PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Challenge of Producing Oil and Gas in Deep Water

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The challenge of producing oil and gas in deep water

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The paper outlines the present state of the art of deep sea drilling and discusses some of the problems with the 'controlled' as well as the 'uncontrolled' techniques.

The first method is being developed by the contract drilling companies under the auspices of the oil industry, while the second method was introduced by the Deep Sea Drilling Project under the guidance of a group of oceanic institutions (Joides).

The oil industry has drilled controlled in water depths of up to 1000 m and slightly over, and is now capable of extending the technique to 2000 m. Joides contemplates controlled drilling in water depths to 3650 m, say by the end of 1981.

It is suggested that not only the slope but also the rise of the continental margin should soon be investigated in a number of suitable localities in order to assess adequately the potential of the last remaining major unexplored frontier for oil and gas.

The paper emphasizes that it is already possible today to carry out controlled exploration even to water depths of over 4000 m. If such exploration were successful, production could also be achieved by making use of the presently developing underwater technology in 200–300 m of water.

1. Introduction

Although it is at present difficult to obtain concessions or drilling permits from individual countries in deep water, especially in view of the uncertainty with regard to ownership, it is hoped that the third 'Law of the Sea' conferences may soon reach an agreement so that the position is clarified. This paper assumes that within a few years exploration on the continental margins will not be unduly restricted even in the absence of international legislation.

In order to assess the possibility of finding hydrocarbon accumulations of sufficient interest in deep water, modern seismic techniques are of great value, especially as not only structures or other traps are located, but even the presence of hydrocarbons may be revealed. However, this feat is at present only possible if a few stratigraphical tests or key wells can be drilled in such areas. Moreover, today it does not seem very clear where on the margin the best prospects for finding large accumulations of hydrocarbons may exist, a statement which calls for a short explanation in appendix 1 of this paper.

It may therefore be of prime importance that such key wells be placed over the total width of the continental margin in order to assess the area in one sweep. This means that also some key wells are to be drilled in water depths of up to 4000 m or perhaps even somewhat deeper. However, such efforts are of little economic interest, if no assurance can be offered, once valuable oil or gas accumulations are discovered, that economic production is also feasible. The trends in past and present developments of off shore drilling and today's underwater production techniques are therefore of particular interest in order to forecast whether in the near future adequate assessment of the deeper offshore could be undertaken, and, if successful, followed by production.

2. Past and present development in controlled offshore drilling

The petroleum industry completed by the end of 1965 two decades of offshore drillship experience. In 1965 an exploratory well was drilled in 192 m of water by the Exxon Corporation in the Santa Barbara channel off the coast of California (Anon 1977). This record was achieved by means of so-called 'controlled drilling' commonly practised by the industry in the offshore. This method is based on techniques developed for land drilling and adapted to a restless and forever changing sea environment. Technology to counteract the motions of the sea has been improving steadily and by 1965 exploration up to the edge of the continental shelf was feasible.

