8. Wireline Formation Tests

Use of the Repeat Formation Tester (RFT) was included in the 31/2 logging programme in order to achieve the following objectives:

(1) measurement of formation fluid pressure at a number of depths, permitting the estimation of fluid pressure gradients, initial reservoir pressure and fluid contacts.

(2) sampling of reservoir fluids at selected depths, to confirm the reservoir contents indicated from petrophysics and from (1) above.

(3) collection of PVT samples of the reservoir fluid to determine composition and yield data for the preliminary design of processing facilities.

(4) indications of formation permeabilities.

While RFT results are not always conclusive in absolute terms, they usually give an early understanding of any hydrocarbon accumulation and the information may be used in formulating further testing programmes and for preliminary field development planning.

Operational Summary

Three sets of RFT runs were made, at well depths of 1533 m, 1701 m and 2432 m. Amerada gauges were also run with the RFT tool when pressure data were of particular interest. The first set at 1533 m was to investigate indications of gas obtained from the intermediate logs, and to obtain early PVT samples to guard against the eventuality that the hole would be inadvertently lost. A total of six runs were made.

The first, RFT-1, confirmed the formation to be gas bearing. Six pressure measurements were made between 1443 m bdf and 1523.5 m bdf. (see fig. 8.1), while a sample was taken at 1482 m. Field analyses of the gas recovered showed it to be rather dry having 94% methane and only traces of $n\text{-}C_4+$ (see table I/8.1). The Amerada run with the RFT proved difficult to interpret accurately, however the order of magnitude of the pressures measured by the RFT tool was confirmed.

Five further RFT runs (RFT-2 through RFT-6) were made to obtain PVT samples. Due to operational problems, such as low sampling pressures, 'O'-ring failures and sample losses at surface, only RFT-5 and RFT-6 at 1482 m and 1443 m respectively resulted in samples being successfully transferred at surface. Some additional low pressure samples were obtained and field measured compositions (see table I/8.3) again indicated the composition of the gas to be principally methane. From the successfully transferred PVT samples, a total of eight PVT bottles were despatched to three PVT laboratories for independent analyses (see table I/8.2).

After penetrating the hydrocarbon/water contact and reaching a depth of 1701 m, a new series of RFT runs (nos. 7-18) was made. RFT-7, essentially for pressures, was designed to confirm (by repetition) the pressures measured previously above 1533 m, and extend the measurements downwards through the suspected hydrocarbon/water contact into the water bearing sands below.

Nine pressure measurements were successfully taken in the gas column down to 1567 m, and six successful water gradient measurements were taken between 1597 m and 1667 m (see fig. 8.1). In the interval 1567 m to 1597 m, six pressure measurements were taken. The first at 1573 m showed an anomalously high pressure of 27 psi above the gas gradient line (RFT 7-10), which was repeated exactly by RFT 7-11. The other four taken deeper down in this interval were not fully built-up as a result of very low formation permeability and were hence unrepresentative.

Eleven further RFT runs were made at the same logging depth (1701 m), primarily to obtain PVT samples of either hydrocarbons or water. Four runs (RFT-10, 12, 14 and 15) resulted in successful PVT sampling and subsequent transfers of gas. PVT sample bottles were despatched to two independent laboratories for analysis. Three runs (RFT-9, 11 and 13) failed to obtain good gas PVT samples for mechanical reasons. The remaining four runs (RFT-8, 16, 17 and 18) made for water samples, were only partially successful as water was recovered but with varying degrees of mud and mud filtrate contamination.

Run RFT-18, the final run of this series, was made specifically in an attempt to locate a permeable zone for sampling within the tight 1575 m - 1595 m interval, and to check again the pressure anomaly found earlier at 1573 m. Tight zones were found at 1595, 1589, 1584.5 and 1580 m. However, at 1573 m and 1574.5 m, successful pressures were obtained indicating permeable intervals. Although the pressures measured were not as high as taken in RFT-7, there is no comparison with values taken above and below to confirm whether the pressure discontinuity observed with RFT-7 is valid. Seven attempts were made to obtain a sample at depths between 1572.8 and 1574.5 but sealing difficulties, a plugged probe and incomplete chamber fill led ultimately to failure.

