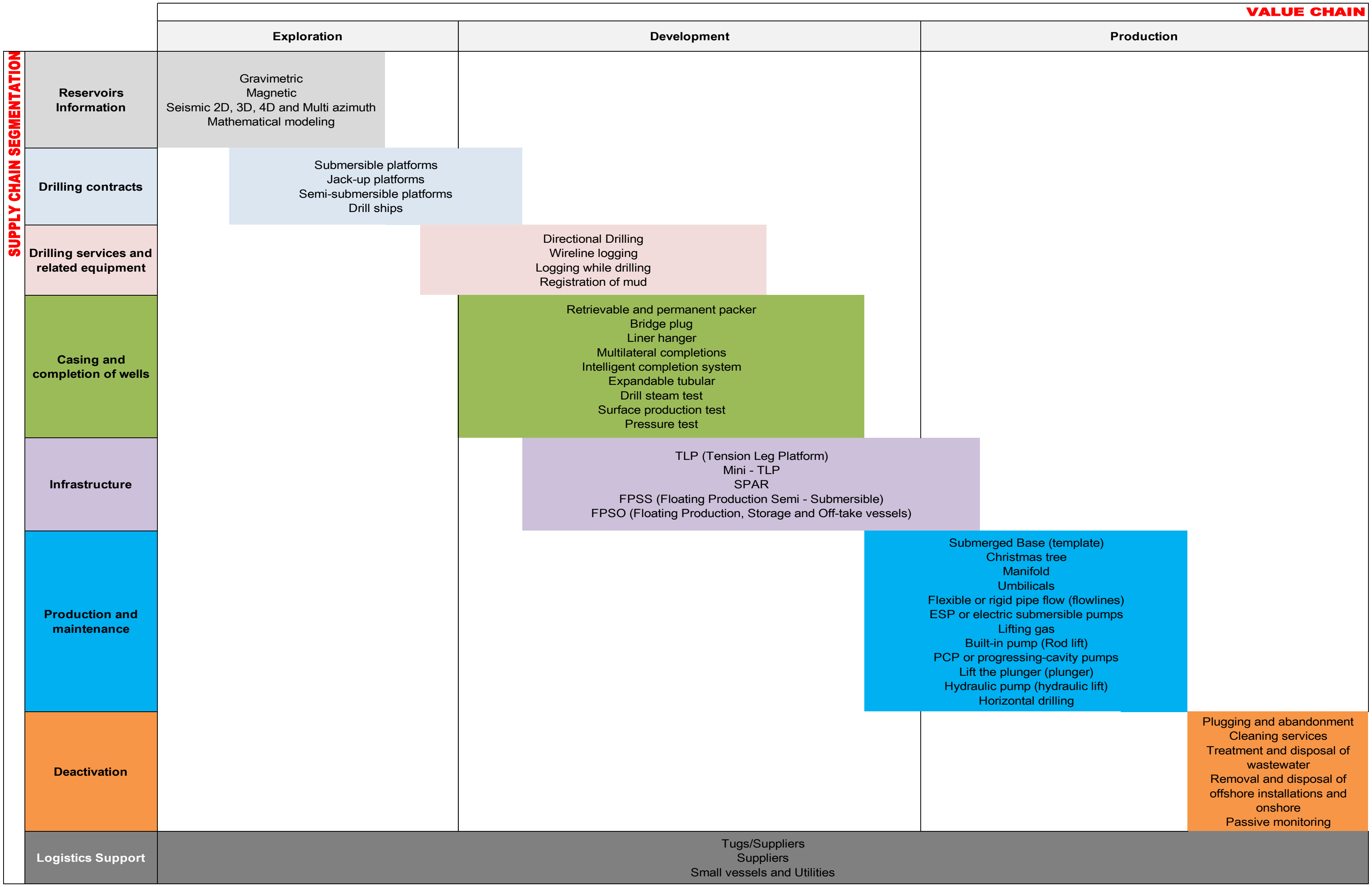

FIGURE 21 – TECHNOLOGIES IN UPSTREAM VALUE CHAIN AND SUPPLY CHAIN SEGMENTATION IN OFFSHORE OIL EXPLORATION.

To continue it is important to explain some assumptions that simplified this study. First of all equipment and services required throughout the production cycle, have their origin in the operator (oil companies), who is responsible for the transformation of the oil reserves, the one that defines the specifications and requirements of service level for the chain as a whole. So the first assumption in this study is that the oil operator is not going to show up in the supply chain matrix, assuming the central character of the operator in the value chain.

On the other hand there are large contractors who sell goods and services directly to the oil companies (supply chain drivers or main contractors). Then there are more specialized companies which sell products and services to contractors. These in turn can have their own subcontractors. So because of this complexity, in this study it is assumed that they are all contractors "at the same level" and try to group them by type of goods or services they provide. The huge fragmentation of this industry with businesses of all backgrounds and abilities adds difficult to the segmentation of the supply chain. Nevertheless according to the scope of the segments served, these companies can be classified in seven different forms (Bain, 2009):

- Integrators: companies like Schlumberger, Halliburton, Baker Hughes and Weatherford, which originated in the early P&G industry and through acquisitions of other companies, currently serving in various segments of the service and E&P equipment with high focus sector in providing services with higher technological content;
- Drillers: companies dedicated to the provision of drilling services;
- EPCists: companies whose original business is providing engineering, procurement and construction services (also called Main Contractors);
- Equipment manufacturers: companies dedicated to the manufacture of equipment and consumables, as well as the provision of services related to these;
- Logistics companies: companies that provide logistics services, such as shipping of supplies and equipment;
- Niche companies: company who focus on a niche market, for example, providers of seismic exploration services;
- Systemists/Module suppliers: Companies that provide large containers in which are housed the various units of equipment such as: energy sources, sets of motor pumps, control equipment, recycling plants dump, etc., installed on a platform.

At this point it's possible to represent a matrix of segmentation *versus* the classification by type of company supplier, like in next figure, according with their main participation in each segment (SPEARS & ASSOCIATES, 2008).

