Final Well Report

Well 25/5-3

Geology / Geophysics
Reservoir Evaluation

Licensees version

Text

elf aquitaine
norge a/s

Stavanger, October 1990

ELF AQUITAINE NORGE A/S
Exploration Division
311Dld/90/R26/CBo/kn

FINAL WELL REPORT

WELL 25/5-3

(GEOLOGY - GEOPHYSICS - RESERVOIR EVALUATION)

LICENSEES VERSION

WELL FILE

Final Well Report, Well 25/5-3
EAN approvals

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Stavanger, October 1990

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Brent drill stem test (DST 1)

1. INTRODUCTION / ABSTRACT

1.1. PURPOSE OF THE WELL (See Figs. 1.1 to 1.6)

The well 25/5-3 had to recognize the petroleum potential of the so-called **"A" prospect, defined at Jurassic level.**

This structure is located near the eastern border of the block 25/5, about 15 km south-southeast from the Frøy oil field.

The well 25/5-3 is the second and last commitment well of the licence PL.102, awarded in March 1985, at the 9th Round of licensing.

1.1.1. Objectives of the well:

- explore the MAUREEN SANDSTONES (Early Paleocene)
- explore the MIDDLE JURASSIC BRENT SANDSTONES (= the main target)
- explore the LOWER JURASSIC STATFJORD SANDSTONES

For all these objectives the expected fluid was oil.

The well had to be bottomed within the Triassic Hegre Formation, as requested by the work program defined for the PL. 102.

1.1.2. Structural aspect

- **At Maureen level**

A sort of mound is observed on the seismic survey EL8902, affecting the basal Tertiary series.
A tentative mapping evidenced a possible closure.

- **At Jurassic level**

The only reliable markers which can be picked and mapped are the Base Cretaceous Unconformity and the Intra-Statfjord marker.

The Brent is not visible (too thin).

Hence, the "A" prospect was defined at Intra-Statfjord level.

It appears as **a horst, along the western edge of the Utsira High**. It is limited to the south by an EW fault.

Closed area	: 13 sq. km
Vertical closure	: 70 m

Closed areas occur at Base Cretaceous and at Top Cretaceous, at the vertical of this horst.

The structure at Brent level is assumed to be similar to the one at Intra-Statfjord level.

A tentative isobath map at Top Brent has been performed by:

- adjusting the fault pattern
- substracting 280m to the Intra-Statfjord isovalues.

1.1.3. Location of the well

It is located on the eastern flank of the structure.

The chosen position was on the seismic line EL8902 at SP830.

This **downflank location** was preferred in order to recognize the total section of the Brent reservoir (it might be reduced on the top of the structure, as it is the case for the overall interval between the Base Cretaceous and the Intra-Statfjord marker.

Due to a possible risk of shallow gas, it was moved southwards, 60 m from this point.

1.2. GENERAL DATA

Country	Norway	
Block	25/5 (offshore North Sea - 190 km southwest of Bergen)	
Licence	PL 102 (awarded March 1st 1985 at 9th Round of licensing)	
Operator	Elf aquitaine Norge A/S	30 %
Partners	Norske Shell A/S Statoil	20 % 50 %
Well indentification Well classification	25/5-3 Exploration (vertical well)	
Well location	60 m south of seismic line EL 8902-111 SP 830	
Coordinates	UTM	X: 479 087 E - Y: 6 605 469 N (ED 50 - UTM zone 31 - CM 3°E)
	Geographical	Longitude 02°37' 46,935"E Latitude 59°35' 08,009"N
Water depth	118 m	
RKB	22 m above MSL	
Rig on location	26/01/1990	
Spud date	27/01/1990	
T.D. reached	21/02/1990	(26 days after spud date)
Completion date	26/03/1990	(60 days after spud date)
Rig	West Vanguard	
Contractors	Drilling Wireline logging Mud logging MWD	Smedvig Schlumberger Geoservices Teleco
Total depth	2900 m (driller) within Hegre Fm.	
Well status	Gas discovery in Brent. Plugged and abandoned.	

1.3. MAIN GEOLOGICAL RESULTS (see Pl. 1.1)

Note: The actual results are close to the prognosis (Fig. 1.7). All the formations have been found a little bit deeper, the interval velocities being slightly higher than forecasted.

Groups Formations	Age	Depths m - RKB	Thicknesses m
Nordland Gr.	no datings	140-1012	872 m
Hordaland Gr.	Oligocene to Mid.Eocene	1012-1928	916 m
Frigg Fm.equiv.	Lower Eocene	1928-1998	70 m
Balder Fm.	Earliest Eocene	1998-2044	46 m
Sele Fm.	Paleocene	2044-2095	51 m
Lista Fm.	Paleocene	2095-2162	67 m
Maureen (Ty) Våle Fms.	Paleocene	2162-2310	148 m
Shetland Gr.	Cretaceous (Maastrichtian)	2310-2347	37 m
Heather Fm.	Upper Jurassic (Oxfordian-Callovian)	2347-2384	37 m
Brent Gr.	Middle Jurassic (Bathonian)	2384-2453	69 m
Dunlin Gr.	Lower Jurassic (Toarcian-Pliensbachian)	2453-2613	160 m
Statfjord Fm.	Lower Jurassic (Sinemurian-Hettangian)	2613-2752	139 m
Hegre Gr.	no datings	2752-2900	

See the main results (Lithology - Datings - Environments - Dips data) on the Figs. 1.8 and 1.9.

The Brent and Statfjord reservoirs are at **hydrostatic regimes.**

The geothermal gradient is = **3.35°C/100m**

1.4. MAIN PETROLEUM RESULTS

- **at Maureen level**

  A good potential sandy reservoir is developed within the Maureen Formation (basal Tertiary):

* Two massive, clean, sandy levels (22 and 61 m) are found between 2211 and 2310 m separated by a shaly layer

* These sands are waterbearing (no shows at all).

- **at Brent level** (See Pl. 4.1 and 4.2)

  The Brent reservoir is 69 m thick (2384-2453 m) consisting of sandstones, generally fine grained, clean, occasionally micaceous/shaly and calcareous cemented

  It is **gas-bearing at top (gas column 42 m).**

  The upper 21 m have very good reservoir qualities.
  (porosities > 25 % - average permeabilities: Kh = 363 mD, Kv = 236 mD).

  The basal part is less good (Øm = 20 %).

  For the total Brent the N/G is estimated around 77 %.

  The top reservoir has been tested: (perforations 2386 - 2405 m)
  maximum flow 585 000 m^3 of gas + condensates (180 - 200 g/m^3) with a choke of 40/64".

- **at Statfjord level** (See Pl. 4.3 and 4.4)

  The Statfjord Formation is 139 m thick (2612-2752 m)
  and consists of an alternance of sandstones and shales.

  The N/G is estimated around 63 % with an average porosity of 25 % for the reservoir levels.

  Some sandy levels have very good petrophysical characteristics (permeabilities > 1D)

  These reservoirs are **water-bearing.**

2. SUMMARY OF DRILLING OPERATIONS

If not otherwise mentioned, all depths in this chapter refer to m.RKB.

2.1. MOVING AND ANCHORING (duration 1 day)

West Vanguard left well 25/2-13 location on the 26.01.90 at 14.30 hrs and was on well 25/5-3 location at 19.00 hrs the same day. The well was spud on the 27.01.90 at 12.00 hrs.

2.2. DRILLING PHASES (See Figs. 2.1 and 2.2)

- **36" phase** = 140 - 200 m (duration 2 days).

  36" hole was drilled to 200 m using sea water, with a 26" bit and a 36" hole opener.
  30" casing shoe was set at 198.5 m.

- **17 1/2" phase** = 200 - 1192 m (duration 10 days).

  Due to possible shallow gases from site survey data, a 8 1/2" pilot hole was drilled down to 350 m (but no gas was found).
  After hole opening, the 17 1/2" phase was continued down to 1192 m.

  The casing shoe 13 3/8" was set at 1176 m.
  Then BOP's were set, after 2,5 days waiting on weather.

  NOTE: The well was drilled without riser down to 1008 m.

- **12 1/4" phase** = 1192 - 2357 m (duration 7.5 days).

  After drilling out the cement and 5 m of formation, a L.O.T. was performed (equivalent mud weight = 1.80).

  No major problem were encountered while drilling down to 2357 m

  The mud weight was 1.25 down to 1800 m, then increased to 1.30.

  Wireline logs were run before setting the casing 9 5/8" at 2350 m.

- **8 1/2" phase** = 2357 - 2900 m T.D. (duration 15,5 days).

  The mud weight was 1.13/1.15 down to the Intra-Stafjord marker, then increased to 1.20.

  After drilling out the cement and 5 m of formation, a L.O.T. was performed (equivalent mud weight = 1.78).

  A drilling break occurred at 2384 m. One core was cut from 2386 to 2404 m (driller depths).