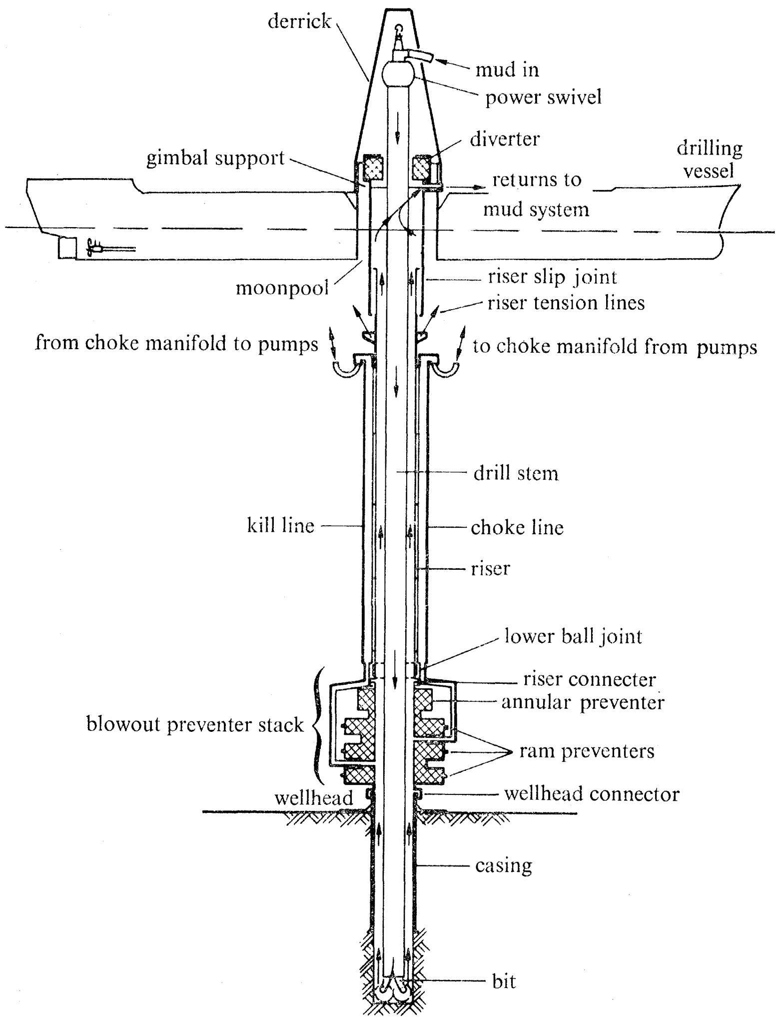

Figure 1. Riser drilling system. Guidelines, buoyancy, subsurface buoys, etc., are not shown.

The control in controlled drilling is exercised by a circulating mudflush of a specific gravity sufficiently high to ensure that the pressure inside the borehole opposite a permeable layer is always in excess of the fluid or gas pressure in the layer itself. The use of the mud is only economical if the mud is returned to the vessel; for this purpose a conductor pipe or riser is used which is firmly fixed to the wellhead connections at the sea bottom and flexibly attached to the drill vessel. The riser should have a diameter large enough to allow the passage of the

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largest drill bits. The procedure is as follows: the mud is circulated downwards through the drillpipe and returns upwards to the drillship through the annular space between the riser and the drillpipe. The horizontal movements of the drillship under normal conditions are sufficiently restricted by its anchoring that the riser cannot be snapped off at the seabed. Moreover, a ball joint is installed at the bottom of the riser and helps to prevent excessive bending (figure 1; McLeod 1976). Finally the drillship's vertical movement or heave can now be compensated satisfactorily for the drillpipe as well as for the riser. The riser has also to be tensioned in order to prevent buckling which is not only caused by its own weight, but also by the difference in specific gravity of the mud inside and the seawater outside the riser. It is easily understood that the deeper the water, the more difficult it becomes to satisfy these requirements.

In case of a threatening blowout when the mud does not adequately equalize the pressure of one or more layers below the seabed, the well can be controlled by closing a blowout preventor valve at the seabed. This is possible if a so-called blowout preventor stack is installed consisting of a number of valves equipped with hydraulic rams which can, for instance, close around the drillpipe. Some type of electro-hydraulic system should be installed together with the riser in order to operate the valves from the drillship.

Once the well is closed in, remedial action should be taken and for this purpose two additional small diameter high-pressure lines need to be placed alongside the riser, the so called choke and kill lines. Such arrangements again add to the technical complications of the riser design, especially as the water becomes deeper.

The industry continued improving its riser design. Shell drilled in 1975 an exploratory well in 700 m of water offshore Gabon, while a year later Exxon drilled a deep test in 1060 m of water offshore Thailand.

The inclusion of buoyancy into the riser design is one of the major improvements which made it possible to achieve these records. The negative buoyancy of the riser is nearly compensated for by placing around the riser in concentric rings so-called syntactic foam made by Emerson & Cumming Inc. (Watkins & Howard 1976), consisting of hollow glass spheres in a binder of epoxy or polyester resin, having a density of about 500 kg/m^3. The material is now proven to withstand for a considerable time pressures equivalent to 2000 m of water, and it is expected that in the near future it can be used to 3000 m. Another system to achieve, say, 95 % buoyancy of the riser is provided by Regan and consists of a number of floats which are regularly spaced along the riser and which can be emptied by air pressure.

Today the weight of a 16–18$\frac{5}{8}$-in riser can be adequately compensated to a water depth of 2000 m. The riser should only be tensioned to take care of the differential weight between mud and seawater and the dynamic forces exerted on the riser by waves, current and surge of the vessel. Nevertheless, the pull to be applied to a 18$\frac{5}{8}$-in riser may well exceed 5000 kN when using heavy muds in bad weather in 2000 m of water. The latest 16–18$\frac{5}{8}$-in riser designs are capable of use in 2000 m of water.

Other necessary techniques of drilling in deep water which are applied by the oil industry are discussed in the next section, as these were initiated or developed by the Deep Sea Drilling Project (D.S.D.P.) (Peterson 1975).

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3. Past and present development in uncontrolled offshore drilling

In the summer of 1965 a proposal was submitted by Scripps Institution of Oceanography, University of California at San Diego, to the National Science Foundation for 'Drilling of Sediments and Shallow Basement Rocks in the Pacific and Atlantic Oceans and Adjacent Seas'. This proposal lead to the formation of Joint Oceanographic Institutions Deep Earth Sampling (Joides). It was decided to initiate the D.S.D.P. under management of the Scripps Institute, the project being financed by the Federal Government of the U.S.A.