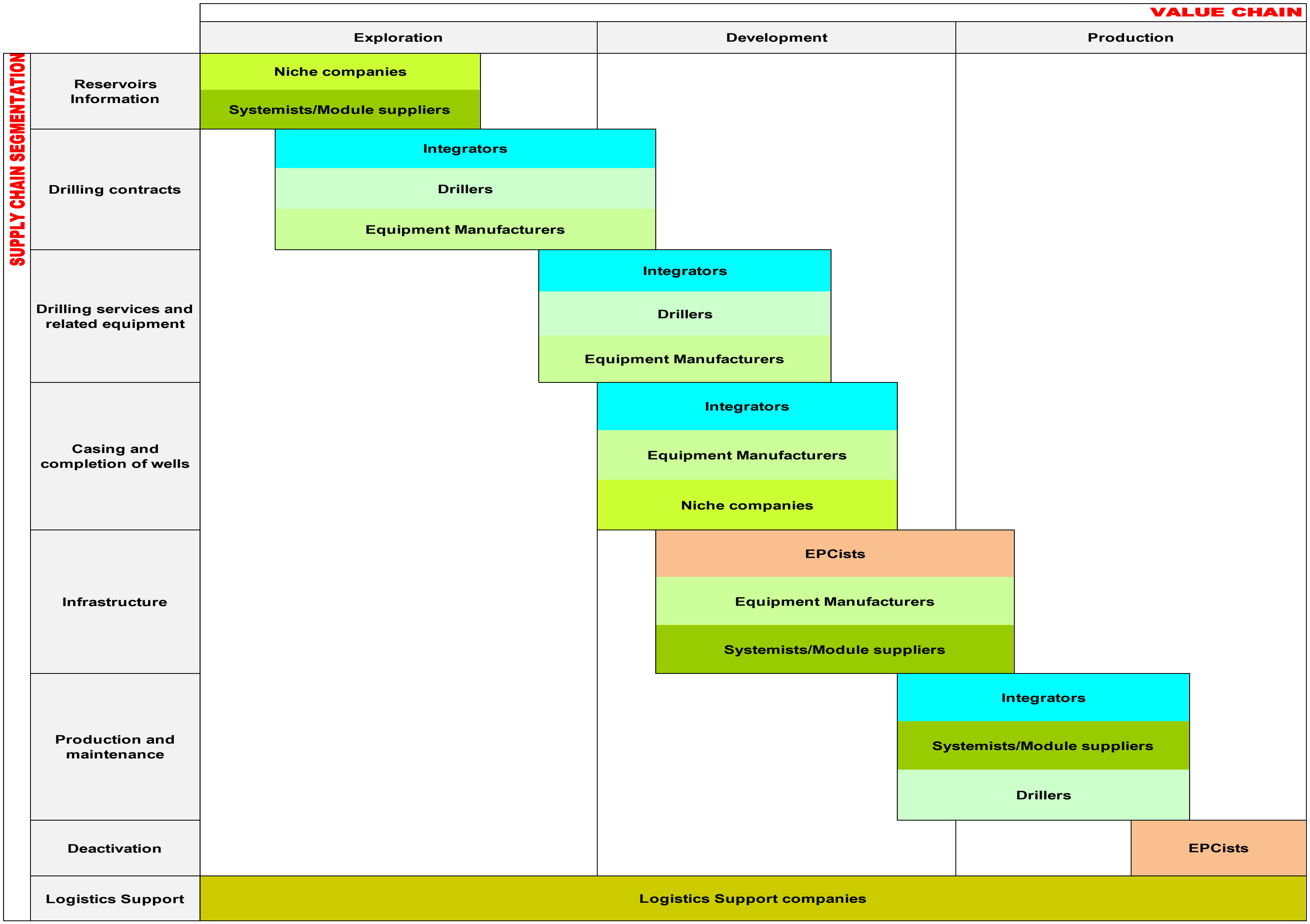

FIGURE 22 – COMPANIES CLASSIFICATION IN THE SUPPLY CHAIN AND VALUE CHAIN MATRIX.

5 TECHNOLOGICAL CHALLENGES OF PRESALT OIL EXPLORATION

Now that we have a representation of the main and known technological matrix for deep water exploration, it is important to know the presalt technological challenges. The first challenge starts with the exploration blocks extension, with over 800 km length by 200 km width, the distance between the blocks and the coastline of about 300 km. In addition to the consequent logistical challenges given the distance from the coast until the oil, there's still a way too long to get there. It is needed to go through 6 km of ocean and 1 km from the post rock-salt layer. Then is still necessary to go through 1 to 2 km of salt layer thickness.

For its geological features, the exploitation of oil in presalt layer marks also new challenges in more resistant technology to corrosion, high temperatures and pressure. Some of the technology areas where the challenges are significant are in materials and temperature. When drilled, the salt can exert tension and close the wells. Therefore it is necessary to create a steel shell filled with special cement. The temperature adjustment is important because the oil comes out of the hot rock and can form precipitation to enter the flexible lines that are in contact with the sea ice.

To overcome these challenges there are technology research ongoing by oil companies and other actors in oil exploration worldwide. So according with this main resource of known and free information, it will be presented next for each supply chain segment the most known technology developments for deepwater and presalt oil exploration.

5.1 Reservoirs information

Coil Shooting

Changes to seismic survey methods aimed at increasing azimuthal coverage have also added to the industry's ability to visualize subsalt formations (Alfaro *et al*., 2007). In addition a new seismic acquisition method, shooting in circles, has been affective at imaging below salt and other reflective layers and requires fewer vessels than wide-azimuth or rich-azimuth techniques (Buia *et al*., 2008). This type of technology, named Coil Shooting, emerged with the conclusion of seismic data processing in presalt Santos Basin, developed and patented by the company WesternGeco. This seismic acquisition technique enables obtaining multi-azimuth data from a single ship sailing in circular paths. Thus, allows multi-azimuth seismic survey into areas with restricted vessels manoeuvres and reduced costs when compared to standard techniques, like Wide-azimuth for areas up to 500 km^2 data acquisition requiring four vessels for that purpose. The main advantages of multi-azimuth techniques such as Coil Shooting and Wide-Azimuth, are the ability to raise data from regions in which the geological complexity would not be properly captured by conventional acquisition techniques (Petrobras, 2013).