  No shows being observed, the drilling resumed and continued down to 2613 m where a second drilling break occurred.

A core was cut between 2615 and 2628 m (driller depths).

Then drilling resumed down to 2900 m (T.D.)

T.D. was reached 26 days after the spud date.

Eight wireline logging operations have been performed.

Note:

. While POOH at 2695 m, the string got stuck with no mud return and with no rotation.
Mud returns were resumed one hour later, and rotation was resumed while jarring after one more hour.

POOH resumed, with back reaming and high torque from 2619 to 2583 m.

The mud weight was increased to 1.20.

. During the final wiper trip, the bottom of the hole was found in bad conditions:
it was necessary to ream from 2735 to 2825 m, and to increase the mud weight to 1.25.

2.3. **TEST PHASE** (duration 7 days)

The well was plugged back to 2502 m and a 7" liner run (2235-2497 m) prior to test the Brent reservoir.

2.4. **ABANDON PHASE** (duration 17 days)

The well was permanently plugged and abandoned.

Bad weather causes 67 hrs of lost time during this operation.

The final status is shown in Fig. 2.3.

Anchor handling started the 20/03 at 18.00 hrs, but was stopped at 21 hrs due to bad weather. After 81 hrs of W.O.W., anchor handling was resumed and West Vanguard left location the 26/03 at 14.00 hrs.

Note: The total operation time of this well is 60 days.

2.5. **DEVIATION SURVEY**

A deviation survey was performed while drilling by Teleco.

The well is vertical, with a drift always lower than 1° (see Table 2.5).

The Fig. 2.4 displays the borehole course : the bottom of the well is located 12 m to the SSE from the starting point.

2.6 CONTRACTOR AND SERVICE COMPANIES

Mud	ELF NORGE
Mud logging	GEOSERVICES
Production testing	FLOPETROL/HALLIBURTON
Fishing	SMITH INTERNATIONAL
Positioning	GEOTEAM
Electrical logging	SCHLUMBERGER
Meteo	T.O.M./METEOMER
Diving	OCEANEERING
H.P. Pumping	BJ HUGHES
Bulking	BJ HUGHES/PROMUD
Under water T.V.	OCEANEERING
Testing	FLOPETROL
Well head	VETCO
Air transportation	HELICOPTER SERVICES
Sea transportation	BERGESEN
Deviation survey	TELECO
Velocity survey	READ
Tubing testing	TROMS OILFIELD SERVICES
Casing	TROMS OILFIELD SERVICES
Cementing	BJ HUGHES

3. GEOLOGY / GEOPHYSICS

(If not otherwise mentioned, all depths in this chapter refer to m. RKB).

3.1. GEOLOGICAL OPERATIONS

3.1.1. Mud logging/sampling

- **Gas detection**

The new Geoservices gas-logger was used.

This system measures the gas from the same amount of mud throughout the well.

So it gives more reliable and comparable data.

It is not affected by non-HC gases. It is a more sensitive tool than the previous ones, detecting gases C1 to C5 with a precision of 10 ppm.

- **Routine cuttings sampling**

Ditch cuttings were collected:
* every 10 m between 1160 and 2330 m
* every 3 m between 2330 and 2357 m
* every 5 m between 2360 and 2900 m (T.D).

3.1.3. Wireline logging

No wireline logging was run within the 17 1/2" section.

Wireline logs were run within the 12 1/4" and 8 1/2" sections before setting respectively the 9 5/8" casing and the 7" liner.

The wireline operations are listed hereafter:

Drilling Phase	Date	Type of Log	Depth Interval	Recorded BHT (°C)	Extrapol. BHT (C°)
12" 1/4	12.02.90 to 13.02-90	DIL-DDBHC-GR-AMS-SP LDL-GR-AMS SHDT-GR-AMS CST (30) CBL-VDL-GR	2327.6-1154 2327.6-1154 2318.5-1170 2296-1812 1176.3-148	61 61 66.7	69
8" 1/2	22.02.90 to 25.02.90	DIL-DDBHC-GR-SP LDL-CNL-NGL-AMS DLL-MSFL-GR FMS-GR-AMS RFT VSP CST (60) CBL-GR	2884-2230 2882.8-2351.3 2481.3-2351.3 2790-2351.3 2638.8-2386.9 2800-1100	76.1 85.6 87.7 88.9	100

Note:
* In the 12 1/4" section it was not possible to pass 2327.6 m.
* In the 8 1/2" section it was not possible to pass 2885.6 m

3.1.4. Sidewall coring

Run	Drilling Phase	Shots	Depths (m)	Full	Empty	Bullets Lost	Misfire	Rec
1	12" 1/4	30	2296 -1812	26	3	1	0	87 %
2	8" 1/2	60	2858.2 -2353	50	0	8	2	83 %

3.1.5. Conventional coring

Two conventional cores have been cut (using fiber glass innertube and a special shoe with cutter):

* one at top of the Brent reservoir
* one at top of the Statfjord reservoir

The results are listed below:

No	Depth (m) Driller	Logger	Recovery m	%	Formation Lithology	Time to cut
1	2386-2404	2388-2406	17.8	99	Brent Sandstone	2h 55
2	2615-2628.4	2617-2630.4	13.4	100	Statfjord Sandstone and shale	2h

Total core cut : 31.4 m
Total recovery : 31.2 m = 99 %
Average ROP : 9.4 mn/m = 10.4 m/h

3.2. GEOPHYSICAL OPERATIONS (VSP)

A zero offset VSP was performed by Read Well Services A/S.

106 levels were recorded with a 20 m interval.

Data acquired above 1280 m (RKB) are anomalous due to a poorly cemented casing.

Hence, only 84 levels between 1280 and 2860 m (RKB) were used for the VSP processing and to calibrate the Sonic.

See the acquisition parameters on Fig. 3.4.0.

3.3. GEOLOGICAL AND PETROLEUM RESULTS

Note:

* The geological column encountered by the well is subdivided in lithostratigraphical units, in accordance with the local nomenclature.

  The biostratigraphical datings are taken into account, and the sequential analysis/log characteristics of the series as well.

* As all the Laboratory studies have been completed, the main results are included in this report.

List of performed Lab. studies.

— **Biostratigraphy**

* **Micropaleontology** (Foraminifera) throughout the Tertiary below 1176 m (13 3/8" casing shoe) (no samples available above) and over the Cretaceous, using cuttings samples.

* **Nannofossils:** only over the Cretaceous between 2310 and 2347 m.

* **Palynology:**
  over the basal Tertiary from 1836 to 2245 m (using the sidewall cores)
  over the Jurassic/Triassic from 2353 to 2857 m (using the sidewall cores)

— **Inorganic geochemistry for the Brent and Statfjord reservoirs.**

* **Standard petrology and mineralogy** (mainly on cores)

  - thin sections mineralology
  - X-ray diffraction
  - clays characterization
  - carbonates characterization: mineralogical and chemical data (stable isotopes study).

Some samples had been chosen in order to calibrate the electric-logs interpretation. (Optim software - see chapter "Reservoirs Evaluation").

* **Reservoir behaviour study.**

  - Analysis of the diagrams porosity vs permeability.
  - Diagenetic sequence and influence of the diagenetic processes on the reservoirs characteristics.

— **Sedimentology of the Brent and Statfjord reservoirs** (cores + electric logs study)

* Autocar photographs of cores
* Cores description
* Electric logs analysis (sequential evolutions)
* Study of the Microscanner images (FMS) and SHDT dips

Results:
- Lithofacies characterization and their vertical association.
- Characterization of the depositional environments.

— **Structural analysis of dipmeter data** from 1176 to 2785 m.

— **Organic Geochemistry**

* **Screening analyses** of rock samples.

  Total organic carbon (TOC)/Rock-eval/Extractable organic matter (EOM)
  * for 1 sample in the Tertiary (the sandy streak which gave a gas peak during drilling)
  * for 2 samples in the Upper Jurassic
  * for some samples in the Brent
  * for 6 samples in the Dunlin
  * for 6 samples in the Statfjord
  * for 2 samples in the Hegre

* **Follow-up analysis** (on rock samples)

  Detailed analyses on selected rock samples after the screening analysis:

  - Thermovaporization
  - EOM-MPLC
  - Gas chromatography/Mass spectrometry
  - Carbon isotopes on total extract
  - Carbon isotopes on all fractions

* **Study of the DST 1 gas/condensate sample**

  Gravity, distillation, fractioning, gas chromatography/mass spectrometry, carbon isotopes.

3.3.1. Lithological formations (See Pl. 1.1 and Figs. 1.8 to 1.11)

RECENT / TERTIARY

NORDLAND GROUP: 140 to 1012 m (872 m).

Definition:

The base corresponds to the base of a massive sandy unit (the so-called Utsira Formation).