In the summer of 1968 the drillship the *Glomar Challenger* began its first round of drilling in the deep sea. The ship was equipped with a dynamic positioning system to keep the ship on station, without anchors. This is achieved by means of additional propellors suitably placed alongside the ship. The position of the ship *vis-à-vis* the seabed is determined acoustically, and signals are translated by means of a computer into the appropriate propeller response.

Many holes were drilled in water depths of over 4000 m and even up to 7000 m during the project, but no riser was used. The bit on the drillpipe enters the seabed, and seawater is circulated through the drillpipe. Drill cuttings do not return to the vessel, but spread out over the ocean bottom. Continuous coring is therefore required and is carried out by means of wireline coring, the core barrel being extracted and reintroduced through the drillstring. This method is called uncontrolled drilling, as no remedial action can be taken against threatening blowouts apart from abandoning the hole by means of placing a cement plug.

In the beginning, trouble was experienced if the bit encountered hard, abrasive streaks of chert. Once the bit was dulled, the hole had to be abandoned. A breakthrough was established by developing a re-entry method. A large funnel-shaped cone is pushed into the seabed, and by means of sonar signals can be relocated with the drillstring. The drillstring extends almost to the rim of the cone, and the ship is slowly moved across it; once the drillstring is directly above the cone, the bit is at once lowered into the cone. The technique is now so well perfected that little time is lost in relocating the hole with a new bit. This method or similar ones are also used by the oil industry before the placing and cementing in of the first casing string. Once this operation is carried out, the blowout preventor stack will be installed together with the riser, and uncontrolled drilling becomes controlled. In 1975 the D.S.D.P. was converted to the International Phase of Ocean Drilling (I.P.O.D.). France, Germany, Great Britain, Japan and Russia participate with the U.S.A. in this project. Recently discussions were started as to whether the project should be continued for a considerable number of years and if so, whether the vessel selected for scientific ocean drilling should be equipped with a riser system.

It is possible that in view of availability of suitable equipment for ocean depths up to 7000 m, the riser problem could be solved in a manner rather different from the one preferred by the oil industry. If the I.P.O.D. project is continued, the experience of controlled drilling in water depths of up to 7000 m may be of great interest to the petroleum industry.

4. Pressure control of wells drilled in great water depths

One could wonder why such large risers of a diameter of 16–18$\frac{5}{8}$ in need to be used at all. The pull required to prevent a 10$\frac{3}{4}$-in riser from buckling is about half that required for a 18$\frac{5}{8}$-in riser under similar conditions, because the 10$\frac{3}{4}$-in riser contains much less mud, while the dynamic forces are also considerably lower. The apparent extravagance of using large risers is, however, caused by the need to balance the pressure in the borehole in such a way that on the one hand the pressure opposite the formation is high enough to prevent influx of fluids or gas into the hole, but on the other hand low enough to avoid fracture initiation (Koch 1975). In figure 2, pressures are plotted against depth for the case where the seabed is at 6000 ft (approx. 1830 m).

The author regrets that the petroleum industry on the whole is not yet using the International System of Units (SI). He personally made a strong plea during the Petroleum Industry

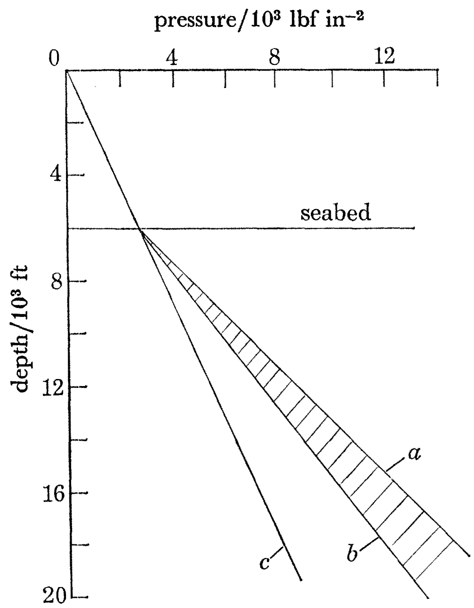

FIGURE 2. Pressure–depth relations: seabed at 6000 ft: line *a*, 1.0 lbf in^{-2}/ft; line *b*, 0.815 lbf in^{-2}/ft; line *c*, hydrostatic gradient of 0.445 lbf in^{-2}/ft.