Full Wave Inversion (FWI)

The seismic model accomplished by Petrobras in the presalt Santos Basin, allows simulations for testing new migration and inversion techniques, Full Wave Inversion (FWI), plus lighting studies. The results will improve presalt targets interpretation conditions, for better seismic images. The developed model - a propagation speed cube of compressional seismic waves - was constructed based on information from seismic and wells data, previously acquired (Petrobras, 2013).

5.2 Drilling contracts, services and equipment

Connector with flexible riser assembly without folding

The new connector on top of flexible risers for application in deep water and ultra-deep water depths is an innovative design that allows the anchoring of the pipe in connector without bending the traction support. This improves the structural performance of traction support, enabling greater fatigue resistance of the riser system. The concept was developed and patented by Petrobras and engineered by Federal University of *Rio Grande do Sul* (UFRGS). A prototype was mounted on a flexible sample line and passed the initial tests. In 2012 performance tests were made in relation to fatigue at UFRGS. Once confirmed by the technology qualification tests, Petrobras may license the connector for the traditional suppliers in the area (Petrobras, 2013).

Drilling without Risers

In the construction of wells, to drill rocks Petrobras currently uses hard risers. Through those risers descend fluids that help drilling and ascend drilling cuttings that come off in the process. The assembly and disassembly of a drilling riser are very time-consuming operations. For this reason, Petrobras is studying drilling technologies without risers. With this technology the fluids and cuttings movement would be made by a pair of flexible pipes connected to a subsea pump. This installation would be simpler, generating time-saving and cost reduction (Petrobras, 2014).

Non-aqueous HPHT drilling fluids

Due to the local geology, Petrobras foresees the existence of high pressure and high temperature zones (HPHT) in future presalt wells. The company, in partnership with Baker Hughes, approved two new formulations of non-aqueous fluids, 100% synthetic, capable of drilling with saline down hole zones temperature, up to 166 °C. The new formulation minimizes salt solubility, avoiding problems related to the well break and allowing a greater stability of the drilling operation. Furthermore, it is possible to perform the transition of the saline zone to the carbonate reservoirs without the need for fluid replacement. For this, with additives supplied by Baker Hughes, adjustments were made by Petrobras for presalt scenarios in two of its fluids formulations. These fluids were then exposed at 166 °C for seven days. The tests found that there were no variations in fluid properties during that period (Petrobras, 2013).

Extended Reach Well (ERW)

Petrobras was well succeeded in January 2012, gaining an 85º angle in drilling saline portions. It is difficult to gain angle in wells saline intervals because of high fluidity salt behaves during drilling operations. That was the main challenge for horizontal drilling and for reaching the presalt (Extended Reach Well - ERW), a technique that minimizes the number of wells and their associated costs. The adoption of this technique to replace the drilling of vertical wells provides greater contact with the reservoir and hence increases production with less producing wells (Petrobras, 2013).

Steel Lazy Wave Riser (SLWR)

The new configuration was chosen by Petrobras for the riser's collection system. This technology enables the use of steel risers directly connected to a floating platform FPSO (Floating Production, Storage and Offloading). This riser system includes the use of floats in mid-water, to give the right geometry to ensure the resistance steel tube fatigue throughout the life of the project. Extensive studies on optimizing the structural system configuration for the scenario of the Santos Basin were developed by Petrobras and enabled the option in the Steel Lazy Wave Riser (SLWR). The studies allowed the minimization of tubes with metallurgical clad in production risers, which can be replaced in 70% length with mechanical clad risers with lower price and higher supply in industry. It will be the first SLWR connected to a FPSO anchored by spread mooring system and the first one in the pre - salt Santos Basin region. This is the fourth system in the world using SLWR after the *Bonga* field in Nigeria, the *Parque das Conchas* in the *Espírito Santo* Basin and Stones field in Mexico's Gulf (Petrobras, 2013).

Signal Acquisition System with Independent Monitoring (SASMI) and Permanent Downhole Gauge (PDG)

Petrobras has developed and demonstrated the Signal Acquisition System with Independent Monitoring (SASMI). Applied in Field of Lula, SASMI got the history of the static pressure measured by the new Permanent Downhole Gauge (PDG) for months after long time test performed in the well. Technology is a joint patent with Petrobras and the Brazilian Transcontrol that performs scanning and local storage of data from PDG, in situations that it's impossible to send information to the surface. Pressure data downhole are valuable for reservoirs outlining, determining the connection between wells and estimation of rocks permeability. The device, also informally called "pen drive ROV", has SD memory card and battery with autonomy of use up to two years. With the new PDGs development, it was necessary to adapt the SASMI, creating a universal interface to read sensors data from different suppliers (Petrobras, 2013).

5.3 Coating and completion of wells

Intelligent completion system

With Petrobras technical specification and executed by Baker Hughes, the system of gas and water injectors, allows the increasing oil production in long term, getting pressure and temperature data in more points inside the well. The system also includes remotely intelligent completion valves that permit to isolate different production zones in the same well. His drive becomes simpler and less expensive (Petrobras, 2013).

Pressure While Drilling Analyzer - PWD

The PWD software was developed by Petrobras with some Brazilian universities support, receives real time drilling parameters from down hole sensors and from surface and interprets them automatically. Comparing predicted values models with actual values, this software detects unexpected behaviour and automatically identifies operating situations inconsistency in real time. Then suggests mitigation and prevention. The system reduces operational costs and risks. It has been applied in 23 subsalt wells, 18 post-salt Campos Basin and four in the international area, as supporting tool for decision making (Petrobras, 2013).

