SPE 30153

DRILLING FLUID PROGRAMMES CAN REDUCE HOLE EROSION AND MINIMISE HOLE PROBLEMS : CASE HISTORIES OFFSHORE VIETNAM

AJ Twynam, PM Collins, MD Jackson, P Forman

This paper was prepared for presentation at the SPE PetroVietnam '95 held in Ho Chi Minh City, SR. Vietnam, 1-3 March 1995.

ABSTRACT

This paper describes technical studies undertaken at BP Exploration Technology Provision Centre and the application of these studies along with transfer of best practice and local knowledge to solve two specific problems encountered in drilling offshore Vietnam.

1. Hole instability in shallow clastics : hole problems related to drilling shallow claystone sections with water based muds were being encountered; tight hole, bit balling, stabiliser balling, overgauge hole. This was causing lost time and increased costs. A technical audit involving the BPX Technology Provision Centre, Dowell IDF and BP Vietnam along with technology transfer from the North Sea Operations allowed the drilling fluid used on the problem section to be modified/optimised resulting in much improved drilling efficiency.

2. Hole erosion in deeper clastics : the hole erosion encountered in deeper clastic sections of wells can lead to several problems, namely the failed attempts to secure adequate wellbore evaluation information in the reservoir section. Cores were available from problem formations and these were used in geomechanical and chemical analysis to ascertain the cause of the problem. Based on the findings it was possible to make recommendations to the drilling fluid programmes and drilling practices, which have lead to enhanced drilling efficiency and much improved wellbores.

References and figures at end of paper

INTRODUCTION

BP Exploration commenced drilling offshore Vietnam in December 1992, operating in Block 5.2, 6 and 118. Several technical challenges were experienced in the drilling of these wells. In an attempt to optimise on drilling performance, several studies were undertaken. This paper details two such studies undertaken by the BP Technology Provision Centre in Sunbury, UK. The first study was to carry out a technical audit on drilling fluids being used in an attempt to improve drilling performance in shallow clastic formations. The second study concerned the observed problem of washed out holes in the deeper clastic formations which had resulted in problems with adequate formation evaluation. This paper describes the problems as identified, the methods used to determine the cause of the problems and discusses the conclusions and recommendations resulting in improved performance.

HOLE INSTABILITY IN SHALLOW CLASTICS

One of the more problematic hole sections on wells in Vietnam (excluding the loss control problems in the carbonates) is the 17" /17-1/2" section through the shallower clastics. These sections were originally drilled using a gel/CMC system which was gradually upgraded to a KCL /Polymer (PHPA) system.

Problems encountered on this section were due to "water base mud" being used to drill shallow clay stones. (Bit balling, tight trips, reaming, shaker blinding, stabilisers caked up). This was leading to expensive mud bills, compromised drilling performance and poor quality hole.

Various analyses of the problem had been carried out, but no definitive answer and forward programme agreed.

As such an independent audit was commissioned by BP Vietnam to audit the drilling fluids used on this section in the past, fully evaluate the problem in co-operation with the mud company and come up with a set of recommendations for an optimised mud programme.

The audit included comprehensive data collection and analysis, interviewing appropriate operational staff (including service company personnel), cutting sample analysis and inhibition tests.

The use of the more inhibitive mud systems did appear to give improved drilling efficiency (see Table 1):

(1) the average metres/day values were generally double those values seen with gel/CMC systems (see example values below).

TABLE 1

	Mud Type and (example well)	COST/BBL (US$)	METRES/ DAY	CONSUMPTION (BBL/M)
17"/22"				
	Gel/CMC (LT OBS)	6.90	25.8	8.33
	KCl/Polymer (HDN/5.2-NT)	13.90	50.4	4.27
17 1/2"				
	Gel/CMC (LD/LT)	7.15	29.3	3.84
	KCl/Polymer (HDB/5.2-NT)	15.52	84.5	2.63
14 3/4"/ 17 1/2"				
	Gel/CMC (LT OBS)	8.41	24.3	4.98
	KCl/Polymer (HDN)	14.90	26.5	4.09
12 1/4"				
	Seawater/Poly (LD)	7.99	6.2	8.16
	KCl/Polymer (HDN/HDB/LT)	27.26	17.2	2.57

(2) Incidents of bit balling were more frequent when using the Gel/CMC fluids.

(3) The inhibitive muds used were particularly beneficial in the mudstones above carbonate from a geological stand point. The cuttings observed when using such muds were able to be used for geological interpretation - an important factor when looking for top carbonate.

The audit report concluded that:

1. The major formation problem was related to dispersion rather than "swelling".

2. The inhibited mud system based on PHPA should continue to be used with optimised polymer makeup.

3. The alternative encapsulator system (here called polymer PA-X) proposed by the mud company as an alternative to PHPA looked promising, but BP had no field data to substantiate its use in shallow sections.

PA-X is a shorter chain PHPA normally used in high temperature mud formulations. Its use in this low temperature, shallower depth application was recommended on the basis it is easier to add and maintain concentration levels in high clay content mud systems. The viscosity humps associated with adding regular PHPA are considerably reduced.

BP had no field data on PA-X used in shallow sections, but Statoil did. They had evaluated its use in Statfjord and concluded that its performance in shallow sediments justified its continued use.