After deepening the hole to 2432 m, a final RFT run (RFT-19) was made to define the pressure regime across this lower part of the hole. Six successful pressure tests were made (see fig. I/8.2). An attempt to obtain a water sample had only limited success with a zero pressure sample of fluid being recovered.

Analysis of Results

Pressures

The RFT pressures obtained were in good agreement with the Amerada measurements giving confidence in their absolute values. The following conclusions are drawn from RFT-7 which gave a consistent set of data points from top reservoir to below the hydrocarbon/water contact and generally reflects the broad range of pressure data obtained (see fig. I/8.2):

- the reservoir is gas bearing between 1442 m and 1567 m (bdf), with a gas gradient of 0.052 psi/ft. It follows that between 1442 m and top reservoir (1439.5 m) the reservoir is also gas bearing. The initial reservoir pressure, estimated at the volumetric centroid is 2286 psig at 1534 m bdf (1510 m ss)

- between 1597 m and 1667 m, the reservoir is water bearing with a measured pressure gradient of 0.427 psi/ft.

- in view of the observed bleeding of oil from cores between 1567 m and 1597 m, and the behaviour of the RFT during pressure measurements, this interval is interpreted as very tight. It is possible that both a gas/oil contact and an oil/ water contact exist in the interval 1567 m to 1597 m. From the pressure data (ignoring the high readings at 1573 m) the plausible interpretation is that a gas/water contact effectively exists at the intersection of the extrapolated gas and water pressure gradients at 1574 m (1550 m ss) which would imply that the oil observed in cores is actually residual.

- the anomalous pressures at 1573 m (RFT-7.10 and 7.11) could be interpreted by the presence of a thin sealing barrier immediately above 1573 m leading to this 27 psi discontinuity in the gas gradient and a gas/water contact at ca. 1597 m. This is not considered probably but should be borne in mind during investigations in future wells.

- the RFT pressure measurements taken between 2096 m and 2417 m (see fig. I/8.2) show that the hydrostatic pressure regime continues to these depths. A gradient of 0.437 psi/ft was measured, which compares with the gradient of 0.427 psi/ft measured at 1650 m.

Gas PVT Samples

It may be noted that the results (see table I/8.2) are remarkably consistent which gives confidence that representatives samples of reservoir content were being obtained. Although the minimum sampling pressure as measured inside the RFT tool was relatively low, the pressure drawdown in the formation during sampling should have been negligible when considering the low sampling rate and the reservoir permeability (which was estimated from the log porosity). It is interpreted that the pressure drop occurs at the probe screen as a result of plugging by mud cake and fines, and this sampling pressure is in no way related to the reservoir flowing pressure. It should be stressed that these analyses are only used as an indication of reservoir content as a carefully monitored production test under stable offtake conditions will be required to yield completely reliable results.

The main conclusions from the RFT samples are as follows:

- the reservoir fluid composition is typical of a dry gas. At the three stage separator conditions assumed in the laboratory of 1700 psig (40^{o} F), 500 psig (40^{o} F) and atmospheric pressure (27^{o} F), some 4 bbls of heavy condensate are recoverable per million SCF of gas. The gas is 93% methane and contains 0.5% CO_2 and 1.5% N_2. There was no H_2S recorded.

- in view of the low liquid yield, dewpoints were difficult to measure. However, it appears that the dewpoint is close to the reservoir pressure which would be consistent with the presence of liquid hydrocarbons at the base of the gas column.

- there is no apparent change of gas composition with depth.

- in view of the general agreement of the analyses, RFT-6.1 as analysed by Core Laboratories (RFLA-79123) has been chosen to represent the reservoir fluid composition until such time as a production test is carried out (see table I/8.2).

Since the seven samples sent to KSEPL, the Shell Laboratory, were found to have similar compositions, they are now being combined in order to flash the reservoir gas to atmospheric pressure and collect as much liquid as possible for compositional analysis of the C-20+ fraction and PNA (paraffins, napthenes and aromatics) determinations. These data are required for modelling fluid compositional behaviour both for reservoir investigations and process design. The results of this work have not yet been received.