Presalt Drilling fluid

While the rate of drilling in the presalt carbonate with conventional fluids ranges is from one to four meters per hour, in traditional sandstone reservoirs (post-salt) this rate reaches 15 m/h. To increase that speed, was identified a chelating additive (chemical substance already used to remove fouling in oil wells) to assist the drilling process in carbonate rocks using their high reactive capacity. Field tests were conducted in two onshore wells with characteristics similar to the presalt Santos Basin. The results are being applied in fluids system optimization in laboratory and for subsequent testing in offshore drilling, combining fluid and drills (Petrobras, 2013).

5.4 Production and maintenance

Optimized Monobuoy Hull

Petrobras has developed and patented innovative monobuoy for operation in deep water. It's an alternative for the disposal of oil produced in the presalt Santos Basin, besides the pipeline and Vessel Dynamic Position (DP - Dynamic Positioning) options. The system provides a single point mooring facility at a water depth of 2200 meters connected to the FPSO producer, which enables the export of oil through conventional tankers. Similar systems have been applied in nine camps on west coast Africa, but with less severe environmental conditions than those identified in the presalt area in Brazil (Petrobras, 2013).

Subsea technology

The deeper the water, the higher the loads due to the weight of the mooring lines. The use of lighter materials with higher stiffness is necessary to limit the motion of the Production Unit. The higher loads due to the riser's weight impact the platform structural engineering and possibly the riser lifetime, possibly requiring special materials. A good alternative solution, which is being applied, is to decouple the risers from the motions of the production floater. The ongoing qualification process of flexible risers for the Presalt environment deserves special attention. Coupled flexible risers have been applied in the Lula Pilot area, and no problems have been detected to date. For the *Guará* and *Lula*-North East Pilots, decoupled steel catenary riser's system were ordered (Estrella, 2011).

Autonomous underwater vehicles

In addition to systems with augmented reality features are being tested robots without cabling to continuously monitor operations. They have sensors and will be controlled from the display rooms on the ground (Petrobras, 2014).

Nanomaterials and nanoparticles

Nanomaterials will be used to improve materials and subsea equipment performance. According to Petrobras, is under study the use of these smart materials for instant repair in coatings scratches and minor damages, avoiding the production disruption for repairs. Nanoparticles are being tested for several purposes. When injected into the reservoirs, for example, certain nanoparticles may facilitate the drainage of oil contained in rocks, boosting field production (Petrobras, 2014).

Processing submarine

Oil, gas and water dividers are now on the platform, but they can be installed on the seabed at great depths. The process will be controlled by sensors, which will facilitate the operation and saves space on the platforms. In some cases, the platforms may not be necessary (Petrobras, 2014).

Underwater power distribution

Subsea electrical distribution systems will feed the equipment on the seabed, transmitting energy over long distances. This could be one of disruptive innovations that will allow the use of transportation systems for production fully underwater (subsea to shore). Thus oil may be sent from sea to land without platforms (Petrobras, 2014).

Oil recovery

Secondary recovery must be implemented to improve oil recovery in the Presalt carbonates. These rocks are usually oil wet, and this characteristic affects the performance of water injection, which will be tested in the Lula Pilot field (Estrella, 2011). Another complication in the case of water injection is related to rock-fluid interaction, which is more important in carbonate. To understand the phenomena and to assess the risks involved, as well as to define mitigation actions, rock-fluid interaction tests are being carried out with the reservoir rock and the salt cap rock. Alternative recovery methods will be implemented in the Presalt reservoirs. Gas injection is already being tested in the Lula Pilot and the water alternating gas method (WAG) will also be tested in the field (Estrella, 2011).

5.5 LOGISTICS SUPPORT

The *Santos* Basin is located around 290 km distant from *Rio de Janeiro* coast and 350 km from *São Paulo* coast, in ultra-deep waters. This poses logistical challenges for the supply of bulk materials, transport of people (helicopters or boats), pipeline laying vessels, drilling and workover rigs, and terminals for oil export through commercial crude carriers As a result there has been studied a selection of existing harbours and airports to be adapted, the design of offshore oil terminals, in deep and in shallow waters, floating hubs for fluids and materials, power generating offshore hubs, design of an auxiliary location for helicopter refuel/maintenance, and extensive automation to manage, control and supervise operations from onshore (Estrella, 2011).

5.6 TECHNOLOGIES MAPPING FOR PRESALT

At this point it is possible to carry on the main objective of this study: mapping technologies developed or in development for presalt oil exploration (see Figure 23).

<table>
<tr><th colspan="4">VALUE CHAIN</th></tr>
<tr><th>SUPPLY CHAIN SEGMENTATION</th><th>Exploration</th><th>Development</th><th>Production</th></tr>
<tr><td>Reservoirs Information</td><td>Coil Shooting
Full Wave Inversion (FWI)</td><td></td><td></td></tr>
<tr><td>Drilling</td><td colspan="2">Connector with flexible riser assembly without folding
Drilling without Risers
Non-aqueous HPHT drilling fluids
Extended Reach Well (ERW)
Steel Lazy Wave Riser (SLWR)
Signal Acquisition System with Independent Monitoring (SASMI) and Permanent Downhole Gauge (PDG)</td><td></td></tr>
<tr><td>Coating and completion of wells</td><td></td><td>Intelligent completion system
Pressure While Drilling Analyzer - PWD
Pre-salt Drilling fluid</td><td></td></tr>
<tr><td>Infrastructure</td><td></td><td></td><td></td></tr>
<tr><td>Production and maintenance</td><td></td><td></td><td>Optimized Monobuoy Hull
Oil recovery
Autonomous underwater vehicles
Nanomaterials/Nanoparticles
Processing submarine
Underwater power distribution
Subsea technology</td></tr>
<tr><td>Deactivation</td><td></td><td></td><td></td></tr>
<tr><td>Logistics Support</td><td colspan="3">Floating hubs for fluids and materials
Power generating offshore hubs
Helicopter refuel/maintenance
Extensive automation from onshore</td></tr>
</table>

FIGURE 23 - TECHNOLOGIES MAPPING FOR PRESALT OIL EXPLORATION.