With this field data available, a trial of the KCL/PA-X system was approved for the 05-2-Bac-1X well. It was successful and has now been used on 06-LT-1XR and 06-LT-2X. The tabulated results are indicative of the success - the real data is the positive feedback from the rig. No blinding shaker screens, minimal bit balling, no reaming, gauge hole, no wiper trip required after logging and no problems running casing. The first wiper trip is still tight - but those of you familiar with the old days using water based mud in the North Sea will remember that! The problems have not disappeared - they are now being managed. The result is that we are now able to drill nearly twice as fast and deliver a better gauge hole for the explorers to log - a definite case of win-win - we pay a small cost in higher mud bills.

In summary this audit illustrates the following:

1. The process to achieve an improvement in performance involving a Technical Audit, Mud Contractor involvement and the use of the Alliance resource.

2. The success of the KCL/PA-X system in this application.

HOLE EROSION IN DEEPER CLASTICS

BP Exploration's Technology Provision in Sunbury-on-Thames, U.K. were asked to evaluate the poor wellbore performance of Well 118/BT-1X in Vietnam. The well proved to be difficult to log, and obtain RFT samples from, due to the frequency and size of borehole enlargements within the reservoir interval. A program was undertaken to review the existing data and perform some basic laboratory tests on core specimens in order to better understand the core behaviour.

The objective was to determine the cause of the borehole enlargements in the reservoir zone which

presented difficulties for subsequent geophysical logging and RFTs, and recommend preventative measures to be taken for a new well in the same area.

METHOD

Historical drilling data, in the form of drilling reports and logs, were examined to gain an understanding of the events that occurred regarding this well. Geophysical logs were studied, particularly the calliper logs and gamma ray traces, to determine where the borehole enlargements occurred and what their probable causes were.

Core reports and geological reports were studied to try to understand the rock's behaviour in response to the drilling operations in order to hypothesise a mode of failure for the wellbore. Once a few possible scenarios were developed, laboratory tests on specimens of sandstone core were performed to determine additional physical properties for the trouble-prone rock. The resulting data were used in subsequent analyses to identify the probable cause of the wellbore instability.

A brief summary of the well geology is provided in the following table:

TOP	FORMATION	CHARACTERISTICS
134mBRT	Bien Dong	silty sandstones to silty mudstones
1238m	Quang Ngai	sst, mudst, volcanics to mudst
2751m	Song Huong	mudst to argillaceous siltst/packstone, with quartzose sst reservoir rock at 3106m. This sst is immature: irregular grains, micaceous, kaolinitic; with some dolomitic grains. Thin interbeds of argillaceous/sandy siltstones with packstone texture occur. Anhydritic cement is also seen.

Two cores were recovered from the well:

1 3150.00 - 3158.78 m
2 3547.25 - 3565.25 m

One hundred and fifty sidewall cores were also taken within the reservoir (1980-3792m). They confirmed the general reservoir description of being an immature sandstone to silty sandstone, with mudstone stringers. The sandstone core has low permeability: 5mD for the upper core, and 0.5mD for the lower core. Porosity within the rock is not all interconnected.

Formation Pressure and Mud Weight Summary

The well is normally pressured in the Bien Dong formation, and at the top of the Quang Ngai formation (1238m) the pressure slowly climbs, reaching a peak of 1.35 to 1.43 S.G. at approximately 2800m. This falls to normal pressures of 0.98 S.G. by 3100m, and remains at that level.

With the formation above the reservoir being overpressured, the reservoir interval (3100-3800m) was drilled with a mud weight of 1.32 S.G. (with normal formation pressures) which resulted in an overbalance of 1500 to 1836 psi. It is worth noting that wellbore instability problems would not normally be expected with such a high overbalance.

The repeat formation tester (RFT) was successful in obtaining pressures about 50% of the time. The high failure rate was due to seal failure which is attributable to the irregular borehole shape after enlargement. Mud weights for the interval tested (3107 - 3787m) were a consistent 1.32 S.G., and equivalent formation fluid densities were reported as 0.98 S.G. Some higher values of EFFD at the top of the interval may have been due to some small overpressure or due to poor sealing.

The formation was generally described as tight, despite the fact that many RFTs were within sandstones. The exception was the sandstone at 3350m that was described as moderate, and produced fluid samples.

CORE ANALYSES

X-Ray Diffraction Analysis

The XRD tests were done to obtain an idea of the mineralogical and structural makeup of the sandstone.

Previous XRD Analysis of Sandstone, 3551m

Mineral	Weight %
Quartz	51
Dolomite	27
Mica	10
Feldspar	09
Pyrite	03

Cation Exchange Capacity

The cation exchange capacity (CEC) is a measure of the ion-exchange reactivity between an adsorbed solid and a solution. The CEC is used measured in units of milli-equivalents of ion per 100g of solid ("meq/100g"). Typical values of CEC are listed below:

Clay CEC Values

Clay Mineral	CEC (meq/100g)
Montmorillonite	100
Illite	10 to 40
Kaolinite	10

The value of CEC obtained from the sandstone core sample (3551m) was 2 meq/100g MBT (methylene blue test). While this is extremely low, it does not indicate that the rock is non-reactive since the number reflects the reactivity of the entire sample and not of the clay portion of the sample. Although this sandstone is mechanically strong, it appears to be friable which would indicate that the sandstone obtains its strength from grain to grain contact and not from strong cementation. The grains consist of inert quartz and dolomite, therefore the reactive elements are concentrated in the binding cementation of the rock. This could mean that very reactive clay particles in the cementation are susceptible to chemical degradation, resulting in a breakdown of the cementation and a weakening of the entire sandstone structure.