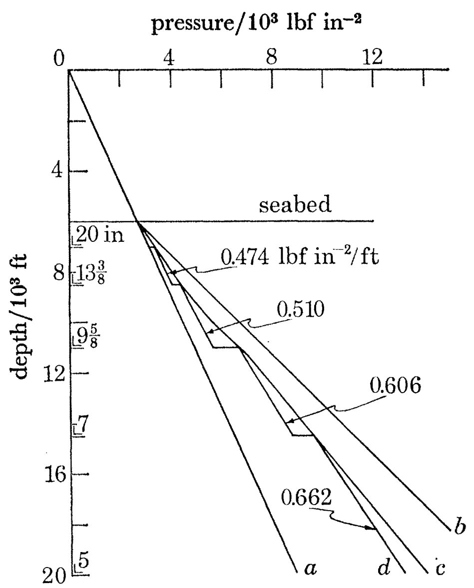

FIGURE 3. Pressure–depth relation for selected casing scheme: seabed at 6000 ft. Line *a*, hydrostatic gradient line (pore pressure trend); line *b*, overburden gradient line; line *c*, formation fracture gradient line; line *d*, maximum mud gradients acceptable.

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Seminar held by the United Nations Environment Programme in Paris, March 1977, to select at least one standard system of units applicable to the well-control programme to avoid calculation errors (van Eek 1977). For the present it seems less appropriate to use SI units in view of the industry's practices.

Figure 2 shows the highest liquid (gas) pressure gradient (*a*) of 1.0 lbf in^{-2}/ft which one can expect below the seabed, as compared with the hydrostatic gradient (*c*) of seawater of 0.445 lbf in^{-2}/ft. If a pressure gradient of 0.815 lbf in^{-2}/ft is reached below the seabed (*b*) the possibility exists that the formation may fracture due to excessive overpressure of the mud in the borehole. This can for instance be initiated at 12000 ft when the mud gradient from sea-level amounts to only $\frac{1}{2}(0.445+0.815) = 0.63$ lbf in^{-2}/ft. Controlling the formation pressures from sealevel is therefore the more difficult, the deeper the water depth becomes.

Figure 3 shows the following relations:

(*a*) The hydrostatic gradient line shows the relation between depth and pressure, if the pore pressure trends hydrostatically.

(*b*) The overburden gradient line shows the maximum pore pressure related to depth which may be expected. This pore pressure then equals the overburden pressure, and any higher pressure would enable the pore contents to lift the overburden.

(*c*) The formation fracture gradient line shows the fracture pressure related to depth. Any higher mud pressures in the boreholes are likely to fracture the formation vertically. This relation being only valid for hydrostatically trending pore pressures, is derived as an average of many field studies.

(*d*) The discontinuous line indicates the maximum mud gradients acceptable in various intervals between successive casing shoes. One runs the risk by exceeding this gradient that the formation will fracture near the casing shoe of the last set casing. The remaining triangles indicate for which pore pressures the maximum allowable mud gradient is insufficient to control the well. Obviously, the interval chosen between casing shoes depends on the risk one wishes to assume, but it is clear that one cannot eliminate this type of risk altogether, unless one would set casings continuously. It is also evident, if one has to set casings frequently for protection, that the advantage of starting with a large marine riser is rather quickly lost.

5. Alternative methods to drill wells in water depths to 4000–5000 m

Large risers have recently been designed for a water depth of up to 2000 m and may eventually be used in these water depths. However, the author does not visualize that these industrial designs can soon be scaled up for use in water depths of around 4000 m. It is therefore interesting to see whether, based on today's available technology, alternative methods can be proposed which in the near future would enable prospecting up to such water depths.

(*a*) It is now suggested using for this purpose a riser of diameter $10\frac{3}{4}$ in because the tensional forces to be applied to this riser in 4000 m water would be no more than those exerted on a 2000 m $18\frac{5}{8}$-in riser. Figure 4 shows how one could possibly overcome the problem of having to set a number of protective casings without having to reduce the hole diameter so quickly that a reasonable penetration below the seabed can no longer be expected.

For instance, a $10\frac{3}{4}$-in conductor is set 1000 ft below the seabed, and the underwater blowout preventor stack together with a $10\frac{3}{4}$-in riser are attached to this conductor. Subsequently a

$9\frac{5}{8}$-in hole is drilled to some 3000 ft below the shoe of the conductor and a 7-in casing is set at the bottom of the hole. Now a $5\frac{7}{8}$-in hole is continued some 3000 ft below the 7-in casing shoe. If neither unexpected pressure increases nor hydrocarbons are found, the 7-in casing is cut just below the shoe of the $10\frac{3}{4}$-in conductor. After recovery of the free part of the 7-in string, the hole is sidetracked and a new $9\frac{5}{8}$-in hole is drilled to the depth which was reached by the $5\frac{7}{8}$-in bit and a 7-in casing is again set. The protection of the 7-in casing is extended another 3000 ft. This procedure could be repeated several times, which may be necessary if one is forced to select short intervals between successive casings.