Lithology:

No cuttings available (return to sea bed).

From MWD (GR/resistivity) this interval can be divided into three units:

- 200 to 417 m:
  Mainly CLAYSTONE with some thin sandy streaks (less than 5 m thick).
- 417 to 495 m:
  Alternating SAND and CLAYSTONE.
- 495 to 1012 m:
  Prominent SAND with some claystone interbeds.

Biostratigraphy:

No datings, probably recent to Upper Oligocene from surrounding data.

- **HORDALAND GROUP**: 1012 to 1928 m (916 m).

Definition:

The base corresponds to a break on Sonic, Density and Resistivity log.

The underlying series, even if shaly as above, have clearly different log characteristics (more resistant, higher density and interval velocity) and have a different colour.

Lithology:

CLAYSTONE light grey/olive to greenish grey, occ. dark grey/brown/black, more or less silty/sandy, slightly calcareous between 1200 and 1350 m, occ. glauconitic between 1070 and 1350 m, occ. micromicaceous and pyritic.

Some thin streaks of Limestone, argillaceous, mainly between 1485 and 1590 m.

Two sandy intervals are encountered in the upper part:

1048-1068 m (alternances clay/sand)
1357-1372 m (massive sand)

Biostratigraphy/Environments:

First datings below 1195 m.
This interval is dated by micropaleontology.
Only two SWC at the very base have been studied by palynology.

* 1195-1250 m: **Late Oligocene** (Asterigerina guerichi zone).
  Outer neritic conditions (prominent calcareous benthic foraminifera).

* 1290-1470 m: **Early Oligocene** (Rotaliatina bulimoides zone).

* 1470-1570 m: **Late Eocene** (Karreriella indigena zone)

* 1570-1928 m: **Middle Eocene**

  (1570-1790 Ammomarginulina foliaceous zone)
  (1790-1928 Cyclammina amplectens zone)

  These intervals between 1290 and 1928 m, dominated by arenaceous benthic foraminifera, correspond to **upper bathyal conditions.**

  The palynodatings III 1 at 1836 and 1918 m confirm a Middle Eocene age.

Dipmeter data:

Scattered dips all over this zone.

Shows:

No shows.
Background gas lower than 1 % with C1 only.

- **FRIGG FORMATION equivalent: 1928-1998 m (70 m)**

Definition:

These shales have specific log responses and colours. They are quite homogeneous. The gamma-ray shows a slight negative trend towards the top.

Lithology:

Silty SHALE, yellowish/brown, occ. dark red, occ. dark greenish grey.

Biostratigraphy/Environments:

Early Eocene/upper bathyal to outer neritic.

Micropal: Spiroplectammina navaroanna zone (arenaceous benthics-1930 to 1990).
Subbotina patagonica (calcareous planktics 1950 to 1990).
Oridorsalis umbonatus (calcareous benthics at 1990).

Palynology: **Upper IIa** zone at 1958 and 1983 m.

Dipmeter data:

The dips are rather scattered
except at base between 1970 and 1992 (14-20° to the ENE locally up to 35°).

Shows:

Background gas lower than 1 % with C1 only.

- **BALDER FORMATION:** 1998-2044 m (46 m).

Definition:

The typical log responses of the tuffaceous facies are obvious between 2014 and 2044 m on the Sonic and Resistivity curves.

The uppermost part is less obvious from these two logs, but a well featured break occurs at 1998 m on the Density log and on the dipmeter (with well organized, stratified dips within the Balder Formation, while they are more scattered above).

From the gamma-ray as well its specific features are recognized (negative trend at base, overlain by several positive trends). But this log is not useful to pick the top of the formation.

Note: As it is the case for all the wells in this area, the Frigg/Balder boundary is difficult to assert; it is not easy to date precisely and the sequential evolutions are not always of help.

Lithology:

SHALE olive grey to dark/medium grey, occ. TUFFACEOUS,
with thin streaks of marl and argillaceous limestone.

Biostratigraphy/Environment

Earliest Eocene/ probably bathyal:

Micropal:	Coscinodiscus (Diatoms) observed at 2010 m only.
Palynology:	**Middle IIa** zone at 2027 and 2045.

Dipmeter data:

Homogeneous dips between 1998 and 2033: 3-5° to NW.
Discontinuities are clear at 1998, 2033 and 2044.
Between 2033 and 2044: 3-6° to the N.

Shows:

Slight increase of the background gas (values between 0.8 and 1.5%),
with first occurrence of C2-C3.

- **SELE FORMATION:** 2044-2095 m (51 m).

Definition:

This shaly unit has very homogeneous Sonic/Resistivity/Density responses, used to pick both top and bottom.

The radioactivity is rather high at top, above 2078 m.

The top and the base of this formation correspond to dipmeter discontinuities.

Lithology:

SHALEs brownish black, occ. olive black, slightly silty.

Biostratigraphy/Environments:

Late Paleocene/probably restricted basinal.

Not characterized by micropaleontology.
Palynology: **Lower IIa** zone at 2061-2076-2095 m.

Dipmeter:

- Very homogeneous dips N56-5°NW.
- Clear discontinuity at base (2095 m)

Shows:

Background gas increasing from top (1-1.5 %) towards base (3 %) with C1 to C3.

- **LISTA FORMATION:** 2095-2162 m (67 m).

Definition:

This shaly unit has Resistivity, Sonic and Density responses more spicky than the overlying series.

The base corresponds to a Gamma-ray maximum between two opposite trends.

The gamma-ray exhibits a basal negative trend up to 2140 m, overlain by a positive trend.

The top is also a gamma-ray peak.

Lithology:

Silty SHALE, brownish black, occ. olive black.
One thin streak of sand, very fine/fine, white, loose (2139-2140 m).

Biostratigraphy/Environments:

Late Paleocene/probably upper bathyal.

Micropal: Spiroplectammina spectabilis zone (arenaceous benthic foraminifera)

Palynology: **Ib zone** between 2105 and 2140 m.

(The studied SWC corresponds to the Ib2 zone).

Dipmeter data:

The mean structural dip remains rather similar to the one of the Sele Formation down to 2140 m : 5 - 10° to the NW.

A discontinuity at 2112 m is interpreted as a fault trending N55 (down to the west).

A discontinuity is encountered at 2140 m, with dips turning to N73-6°N.

Below 2152, the dips become scattered, due to a caved hole.

Shows:

* Background gas decreasing from 3 % at top to 1 % at base, with C1 to C3.
* Gas peak (22 %) at 2140 m (C1-C3), corresponding to a thin sandy streak.

Note:
No shows on SWC taken at 2140 m (and no significant amount of extractable hydrocarbons from the geochemical study).

- **MAUREEN (TY) / VÅLE FORMATION:** 2162-2310 m (148 m).

Definition:

The top corresponds to the top of a gamma-ray positive trend, (increasing shaliness) together with the top of the Ia palynozone.

These Våle shales have an homogeneous Resistivity response.

The basal part consists of massive sands, resting directly onto the massive Cretaceous carbonates.

Lithology:

* 2162-2211 m: SHALE, brownish black, occ. olive black, silty, with stringers of limestone, slightly argillaceous and silty.

* 2211-2310 m: two levels of massive SAND (22 and 61 m thick), fine/medium, occ. coarse, loose, clean, well to moderately sorted (good reservoir), separated by an interbed of shale a/a with some stringers of limestone, slightly argillaceous and silty (0.5 to 3 m thick).

Biostratigraphy/Environments:

2162-2195:	**Late Paleocene - upper bathyal**
Micropal:	Hormosina ovulum gigantea zone (arenaceous benthic foraminifera) Radiolaria (1st event) observed at 2180-2190 m.
Palynology:	Ia3 palynozone from 2165 to 2195 m.
2200-2310:	**Early Paleocene - outer neritic.**
Micropal:	Gavelinella beccariiformis zone (calcareous benthic foraminifera) Matanzia varians (arenaceous benthic foraminifera) below 2220 m Occurrence of planktic foraminifera: Planorotalites compressus / Morozovella pseudobulloides below 2200 m Globoconusa daubjergensis at 2300
Palynology:	Ia2 zone at 2245 m.

Dipmeter data:

Poor data due to caved shales at top. Scattered data within the basal sand.

Shows:

2162-2195: Background gas 0.7-1 % (C1 to C3) SHALES
2195-2311: Background gas 0.15 %

2211-2310 (SANDS): Background gas 0.2-0.5 % at top (C1-C2)
decreasing to 0.15 % (C1 only) below 2243 m

No oil shows

The Maureen (Ty) sands are waterbearing.

CRETACEOUS

- **SHETLAND GROUP:** 2310-2347 (37 M).

Definition:

Massive carbonates.

Lithology:

LIMESTONE, white, chalky, occ. argillaceous and silty, occ. greenish grey with one interbedel of marl, grey, silty.