TRANSMISSIBILITY ANALYSIS OF CORE TESTS

In addition to the original core studies, new tests were performed for this study. A dozen rock strength test were performed on core plugs in order to obtain a base-line rock strength (unconfined compressive strength = UCS). Half the samples were steeped in drilling filtrate at well temperatures and tested to see if the UCS had changed. Mud filtrate tests were performed on core disks. The results of these tests, and their interpretation, are summarised below.

An interpretation of the mud filtrate tests, relating the development of the mudcake to the required UCS for the rock, is presented below in theoretical terms, followed by an examination of the laboratory data.

One-Dimensional Filtrate Flow

The approach taken in examining the effect of a developing mudcake was to consider the transient flow from a wellbore as a problem of impeded single phase flow, where the flow impedance was dynamically increased due to the accumulating thickness of mudcake on the borehole wall.

In a one-dimensional analysis, the reference state for fluid flow from the drilling mud through the formation is the case of filtrate with no solids. Assuming that the filtrate has displaced the mobile pore fluids and has reached a constant saturation, the flow rate across a given length should be constant. This assumes that there is no core:filtrate interaction that would affect the fluid flow characteristics.

The Darcy's Law flow velocity would be defined as

$$v = -\lambda(\nabla p - \gamma \nabla z) \qquad [1.1]$$

where

- ∇p is the pressure gradient
- γ is the weight density gradient
- ∇z is the elevation gradient
- λ is the mobility

The mobility is defined as:

$$\lambda = k\, k_r/\mu \qquad [1.2]$$

where

- k is the absolute permeability
- k_r is the relative permeability to filtrate
- μ is the filtrate viscosity

If gravity effects are excluded as being second-order effects, the flow rate can be defined as:

$$q = vA \qquad [1.3]$$

$$= -\lambda\, \nabla p\, A$$

$$= -\lambda\, \Delta p/\Delta l\, A$$

$$q = T\, \Delta p \qquad [1.4]$$

where

- A is the cross-sectional area
- T is the transmissibility of the plug to filtrate
- Δp is the pressure difference across the plug
- Δl is the length of the plug

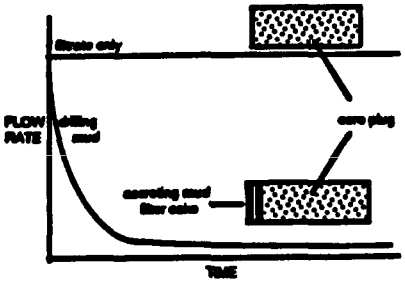
Equation 1.4 states that, for a constant pressure drop along the plug, the flow rate will be controlled by the effective transmissibility of the sample to filtrate flow.

One-Dimensional Flow with Accretion of Mud Filter Cake

The addition of drilling mud solids to the filtrate results in an impedance to filtrate flow as the solids are deposited on the face of the plug. These solids are designed to plug the pore throats, thus reducing the effective area for fluid flow into the core. In addition, the continuous accumulation of additional solids forms a mud filter cake that has two effects on fluid flow: first, the additional material results in a tortuous flow path for filtrate passing from the drilling mud into the core plug, and secondly, the resulting increased pressure drop across the mud cake results in compaction of the mudcake, which further reduces the effective permeability of the mudcake. A schematic of the flow rates is shown in Figure 1, in which the

expected filtrate flow characteristics are shown for the case of pure filtrate flow and filtrate flow with an accreting mudcake.

Fig. 1 COMPARITIVE FLOW RATES



If the system of mudcake and core plug is considered as a single unit, the effective transmissibility of the unit is :

$$q(t) = T_{eff}\,\Delta p \qquad [1.5]$$

$$T_{eff} = q(t) / \Delta p \qquad [1.6]$$

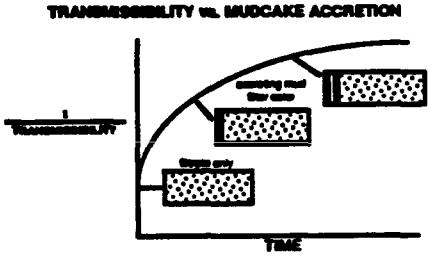
Since the mudcake and plug are acting in series, the effective transmissibility is comprised of the two separate transmissibilities:

$$(T_{eff})^{-1} = (T_{mudcake})^{-1} + (T_{coreplug})^{-1} \qquad [1.7]$$

$$\Delta p / q(t) = \Delta p_{mudcake} / q(t) + \Delta p_{coreplug} / q(t) \qquad [1.8]$$

By plotting Δp / q over the test, a curve similar to Figure 2 should be obtained. The y-axis intercept represents the condition of zero mudcake thickness, which should be the same as the case of pure filtrate flow with no solids.