As can be seen in the technologies mapping for presalt oil exploration there is a clear focus on developing technologies that address the key challenges of oil exploration in that technological frontier: the high drilling costs in high depths oil reservoirs and consequent high pressures and temperatures and the reservoirs distance from the coast line.

As mentioned earlier in this study, the presalt oil is in a deep level of the bedrock under high depth, which turns seismic and reservoir analysis more complex, more time consuming, less reliable and consequently more expensive. Since this phase of exploration is the most critical in decision process of whether or not to continue to the next phase of drilling, there has been a focus on developing new technologies that reduce both uncertainties and obviously, costs. Coil shooting and Full Wave Inversion are techniques that can solve those problems.

When it go beyond the phase of seismic analysis and well, even when data points towards to advance the exploration, the success of found reservoir will only be confirmed after the drilling. However, drilling in such high depths, plus high temperatures, pressures and in the instability of the presalt layer has also been a concern for those actors involved in oil exploration. At this stage and at the stage of completion of oil wells, high pressures and temperatures also put into question the resistance of materials used. In such extreme contexts obviously other issues rise, which are related to the operation and production safety. Because drilling costs represent one of the biggest hurdles associated with presalt field development (Muniz, 2013), consequently there is a greater demand for new ways to overcome all these obstacles in those phases (see Figure 23).

Other areas of research interest are lost circulation prevention, drill string vibration and stuck pipe. To address these challenges a number of efforts are under way such as: improving bit design with emerging new designs; optimizing the bottom hole assembly to reduce drill string vibration and developing micro emulsions that can provide proper to the lubrication to the drill string (Muniz, 2013).

An additional problem associated with presalt development is well stability during the production. In order to minimize possible geomechanical impacts in the reservoir, flow simulation two-way coupling will help predict stresses and strains acting upon well structures and will provide safer well trajectories as field's development advances. Seismic inversion may provide the means to update and calibrate the flux-deformation model (Muniz, 2013).

Another technology frontier is to use nano-scale materials. High temperatures and pressures in such high depth, causes rapid wear and corrosive materials in the used equipment. Being so slow and expensive operations, the permanent replacement of such equipment could easily become infeasible in this sector. That's the reason why nanotechnology can be applied to develop nano-membranes to be used in production facilities, reducing the size of the processing equipment, which helps reduce the corresponding environmental impact of such installations (Muniz, 2013).

However, this does not mean that for the other stages of the chain are not to be developments. On the contrary. They are technologies that are not just for presalt exploration use. Although an example of that technology is the Flexible Floating Production, Storage and Offloading (FPSO). Petrobras began in 2012 producing oil and gas located in the Gulf of Mexico American fields. Due to the distance between field and the oil and gas transportation infrastructure in the Gulf, the company opted to use a production system with early FPSO (Floating Production, Storage and Offloading), associated with complex and innovative technologies. New in the Gulf of Mexico, the system was installed in water depths greater than 2,500 meters. The FPSO, moored to a buoy, disconnects in case of hurricane or more severe storms, allowing its transportation to a safe place. In turn, the buoy - coupled to self-sustaining underwater lines and risers (vertical production lines) - remains floating 200 meters from surface. The system then can be reconnected, restoring operation in a few days. Other advances in the project were (Petrobras, 2013):

- First operation of the pull-in umbilical using a submarine winch performed by ROV (remotely operated vehicle).
- Use of self-sustaining hybrid riser in high pressure and depth (current record).
- Deeper line of pipe-in -pipe type, the 2682 meters.
- Deeper underwater pumping system, the 2682 meters.
- Deeper line of pipeline, 2,500 m.
- First use of Single Trip Multi - Zone Frac Pack system for high depth wells (8239 meters).

Additionally, the analysis of technology matrix in Figure 23, indicate that development of new technological trajectories for oil exploration in deep waters is taking technology to new frontiers of research such as the possibility to explore and produce oil from a remote control room on shore. Robotics and remote control technologies are emerging in other application areas and are also thought to be applied in the oil sector. This new technological trajectory would change the way to explore oil with gains in human security and reducing the risk of human error as well. This technology area will also facilitate and reduce the constraints arising from the distance at which the reserves are to coastlines. The transport of materials and people taken in a conventional manner in this particular case (300km from the coast) can make many operations economically unviable and emergency rescue of persons and property may be at great risk. Intelligent production equipment, coupled with supervisory algorithms, helps automate well operations and optimize reservoir management and productivity.

6 Conclusions

Since the moment Edwin Drake found oil in 1859 in the Pennsylvania State, US, and developed the oil-water separation technology, oil exploration has crossed a development road full of successive technological challenges. Technology and science have changed dramatically the way that oil is identified, produced and distributed.

Just when the oil prices raised and the demand on energy by the emerging countries and technology progress increased, it became a good opportunity to re-explore oil and gas reserves previously considered not economically viable. Thus, the presalt discoveries opened a possibility for a new technological trajectory change in the offshore oil exploration.

Presalt exploration brought big technological challenges to surpass by oil companies and the equipment and services suppliers, such as: i) the high depth of the reservoir; ii) the high temperature and pressure; iii) the instable presalt rock; and iv) the high distance of reservoirs to the shore.

To surpass those challenges companies start to put a development plan into action and there are technology developments mostly in the seismic and reservoirs segment, in the drilling and in the production of oil. Materials field, robotics and remote control, and in seismic and analytical software are the main areas of research for the presalt exploration. Actually these are areas that can change the technology trajectory of oil offshore exploration and the robotics and remote control of machines in such hard conditions could be a radical change in offshore exploration industry.

With today's world technology development, new information and communication technologies evolution turned almost everyone in the world closer. In particular case of offshore oil exploration, it would be important to understand, how this changed or not the way this industry faces technology research and development in the sense of shorten time of technology development life cycle. First of all it would be interesting to know who the actual actors are moving behind the scene in this industry and their physiognomy. In seismic and software development for reservoirs analysis, for example, there are several high-tech startups surging in the picture. It would also be interesting to study how these startups are changing or not this particular industry, in relations, in knowledge sharing, in the life time cycle of products and processes, or in easiness in cooperation and R&D projects development.

