2 Overview of the oil and gas exploration and production process

The oil and gas industry comprises two parts: 'upstream'—the exploration and production sector of the industry; and 'downstream'—the sector which deals with refining and processing of crude oil and gas products, their distribution and marketing. Companies operating in the industry may be regarded as fully integrated, (i.e. have both upstream and downstream interests), or may concentrate on a particular sector, such as exploration and production, commonly known as an E&P company, or just on refining and marketing (a R&M company). Many large companies operate globally and are described as 'multi-nationals', whilst other smaller companies concentrate on specific areas of the world and are often referred to as 'independents'. Frequently, a specific country has vested its interests in oil and gas in a national company, with its name often reflecting its national parenthood. In the upstream sector, much reliance is placed upon service and upon contractor companies who provide specialist technical services to the industry, ranging from geophysical surveys, drilling and cementing, to catering and hotel services in support of operations. This relationship between contractors and the oil companies has fostered a close partnership, and increasingly, contractors are fully integrated with the structure and culture of their clients.

Scientific exploration for oil, in the modern sense, began in 1912 when geologists were first involved in the discovery of the Cushing Field in Oklahoma, USA. The fundamental process remains the same, but modern technology and engineering have vastly improved performance and safety.

In order to appreciate the origins of the potential impacts of oil development upon the environment, it is important to understand the activities involved. This section briefly describes the process, but those requiring more in-depth information should refer to literature available from industry groups and academia. Table 1 provides a summary of the principal steps in the process and relates these to operations on the ground.

Exploration surveying

In the first stage of the search for hydrocarbon-bearing rock formations, geological maps are reviewed in desk studies to identify major sedimentary basins. Aerial photography may then be used to identify promising landscape formations such as faults or anticlines. More detailed information is assembled using a field geological assessment, followed by one of three main survey methods: magnetic, gravimetric and seismic.

The Magnetic Method depends upon measuring the variations in intensity of the magnetic field which reflects the magnetic character of the various rocks present, while the Gravimetric Method involves the measurements of small variations in the gravitational field at the surface of the earth. Measurements are made, on land and at sea, using an aircraft or a survey ship respectively.

A seismic survey, as illustrated in Figure 1 on page 6, is the most common assessment method and is often the first field activity undertaken. The Seismic Method is used for identifying geological structures and relies on the differing reflective properties of soundwaves to various rock strata, beneath terrestrial or oceanic surfaces. An energy source transmits a pulse of acoustic energy into the ground which travels as a wave into the earth. At each point where different geological strata exist, a part of the energy is transmitted down to deeper layers within the earth, while the remainder is reflected back to the surface. Here it is picked up by a series of sensitive receivers called geophones or seismometers on land, or hydrophones submerged in water.

Special cables transmit the electrical signals received to a mobile laboratory, where they are amplified and filtered and then digitized and recorded on magnetic tapes for interpretation.

Dynamite was once widely used as the energy source, but environmental considerations now generally favour lower-energy sources such as vibroseis on land (composed of a generator that hydraulically transmits vibrations into the earth) and the air gun (which releases compressed air) in offshore exploration. In areas where preservation of vegetation cover is important, the shot hole (dynamite) method is preferable to vibroseis.