Fig. 2
TRANSMISSIBILITY vs. MUDCAKE ACCRETION



The exponential form of the curve is due to the accretion of mud solids on the face of the core plug as filtrate is forced through the sample. If it is assumed that the thickness of the mudcake is directly proportional to the volume of filtrate that has flowed through the plug, the mudcake transmissibility can be expressed as a function of filtrate flow. From Equations 1.3 and 1.4:

$$T(t)_{mudcake} = \lambda A / \Delta l(t) \qquad [1.9]$$

$$= \lambda A / (g Q(t)) \qquad [1.10]$$

where

Qis the cumulative filtrate flow, as a function of time gis a proportionality constant

By combining Equations 1.10, 1.2 and 1.8,

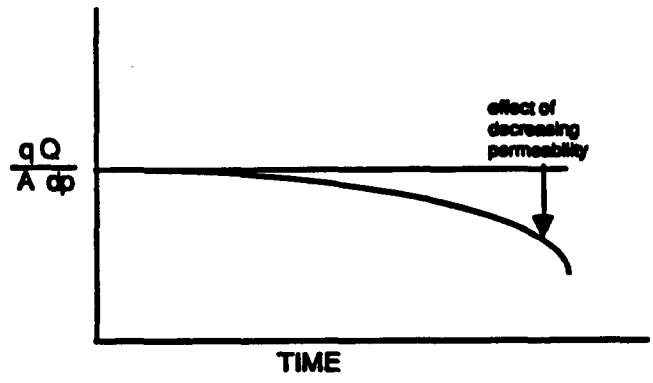
$$\lambda = g\,Q(t)\,T(t)_{mudcake} / A \qquad [1.11]$$

$$\lambda / g = qQ / \Delta p\,A \qquad [1.12]$$

Note that the equation assumes that the permeabilities in λ remain constant;. However, as the volume of mud solids deposited as the filtercake increases, the pressure drop across the mudcake increases, which should compact the mudcake and decrease its absolute permeability, as seen in Figure 3.

Fig. 3

MOBILITY vs. MUDCAKE ACCRETION



Theory

Since the total flow through the sample is the same for any cross-section, the following relations can be stated:

$$q(t) = T_{eff}\,\Delta p_{total} = T_{mudcake}\,\Delta p_{mudcake}$$
$$= T_{coreplug}\,\Delta p_{coreplug} \qquad [1.13]$$

Mudcake efficiency "η" is defined as the effectiveness of the mudcake in maintaining the total overbalance pressure drop within the mudcake:

$$\eta = \Delta p_{mudcake} / \Delta p_{total}$$
$$= T_{eff} / T_{mudcake} \qquad [1.14]$$

From [1.7],

$$\eta = 1 - T_{eff} / T_{coreplug} \qquad [1.15]$$

The transmissibility of the coreplug can be obtained by extrapolating the total transmissibility to time=0 when the mudcake did not exist. A continuous plot of mudcake efficiency can be obtained by knowing the coreplug transmissibility and the total transmissibility.

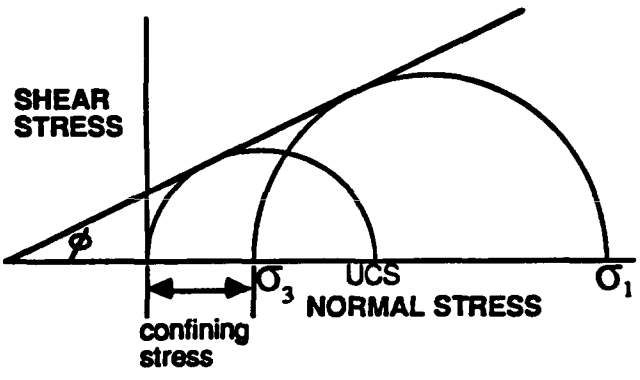
There are some assumptions made with these equations. First, it is assumed that the pressure distribution across the sample is pseudo steady state in that the pressure transients established after applying the 1800 psi Δp_{total} across the sample have occurred instantaneously. This simplification would overestimate the coreplug transmissibility because it would initially be easier for filtrate to flow into the unpressured coreplug. Second, it assumes that this value remains constant throughout the test and does not change due to dissolution of soluble minerals or by the formation of an internal mudcake with fines disturbed by, or transported by, the filtrate.

The efficiency of the mudcake affects the stability of the wellbore because it is the effect of the stress applied to the sandface that strengthens a frictional rock such as this sandstone. When the mudcake is ineffective, there is no applied confining pressure, and the strength of the rock is greatly reduced. The benefit of the confining pressure is of greater importance than the intrinsic unconfined compressive strength (UCS) of the rock since the strength gains with a confining pressure far exceed the UCS.

This can be seen in Figure 4, in which a Mohr-Coulomb failure criterion is shown:

Fig. 4

MOHR-COULOMB FAILURE CRITERION



N.B.: stresses are effective stresses

The value for the friction angle, ϕ, used in the analysis was only an estimate since its determination would have required a set of triaxial tests. However, the usual range of friction angles is 32 to 40 degrees for weak to strong sandstones. The UCS values obtained from the laboratory testing on 1 inch diameter plugs indicate that the sandstone is moderately strong, as seen in Table 2. Note that the UCS values for all samples (untreated, and filtrate-treated) are essentially the same. When examining the core, however, it was friable, indicating that the rock could be susceptible to damage, such as erosion.

Table 2
Unconfined Compressive Strengths of Sandstone Specimens

DEPTH	UCS (psi)	UCS in Filtrate [1] (psi)
3151.7	4840	4830
3153.0	6780	6430
3155.0	6530	5080
3551.0	6410	6560
3551.7	4840	4480
3555.0[2]	6230	5290

1 These samples were flushed with 5 pore volumes of filtrate at 150°C, then held at that temperature with no flow for 1 hour. After cooling, UCS tests were done.