Water Samples

Attempts to obtain RFT samples of formation water immediately below the gas reservoir were unsuccessful due mainly to low formation permeability resulting in protracted sampling times. This resulted in terminating sampling before the chamber was full due to operational considerations. In some cases, sampling was continued at another depth. Therefore it was not considered warranted to carry out the PVT transfer and samples were collected into plastic bottles and despatched for laboratory analysis.

The results of the analyses are summarised in table I/8.3. All samples retained a yellow colouration after laboratory filtraton indicating they were contaminated to some extent by mud filtrate. Average resistivity was approximately 0.30 ohm-m at 60°F. Since the formation water is estimated from log analysis to have a resistivity of 0.14 ohm-m at 60°F and the mud has a resistivity of 0.32 ohm-m at 60°F, the samples are most probably very severely contaminated by mud-filtrate and are therefore not representative of the true formation water.

31/2-1 RFT's FIELD MEASURED GAS COMPOSITIONS

(IN ORDER OF DEPTH)

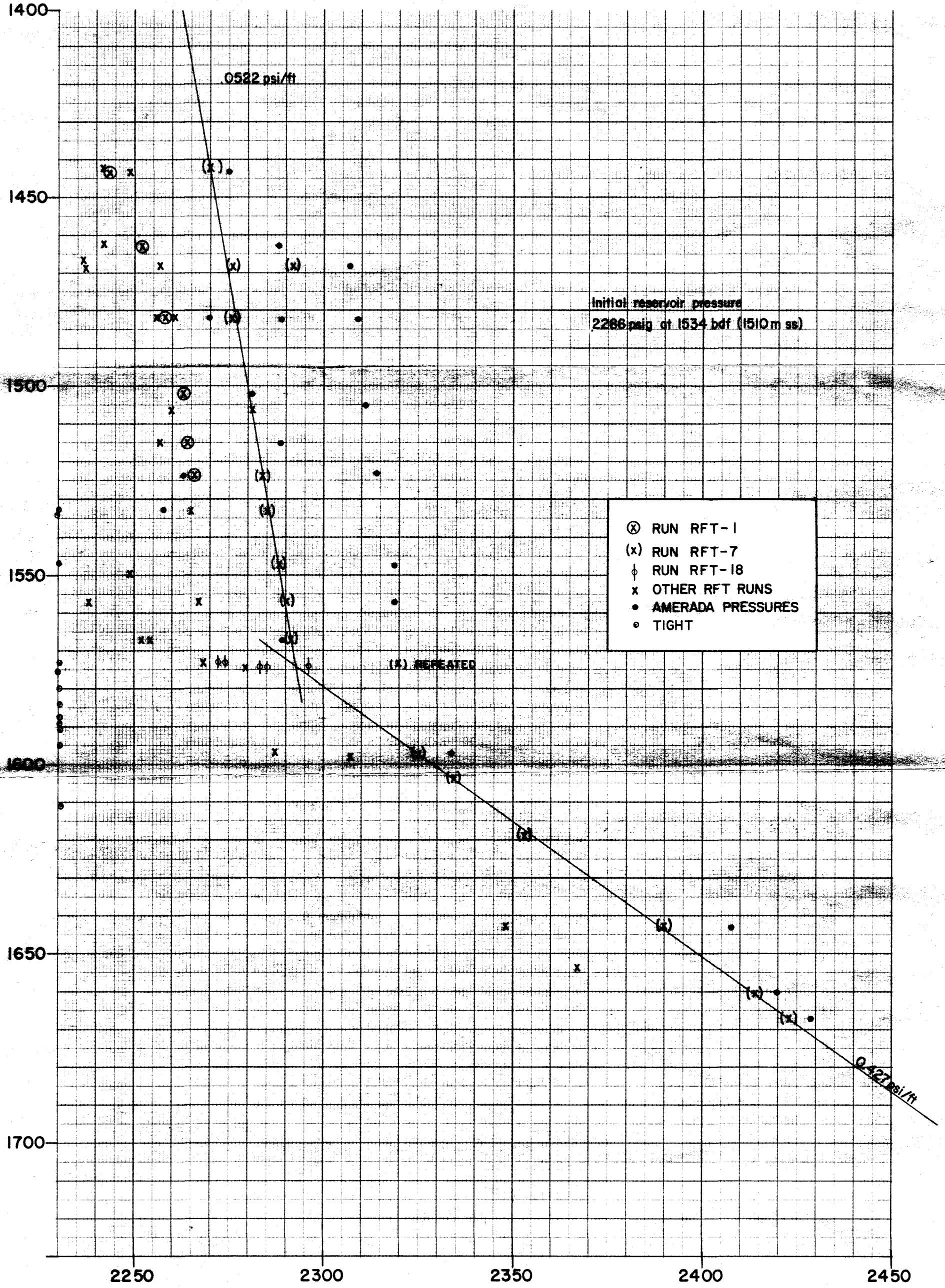
RFT NUMBER	4.1	15.1	1.7	9.1	2.1	18.8	18.8	MOST RELIABLE ANALYSIS (from RFT 6.1)
DEPTH (BDF)	1442	1547.5	1482	1468	1515	1573/74	1573/74	1443
DEPTH (SS)	1418	1523.5	1458	1444	1491	1549/50	1549/50	1419
COMPOSITION (VOL. PERCENT)								
C1	94.00	95.00	94.37	97.00	93.00	90.00	85.00	93.31
C2	4.30	3.50	4.80	3.00	5.50	4.20	3.40	3.43
C3	0.58	0.56	0.46	0.40	0.42	0.35	0.32	0.40
i-C4	0.40	0.48	0.37	0.20	0.38	0.18	0.14	0.28
n-C4	0.17		tr.		0.18	tr.	tr.	0.04
C5	0.04		tr.		tr.			0.02