Biostratigraphy:

Late Maastrichtian.

Characteristic planktonic foraminifera and Nannofossils from 2320 to 2345 m.

No dipmeter data.

Shows:

Only traces of C1.

UPPER JURASSIC

- **VIKING GROUP - HEATHER FORMATION:** 2347-2384 m (37 m)

Definition:

The gamma-ray response indicated the possible absence of the Draupne Formation (absence of very radioactive shales).
The datings confirms this hypothesis (there is only 6 m non dated at top).

Lithology:

SHALE, brownish black, slightly lignitic.

Biostratigraphy:

Palynology:	J6a zone at 2353, i.e Oxfordian
	J5b1 at 2362, i.e Callovian
	J5a from 2367 to 2382, i.e Callovian

Environments:

No precise data from this well.
This formation is thought to correspond to open marine environments.

Dipmeter data:

Only the basal part, below 2370 m gives reliable data. The mean dip is: N15 / 2 to 5° ESE.

Shows:

Increasing background gas from 0,2 % at top to 1,5 % at base, with C1 to C3 and traces of iC4, nC4.

MIDDLE JURASSIC

- **BRENT GROUP (TARBERT FORMATION) 2384-2453 M (69 M).**

Definition:

The top and base of this sandy unit are based on Gamma-ray breaks.

It is an equivalent of the Tarbert Formation.

Biostratigraphy:

The upper part cannot be dated (facies devoid of any organisms).
It is dated **Lower Bathonian** at 2445 and 2451 m (J4b1 palynozone).
So the Upper part is very likely Bathonian as well.

The Bajocian and Aalenian series are missing in this well.

Lithology:

2384 - 2405 m	SANDSTONE white/light grey, fine/very fine, well sorted, angular, clean, slightly micaceous, poorly cemented (good reservoir), with common shell debris and pyritic modules.

(Description from CORE NO 1: 2388-2406 depths logger = depths driller + 2 m) (Fig. 3.3.3)

2405 - 2424 m	SANDSTONE a/a but generally more cemented (calcareous/dolomitic)
2424 - 2442 m	SANDSTONE a/a rather poorly cemented COAL layer 2431 - 2433 m
2442 - 2453 m	SANDSTONE, brownish grey, fine to coarse, micaceous/shaly with stringers and laminations of SHALE, brownish grey, silty/sandy

Petrography/Mineralogy

Characteristics of the cored section (Lab. studies):

Sandstone:
- Average grain size = 80 - 100 microns (maxi 200)
- Good sorting / Angular elements
- Quartz prominent = 50 to 75 %
- Feldspars (both orthoclase and plagioclase) = 10 to 20 %
- Micas (muscovite) = 2 - 4 % (up to 10 %)
- Clays (mainly kaolinite) = 4 - 6 % (up to 10 %)
- Carbonates (disseminated siderite, locally ankerite) = 0-10%

Note: Kaolinite, siderite and ankerite are authigenic.

Below the core some SWC have been studied.

quartz	= 30 to 70 %
feldspar	= 6 to 12 %
micas	= 4 to 15 %
carbonates	= 1 to 25 %

Sedimentology (from Lab. report) (See Fig. 3.3.4)

The Brent can be subdivided into 3 **main units**, which correspond to **margino-littoral environments.**

Lower unit (2453-2430 m):

It is a **sanding upward sequence** (capped by a coal bed), interpreted as a **prograding shoreface** sequence (southeastward progradations from the dipmeter rose diagrams).

Middle unit (2430-2405 m):

It consists mainly of shaling upward sequences interpreted as **tidal channels in a mid/upper shoreface** environment. Some sanding-upward sequences occur and are interpreted as **prograding shoreface** sequences.

Upper unit (2405-2384 m): (cored section)

These homogeneous sandstones are thought to be deposited in environments ranging between **mid-shoreface to foreshore.**

Three lithofacies can be observed on the core

1) structureless sandstones

2) sandstones with low angle planar laminations (probably created by waves action)

3) sandstones with flat cross-stratification (probably the result of storm events)

Note: The Rose diagram (from dipmeter data) for the laminated sandstones indicate a paleoshore trending NE-SW, with the open marine side to the SE.

Reservoir behaviour / Diagenetic processes (from the cored section only) (See Fig. 3.3.7 and 3.3.8)

The plot PHI/K (for the cored section) exhibit correlative evolutions of these two parameters:
the permeability variations from 1000 to 40 mD correspond to a decreasing porosity from 30 to 20 %.

This reservoir has not been affected by permeability destructive material (low authigenic clay content).

The diagenetic processes have preserved the reservoir characteristics.

The reservoir qualities are only linked to the sedimentology (granulometry, sorting....)

The **observed diagenetic processes** are the following:

- **A first phase**, characterized by a discrete kaolinite growth.

- **A second step**, characterized by potassic feldspar overgrowth, authigenetic albite and ankerite crystallization.

Notes: . The feldspar dissolution observed in the surrounding wells (first step of the diagenetic sequence), is not evidenced in 25/5-3.

. The late calcite crystallization, known regionally, is not observed on this core.

Dipmeter data

The dipmeter data are rather scattered within the uppermost Brent between 2384 and 2402 m.

Between 2402 and 2445 m, the strata trend from N83 to N95 with dips toward south (4 to 8°): (good and rather homogeneous data)

Notes:

* **The Upper Jurassic and Middle Jurassic series are not conformable.**

* **The Brent, the Dunlin and the Upper Statfjord seem to be conformable**, the average computed dip being **N 80 - 5°S** for the interval 2384 m - 2720 m.

There is no evidence of angular unconformity between the Brent Group and the Dunlin Group, although there is an important time hiatus.

Shows

A gas peak 13.7 % occured at top (C1 to C4).

Below the cored section, between 2406 and 2440, occured a series of peaks, 5 to 12 % (C1 to C4).

2440-2453: the background gas decrease to 1 % (C1 to C3).

No oil shows were observed during drilling and on the core no. 1.

Among the sidewall cores, two of them displayed weak oil shows:

- SWC 2425: traces of dull yellow direct fluorescence - no cut.
- SWC 2428.7: 50 % pin-point dull yellow direct fluorescence + weak milky cut.

But the geochemical studies (Iatroscan) did not find significant amounts of hydrocarbons in these two SWC.

Note: The upper part of the Brent reservoir (2384 - 2426 m i.e. 42 m) is gas-bearing.

LOWER JURASSIC

- **DUNLIN GROUP** = 2453-2613 (160 m)

Definition:

The top and base of this shaly unit are picked from the gamma-ray breaks.

Lithology:

SHALE, light olive grey to grey or brown more or less dark, silty,
with thin rare stringers of limestone, silty/sandy.

Biostratigraphy:

Palynology:
* J3a4 zone at top (SWC 2456-2476) i.e. Late Toarcian.
* J3a1 zone at base (SWC 2502 to 2605) i.e. Early Pliensbachian.

Note:

* There is very likely no hiatus within this series.

  The apparent lack of the J3a3 and J3a2 palynozones is thought to be due to the lack of specific marine microorganisms and specific palynofacies, in an area where continental species dominate.

  In fact the continental species are the same within these three palynozones.

  So the basal J3a4 datings are very likely wrong, and must correspond to the Early Toarcian and Late Pliensbachian.

* An important hiatus occurs at the boundary between the Dunlin and Brent groups, with the absence of Bajocian.

Environments:

No precise data available for this well. These deposits are thought to correspond to marine environments, rather shallow, becoming more or less restricted at top.

Dipmeter data:

Good data down to 2588 (monocline N80 5°S) showing that Brent and Dunlin strata are conformable.

In details the strata trend from N70 to N110 with dips to the SSW or SSE (2 to 5 °).

The upper part of the Dunlin might be a weathered zone from the FMS images.

Below 2589 m the dips become scattered.

Shows:

* Net decrease of background gas at top from 1 % to 0.5 % (C1 to C3).
* 2484-2570 m: background gas around 0.2 % (C1 to C2).
* 2570-2613 m: Background gas around 0.1 % (C1).

- **STATFJORD FORMATION** : 2613-2752 m (139 m).

Definition:

The top is easy to pick at a Gamma-ray break.

The bottom is based first on lithological criteria, with the occurrence of the Hegre green/brown reddish facies. On the logs it corresponds to the base of a fining-upward megasequence.

Biostratigraphy:

The **Upper Statfjord** (above the so-called Intra-Statfjord marker at 2685 m) is dated **Sinemurian** : J2 palynozone evidenced on core no. 2 and SWC 2656-2678.

The **Lower Statfjord** (below 2685 m) could be **Hettangian** (J1 palynozone) but the typical zonal markers have not been observed.

Lithology:

Alternating:

SANDSTONE, fine to coarse, occ. very coarse, occ. clean/loose (good reservoirs), occ. micaceous/shaly and tight.