2 This sample is a siltstone/mudstone.

By knowing the friction angle and UCS, the strength of a rock can be determined for any confining pressure from the equation:

$$\sigma_1 = \sigma_3 (1+\sin\phi)/(1-\sin\phi) + UCS \qquad [1.16]$$

Conversely, the UCS for failure can be determined for any principal stress state:

$$UCS = \sigma_1 - \sigma_3 (1+\sin\phi)/(1-\sin\phi) \qquad [1.17]$$

In Situ Stress State

The stress state at the borehole wall was determined by assuming an overburden gradient of 1 psi/ft, normally-pressured formation fluids for the reservoir elevation, and a Poisson's ratio for sand of $\nu = 0.25$.

Quiescent Depositional Basin

The common assumption for the stress state for a basin is that it is a result of the accumulation of sediments, and that the horizontal stresses are a result of the elastic response of the rock to the overlying weight. The Lan Tay reservoir is not in an extensional or compressional field, therefore this assumption is justified. Also, in the absence of any indication that the horizontal stresses are very different, the assumption has been made that they are equal. This is rarely the case, however if the stress difference is small, the error introduced will be minor. In this instance, the in situ stresses are:

$$\sigma_v = \gamma_{ob} z \quad [1.18]$$

$$f = \gamma_{effd} z \quad [1.19]$$

$$\sigma_h = \nu/(1-\nu)(\sigma_v - p_f) + p_f \quad [1.20]$$

where

σ_v is the total vertical stress
γ_{ob} is the overburden gradient (e.g.: 1 psi/ft)
z is the vertical depth
p_f is the formation fluid pressure
γ_{effd} is the equivalent formation fluid density
σ_h is the total horizontal stress
ν is Poisson's ratio

As a check on this assumption, the LOT at the mudstone at a depth of 1978m was analysed, assuming an overpressure of 1.29 S.G. With the recorded LOT gradient of 1.74 S.G., and using Equation 1.20, the Poisson's ratio was found to be n = 0.30 which is reasonable for a claystone.

The drilling of the borehole alters the stresses in the rock from the in situ stress state to one of stress concentrations around the borehole. The vertical stress remains essentially the same, but the tangential tresses are raised while the radial stresses are lowered. However, the application of a radial supporting pressure through the use of a heavy mud weight and effective mudcake reduces the stress difference between the tangential and radial stress. Without such support, the borehole usually fails in a classic breakout, with failure occurring by a constricting shearing of the rock mass in towards the borehole.

In addition to the changes due to stress concentrations are poroelastic effects. These are the changes in rock stress as a result of changes in the fluid pressure in the rock. As these fluid pressures vary, the proportion of the total stress borne by the rock mass varies inversely, which causes stress changes or displacements in all three principal directions. With an imperfect mudcake, the fluid pressure changes resulting from the influx of filtrate alter the rock stresses at the sandface. Since this is where stress concentrations are commonly the highest, the state of stress at the sandface with an imperfect mudcake will be examined.

The three principal stresses at the sandface are (McLean, 1988):

$$\sigma_z = \sigma_z + (1-\eta)(p_{well} - p_f)(1-2\nu)/(1-\nu) \quad [1.21]$$

$$\sigma_\theta = 2\sigma_h - p_f + \eta(p_{well} - p_f)(1-2\nu)/(1-\nu) \quad [1.22]$$

$$\sigma_r = p_{well} \quad [1.23]$$

The pore fluid pressure just inside the sand face is:

$$p_{sf} = p_f + (1-\eta)(p_{well} - p_f) \quad [1.24]$$

Therefore, the three principal *effective* stresses at the sandface, meaning that portion of the stresses borne by the rock matrix as opposed to the fluid phase, are:

$$\sigma_z' = \sigma_z - p_{sf} \quad [1.25]$$

$$\sigma_\theta' = \sigma_\theta - p_{sf} \quad [1.26]$$

$$\sigma_r' = \sigma_r - p_{sf} \quad [1.27]$$

The principal effective stresses σ_1 and σ_2 are the maximum and minimum of these. The UCS at failure can then be calculated using Equation 1.17 for any level of mudcake efficiency. Note that this type of analysis assumes that the sandstone behaves in a linearly-elastic manner, and that the pressure transient effects at the start of the test are ignored.

Such an analysis was done for the five mudcake/filtrate test samples. An analysis was done of the varying flow rates, in order to determine the transmissibilities. These were used to calculate the mudcake effectiveness over time, which were used to get the pore pressure and effective stresses at the sandface. With these, the UCS at failure was calculated.

GEOMECHANICS ANALYSIS OF THE HUXLEY BERTRAM FLUID LOSS MEASUREMENTS

The drilling filtrate loss tests were conducted on five disks of core. Three were obtained from the upper cored interval (3151m, 3153m, 3155m) and two from the tighter sandstone at the top of the lower core (3151m, 3151.57m). Most of the lower core was siltstone/mudstone, with the more permeable sandstone appearing at the top of the interval.

Drilling mud of the type used in Well 118/BT-1X was used for these tests. Core disks of 25mm in height were prepared for the flow tests. The temperature was raised to 124°C (as compared with the estimated bottomhole temperature of 150°C) and a differential pressure of 1800 psi was applied. Flow rates were continually monitored.

1 Upper Core (Zone A)

The specimen from 3151m is anomalous in that the observed flow rates are four times higher than the other two specimens. This may be due to some local interconnectivity of pore space that is not extensive in a larger sample, and is therefore not representative of the upper core. Certainly the two increases in transmissibility during the test are indicative of an increase in the permeability of the specimen/mudcake,

which would make the test results for this sample very suspect.