NOTE: 1. Analyses were performed at well site, are approximate, and may not sum to 100%

2. Most reliable analysis data (from RFT 6.1) is included for comparative purposes

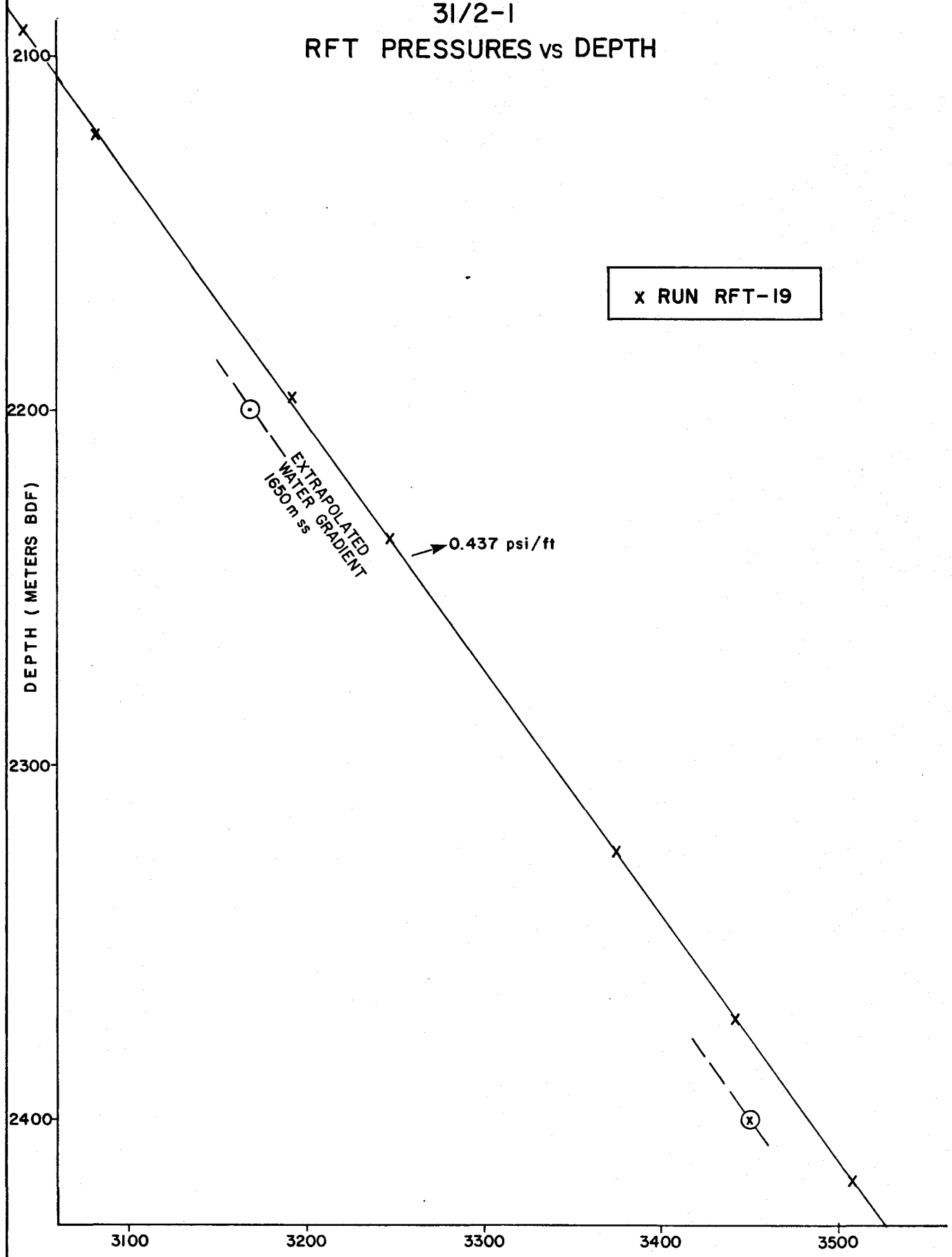
TABLE I/8.1

RFT PRESSURES vs DEPTH



a·s Norske Shell EXPLORATION & PRODUCTION TANANGER		
31/2-1 EXPLORATION WELL RESUME RFT PRESSURES vs DEPTH		
AUTHOR EF PP/ 2	FIG.	DATE January '80
REPORT NO.: NSEP 76	I/8.1	DRAW NO.: 582/11

31/2-1
RFT PRESSURES vs DEPTH



a·s Norske Shell
EXPLORATION & PRODUCTION FORUS

31/2-1
EXPLORATION WELL RESUME
RFT PRESSURES vs DEPTH

AUTHOR EPPP/ 2	FIG.	DATE January'80
REPORT NO. NSEP 76	I/8.2	DRAW. NO. 582/12

31/2-1 SUMMARY OF GAS PVT ANALYSIS RESULTS

(COMPOSITIONAL DATA IN MOLE PERCENT)