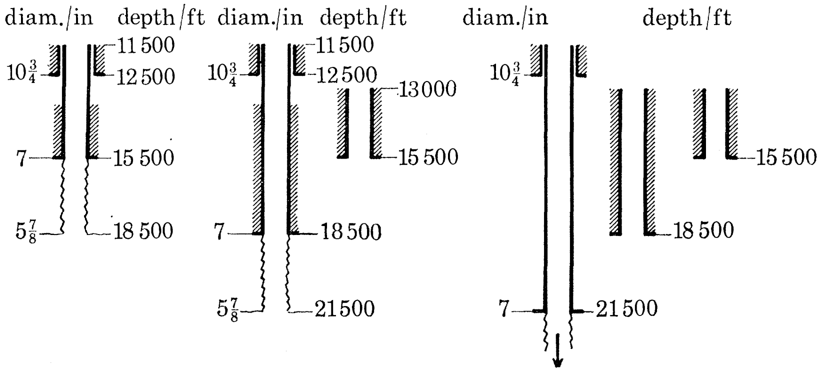

FIGURE 4. Sidetracking method avoiding loss of hole diameter when setting protective strings.

The drawback of this procedure is obvious; the hole may have to be redrilled several times and sidetracking is costly. The method becomes attractive if the technique is only required in certain holes which are planned for deep penetration. It allows the use of a smaller ship, a more manageable riser pipe, and above all, it may provide right now a technique of drilling holes in water depths of over 13 000 ft (4000 m).

(*b*) Another alternative is the use of an underwater float, or buoy, sometimes called a pedestal.

The underwater buoy aims to place the underwater blowout preventor stack just deep enough so that the dynamic forces are greatly reduced, although the current influence can never be eliminated completely. In this manner a long riser is avoided, and the wellhead is within the diver's reach. Moreover, in extremely bad weather when sufficiently exact positioning of the drillship is no longer possible, the riser needs to be disconnected from the underwater stack at the seabed. Drillpipe and riser are then usually pulled. The longer the riser, the costlier such an operation becomes. In the past this system was rejected.

First, it just did not seem possible to design a conductor between the seabed and the underwater float which was able to withstand the pull needed to compensate the static forces as well as the dynamic forces caused by the drift of the buoy due to the assumed underwater currents; secondly, failure of the conductor between seabed and float (its weakest point being at the float) would endanger the drillship, as the positively buoyant float could hit the vessel with tremendous impact.

(1) D. Meyer-Detring (1976) describes the use of a disconnectable floating riser carrier (figure 5). This project was undertaken by a number of German industrial firms. The patent claims that the use of this float would overcome the extraordinarily high cost of uncoupling and pulling a 2000 m riser, equipped with buoyancy material in heavy weather. It works as

follows: during bad weather the floating riser carrier is disconnected from the drillship and pulled by winches installed on the float to about 200 m under the water surface. The shortened riser (by means of a telescopic construction) is kept under tension by the tensioners of the float. The float itself is dynamically positioned. Presumably the float's positive buoyancy equals the tension which has to be pulled on the riser. It is then kept by the riser itself in place. Because the ship is only connected by an umbilical cable to supply energy to the float, it can move away from the float, so that in case of riser failure the ship cannot be damaged. The riser carrier is again coupled back to the mother unit when weather conditions permit to resume operations. By equipping the float with dynamic positioning, and safeguarding the ship against riser failure, the previous objections are overcome.