The specimens at 3153m and 3155m are more typical, in that the transmissibility decreases at a slower rate with time. Mudcake efficiency is at 80% within 2 minutes , with the required UCS dropping from an initial 5417 psi to an average of 1285 psi. Recall that the average UCS for the upper core was 5748 psi (six samples) as seen in Table 2 above.

A stability analysis of this interval was performed, assuming mudcake efficiencies of 0%, 50%, and 100%. The required UCS values were 5403psi, 2798 psi, and 193psi. Clearly the confining pressure of the mudcake adds considerably to the strength of the rock.

2 Lower Core (Zone B)

The two specimens from the lower core appear to have even higher permeabilities than the upper core, as seen in the volume of fluid loss reported over the test after 20 minutes. This is contrary to the previous and current physical laboratory core testing that found a factor of 10 difference in permeabilities, with the upper core being more permeable.

During the test, both samples behaved similarly in that the drop in transmissibility with time was much more gradual. Mudcake efficiencies developed more slowly, reaching 80% after 4 and 6 minutes. The required UCS strength at 0% efficiency is 6098 psi, and for 80% efficiency it is 1403 psi. These required strengths are larger than for the upper core because of the increase in well depth. The predicted stress level with no mudcake is higher than the average UCS obtained from the lower core was 5572 psi (exclusive of the mudstone results at 3555m). Required UCS values for 0%, 50%, and 100% mudcake efficiency were 6089 psi, 3153 psi, and 218 psi.

RECOMMENDATIONS ON DRILLING FLUID PROGRAMMES FOR FUTURE WELLS

The preceding sections of this paper detail the tests carried out on the core samples taken from well 118-BT-1X. The major points to consider from this analysis are as follows:

* The Drilling Completion Report and the calliper logs were used to identify the severity of the washed out sandstone sections. A typical zone was identified which was relatively stable (Zone A : 3151m - 3155m) and another typical zone which had experienced washouts (Zone B : 3551m - 3555m).

* Samples were taken as required from cores available at Sunbury from these depths to carry out several tests.

* XRD analysis was carried out on the samples. These results can be seen in Appendix A. One obvious conclusion is that the samples from the washed out section contains a high percentage of dolomite (~10% up to 27%) when compared to the in-gauge section (<5%). This was an interesting point and early conclusions were drawn that the highly soluble dolomite matrix in the sandstone could have been leached out by drilling mud filtrate, hence weakening the rock strength. Unfortunately, this was not really confirmed by later unconfined compressive strength (UCS) tests (see below), but we believe the high presence of dolomite in the sand matrix could have possibly lead to an increase in filtration rates, and subsequent reduced rock strength as the sand matrix was dissolved.

Results were as follows:

		Average UCS	Average Permeability
Zone A : 3151 - 3155m	In-gauge	5748 psi	5 mD
Zone B : 3551 - 3555m	Washed-out	5596 psi	0.5 mD

The average UCS results from both samples indicated a very strong sandstone. An expert opinion suggests that any UCS value above 2000 psi indicates a competent sand. Although the sandstone in zone B had lower UCS, the difference was not large enough to explain the erosion which had taken place.

* Using the same core samples, the effect of mud filtrate on the cores was investigated. A mud was mixed to simulate that used to drill the original well and filtrate collected from the mud. This filtrate was then passed through the cores (1" diameter, 2" long) and UCS tests carried out before and after filtrate invasion. The FracTech report concluded that there was no evidence of mud filtrate interaction with the sandstone matrix, either in the core sample from the in gauge section (zone A) or samples taken from the washed out section (zone B).

* Further core discs were cut (25mm) from both zones A and B. Dynamic filtration tests were carried out on the Huxley Bertram with simulated drilling mud as used in the original well. From the results obtained, a geomechanics analysis showed that sand cores from the upper in gauge zone A achieved 80% cake effectiveness within 2 minutes, indicating that the cake building efficiency lead to early strengthening of the rock. However, zone B showed a much slower rate of cake building efficiency at identical parameters (124'C with 1800 psi overbalance), due to its reduced permeability. It was concluded that the washed out zone B cores showed poor mud cake building efficiency even at such high overbalance. This

would have lead to a reduced confining pressure of mudcake to add to the rock strength.

. seems probable from the above results that any future attempt to minimise hole erosion needs to concentrate on two key issues:

- optimise mud type to minimise chemical interaction with the sand matrix
- optimise mud formulation to enhance filtration control and attempt to (a) reduce filtration rates even further and (b) assist in the cake building quality of the mud system.

Other relevant studies

A recent study by P. Page and M. Hogan at XTP Sunbury (ref.) looked at fluid loss mechanisms under dynamic conditions. This report describes work carried out on WBM's (primarily KCl / polymer muds) to establish the impact and relative significance of the following parameters on dynamic filtration rate:

- mud weight
- mud solids particle size
- differential pressure
- temperature
- mud rheology
- formation permeability and porosity

The relevant conclusions of the report were as follows:

1. The dynamic filtration rate of KCl / polymer water based mud was strongly dependent on the temperature, mud solids content, mud rheology, shear rate at the filter cake surface, and the pore throat size distribution of the formation.

2. By comparison, dynamic filtration was insensitive to changes in differential pressure over the range 250 - 1,800 psi. This effect is attributed to filter cake compression.

3. Defining rock samples in terms of permeability can be misleading in predicting filtration behaviour. Comparing fluid losses through synthetic and outcrop cores has demonstrated that the pore size distribution of the mud is more important in influencing the filtration rate.