In a world so technologically accelerated we live in today, it is important to continue to monitor the technological challenges that oil exploration faces with the presalt discoveries and how the industry will behave in the coming years kin to a growing environmental apprehension and the significant commitment and investment that is being made in alternative and unconventional energy sources.

7 REFERENCES

ABERNATHY, W J. (1978). *The Productivity Dilemma*. Johns Hopkins University Press: Baltimore.

ABERNATHY, W J. and UTTERBACK, J. M. (1978). *Patterns of Industrial Innovation*. Technology Review, 80, 41-47.

ADREZIN, R. and BENAROYA, H. (1999). *Non-linear stochastic dynamics of tension leg platforms*. Journal of Sound and Vibration. v. 1, n. 220, p. 27-65, 1999.

ALBAUGH, E. K. and NUTTER, T. (2005). *Deepwater solutions & Records for concept selection: going deeper with production technology*. Offshore Magazine, Special Issue.

ALFARO, J. C., CORCORAN, C., DAVIES, K., PINEDA, F. G., HAMPSON, G., HILL D., HOWARD M., KAPOOR, J., MOLDOVEANU, N. and KRAGH E. (2007). *Reducing Exploration risk*. Oilfield Review 19, no. 1, Spring 2007, 26-43.

ANDERSON, M. A. (2011). *Discovering the secrets of the Earth*. Schlumberger Oilfield Review Spring 2011:23, no. 1, Schlumberger Publications.

ANDERSON, P. and TUSHMAN, M. (1990). *Technological discontinuities and Dominant Designs: A Cyclical Model of Technological Change*. Administrative Science Quarterly, 35:604-633.

ARAÚJO, B. P., MENDES, A. P. and COSTA, R. C. (2012). *Perspectivas para o desenvolvimento industrial e tecnológico na cadeia de fornecedores de bens e serviços relacionados ao sector de P&G*. BNDES 60 ANOS – PERSPECTIVAS SETORIAIS.

AUSTIN, D. B., CARRIKER, T., MCGUIRE J., PRATT, T. & PRIEST, A. G. (2004). *History of the offshore oil and gas industry in southern Louisiana: interim report.* Papers on the evolving offshore industry. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, Nova Orleans, L.A., v.1, 98p.

BAIN & COMPANY, TOZZINI FREIRE ADVOGADOS - *Estudos de alternativas regulatórias, institucionais e financeiras para a exploração e produção de petróleo e gás natural e para o desenvolvimento industrial da cadeia produtiva de petróleo e gás natural no brasil.* São Paulo: Bain, 2009.

BARBOSA, R. (2004). *Plataformas offshore ontem, hoje e amanhã*. Editora Brasil Energia.

BAUM, J. A. C., KORN, H. J. and KOTHA, S. (1995). *Dominant designs and population dynamics in telecommunications services: founding and failure of facsimile transmission service organizations, 1965-1992.* Social science Research 24, 97-135.

BEASLEY, C. J., FIDUK, J. C., BIZE, E., BOYD, A., FRYDMAN, M., ZERILLI, A., DRIBUS, J. R., MOREIRA, J.L.P. and PINTO, A.C.C. (2010). *Brazil's Presalt Play*. Oilfield Review Autunm 2010: 22, no. 3. Schlumberger Publications.

BELTRÃO, R.L.C., SOMBRA, C.L., LAGE, A.C.V.M., FAGUNDES NETTO, J.R. and HENRIQUES C.C.D – *Challenges and new technologies for the development of the presalt cluster, Santos Basin, Brazil*. In Offshore technology Conference, Houston, May 4-7, 2009, Working Paper OTC 19880.

BEYNON, R. C. (2006). *What can the North Sea teach the world*. Exam Consultants Publications.

BP Economics Team (2008). *BP Statistical Review of World Energy*, BP plc, London.

BP Economics Team (2011). *BP Statistical Review of World Energy*, BP plc, London.

BP Economics Team (2013). *BP Btatistical Review of World Energy*. BP plc, London.

BP Economics Team (2014). *BP Energy Outlook 2035*. BP plc, London.

BUIA, M., FLORES, P.E., HILL, D., PALMER, E., ROSS, R., WALKER, R., HOUBIERS, M., THOMPSON, M., LAURA, S., MENLIKLI, C., MOLDOVEANU, N. and SNYDER, E. (2008). *Shooting seismic surveys in cycles.* Schlumberger Oilfield Review 20 (Autumn 2008), no. 3, 18-31. Schlumberger Publications.

CAMERON, P. (1986). *The Oil Supplies Industry: A Comparative Study of Legislative Restrictions*. Report written for FT Business Information.

CASTELLACCI, F. (2008). *Technological paradigms, regimes and trajectories: Manufacturing and service industries in a new taxonomy of sectorial patterns of innovation*. Research Policy 37, 978–994.

CLARK, K. B. (1985). *The Interaction of Design Hierarchies and Market Concepts in Technological Evolution*, Research Policy 14, 235-251.

COOK, L. (1983). *Government Policy for Offshore Supplies Industry: Britain compared with Norway and France*: SPRU Occasional Paper Series No. 31.

CRABTREE, E., BOWER, J. and KEOGH, W. (1997). *Conflict or Collaboration: The Changing Nature of Inter-firm Relationships in the UK Oil and Gas Industry*. Technology Analysis & Strategic Management, 9(2).

DANTAS, A. (1999). *Capacitação Tecnológica de Fornecedores em Redes de Firmas: O Caso da Indústria do Petróleo Offshore no Brasil*. PhD Thesis, Rio de Janeiro, IE/UFRJ.

DANTAS, E. and BELL, M. (2009). *Latecomer firms and the emergence and development of knowledge networks: the case of Petrobras in Brazil*. Research Policy. 38, 829–844.

DOSI, G. - *The nature of the innovative process: Technical Change and Economic Theory*. London & New York: Pinter Publisher, 1988, p.221-238.

DOSI, G. (1982). *Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Direction of Technical Change*. Research Policy, Amsterdam, 11, 147-162.