SHALE, grey, more or less dark, occ. brownish or greenish, more or less silty/sandy with traces or stringers of coal (mainly between 2655-2665 and 2705-2745).

Notes:

. The Statfjord Fm can be subdivided into two lithological units: 2613-2685 m / 2685-2752 m. This boundary at 2685 m, corresponding to the seismic Intra-Stafjord marker, is the top of a more massive shaly interval. The shales seem to have different characteristics apart from this boundary (density, sonic).

. The uppermost Statfjord is characterized by one coarsening-upward sequence.

Below, all the formation consists of stacked fining-upward sequences.

Petrology / Mineralogy:

Characteristics of the cored section

Clean coarse sandstones: (2617 - 2624 m) depths logger

average grain size from 200 microns at base of the sequence, to 350 microns at top; the maximum observed sizes being 1.5/2 mm

Quartz prominent	65 to 85 %
Feldspar (equally orthoclase/plagioclase)	5 to 13 %
Micas	0 to 3 %
Carbonates (siderite - calcite)	0 to 5 %
except around 2622:	15 to 30 %
Clays (authigenic kaolonite)	1 to 3 %

Shaly fine sandstones: (below 2624 m)	Average grain size 80 microns at base of the sequence, to 200 microns at top with a maximum grain size from 250 to 800 microns.	
	Quartz	55 - 65 %
	Feldspar	5 - 13 %
	Micas	3 - 12 %
	Carbonates	0 - 5 %
	Clays	10 - 20 %

Sedimentology (from lab-report) (See Fig. 3.3.6)

Lithofacies/Sequential evolutions/Depositional environments

The Statfjord Fm can be subdivided into **4 sequences** (from base to top).

- **2752-2685 m:**

A **shaling-upward megasequence**, made up with:

* **At base** stacked plurimetric **fining-upward sequences** interpreted as: from base to top: channel-fill to point bars to flood-plain deposits (belonging to a **meandering river** system).

* At top, a more massive shaly/coaly unit interpreted as **flood-plain** deposits.

- **2685-2655 m:**

A **shaling upward megasequence** made up with several fining-upward sequences thought to have been formed by a **meandering river** system (channel-fill, point-bar and flood plain deposits).

- **2655-2630 m:**

3 shaling upward sequences (15m-5m-5m) interpreted as previously.

- **2630-2615 m:** (cored section)

A **coarsening upward sequence,** which lithofacies are observed on core no. 2:

from top to base:

Coarse sandstones with planar oblique laminations.
Fine grained sandstones with disrupted shaly/coaly laminations.
Bioturbated silty shales.

They are thought to represent a **prograding deltaic system** (toward the south, from dipmeter data), with prodelta/delta front-facies at base, overlain by shelf deposits).

Reservoir behaviour / Diagenetic processes: (from the cored section only) (See Figs. 3.3.7 and 3.3.8)

The porosity/permeability evolutions are linked to the detrital clays contents:

20-27 %, 300-4000 mD, for the clean coarse sandstone
15-26 %, 2-10 mD, for the fine grained facies

As for the Brent reservoirs, the **diagenetic processes have not affected a lot the coarse grained good reservoirs**, and the sedimentology is the main factor for the variations of their qualities.

The observed diagenetic processes are similar to the ones of the Brent.

The Statfjord sandstones are richer in siderite (early diagenetic phase). They exhibit a second kaolinite generation and a late calcite crystallization in addition to the minerals found in the Brent. Chlorite is also observed locally.

Dipmeter data:

Between 2623 and 2645, the structural dips indicate strata trending NS to N50 (average N33) and dipping to the E or SE (1-5 °).

Between 2645 and 2685 occur mainly sedimentary dips.
Then the data are affected by caving between 2685 and 2707 m.

The basal Statfjord below 2707 m shows rather scattered data, probably due to sedimentary features. The computed mean structural dips over the interval 2707-2725 indicate strata trending N70 to N110 and dipping to the south (2 to 7°).

Shows:

- at top a weak gas peak 0.5 % (C1-C3)
- then, background gas 0.1 to 0.2 % (C1)
  with 2 gas peaks (0.3 and 0.7 % - C1 + C2), linked with coal layers.

No shows on core no. 2.
No fluorescence during drilling on cuttings.

- **HEGRE GROUP 2752-2900m (T.D).**

Definition:

It is based only on lithological criteria, as this interval is azoic.

Biostratigraphy:

The studied samples are devoid of microorganisms and no age assignment is possible.

Lithology:

SHALE, brown reddish, occ. greenish or grey, slightly calcareous, slightly to very silty, with some layers of sandstone, silty to medium, generally calcareous cemented, micaceous/shaly.

Poor dip meter data at top. No data below 2790.

Shows:

Very weak background gas, decreasing from top to bottom (0.04 to 0.02 %) (C1).

3.3.2. Formation pressure

From the RFT measurements:

* **Brent reservoir:**

  In the gas-bearing zone (2384 - 2426 m RKB) the gradient indicates a gas density of 0.227 g/cc (bottom conditions).

  The formation pressure is 244.8 bars (abs.) at GWC (2426 m RKB i.e 2404 m MSL).

  In the waterbearing zone (2426 - 2453 m RKB) the gradient indicates a water density of 1.044 g/cc (bottom conditions).

* **Statfjord reservoir:** (water bearing)

  The formation pressure is 264.3 bars (abs.) at 2617.5 m RKB, a point which is located on the water gradient line of the Basal Brent.

Note: **Both reservoirs are hydrostatic** (equivalent mud weight of 1.04).

3.3.3. Formation temperature (See Fig. 1.13)

The more reliable data is the temperature recorded during the DST 1:

85°C at top Brent (2484 m) (at the end of the build-up)

It corresponds to a **geothermal gradient** of **3.35°C/100 m**
(taking an annual mean temperature of 5°C at sea bottom).

3.3.4. **Prognosis vs actual** (Fig. 1.7)

All the formations have been found slightly deeper than on the prognosis,
due to slightly greater actual interval velocities:

+ 19 m at Balder marker
+ 40 m at Top Cretaceous
+ 24 m at Top Brent
+ 61 m at Intra-Statfjord marker

Note:
The top of the Maureen sands do not correspond to the seismic anomaly, as previously picked.

3.4. GEOPHYSICAL RESULTS (See Figs. 3.4.0 to 3.4.5)

3.4.1. Sonic and Density logs

Sonic and Density logs were not recorded between 140 m RKB (sea bottom) and 1176 m RKB (13 3/8" casing shoe), i.e. in the 17 1/2" section.

Above 1176 m RKB the following velocity and density model has been used:

MSL to 140 m RKB:	1478 m/s - d = 1.0
140 to 1176 m RKB:	2015 m/s - d = 1.9

Between 2308 and 2350 m RKB (i.e. from Top to Base Cretaceous), Sonic and Density logs are missing (impossible to run the tool down to the 12 1/4" bottom hole).

For this interval, both logs were reconstructed taking into account the logs of the wells 25/5-1 and 25/6-1.

3.4.2. Sonic calibration - time-depth diagrams - interval velocities means velocities - RMS velocities

The Sonic log was calibrated using the first arrival times from the check shot survey.

The first arrival was defined by the trough to trough method.

The table and the diagrams hereafter (Figs.3.4.1 and 3.4.2) give the times/depths correspondances,
the interval velocities, the mean velocities and RMS velocities.

3.5. DISCUSSION ABOUT THE NEGATIVE RESULTS AT TERTIARY AND AT STATFJORD LEVELS

- **at Tertiary level**

The well encountered good potential reservoir at the very base of the Tertiary, the Maureen sands.

They are water-bearing.

These sands are capped by late Paleocene / Eocene shaly series, with no other sandy levels.

The absence of hydrocarbons might be explained by the lack of structure.
The possible weak closure at Top Cretaceous cannot be asserted and at the top of the sands (which cannot be picked), there might be no closure.

- **at Statfjord level**

The failure at Statfjord might be due to

* non-sealing faults
or
* contact with the Brent sandstones, along the western border of the structure, through the fault which limits the Utsira High. But this hypothesis cannot be checked as the Brent is not pickable in this area.

4. RESERVOIRS EVALUATION

4.1 Results Summary

25/5-3 well discovered two reservoirs in the Jurassic:

- A Brent reservoir (2384 - 2453 mRKB)
  - Gas bearing (2384 - 2426 m RKB, 2362 - 2404 mMSL)
  - Water bearing (2426 - 2453 mRKB, 2404 - 2431 mMSL)
- A Statfjord water bearing reservoir (2613 - 2752 mRKB, 2591 - 2730 mMSL)

The following table summarizes the main result.