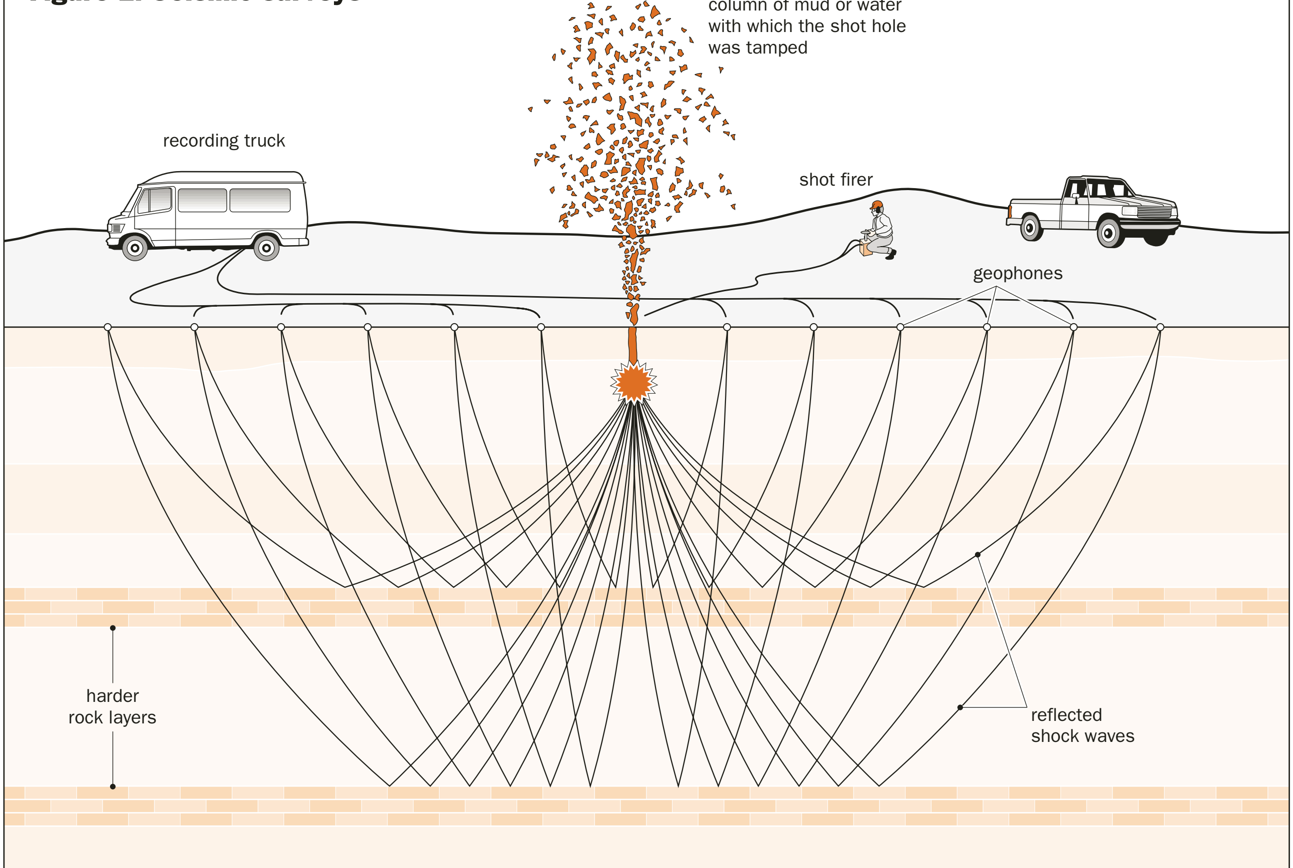
Exploration drilling

Once a promising geological structure has been identified, the only way to confirm the presence of hydrocarbons and the thickness and internal pressure of a reservoir is to drill

Table 1: Summary of the exploration and production process

Activity	Potential requirement on ground
Desk study: identifies area with favourable geological conditions	None
Aerial survey: if favourable features revealed, then	Low-flying aircraft over study area
Seismic survey: provides detailed information on geology	Access to onshore sites and marine resource areas Possible onshore extension of marine seismic lines Onshore navigational beacons Onshore seismic lines Seismic operation camps
Exploratory drilling: verifies the presence or absence of a hydrocarbon reservoir and quantifies the reserves	Access for drilling unit and supply units Storage facilities Waste disposal facilities Testing capabilities Accommodation
Appraisal: determines if the reservoir is economically feasible to develop	Additional drill sites Additional access for drilling units and supply units Additional waste disposal and storage facilities
Development and production: produces oil and gas from the reservoir through formation pressure, artificial lift, and possibly advanced recovery techniques, until economically feasible reserves are depleted	Improved access, storage and waste disposal facilities Wellheads Flowlines Separation/treatment facilities Increased oil storage Facilities to export product Flares Gas production plant Accommodation, infrastructure Transport equipment
Decommissioning and rehabilitation may occur for each of above phases.	Equipment to plug wells Equipment to demolish and remove installations Equipment to restore site