DRIBUS, J. R., JACKSON, M. P. A., KAPOOR, J. and SMITH, M. F. (2008). *The prize beneath the salt*. Schlumberger Oilfield Review 20 (Autumn 2008), no. 3, 4-17. Schlumberger Publications.

DUNCAN (2001). *Benchmarking the Norwegian Offshore Industry*, Presentation held by Mr. Duncan from Independent Project Analysis at the Norwegian Strategy Conference in Stavanger 12.12.2001.

ESTRELLA, G. (2011). *Presalt production development in Brazil. In 20th World Petroleum Congress, Energy solutions for all - Promoting Co-Operation, Innovation and Investment*, The Official Publication of the 20th World Petroleum Congress, First World Petroleum, London.

FERNÁNDEZ, E. and MUSSO, B. - *Oportunidades e Desafios da Agenda de Competitividade para Construção de uma Política Industrial na Área de Petróleo: Propostas para um Novo Ciclo de Desenvolvimento Industrial: Agenda da Competitividade da Onip*. In XXIII Fórum Nacional, Rio de Janeiro, 2011, Instituto Nacional de Altos Estudos (INAE), 2011.

FLATERN, R. von (2011/2013). *The science of oil and gas well construction*. Schlumberger Oilfield Review Winter 2011/2012:23, no. 4, Schlumberger Publications.

FREEMAN, C. and LOUÇÃ F. *As Time Goes by: From the Industrial Revolutions to the Information Revolution*. Oxford: Oxford University Press, 2001.

FREEMAN, C., CLARK, J. and SOETE, L. *Unemployment and Technical Innovation*. London: Pinter, 1982.

FREITAS, A. G. (1993). *Capacitação tecnológica em sistemas de produção para águas profundas.* Campinas: Universidade Estadual de Campinas - Instituto de Geociências.

FURTADO, A. (1995). *Petróleo e Política Tecnológica: O Que Aprender com as Experiências Brasileiras e Francesas.* Habilitation Thesis, Campinas, DPCT/UNICAMP.

FURTADO, A. T. (1996). *A trajetória tecnológica da Petrobrás na produção offshore*. Revista Espacios, Vol. 17 (3).

HATAKENAKA, S., WESTNES, P., GJELSVIK, M. and LESTER, R. K. (2006). *From "Black Gold" to "Human Gold" – A Comparative study of the Oil and Gas Industry in Stavanger and Aberdeen*. Cambridge: MIT Industrial Performance Center Working Paper.

HATAKENAKA, S., WESTNES, P., GJELSVIK, M. and LESTER, R. K. (2006). *The regional dynamics of innovation: A comparative case study of oil and gas industry development in Stavanger and Aberdeen.* MIT Industrial Performance Center Paper Series.

HERRMANN, L., DUNPHY, E. and COPUS, J. (2010). *Oil & Gas for Beginners: A guide to the oil & gas industry.* Global Markets Research, Deutsche Bank AG, London.

HYNE, N. J. (2001). *Non-technical Guide to Petroleum Geology, Exploration, Drilling & Production*. 2. ed. PennWell Corporation: Tulsa, Oklahoma.

IEA, *World Energy Outlook 2010*.

INTSOK (2005). *Norwegian petroleum technology – a success story*. Norwegian Academy of Technological Sciences (NTVA) and Offshore Media Group.

JARDINE, R. J. and POTTS, D. M. (1988). *Hutton tension leg platform foundations: prediction of driven pile behaviour*. Géotechnique, v. 38, n. 2, p. 231-252.

KEILEN, H. (2005). *Norwegian Petroleum Technology: a success story*. Norwegian Academy of Technological Sciences and Offshore Media Group: NTVA, Trondheim, Norway, 98p.

LAPPEGAARD, O. T.; SOLHEIM, B. J. and PLUMMER, F. B. (1991). *Snorre project strategies and status*. In 23rd Annual Offshore Technology Conference, Houston: Texas.

LAUSAIRE, N., NOMBO-MAKAYA and HONG HAN, C. (2009). *Presalt Petroleum System of Vandji-Conkouati Structure (Lower Congo Basin), Republic of Congo*. Research Journal of Applied Sciences, Volume 4, Issue 3, p. 101-107.

MANTLE, K. (2013/2014). *The art of controlling wellbore trajectory*. Schlumberger Oilfield Review Winter 2013/2014, Schlumberger Publications.

MAUGERI, L. (2012). *Oil: the next revolution the unprecedented upsurge of oil production capacity and what it means for the world*. Geopolitics of Energy Project Belfer Center for Science and International Affairs, John F. Kennedy School, Harvard University.

MCKINSEY&COMPANY - *A new regime for innovation and technology management in the E&P industry*, McKinsey Research Project for Shell, July 2001.

MILES, L. (2005). *Offshore Pioneers: Hermans and George Brown sought adventure through engineering*. Insight Magazine: Process, Power & Marine.

MUELLER, D. C. and TILTON, J. (1969). *Research and Development Costs as a Barrier to Entry*. Canadian Journal of Economics, 2, 570-579.

MUNIZ, C. (2013). *Deepwater Brazilian presalt: the way ahead for research and development*. Academia, Volume 9, no. 1. Baker Hughes.

NEAL, W. H., BELL, M. R. G., HANSEN, C. A. and SIEGFRIED, R. W. (2007). *Oil and gas technology development*, Working Document of the National Petroleum Council, Global Oil & Gas Study.

NELSON, E. B. (2012). *Well cementing fundamentals*. Schlumberger Oilfield Review Summer 2012:24, no. 2. Schlumberger Publications.

NETO, J. B. O. and COSTA, A. D. (2007). *A Petrobrás e a exploração de Petróleo Offshore no Brasil: um approach evolucionário*. Revista Brasileira de Economia, Fundação Getúlio Vargas.

NETO, J. B. O. and SHIMA, W. T. (2008). *Trajetórias tecnológicas no segmento offshore: ambiente e oportunidades*. R. Econ. Contemp., Rio de Janeiro, v. 12, n. 2, p. 301-332.