DEPTHS

Reservoir	Top (mRKB)	Bottom (mRKB)	G/L contact (mRKB)
Brent	2384	2453	2426
Statfjord	2613	2752	-

z RKB = 22 m

CPI

Reservoir	Ht (m)	Hn (m)	N/G (%)	Φ (%)	Sw (%)
Brent	69	53	77	22	23 *
Statfjord	139	88	63	25	100

Cutoffs : Φ > 5% ; Vsh < 40 % ; Sw < 60 % (in the gas zone) Brent
Cutoffs : Φ > 12% ; Vsh < 30 % Statfjord

* : average water saturation in the gas zone

CORES

Reservoir	Cored interval (mRKB)		Φ (%)	Kh arith. (mD)	Kv geom. (mD)	Kv arith. (mD)
Brent	2388.00	2406.00	27.1	363	2 *	236
Statfjord	2617.00	2630.40	23.0	687	29	333

* Due to a few cores with very low permeability (cementation)

MISC.

Reservoir	Ref. level (mRKB)	Pi (bara)	Ti (oC)
Brent	2426	244.8	84.6
Statfjord	2682	270.9	94.0

PVT

Brent wet gas bearing ; no PVT study achieved (test GOR 5100 to 6200)
Statfjord water bearing
No water sample available

Brent gas density : 0.227 g/cm3 at bottom hole conditions (RFT)
Brent condensate density : 0.760 g/cm3 at surface conditions

DST

Upper part of the Brent tested : perforated interval : 2386 - 2405 mRKB
maximum gas rate : 585000 m3/d

Interpretation :

H (m)	k (mD)	S
21.5	286	35

4.2 Available data

4.2.1 ELECTRICAL WIRELINE LOGS

4.2.1.1 Available logs

After the well has reached TD (2900 m/RKB), logs were run over the following intervals (log depths):

DIL/LSS/GR/SP	2884.0 - 2230.0
LDL/CNL/NGS	2882.8 - 2351.3
DLL/MSFL/GR	2481.3 - 2351.3
FMS/GR	2790.0 - 2351.3
RFT/HP (17 points)	2638.8 - 2386.9
VSP	2800.0 - 1100.0
Sidewall cores (50)	2858.2 - 2353.0

The logs are plotted in a composite log : PL. 4.1 for the Brent formation and PL 4.3 for the Statfjord formation.

4.2.1.2 Logs correction and depth match

All the logs are generally well in depth, so only minor depth shifts were needed. The logs were environmentally corrected using standard Schlumberger chart book corrections.

NGL was corrected in real time for potassium.
Rt and Rxo curves were computed using Tornado charts for the Brent formation, whereas for the Statfjord formation, the bore hole corrected ILD and SFLU curves were used directly.

4.2.2 CORES

4.2.2.1 Available cores

Two cores were cut for which depths are given corrected to logger depths (+ 2 m according to gamma-ray correlation):

Core 1 (2388.0 - 2406.0 mRKB) in the upper part of the Brent reservoir
Core 2 (2617.0 - 2630.4 mRKB) in the upper part of the Statfjord reservoir

50 sidewall cores were recovered out of which 10 are in the lower Brent.

4.2.2.2 Routine core analysis

Routine core analysis was performed on 1" plugs taken every 30 cm.

The routine core analysis includes helium porosity, grain density, horizontal and vertical permeability.

4.2.2.3 Special core analysis

Different special core analysis are under way or planned for core material from 25/5-3.

- Mineralogical and sedimentological studies in SNEA(P)-Pau. This is part of a larger "geological" study.

- Study on five 1.5" plugs from the Brent at NORCORE Stavanger including:
  - Formation factor, resistivity index and air brine capillary pressure
  - Evolution with overburden pressure of porosity liquid permeability and formation factor

- Displacement experiments on 3 full size core samples at SNEA(P)-Pau.
  The objective is to obtain end points of relative permeability curves between gas and water.

4.2.3 OTHER DATA

4.2.3.1 Mud characteristics

A BKC mud type was used to drill the reservoirs.
The mud is based on sea-water with added KCl and polymers. The KCl salinity varied from 45 g/l at top reservoir to 16 g/l when logging.

Summary of Mud Characteristics:

Rm	:	0.461 ohm-m at	19°C
Rmf	:	0.431 ohm-m at	17°C
Rmc	:	0.775 ohm-m at	11°C
Density	:	1.20 g/cc	
Viscosity	:	56 s	
pH	:	7.9	
Salinity	:	16 g/l KCl	
Potassium	:	8 g/l	
Barite content	:	14% (weight)	

4.2.3.3 Formation water characteristics

No data are available.

Density was calculated from RFT gradient, resistivity was estimated from logs.
The rw appears to be the same for the Brent and Statfjord formations, considering the accuracy of the method used..

The retained values are:

Density (bottom hole conditions)	:	1.044 g/cm^3
Resistivity (bottom hole conditions)	:	0.05 ohm-m
Equivalent salinity	:	75 g/l NaCl

4.3 Brent evaluation

4.3.1 PETROPHYSICS

4.3.1.1 Log interpretation

- **Optim Software**

The Brent log interpretation was performed using OPTIM model, an Elf in house log interpretation software. This software is a GLOBAL (Schlumberger) equivalent.

It is an interactive model which, from matrix/fluid composition and properties and log responses calculates and minimizes an error function represented by the difference between calculated and measured log responses.

POUPON equation is used for water saturation calculations.

- **Model description**

The following logs were used as input:

NPOR	:	neutron porosity (%)
RHOB	:	bulk density (g/cm3)
DT	:	transit time from LSS (s/ft)
POTA	:	potassium counts from NGS (%)
THOR	:	thorium counts from NGS (ppm)
R_t, Rxo	:	calculated from (LLD, LLS, MSFL) using Tornado charts

In Optim, a general mineralogical model must be defined for a zone. In addition, it is possible to define one or more conditional models which come into effect if the user's defined criteria connected to each model are fulfilled.

For this study, one general model and one conditional model were defined within the Brent reservoir:

General Model:

	Neutron	Density	Sonic	Potassium	Thorium
SAND	-0.02	2.67	56	2.0	2.0
FELDSPAR	-0.03	2.56	45	11.0	0.0
MICA	0.16	2.90	50	7.0	50.0
SHALE	0.60	2.40	110	2.5	15.0

Carbonate - cemented zones (conditional model)   criterion: DT<90

	Neutron	Density	Sonic	Potassium	Thorium
SAND	-0.02	2.67	56	2.0	2.0
FELDSPAR	-0.03	2.56	45	11.0	0.0
CARBONATE	0.03	3.00	43	0.6	10.0
SHALE	0.60	2.40	110	2.0	15.0

These models were built according to the preliminary-mineralogical study and core description.

The mineral "SAND" includes quartz in addition to small amounts of different minerals: complex carbonates (siderite, dolomite calcite), pyrite, authigenic-kaolinite.

As the thorium response is not correlated with shale content, a large thorium response was assumed in mica and to a less extent in carbonate. The carbonate pole is heavier due to the presence of siderite.

As no data are available, the saturation equation constants are:

a = 0.8 (lithology factor)
m = 2 (cementation exponent)
n = 2 (saturation exponent)

The resistivity responses in ohm-m are:

	R_t	Rxo
Formation water	0.05	-
Mud filtrate	-	0.3
Shale	5	7

- **Zonation**

The Brent reservoir was divided into three zones according to petrophysics and fluid content:

Nb	Name	Depth (mRKB))
1	"Good gas sand"	2384.0 - 2405.5
2	"Poor gas sand"	2405.5 - 2426.5
3	"Water sand"	2426.5 - 2453

- **Results** **(Fig.4.8/Fig.4.9) (Fig.4.1)**

The averaged petrophysical results from the OPTIM log interpretation are presented below:

Depth (mMSL)	Layer	Gross pay (m)	Net pay (m)	N/G (%)	PHI (%)	Sw (%)	Vsh (%)	Porous height (m)
2362.0-2383.5	"Good gas"	21.5	21.35	98.6	25.3	12.9	6.8	5.43
2385.5-2404.5	"Poor gas"	21	13.84	68.8	20.4	37.5	16.1	2.83
2404.5-2431.0	"Water"	26.5	17.84	61.6	18.9	96.2	24.5	3.37
2362.0-2431.0	Total Brent	69	53.03	76.9	21.9	22.6*	16.4	11.63

* in the gas zone

Cut-off values used are the following:

PHI = 5%
Vsh = 40%
Sw = 60% (in the hydrocarbon zone)

The porosity cut-off corresponds to a permeability cut-off of 0.1 mD from core measurements

Log interpretation results are shown in PL.4.2.

The gas liquid contact seen on log interpretation is at 2426.5 mRKB. This is 0.7 m lower than the value estimated by RFT. It is then decided to fix the GWC at 2426 mRKB ± 0.5 m

4.3.1.2 Core results

Core 1 is entirely taken from the "Good sand zone" except from the last 0.5 m.