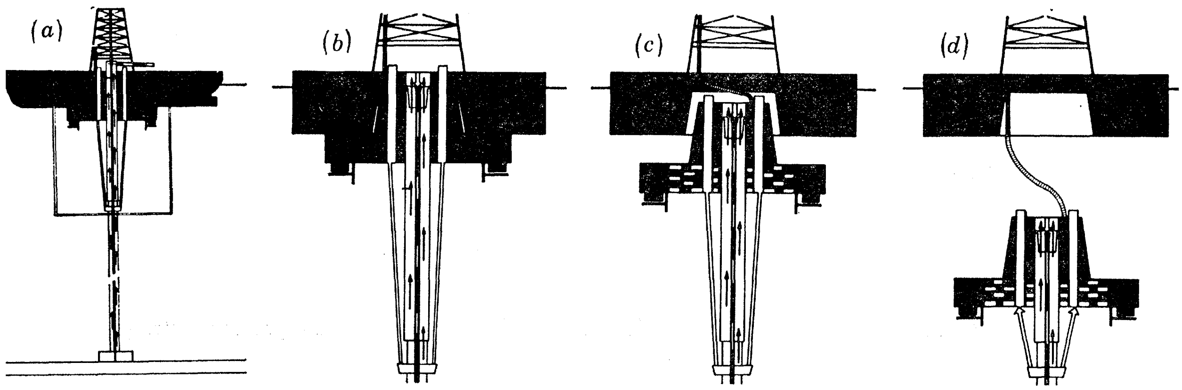

FIGURE 5. Disconnectable floating riser carrier. (*a*) General view. (*b*) Phase 1: disconnection. Enlarged section of (*a*). The drill string is fastened to the riser carrier, the flow line is replaced by a circulating pump. (*c*) Phase 2: flooding. The riser telescoping joint is pushed together about 3 m. The umbilical cable is connected with the riser carrier. (*d*) Phase 3: diving. The tensioners have pulled the unit about 200 m below the water surface. The telescoping capacity of the riser is reached.

(2) As an alternative to having a float which can be lowered from the ship, a permanent pedestal could be installed which also avoids the previously mentioned objections.

Although many designs of the pedestal are possible, the pedestal chosen in this paper (figure 6) consists of a number of large diameter pipes and flotation chambers at its lower end. Total height is about 100 m. The pedestal is towed in a horizontal position similar to the way large jackets are now being floated out. By properly manipulating the flotation chambers the pedestal is placed at the drilling site in an upward position. Thereafter it is made slightly negatively buoyant, but supported at some 15–20 m below the sea surface by means of some floats at sea level. The drillship is now placed over the pedestal and drills through the pedestal. The pedestal is kept in place by dynamic positioning. The drillstring is drilled a 300 m into the seabed. Before cementing, the drillpipe pushes the pedestal to 200 or 300 m below sea level and is then cemented in. After the cement has hardened, the pedestal is given some positive buoyancy, being kept in place by the drillpipe. The drillship can now disconnect the drillpipe at the pedestal. The main hole is then drilled through the pedestal and the conductor cemented in. Now by making the pedestal sufficiently positively buoyant, it will exert the necessary pull on the conductor. In case of conductor failure the ship is protected, because the drillpipe will still hold the pedestal in place. It speaks for itself that drillpipe and conductor below the pedestal will also make use of syntactic foam or apply the Regan's flotation cans. In this manner the pedestal does not need to carry more than the excess mud weight, while the horizontal forces are taken care of by the dynamic positioning system. Figure 7 compares the conventional method with this alternative.

(3) In appendix 2 a slim hole drilling method is described, which could eventually be an attractive alternative, provided field tests prove the soundness of the research.