Figure 1: Seismic surveys

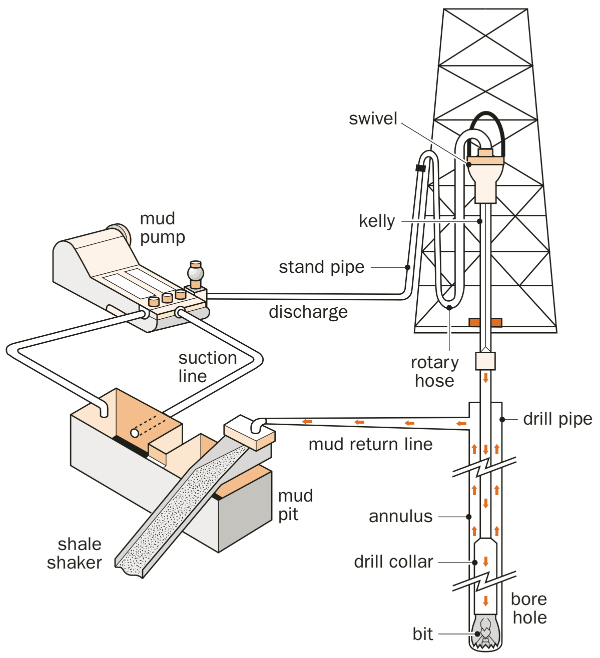


exploratory boreholes. All wells that are drilled to discover hydrocarbons are called 'exploration' wells, commonly known by drillers as 'wildcats'. The location of a drill site depends on the characteristics of the underlying geological formations. It is generally possible to balance environmental protection criteria with logistical needs, and the need for efficient drilling.

For land-based operations a pad is constructed at the chosen site to accommodate drilling equipment and support services. A pad for a single exploration well occupies between 4000–15 000 m^2. The type of pad construction depends on terrain, soil conditions and seasonal constraints. Operations over water can be conducted using a variety of self-contained mobile offshore drilling units (MODUs), the choice of which depends on the depth of water, seabed conditions and prevailing meteorological conditions,—particularly wind speed, wave height and current speed. Mobile rigs commonly used offshore include jack-ups, semi-submersibles and drillships, whilst in shallow protected waters barges may be used.

Land-based drilling rigs and support equipment are normally split into modules to make them easier to move. Drilling rigs may be moved by land, air or water depending on access, site location and module size and weight. Once on site, the rig and a self-contained support camp are then assembled. Typical drilling rig modules include a derrick, drilling mud handling equipment, power generators, cementing equipment and tanks for fuel and water (see Figure 2). The support camp is self-contained and generally provides workforce accommodation, canteen facilities, communications, vehicle maintenance and parking areas, a helipad for

Figure 2: Drilling



remote sites, fuel handling and storage areas, and provision for the collection, treatment and disposal of wastes. The camp should occupy a small area (typically 1000 m^2), and be located away from the immediate area of the drilling rig—upstream from the prevailing wind direction.

Once drilling commences, drilling fluid or mud is continuously circulated down the drill pipe and back to the surface equipment. Its purpose is to balance underground hydrostatic pressure, cool the bit and flush out rock cuttings. The risk of an uncontrolled flow from the reservoir to the surface is greatly reduced by using blowout preventers—a series of hydraulically actuated steel rams that can close quickly around the drill string or casing to seal off a well. Steel casing is run into completed sections of the borehole and cemented into place. The casing provides structural support to maintain the integrity of the borehole and isolates underground formations.