The averaged values from routine core measurements are presented below. Note that these values are not corrected for overburden. (Fig.4.2)

Depth mRKB (mMSL)	Ø (%)	Grain dens. (g/cm^3)	Khor(arith) (mD)	Kvert.(Geom) (mD)	Kvert.(arith) (mD)
2366-2385.5	27.1	2.66	363	142	236

Core data crossplots show reasonable correlation trends: (Fig. 4.3)

$Log_{10}(Kh) = 1.5864 + 0.147 + Ø$ R = 0.86 (correlation coef.)
$Log_{10}(Kv) = 0.594 + 1.142 \log_{10}(Kh)$ R = 0.93 (correlation coef.)
$Kv = 0.255 * Kh^{1.142}$

The comparison between log and core porosity gives the following result:

Depth (mRKB)	Log Porosity (%)	Core Porosity (%)
2388-2405.5	25.7	27.1

4.3.2 FLUIDS/DRILL STEM TEST

4.3.2.1 Introduction

One DST was done in the upper part of the Brent.

The perforated interval was: 2386 - 2405 mRKB corresponding the best sand zone in the gas interval.

Perforations were done using TCP with 5 shot per foot.

The main objectives of the test were:

- Obtain reliable fluid samples
- Evaluate reservoir permeability, productivity
- Estimate possible heterogeneities, boundaries

4.3.2.2 Equipment

Two Geoservices Quartz gauges (TERRATEC), two Halliburton Quarts gauges (HMR) and two Flopetrol strain gauges (FHPR-B) were set in gauge carriers. All were reading the tubing pressure and temperature.

4.3.2.3 Quality of the measurements

Some discrepancy in the pressure and temperature readings can be seen between the different gauges. (Figs. 4.13/4.14)

At the end of the main build-up, the pressure ranges form 242.5 to 243.3 bara, and the temperature from 83.1 to 85°C.

Gauge Halliburton 2 was discarded due to obvious problems on temperature readings leading to erroneous pressure corrections.

Flopetrol gauges show pressure unstabilities due to sensitivity to annulus pressure changes. Flopetrol 1 is more than 1/2 bar too low compared with the other gauges and RFT pressures.

Both Geoservices gauges are almost perfectly overlayed.

It was then decided to interpret the build up on three gauges:
Geoservices 2, Halliburton 1 and Flopetrol 2.

4.3.2.4 Test data (Fig. 4.18)

Average data for the different test periods are summarized in the following table:

Pressures are given at the end of each period and bottom hole pressures are taken from gauge Haliburton 1. Gas rate and GOR are average values over flow periods. They were only corrected off-shore.

Date	Time	Choke size	W.H.P (bara)	B.H.P (bara)	Qgas m3/d	GOR vol/vol	Remark
06/03/90	23h14 to 24h00	16/64			NS	NS	Clean-up flow
07/03/90	00h00 to 01h00	16/64	177.9	240.4	100000*	NS	idem
07/03/90	01h00 to 02h09	20/64	182.5	239.2	200000*	NS	idem
07/03/90	02h09 to 03h31		186.1	243.1	0		Shut-in (leak)
07/03/90	03h31 to 03h37	16/64					Clean-up flow
07/03/90	03h37 to 07h15	20/64	181.4	239.7	200000	NS	
07/03/90	07h15 to 15h50	28/64	177.4	238.9	355000	6200**	
07/03/90	15h50 to 21h17	40/64	155.8	235.2	585000	5100**	
07/03/90	from 21h17						Build-up
08/03/90	12h00			243.1	0		End of build-up

N.S. = non stabilized
* = values estimated for test interpretation
** = GOR variation coherent with separator temperature changes

4.3.2.5 PVT data (Fig. 4.15)

No PVT sample was taken during RFT
Five complete sets of PVT samples (gas + oil) were taken during test production period:

Set Nb	Choke size	Gas bottles	Oil bottles	Remark
1	28/64	3	1	
2	28/64	4	1	
3	28/64	6		Isokinetic gas samples, mercury free oil sample
4	28/64	4	1	
5	40/64	2	1	mercury free oil sample

The PVT results are not yet available.

The only available data are the following:

GOR = 5100 to 6200 depending on separator temperature
Bottom hole gradient from RFT: 0.227 g/cm³
Condensate densities: 0.755 to 0.766 g/cm³ at 1 bar and 15°C
Gas gravity: 0.678 to 0.692

This is coherent with a medium condensate gas with condensate content in the range of 200 g/m³

4.3.2.6 Test interpretation (Figs. 4.16/4.17)

- **General remarks**

The test was designed and conducted in order to prevent sand production before good PVT sampling could be done. At each choke size increase, a small sand production could be observed, with a clear skin evolution, visible on downhole pressure curves.

Due to this, the different flow rates cannot be used to calculate a flow potential.

- **Hypothesis**

PVT data were approximated from correlations.

Static data used for the interpretation are:

Gas Z-factor	:	0.851	Porosity	:	27%
Gas Viscosity	:	0.023 cp	Thickness	:	21.5m
Gas Compressibility	:	0.030 1/bar			
Water Compressibility	:	$5\ 10^{-5}$ 1/bar	Wellbore diam.	:	0.1778 m
Roc Compressibility	:	$8\ 10^{-5}$ 1/bar			

The final pressure build up was interpreted with PIE in house software. A homogeneous reservoir model was assumed.

The final temperature build-up was interpreted with a Horner plot. (Fig. 4.19)

As no clear gradient in pressure or temperature can be derived from the gauges readings, the following values were assumed to calculate values at the reference depth:

Pressure gradient	:	0.227 g/cm³ (from RFT)
Temperature gradient	:	3°C/100 m

4.3.3 Synthetic seismograms (Fig.3.4.4).

Several synthetic seismograms were computed with different wavelets.

* Butterworth wavelets with different characteristics
  Zero and Minimum phase
  Reverse and Normal polarity

* Ricker wavelets 20/25/30/35/40/45 Hz
  Primaries without transmission loss
  Zero and Minimum phase
  Reverse and Normal polarity

* Ricker wavelet 25 Hz
  Primaries with and without transmission loss
  With and without multiples
  Zero and minimum phase
  Reverse and normal polarity

From these computations and displays, it can be asserted:

* At ordinary frequences (25 Hz), due to interferences, both Top and base Cretaceous seismic markers are shifted upward by 10 msec TWT compared to the breaks on the impedance log. This phenomenon does not exist at higher frequencies e.g. 45 Hz.

* *There is no marker directly related to either the Top or to the Base Brent.*

There is a positive contrast of impedance at the top of the cemented part of the Brent reservoir, which is emphasized by the gas-effect on the density log. (This effect is much more obvious on the impedance log than on the sonic/velocity log).

On the synthetic seismogram (Zero phase, reverse SEG, 25Hz ricker) this contrast corresponds to the lowermost lobe of the positive doublet located below the strong trough corresponding to the Base Cretaceous.

4.3.4 Match between synthetic seismogram and V.S.P.

There is a *good fit between the corridor stack from the VSP and the synthetic seismogram* .

The discrepancies are related to the amplitudes, specially that of Top Cretaceous and below Base Cretaceous.

4.3.5 Match with surface seismic (line EL 8902-111) (Fig. 3.4.5)

The very good fit between the synthetic seismogram (computed with a 25 Hz- Zero phase Ricker displayed with the reverse SEG polarity), and the seismic line at the well location (SP 830 on line EL 8902-111) confirms that the surface seismic is very close to be zero phase, reverse SEG-convention and that the dominant frequency is around 25 Hz.

The only discrepancy with the actual seismic trace is the amplitude of the horizon corresponding to the top of the Maureen sand, the amplitude of which is too high on the synthetic trace.

There is a constant shift of about 35 msec TWT between the VSP times and the surface seismic times, the latter being greater.

This shift might be partly due to the phase rotation of the seismic and also to the way of picking the first arrival of the check shot.

An inversion of the VSP followed by a phase deconvolution (stratigraphic deconvolution) are underway in order to get the best calibration possible.

Note:
The Gamma-ray, Sonic and Acoustic Impedance displayed on Fig.3.4.5 have been smoothed (2.25 m sliding window).

Geological attribution of the markers (see the geological composite log 1/500).

- The Balder marker does not correspond to the Top Balder formation as picked on the logs.
- The Intra-Statfjord marker correspond to the top of a massive shaly interval capping a fining-upward megasequence, attributed to the Hettangian, while the Upper Statfjord above the marker is dated Sinemurian.

- **Results**

The average values are the following at the reference depth (2426 mRKB).

Extrapolated pressure	:	244.8 bara
Extrapolated temperature	:	84.6°C
Skin	:	34.5
Permeability thickness	:	6150 mD x m
Permeability	:	286 mD

It can be noted that extrapolated pressure is perfectly in line with RFT measurements.