4. Fluid loss can be significantly reduced by the formation of internal filter cakes. The ability of a mud to form internal cakes depends on the pore size to mud solids particle size ratio (PPR).

5. The results show the importance of determining the pore throat size distribution of the formations being drilled plus the particle size distribution of the mud solids if an assessment is to be made of the effectiveness of downhole filtration. This information can be used to identify whether an internal filter cake is likely to form, and more proactively, whether an adjustment to the size distribution of the mud solids would improve filter loss control. Although the Abrams (ref. 6) rule-of-thumb is widely used as a guideline to minimise solids invasion, the test work results suggest that to promote the formation of an internal filter cake the size distribution of the mud solids should simply be broad enough to overlap and mirror the pore throat size distribution of the formation.

6. The solids content of the mud was found to be the parameter with most influence on the effectiveness of some glycols as a fluid loss additive. At a mud SG of 1.1 (2.3% vol. total solids), DCP 101 had no affect on fluid loss, but at mud SGs > @ 1.2 (5.4% vol. total solids), the addition of 3 - 6% DCP 101 glycol to a KCl / polymer mud generally reduced the dynamic filtration rate by 10 - 20% compared to that obtained with the base mud. The addition of 3% DCP 208 glycol reduced the rate by only 3%. Similar tests with starch reduced the dynamic filtration rate more than with DCP 101 (a 25% reduction) and this was achieved at much lower dosages.

7. The results suggest that two filtration control mechanisms may be in operation when glycols are present in the mud:

(1) The viscosity of the glycol solution is higher than that of a plain aqueous salt solution, hence in the pores of the filter cake the filtrate invasion rate is slowed.

(2) When glycols like DCP 101 cloud out, the micro emulsion formed may plug pores and cracks in the formation in the same way as the emulsion phase in an invert OBM does.

8. The results have demonstrated the importance of temperature in determining the rate of fluid invasion. Until recently, reducing mud temperature has never been considered as a practical option for reducing fluid loss. However, Elf and Alfa-Laval (ref. 7) have recently demonstrated that cooling the mud at surface using heat exchanges can provide significant benefits in terms of improved wellbore stability / reduced fluids invasion to be justified on economic grounds for certain wells.

Forward Programme

Based on the above information, and a consideration of current "best practice" guidelines, a few recommendations can be made in an attempt to minimise erosion on future wells.

* Superior fluid loss control is exhibited by oil based muds (OBMs) over water based muds (WBMs) and this is usually attributed to the fact that OBMs contain water droplets which can deform to produce a filter cake with very low permeability (micro darcy). Oil base muds also minimise mud/rock interactivity due to the inert

external phase oil. For these reasons, it is recommended that oil muds should be the first choice drilling fluids for any formations with potential washouts which may be due to chemical reactivity.

* However, use of oil base muds may not be possible or desirable due to economic, logistics and/or environmental considerations. In this case, one must quantify the potential problem of washed out sections within the wellbore. What extra costs may be involved if washouts can not be eradicated from a particular area, for example, poor hole cleaning resulting in prolonged circulating times and hole conditioning; poor cement jobs; poor logging data or formation evaluation etc? Extra costs incurred by the Operator in preparation for use and handling of oil base muds may be offset in many cases by the improved drilling efficiency, reduced hole erosion and enhanced formation evaluation performance. This option should be seriously considered if possible.

* If oil based muds cannot be used, or are deemed to be not cost effective for the project, then optimising the water based mud programme can be attempted. A number of options are discussed below.

* Recent advances in WBM chemistry has seen the increasing use of a new generation of WBM systems containing glycols. Glycols are added primarily to promote shale inhibition, however, there is some evidence to suggest that they also reduce fluid loss. Field evidence also indicates that, generally, hole condition and stability is improved when using KCl/Glycol systems over less inhibiting water based muds. For this reason, KCl/Glycol has become the standard water based mud in XEU for technically challenging wells where oil base muds can not be used. Of relevance to this study is the observed reduction of filtration rates at high overbalance when using glycol muds.

* Filtration rate reduction can also be achieved by other means. Improved filtration control can be realised by using various mud additives in conjunction with or instead of glycol. Starch is a very effective additive and should be considered. In Vietnam, however, the strong possibility of bacterial activity may preclude dependence on starch alone for effective filtration control. Use of asphalts will also be effective here, particularly with the BHT's to be encountered in these formations. The downside of asphalts may be formation damage considerations. This could be investigated further using reservoir core if necessary.

* It is recommended that effective bridging agents be built into the mud system. One of the conclusions from the geomechanics analysis of the core from 118-BT-1X, was that the sand prone to washout had a much lower permeability and hence a reduced capability to effectively promote a strengthening wall cake. One option here could be to effectively increase filtration rate of the mud system thereby resulting in an increased efficiency to build a mud cake. The downside of this would be that filtrate invasion would be increased, possibly leading to an increase in chemical interactivity within the sandstone. A better option, we believe, would be to use a suitable bridging material to promote a rapid wallcake deposition, thereby effectively strengthening the wellbore. A mixture of bentonite and fine calcium carbonate would be recommended. Concerns over formation damage if using this method would be over-ruled if the well was to be perforated, as the perfs would most certainly exceed the "damaged" zone. This method would not be desirable, however, if the well was to be completed without the requirement to perforate.