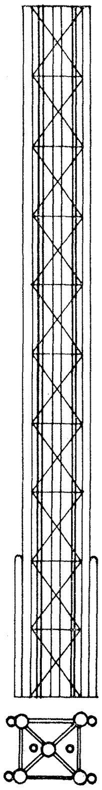

FIGURE 6

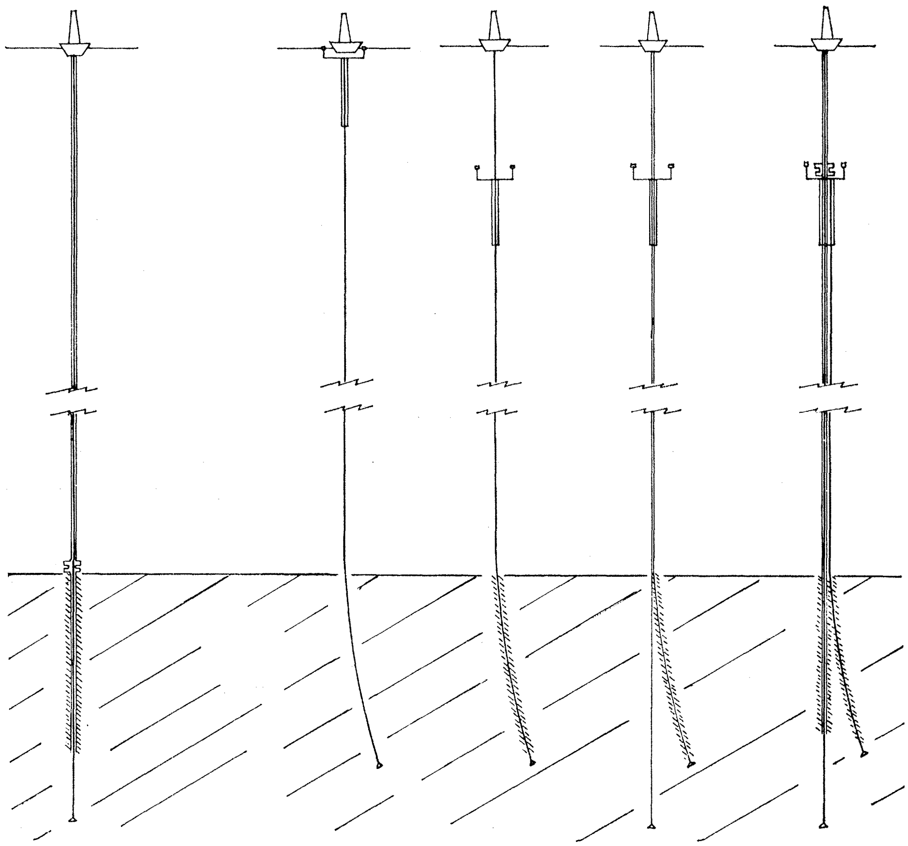

FIGURE 7

FIGURE 6. Sketch of suggested pedestal design.

FIGURE 7. Conventional controlled drilling method versus pedestal operation.

6. Production technology in deep water

Production platforms like the ones set in the North Sea may be set in water depths of up to 300 m or even a little deeper within the next few years. However, the industry is convinced that in real deep water underwater completions have to be used. So far, underwater completions are installed in isolated instances, and although these completions have been successful in water as deep as 100–150 m, their use is still considered experimental by industry. The paper by Goldman (1978, this volume) covers the technological progress which has been made in the last few years. Perhaps one is now allowed to assume that soon underwater completions can successfully compete with large production platforms in water depths of around 150–200 m.

During the next five to ten years a number of offshore fields may be developed mainly by underwater completions, and further experience will be gained in offshore fields in up to

200 m of water. Having said this, it is thus the present lack of experience which slows down the incentive to explore in water much deeper than 200 m.

However, by making use of dynamically positioned production pedestals placed 200 m below sealevel and being equipped for a cluster of six to eight producers, today's technology could be used. For instance, the wells could be deviated below the seabed, like the producers now being drilled directionally from production platforms. A dynamically stationed spar or tanker-hulk could be installed above the pedestal, not only for the purpose of oil storage, but also equipped with the necessary production facilities. It would provide a source of energy for the pedestal.

As a matter of fact, even if wells could be produced from 2000–4000 m by underwater completions at the seabed, it is questionable whether a pedestal would not provide a better answer. In any case it would avoid the long and tricky connecting of flowlines between production facilities at the seabed and the floating storage at the sea level. It will also allow diver's access. A study was made to compare both production methods, while assuming that either one would be feasible technically. It was found that in either case the same optimum production could be achieved.

7. Conclusions

(*a*) It is believed that within the reach of today's technology the industry can drill and produce hydrocarbons in water depths of up to around 4000 m, provided the production per well is large enough to justify such a project economically.

(*b*) In view of the looming long-range shortage of hydrocarbons the petroleum industry should be encouraged to commence testing of the deeper offshore over the entire width of the margins in a number of suitable localities.

(*c*) The hope is expressed that governments will encourage the petroleum industry by making prospecting of the margins attractive.

Appendix 1. A justification to look not only on the continental slope but also on the continental rise for hydrocarbon accumulations

The *Glomar Challenger* found on leg 48 (*Geotimes* 1976) large hiatuses in the stratigraphical series above the Aptian–Albian, the upper Lower Cretaceous, at the edge of the margin in the Bay of Biscay. It is noted that the hiatus in the Upper Cretaceous is contemporaneous with the well-known global transgression, although its origin is uncertain. It is thought by the authors of the article in *Geotimes* that the relation is unrelated to the subsidence of the margin. They suggest, however, that the effect of the transgression was to concentrate carbonate production in warm shelf seas, depleting the oceanic water of carbonate.

One may perhaps speculate in view of the global nature of the Upper Cretaceous transgression that the environment along the width of the passive margin may have been sufficiently favourable to allow the formation of abundant carbonate source rocks in a number of localities before the major subsidence of the margin took place. If this had been the case, then generation of hydrocarbons could have been initiated after sufficient subsidence and coverage by sediments; and although vertical migration should not be excluded, horizontal migration could have played a more important rôle.

In the article 'The habitat of some oil' Knebel & Rodriguez (1956) reported their study of a large number of basins and showed that in general, hydrocarbons migrate preferably towards the stable part of the basin.

The gentle slope of the formations underneath the continental rise away from the edge of the margin seems to resemble the favourable conditions for migration towards the stable part of the basin as described in the article. It is therefore suggested that preferential migration towards the edge of the margin could have occurred in a similar manner, the hydrocarbons being trapped *en route* under favourable circumstances.

It could even be imagined that hydrocarbons might be found in stratigraphical traps in the sediments overlying the ocean crust, provided, for instance, at least some sediments with reservoir characteristics were deposited during important regressions. Although the subject can only be touched briefly in this paper, there seems to be every reason to consider these areas as prospective.