4.3.3 FORMATION PRESSURE

4.3.3.1 RFT measurements (Fig.4.5) (Fig.4.6)

- **Data, quality of the measurements**

A total of 17 RFT pressure measurements were done in the Brent formation. The tool used was equipped with a HP crystal gauge and a strain gauge. Due to a failure of the HP gauge, the measures were done in two runs.
In order to fit the measurements of the two gauges, two of points were duplicated (2389 and 2420.8 mRKB). The medium pressure difference on these two points is P = 0.096 bars.

The points of the first RFT were then shifted by this value to fit the measurements of the second RFT for gradient calculation purposes.

All the points give good quality results except point 17 which appears to be slightly overcharged. It was then excluded from regression calculations. No sampling was done during RFT.

- **Interpretation**

A clear condensate gas gradient can be extrapolated from the 13 first points in the upper part of the Brent formation.

ρ_g = 0.227 g/cm^3
R = 0.9993 (regression coef.)
σ = 0.09 bara (standard deviation)

A water gradient can be defined in the lower part of the Brent (points 14 to 16)

ρ_w = 1.044 g/cm^3
R = 0.9999
σ = 0.06 bara

The intersection of these two lines gives an initial free water level.

FWL = 2425.8 mRKB (2403.8 m/MSL)
Pressure at FWL = 244.8 bara

Oil shows were observed on two sidewall cores at 2425 and 2428.7 mRKB, but the amount of hydrocarbons (Iatroscan) obtained by the geochemical studies were very low. No evidence of an oil ring can be seen on the RFT plot.

4.3.3.2 DST data

Applying the pressure gradient from RFT (0.227 g/sm^3), the extrapolated pressure obtained from DST data is perfectly in line with RFT messurements

4.3.4 FORMATION TEMPERATURE

Temperatures during the build up were Horner extrapolated to give intial temperatures at gauge depth. A temperature gradient of 3°C/100m was applyed to estimate initial temperature at reference depth. Initial temperature = 84.6°C @ 2404 m MSL.

4.4 Statfjord evaluation

4.4.1 PETROPHYSICS

4.4.1.1 Log interpretation

The Elf inhouse software OPTIM was used, see 4.2.4.1.

- **Model description**

The following logs were used as input:

NPOR : neutron porosity (%)
RHOB : bulk density (g/cm^3)
DT : transit travel from LSS (s/ft)
POTA : potassium counts from NGS (%)
THOR : thorium counts from NGS (ppm)
ILD : deep induction, used at R_t
SFLU : sphitically focused log, used as Rxo

In Optim, a general mineralogical model must be defined for a zone. In addition, it is possible to define one or more conditional models which come into effect if the user's defined criteria connected to each model are fulfilled.

For this study, one general model and one conditional model were defined within the Statfjord reservoir:

General Model:

	Neutron	Density	Sonic	Potassium	Thorium
SAND	-0.02	2.67	56	0.0	2.0
FELDSPAR	-0.03	2.56	45	11.0	8.0
MICA	0.22	2.83	55	8.0	25.0
SHALE	0.40	2.60	110	1.0	22.0

Carbonate - cemented zones (conditional model) criterion: DT<80, NPOR<21, RKOB>2.35

	Neutron	Density	Sonic	Potassium	Thorium
SAND	-0.02	2.67	56	0.0	2.0
FELDSPAR	-0.03	2.56	45	11.0	8.0
CARBONATE	0.01	2.88	43	2.0	7.0
SHALE	0.40	2.60	110	1.0	22.0

These models are based on the preliminary-minerological study and core description.

However, as the purpose of interpreting the waterbearing Statfjord formation is to determine the porosity and net to gross ratio, the emphasis has been put on matching the porosity and grain density measured on core plugs with a simplified mineralogical model. The mineralogical study and core description indicate presence of, in addition to the minerals included in the models: Pyrite, Siderite, Coal fragments, different types of clays, Feldspars and carbonates.

In the shales above and below the reservoir, a simplified model was used.

Shale Model:

	Neutron	Density	Thorium
Sand	-0.02	2.67	0.0
Shale	0.4	2.60	14.0

- If the caliper exceeds 10". This occurs just above the reservoir and a little bit into it (shale) and several places inside the reservoir (coal).
- If the Neutron exceeds 0.4 and the Density drops below 2.15 (coal).

As constants in the saturation equation (Poupon), general values were used:

a	=	0.8	(lithology factor)
m	=	2	(cementation exponent)
n	=	2	(saturation exponent)

Retained resistivity values are:

Formation water, Rw	:	0.05 @ 87°C
Mud filtrate, Rmf	:	0.17 @ 76°C

	Rt	Rxo
Shale:	5	7

- **Zonation**

The entire Statfjord formation has been treated as one zone.

- **Results** (Fig.4.10) (Fig.4.11) (Fig.4.12)

Ref. composite log Pl. 4.3 and CPI plot Pl. 4.4

The averaged petrophysical results from the OPTIM log interpretation are presented below (Statfjord formation):

Depth mRKB (mMSL)	Gross pay (m)	Net pay (m)	N/G (%)	PHI (%)
2613 - 2752 (2591-2730)	139	88.1	63	25

Cut off values used:

PHI = 12% (corresponding to 1 mD, ref. core crossplot, Fig. 19)
Vsh = 30%

4.4.1.2 Core results (Fig.4.2) (Fig.4.4)

The core data have not been corrected for overburden.
The averaged values presented below have been subjected to the same cut offs as the log results:

Depth mRKB (mMSL)	PHI %	Grain dens. g/cm^3	Khor (arit) mD	Kvert(geom) mD	Kvert(arith) mD
2617-2630.4 (2595-2608)	23	2.68	687	28.5	333

The log interpreted porosity,averaged over the same interval,gives exactly the same, 23%.

4.4.2 FLUIDS

No DST or RFT samplings were carried out. Log interpretation gives 100% watersaturation and RFT measurements confirms a watergradient.

Rw is estimated from logs (0.05 ohm-m @ 87°C) and corresponds to an equivalent NaCl content of 58 g/l.

4.4.3 FORMATION PRESSURE (Fig.4.7)

The water gradient defined in Brent zone fits correctly the two RFT points in the Statfjord reservoir formation showing hydrostatic pressure regime in both reservoirs. The reference pressure in the Statfjord is:

Pi = 270.9 bara at 2682 mRKB (2660 mMSL)

4.4.4 FORMATION TEMPERATURE

For the formation temperature, the Brent temperature was extrapolated using 3°C/100m, hence the Statfjord temperature became

At top reservoir, 2613 mRKB	T=91°C
At base reservoir, 2752 mRKB	T=95.6°C

BOREHULL: 25/5-3 PL: 102 OPERATØR: ELF AVSLUTNINGSDATO: 26.03.90

BOREHULLSDATA: No shallow gas

1. Avstand fra boredekk til havnivå 22 m

2. Vanndyp 118 m

3a. Settedyp for lederør (m RKB) 30" - 198,5 m

3b. Evt. formasjonsstyrketest (g/cc):...

4a. Settedyp for foringsrør hvorpå BOP monteres (m RKB) 131m

4b. Formasjonsstyrketest (g/cc) : 1,80

5. Dyp (m RKB og toveis gangtid) til formasjons-/ledd-/lag-topper.

Top UTSIRA Formation - 495 m RKB (530 ms TVG)

Top Hordaland Group - 1012 m RKB (1034 ms TVG)

6. Dybdeintervall (m RKB og TVG) og alder for sandlag grunnere enn 1000 m under havbunnen. Oppgi hvilke lag som evt. inneholder gass.

288 - 291 m: sand, 388 - 392 m: sand, 417 - 495 m: sand/skifer,
495 - 1012 m: hovedsakelig sand

7. På hvilken måte er gassen påvist?

8. Sammensetning av og opprinnelse til gassen.

9. Beskriv alle målinger foretatt i gassførende lag.

SEISMISKE DATA:

10. Angi dyp (m RKB og TVG) til inkonformiteter i borehullsposisjonen. . ...

....

....

11. Angi dyp og utbredelse til sandlagene (kommunikasjon, kontinuitet, trunkering etc.). ....

....

....

12. Angi dyp og utbredelse til evt. gass-skygging ("gas blanking"), seismiske anomalier etc. ....

....

....

13. Angi evt. seismiske indikasjoner på at gassen stammer fra dypere nivå. Beskrivelse dersom gassen stammer fra dypere nivå. ....

....

....

14. Hvordan samsvarer tolkningen av borestedsundersøkelsen med borehullsdata m.h.t.:

grunn gass . From site survey: possible shallow gas at 218 m MSL (270 ms) and 244 m MSL (293 ms) ....

sandlag ..From site survey sands layers expected at (in MSL) .... (193-204 m) (244-263 m) (prominent sands 375-1015 m) ....

inkonformiteter..

....

korrelasjon til nærliggende borehull...

....