* Use of encapsulating polymers, such as poly anionic cellulose (PAC) or poly-acrylamide (PHPA) would also aid in strengthening of the wellbore by promoting a polymer coating on the wellbore, and secondly, by viscosifying the mud filtrate to effectively reduce filtration.

* Another means of minimising wellbore erosion is to control the fluid mechanical activity. It is thought by some experts that wellbore erosion can be induced by turbulent flow of the annular fluid. This can therefore be minimised by control of annular hydraulics and design of fluid rheology to promote laminar flow. A recommendation which can be made to achieve this would be to increase the low shear rate viscosity of the fluid thereby allowing a decrease in annular velocity or flow rate without compromising effective hole cleaning. There are several mud systems on the market which can be applied to this situation, for example, a Mixed Metal Hydroxide (MMH) system and a polymer shear thinning system. Both mud systems show high viscosity at low shear rates and have been used by BPX in several applications to enhance hole cleaning at low flow rates.

CONCLUSIONS AND RECOMMENDATIONS

The majority of the overgauge intervals of the wellbore within the reservoir were due to washouts. In particular, the large washout at a depth of 3560m was a result of a drillstring washout.

It is tempting to state that the strength analysis proves that the upper core was stronger than the required strength, whereas the lower core was not, and that explains the difference in performance. However, it should be remembered that the analysis is based on a linearly elastic analysis that commonly under-

estimates rock strengths by a factor of 3 to 6, and therefore the stress analysis is not conclusive proof of wellbore instability.

Although an elastic analysis typically underestimates the true strength of the wellbore, it is likely that this factor should be low for this well for the following reasons:

- the rock is unconfined because of the poor mudcake, and will therefore not behave plastically as it approaches failure (the UCS specimens failed bitterly)
- the lack of a mudcake will prevent the development of a stable plastic failed zone at the borehole that acts to support the stronger, unfailed rock farther from the wellbore
- the type of breakout anticipated with this stress regime is conchoidal vertically, therefore there would be no inherent arching of the failed material if indeed borehole breakouts are occurring, therefore no post-peak strength would be available

Rocks can withstand some short-term overloading, and it is likely that the major strength difference is a result of the different rates of mudcake build-up. As seen in the plots of the required UCS versus time, the strengthening effect of the confining stress is far larger than the need for a high UCS value. Effective mud design is the solution to strength problems in frictional rocks such as sandstones.

Lastly, it should be remembered that the majority of borehole enlargements were washouts. It is likely that these could be reduced in frequency and diameter if a more effective mudcake were used.

To this end, it is recommended that several changes to the drilling fluid programme may be attempted. The use of oil based mud would certainly minimise any wellbore erosion due to chemical interactivity between drilling fluid and the formation. However, it is realised that this may not be a cost effective answer. Therefore, it is recommended to enhance the performance of the water based mud programmes to be used in an attempt to:

a. minimise filtration rates of the fluid by use of mud additives such as glycols, specialist polymers and perhaps asphalts.

b. minimise mechanical erosion potential by increasing low shear rate viscosities, thereby allowing reduction of flow rates to attempt a more laminar annular flow profile, without compromising hole cleaning.

c. addition of bridging agents and small addition of bentonite in an attempt to promote more effective cake building potential across the sandstone.

REFERENCES

1. McLean, Michael (1988) PhD thesis, Imperial College.

2. Abrams, A. Mud design to minimise rock impairment due to particle invasion, JPT, 1977, pp. 586-592.

3. Maury, V. and Guenott,A. Practical advantages of mud cooling systems for drilling SPE/IADC 25732, 1993.

APPENDIX A

XRD ANALYSIS OF VIETNAM SAMPLE
ZONE A (IN GAUGE)

Table 1
Semi-Quantitative Clay Mineral XRD Results

	118-BT-1X 3151.9m
Illite	58%
Kaolinite + Chlorite	5%
Smectite	37%
Total	100%

Table 2
Semi-Quantitative Whole Rock XRD Results

	118-BT-1X 3151.9m
Mica+Illite	3%
Quartz	86%
K-Feldspar	3%
Calcite	2%
Pyrite	1%
Plagioclase	3%
Dolomite	0%

ZONE B (WASHED OUT)

Table 3
Semi-Quantitative Clay Mineral XRD Results

	118-BT-1X 3551.37-3551.39m
Illite	99%
Kaolinite + Chlorite	1%
Total	100%

Table 4
Semi-Quantitative Whole Rock XRD Results

	118-BT-1X 3551.37-3551.39m
Mica+Illite	5%
Quartz	82%
K-Feldspar	2%
Plagioclase	1%
Dolomite	10%

WELL NAME	SECTION LENGTH	DAYS DRILLING	METRES/ DAY	COST/ METRE	MUD SYSTEM	COMMENT
06-LD-1X	232	4	58	1724	GEL/CMC	Includes wiper trip for logging problems
06-LT-1X	661	6	110	907	GEL/CMC	Up to well control incident
06-HDB-1X	1049	11	95	1049	KCL/POLYMER	Includes intermediate logs
052-NT-1RX	1221	9	136	737	KCL POLYMER	Excludes weather downtime adjusted for re-drill of section
052-BAC-1X	339	1	339	294	KCL/PA-X	18" gauge hole
06-LT-1XR	572	3.5	163	612	KCL/PA-X	18" gauge hole - includes VSP log
06-LT-2X	642	2.8	229	436	KCL/PA-X	17.75" gauge hole