Appendix 2. A slim hole drilling method

It is suggested to use a slim hole drilling method by means of diamond bits which can make progress through unconsolidated formations because the temperature of the circulating mud is minus 21 °C. The method of drilling with fluids which freeze the formation on contact is not new and has been used in several projects in order to improve coring recoveries in unconsolidated formations. However, the method has only been applied in shallow boreholes. The circulating fluid normally consists of diesel oil. The cooling power carried by the circulating fluid in order to freeze the fluid contents of the formation should be delivered at a sufficiently low temperature. Research was undertaken in Delft on the possibility of carrying eutectic ice in the mudstream in order to keep the temperature at minus 21 °C. The advantages are manifold. In the first place, clays will be frozen while drilling with the diamond bit so that progress will not be hampered. In the second place, it is hoped that the borehole will be sufficiently round and not oversized, so that just above the drill collars one or more packers can effectively be set in case of penetrating a formation with pressures higher than usual. In other words, blowout prevention takes place as near as possible to the fluid entry. The density of the fluid should be so low as to be slightly lower than the hydrostatic head which is expected to be present in permeable formations. This can be achieved by mixing kerosine or diesel oil with a solution of sodium chloride of a eutectic composition. The formations will not be entered by the fluid with high salt content, thus preventing freezing. On the contrary, just above the bit, freezing will commence and the borehole walls will be sealed off.

Continuous coring will be done through the centre of the bit, the cores will be ejected at the side of the bit and carried to the surface in the annular space by the mudstream. At the surface a certain amount of backpressure will be applied in order to keep the borehole under pressure. The bit is preferably rotated by a mud motor, like for instance a dynadrill. In case hydrocarbon-bearing formations with high pressures are encountered, their presence should immediately be revealed by a considerable outflow of the mud and the packer should then be set. Pre-prepared heavy mud can then be circulated above the packer in order to control the well or alternatively squeezed into the formation. In emergencies, cement can be placed above the packer. As the circulating fluid used should normally be of a lower density than the seawater, the riser pipe which is attached to the conductor should not need any more buoyancy then it already posesses due to the presence of syntactic foam (which, by the way is also an excellent thermal insulator).

Before disconnecting during bad weather, seawater will be circulated and the drillpipe pulled. The method is practically worked out as far as the initial research is concerned and a drilling test should now be programmed in the first place for a shallow hole onshore, say a few thousand feet deep. The calculations showed that the method can be employed at least up to 10000 ft of formation which should be ample for reconnaissance in the deep offshore. A patent has been applied for and it is hoped that in the near future Delft can find sponsors to try out this method in view of the very interesting possibilities which it can offer in case of success. Of course, it is realized that unforeseen difficulties may still develop making the method unattractive.

References (van Eek)

Anon. 1976 Glomar Challenger sails on Leg 48. *Geotimes*, December, pp. 19–23.

Anon. 1977 World, Europe deep water-drilling records set. *Oil & Gas J.* 7 February, 34–35.

van Eek, W. H. 1977 *State of the art of environmental conservation, exploration and production.* United Nations Environment Programme – Industry Sector Seminars Petroleum Industry Meeting, Paris 29 March to 1 April. Published as *Petroleum Industry and the Environment Seminar Papers & Documents*, Vol. 1, pp. 59–100.

Goldman, E. C. 1978 Offshore subsea engineering. *Phil. Trans. R. Soc. Lond.* A **290**, 99–111. (This volume.)

Knebel, M. G. & Rodriguez-Eraso, G. 1956 The habitat of some oil. *Bull. Am. Ass. Petrol. Geol.* **40**, 547–561.

Koch, R. D. 1975 Drilling in deep waters: casing setting depths. *Colloque International sur les Techniques d'Exploration de Hydrocardures; Forage et Production en Mers Profondes, Paris.*

McLeod, W. D. R. 1976 A review of riserless drilling alternatives. *S.P.E. European Spring Meeting, Amsterdam.* Society of Petroleum Engineers A.I.M.E., S.P.E. 5768.

Meyer-Detring, D. 1976 Project of a floating drilling unit for waterdepths up to 2000 m. *Erdoel-Erdgas Zeitschrift*, International Edn 1976, volume 2, 33–36.

Peterson, M. N. A. 1975 Deep Sea Drilling Project technical contribution to deep offshore oil and gas exploration and eventual production. *Ninth World Petroleum Congress Proceedings*, vol. 4, PD(10)1, 3–14.

Watkins, L. W. & Howard, M. J. 1976 Buoyancy materials for offshore riser pipe. *Offshore Technology Conference:* O.T.C. 2654.