Drilling operations are generally conducted around-the-clock. The time taken to drill a bore hole depends on the depth of the hydrocarbon bearing formation and the geological conditions, but it is commonly of the order of one or two months. Where a hydrocarbon formation is found, initial well tests—possibly lasting another month—are conducted to establish flow rates and formation pressure. These tests may generate oil, gas and formation water—each of which needs to be disposed of.

After drilling and initial testing, the rig is usually dismantled and moved to the next site. If the exploratory drilling has discovered commercial quantities of hydrocarbons, a wellhead valve assembly may be installed. If the well does not contain commercial quantities of hydrocarbon, the site is decommissioned to a safe and stable condition and restored to its original state or an agreed after use. Open rock formations are sealed with cement plugs to prevent upward migration of wellbore fluids. The casing wellhead and the top joint of the casings are cut below the ground level and capped with a cement plug.

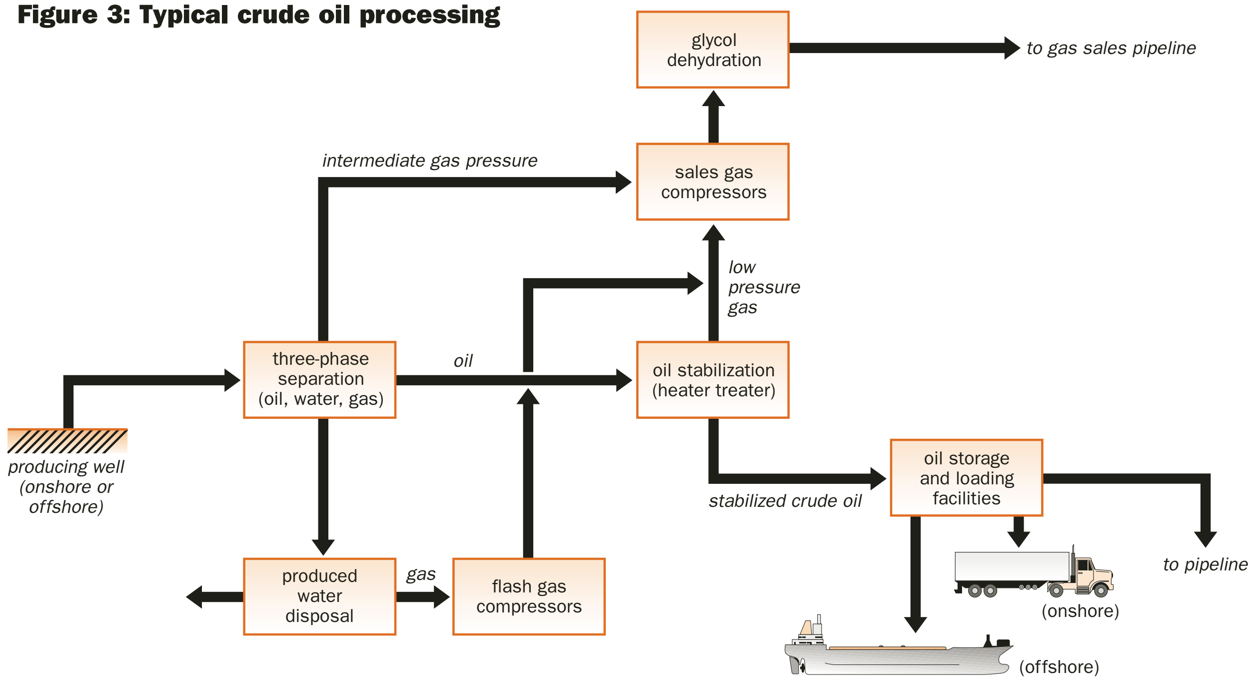
Appraisal

When exploratory drilling is successful, more wells are drilled to determine the size and the extent of the field. Wells drilled to quantify the hydrocarbon reserves found are called 'outstep' or 'appraisal' wells. The appraisal stage aims to evaluate the size and nature of the reservoir, to determine the number of confirming or appraisal wells required, and whether any further seismic work is necessary. The technical procedures in appraisal drilling are the same as those employed for exploration wells, and the description provided above applies equally to appraisal operations. A number of wells may be drilled from a single site, which increases the time during which the site is occupied. Deviated or directional drilling at an angle from a site adjacent to the original discovery borehole may be used to appraise other parts of the reservoir, in order to reduce the land used or 'foot print'.