NORENG, O. (1980). *The Oil Industry and Government Strategy in the North Sea*. London: Croom Helm.

NORWEGIAN MINISTRY OF PETROLEUM AND ENERGY (2006). *Norwegian Oil history in brief*. Norway.

OLIVEIRA, A. and ROA, D. - *Innovation in Brazilian Oil Industry: From Learning by Using to Prospective Capacity to Innovate in the Technological Frontier*. In The 9th Globelics International Conference, Buenos Aires, 2011.

ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD) (1992). *Technology and the economy: the key relationships*. OECD: Paris, 328p.

PEREZ, M. A., CLYDE, R., D'AMBROSIO, P., ISRAEL, R., LEAVITT, T., NUTT, L., JOHNSON, C. and WILLIAMSON, D. (2008). *Meeting the subsalt challenge*. Schlumberger Oilfield Review 20 (Autumn 2008), no. 3, 32-45. Schlumberger Publications.

PETROBRAS (2005). *Petrobrás 30 years of deep water technology*. Petrobras Magazine: International Communications, 77 p.

PETROBRAS (2013). *Tecnologia Petrobras 2012*. Relatório de Tecnologia Petrobras 2012.

PETROBRAS (2014). *Tecnologias do Futuro*. Infographic of future technologies.

PINTO, M., ANDRADE, B., MACHADO, G., COLIN, E., FURTADO, J., SANTORO, M., SABBATINI, R., COUTINHO, L., PRIMO, M., WAISS, J. and GONÇALVES, N. (2006). *Implantação e consolidação de laboratório de gestão de operações e da cadeia de suprimento da indústria de construção naval: Avaliação de nichos de mercado potencialmente atraentes ao Brasil.* Centro de Estudos em Gestão Naval (CEGN), São Paulo.

PLATT, N., PHILIP, P. and WALTER, S. (1993). *Going for the Play: structural interpretation in offshore Congo*. Oilfield Review 5, no. 1, 14-27. Schlumberger Publications.

PORTER, M. (1986). *Competition in global industries*. Harvard Business School Press, Boston.

PROMINP (2008). *Estudo de competitividade da indústria brasileira de bens e serviços do setor de P&G: Setor Siderúrgico e tubos de aço*.

SAHAL, D. (1985). *Technological guideposts and innovation avenues*. Research Policy, 14, 61-82.

SCHUMPETER, J.. *Business Cycles*. Philadelphia: Porcupine Press, 1939.

SHEPLER, R., WHITE, T., AMIN, A. and SHIPPEN, M. - *Lifting, Flow Boosting Key to Subsea Well Productivity*. In Deepwater Offshore Technology Conference, New Orleans, 2004.

SPEARS & ASSOCIATES - *Oilfield Market Report: Covering the years 1999-2009*. Tulsa, 2008.

TUSHMAN, M. and ANDERSON, P. (1986). *Technological Discontinuities and Organizational Environments*. Administrative Science Quarterly 31, 439-465.

UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT (UNCTAD) (2012). *United Nations Commodities at a glance - Special Issue in Energy.* Commodities at a glance 3.

United States Geological Survey (USGS) (2000). *World Petroleum Assessment*.

UTTERBACK, J. M. (1979). *The Dynamics of Product and Process Innovation in Industry*, in C T. Hill and J. M. Utterback (eds), Technological Innovation for a Dynamic Economy. Pergamon Press: Elmsford, New York.

UTTERBACK, J. M. and ABERNATHY, W. J. (1975). *A Dynamic Model of Process and Product Innovation*. Omega, 3, 639-656.

UTTERBACK, J. M. and KIM L. (1986). *Invasion of a Stable Business by Radical Innovation.* In PR Kleindorfer (ed.), The Management of Productivity and Technology in Manufacturing. Plenum Press: New York.

UTTERBACK, J. M. and SUAREZ, F. F. (1993). *Innovation, competition, and industry structure*. Research Policy 22, 1-21.

VARHAUG, M. (2011). *Turning to the right – an overview of drilling Operations*. Schlumberger Oilfield Review Autunm 2011, Schlumberger Publications.

VIEGAS, T. (2011). *Exploração e produção de petróleo e gás em águas profundas: evolução e tendências.* Universidade Federal do Rio de Janeiro (UFRJ): Grupo de Economia da Energia (GEE), Instituto de Economia (IE), Infopetro Word Press Blog.

WILSON, M. (1992). *Magmatism and continental rifting during the opening of the South Atlantic Ocean: A consequence of lower Cretaceous Super-plume activity*. In Storey BC, Alabaster, T. and Pankhurst, R.J. (eds): Magmatism and the causes of continental break-up. London: Geological Society, Special Publication 68, 241-255.

TÉCNICO LISBOA

DECLARAÇÃO

Eu Sónia Maria da Luz Coelho Romão, aluno do Instituto Superior Técnico nº 39392 autor da dissertação para obtenção do Grau de Mestre em Engenharia Química, com o título Mapping technologies in the value chain and supply chain for the oil exploration

concedo ao Instituto Superior Técnico uma licença perpétua, mas não exclusiva, para utilizar esta dissertação para fins de ensino ou investigação e autorizo-o a inseri-la, bem como ao seu resumo alargado, em formato pdf, na sua página da internet, com endereço www.tecnico.ulisboa.pt de modo a permitir a sua divulgação junto de todos os que acedam àquela página, e, com o mesmo propósito de divulgação, a responder favoravelmente aos pedidos de instituições de ensino ou de investigação e Centros de Documentação ou Bibliotecas, remetendo-lhes aqueles mesmos ficheiros em formato pdf, mas fazendo uma expressa menção, seja na sua página na internet seja quando da remessa atrás referida, à obrigação de quem assim aceda àquela minha dissertação e respectivo resumo alargado em salvaguardar os meus direitos de autor sobre estes documentos, que me são conferidos pelo Código do Direito de Autor e dos Direitos Conexos.

Lisboa, a 22 de Maio de 2014

O aluno n.º 39392

Sónia Maria da Luz Coelho Romão

(nome)