Development and production

Having established the size of the oil field, the subsequent wells drilled are called 'development' or 'production' wells. A small reservoir may be developed using one or more of the appraisal wells. A larger reservoir will require the drilling of

Figure 3: Typical crude oil processing



additional production wells. Multiple production wells are often drilled from one pad to reduce land requirements and the overall infrastructure cost. The number of wells required to exploit the hydrocarbon reservoir varies with the size of the reservoir and its geology. Large oilfields can require a hundred or more wells to be drilled, whereas smaller fields may only require ten or so. The drilling procedure involves similar techniques to those described for exploration; however, with a larger number of wells being drilled, the level of activity obviously increases in proportion. The well sites will be occupied for longer, and support services—workforce accommodation, water supply, waste management, and other services—will correspondingly increase. As each well is drilled it has to be prepared for production before the drilling rig departs. The heavy drill pipe is replaced by a lighter weight tubing in the well and occasionally one well may carry two or three strings of tubing, each one producing from different layers of reservoir rock. At this stage the blowout preventer is replaced by a control valve assembly or 'Christmas Tree'.

Most new commercial oil and gas wells are initially free flowing: the underground pressures drive the liquid and gas up the well bore to the surface. The rate of flow depends on a number of factors such as the properties of the reservoir rock, the underground pressures, the viscosity of the oil, and the oil/gas ratio. These factors, however, are not constant during the commercial life of a well, and when the oil cannot reach the surface unaided, some form of additional lift is required, such as a pumping mechanism or the injection of gas or water to maintain reservoir pressures. It is now quite common to inject gas, water, or steam into the reservoir at the start of the field's life in order to maintain pressures and optimize production rates and the ultimate recovery potential of oil and gas. This in turn may require the drilling of additional wells, called injection wells. Other methods of stimulating production can be used, such as hydraulic fracturing of the hydrocarbon bearing formation, and acid treatment (particularly in limestones) to increase and enlarge flow channels.

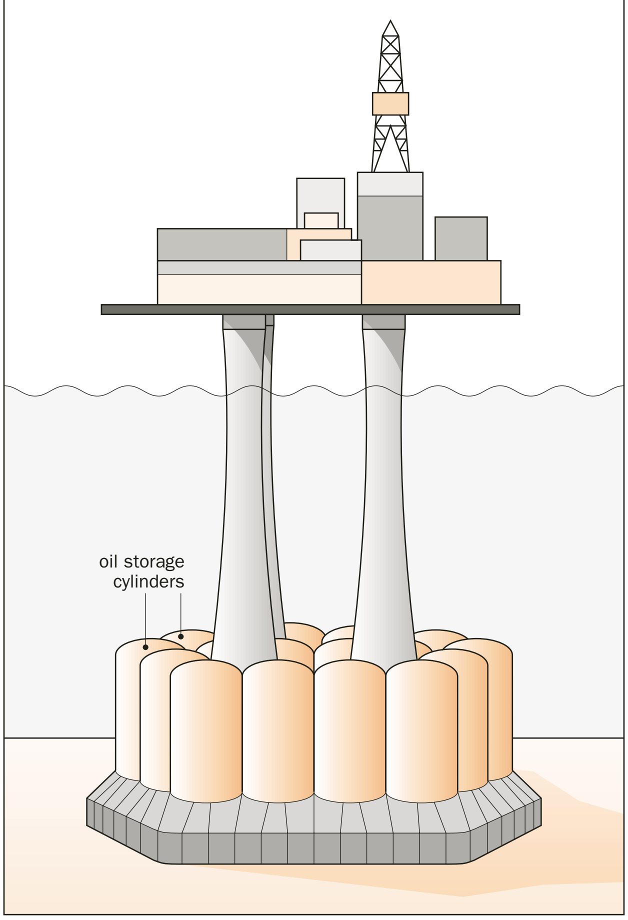
Once the hydrocarbon reaches the surface, it is routed to the central production facility which gathers and separates the produced fluids (oil, gas and water). The size and type of the installation will depend on the nature of the reservoir, the volume and nature of produced fluids, and the export option selected.

The production facility processes the hydrocarbon fluids and separates oil, gas and water. The oil must usually be free of dissolved gas before export. Similarly, the gas must be stabilized and free of liquids and unwanted components such as hydrogen sulphide and carbon dioxide. Any water produced is treated before disposal. A schematic representation of a typical crude oil processing facility is shown in Figure 3.

Routine operations on a producing well would include a number of monitoring, safety and security programmes, maintenance tasks, and periodic downhole servicing using a wire line unit or a workover rig to maintain production. The operator will be able to extract only a portion of the oil present using primary recovery (i.e. natural pressure and simple pumping) but a range of additional recovery methods are available as discussed above. For example, secondary recovery uses waterflood or gas injection, and tertiary methods employing chemicals, gases or heat may also be used to increase the efficiency of oil recovery.

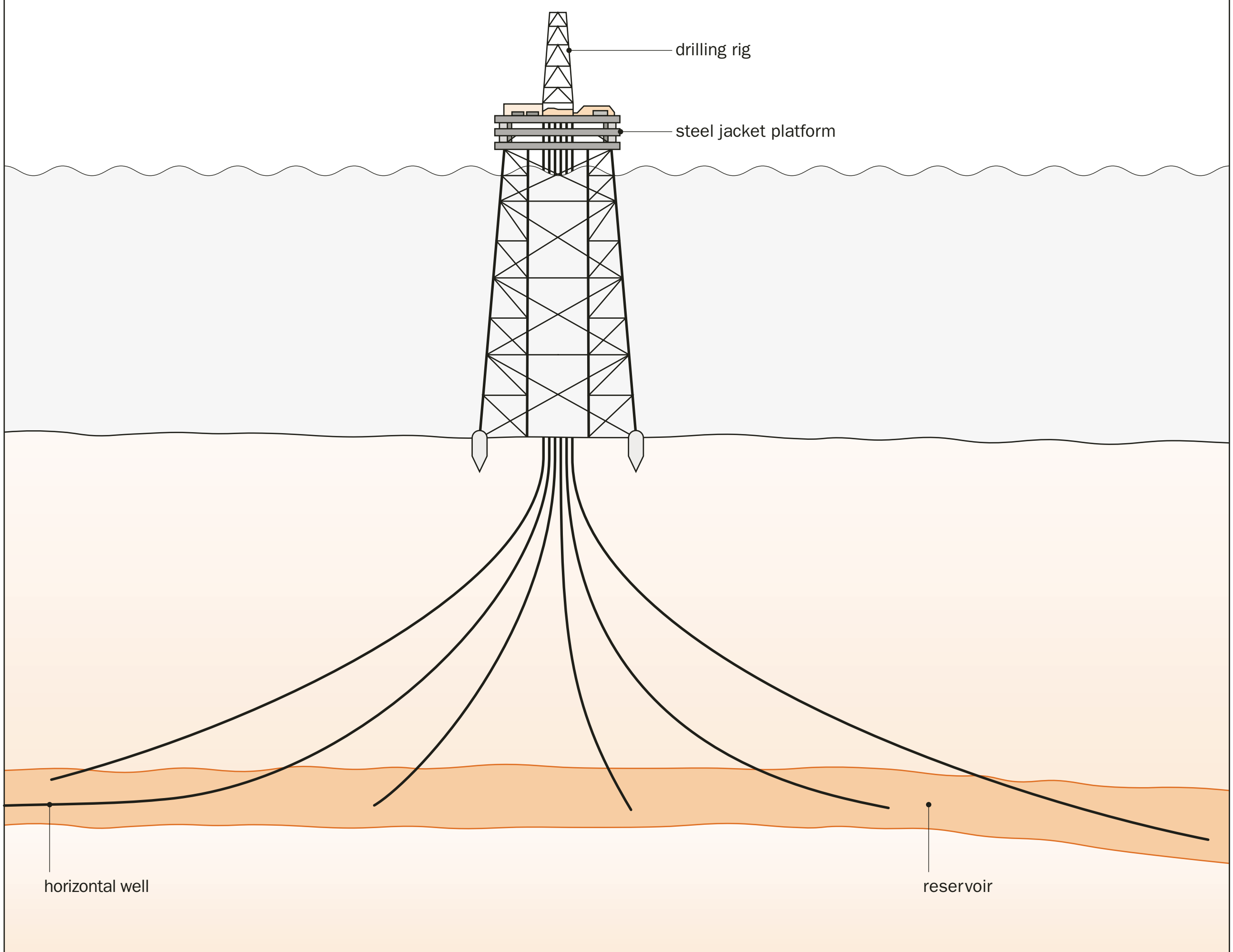
The infrastructure required for development drilling in onshore operations is similar to that described above for exploration. However, once drilling is completed, the individual wellhead assemblies and well sites are considerably smaller than when the drill rig was on site. Typically, each well requires an area of some 10 m^2 surrounded by a security fence. Often the well sites are concentrated within a central area, which includes processing facilities, offices and workshops, and this would typically occupy an area of several hectares, depending upon the capacity of the field. Since the production operation is a long-term development, the temporary facilities used in exploration are replaced by permanent facilities and are subject to detailed planning, design and engineering and construction. The temporary workforce associated with exploration activity is replaced by a permanent workforce, usually accommodated in the local area and, where desirable, fully integrated with the local community: indeed a large proportion of the workforce may be recruited locally and receive specialized training. Similarly, the local infrastructure will need to provide a variety of requirements in addition to labour, such as materials supplies, education, medical, etc.

Figure 4: Concrete gravity platform



In offshore production developments, permanent structures are necessary to support the required facilities, since typical exploration units are not designed for full scale production operations. Normally, a steel platform is installed to serve as the gathering and processing centre and more than 40 wells may be drilled directionally from this platform. Concrete platforms are sometimes used (see Figure 4). If the field is large enough, additional 'satellite' platforms may be needed, linked by subsea flowlines to the central facility. In shallow water areas, typically a central processing facility is supported by a number of smaller

Figure 5: Directional drilling



wellhead platforms. Recent technological developments, aimed at optimizing operations, include remotely operated subsea systems which remove the requirement for satellite platforms. This technology is also being used in deep water where platforms are unsuitable, and for marginal fields where platforms would be uneconomic. In these cases, floating systems—ships and semi-submersibles—'service' the subsea wells on a regular basis.

Recent advances in horizontal drilling have enhanced directional drilling as a means of concentrating operations at one site and reducing the 'footprint' on land of production operations (Figure 5) and the number of platforms offshore. The technology now enables access to a reservoir up to several kilometres from the drill rig, while technology is developing to permit even wider range. This further minimizes the 'footprint' by reducing the need for satellite wells. It also allows for more flexibility in selecting a drill site, particularly where environmental concerns are raised.

Decommissioning and rehabilitation

The decommissioning of onshore production installations at the end of their commercial life, typically 20–40 years, may involve removal of buildings and equipment, restoration of the site to environmentally-sound conditions, implementation of measures to encourage site re-vegetation, and continued monitoring of the site after closure. Planning for decommissioning is an integral part of the overall management process and should be considered at the beginning of the development during design, and is equally applicable to both onshore and offshore operations. Section 6 provides more detailed discussion on decommissioning and rehabilitation.

By their nature, most exploration wells will be unsuccessful and will be decommissioned after the initial one-to-three months of activity. It is, therefore, prudent to plan for this from the outset, and ensure minimal environmental disruption. Decommissioning and rehabilitation will, subsequently, be simplified.