RFT NO.	6.1	6.1	6.1	14.1	5.1	5.1	5.1	5.1	10.2	10.2	15.1	12.1	12.1
SAMPLE REF NO.	1C	2R	3F	4C	5C	6R	7R	8F	9R	10R	11C	12R	13R
Depth mRTKB	1443	1443	1443	1467	1482	1482	1482	1482	1506	1506	1547.5	1557	1557
Depth ss	1419	1419	1419	1443	1458	1458	1458	1458	1482	1482	1523.5	1533	1533
Bottle No.	20584-81	8088-28	8088/82	8088/48	20584-2	8088-63	8088-92	8088/51 8088/86	8088.34	20584-8	2674-33	20584.92	20584.10
Analysis	CORLAB RFLA 79123	RIJWIK TLX 3322 4147	FLOPET 79/L/65	CORLAB RFLA 79145	CORLAB RFLA 79123	RIJWIK TLX 2726 4147	RIJWIK TLX 4147	FLOPET 79/L/65	RIJWIK TLX 4147	RIJWIK TLX 4147	CORLAB RFLA 79144	RIJWIK TLX 4147	RIJWIK TLX 4147
COND. BBLS/MMSCF[1]	4.61	3.3	-	6.19	3.79	-	-	-	-	-	4.19	-	-
Min. sampling pressure (psig)		1163		1085		640			1369		1156	605	
Measured formation pressure (psig)		2249		2242		2263			2252		2254	2248	
Est. formation permeability(mD)		400		400		90			400		400	100	
DEWPOINT (psig)	2159	3558	N.D.	2166	2023	2257	3399	N.D.	2417	2413	2103	2360	2261
Z at Pdp [2]	0.836	.811	0.827	0.826	0.839	.813		0.825			0.831		
Co_2	0.51	0.56	0.42	0.48	0.59	0.59	0.79	0.39	0.86	0.77	0.37	0.36	0.38
H_2S	-	-	-	-	-	-	-	-	-	-	-	-	
N_2	1.48	1.43	1.48	1.52	1.53	1.37	1.54	1.53	1.45	1.57	1.00	1.52	1.56
C1	93.31	92.56	93.82	93.19	93.05	92.57	92.19	93.56	92.14	92.06	94.00	92.56	92.51
C2	3.43	4.06	3.26	3.37	3.53	4.08	4.14	3.37	4.11	4.19	3.42	4.16	4.17
C3	0.40	0.48	0.39	0.37	0.39	0.51	0.54	0.43	0.53	0.51	0.38	0.55	052
i-C4	0.28	0.41	0.34	0.28	0.16	0.41	0.41	0.36	0.42	0.42	0.26	0.42	0.41
n-C4	0.04	0.06	0.05	0.04	0.17	0.05	0.06	0.06	0.06	0.06	0.04	0.07	0.07
i-C5	0.02	0.06	0.05	0.06	0.05	0.06	0.06	0.06	0.07	0.07	0.02	0.07	0.07
n-C5	Tr.	0.02	0.01	0.01	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
C6	0.02	0.10	0.07	0.07	0.08	0.10	0.10	0.09	0.10	0.10	0.06	0.11	0.10
C7	0.18	0.26+	0.11	0.22	0.12	0.24+	0.15+	0.13	0.24+	0.23+	0.17	0.16+	0.19+
C8	0.20		0.00	0.21	0.13			0.00			0.15		
C9	0.08		0.00	0.09	0.06			0.00			0.06		
C10	0.03		0.00	0.05	0.04			0.00			0.03		
C11	0.01		0.00	0.02	0.02			0.00			0.01		
C12	0.01		0.00+	0.01	0.01			0.00+			0.01		
C13	Tr.			Tr.	Tr.						Tr.		
C14	Tr.			Tr.	Tr.						Tr.		
C15	Tr.			Tr.	Tr.						Tr.		
C16	Tr.			Tr.	Tr.						Tr.		
C17	Tr.			Tr.	Tr.						Tr.		
C18	Tr.			Tr.	Tr.						Tr.		
C19	-			Tr.	Tr.						Tr.		
C20	-			Tr.	Tr.						Tr.		
Molecular weight	17.60					17.61	17.63		17.72	17.71		17.54	17.56

(1) RFT 5.1 and 6.1 Separation at 1700/500/0 psig and 40/ 40/27 °F

RFT 14.1 and 15.1 Separation at 1250/50/0 psig and 40/ 40/27 °F

(2) Gas deviation factor, at initial pressure + indicates "plus"

TABLE I/8.2

31/2-1 WATER SAMPLES ANALYSES

Sample Sequence No.	1	2	3	4	5	6	7	8	9	10
RFT No.	9.1	9.1	17.1/1	17.1/1	17.1/2	17.1/2	7L	19.7L	7U	19.7U
Depth BDF	1468	1468	1642.5	1642.5	1642.5	1642.5	2096	2096	2096	2096
Depth m. ss	1444	1444	1618.5	1618.5	1618.5	1618.5	2072	2072	2072	2072
Lab.	CORELAB	KSEPL	CORELAB	KSEPL	CORELAB	KSEPL	CORELAB	KSEPL	CORELAB	KSEPL
colour	yellow/brn	-	yellow	-	yellow	-	yellow	-	yellow/brn	-
Appearance bef. filtr.	murky	-	cloudy	-	cloudy	-	cloudy	-	cloudy	-
after filtr.	hazy	-	clear	-	clear	-	hazy	-	hazy	-
SG	1.01	1.013	1.027	1.025	1.027	1.026	1.010	1.008	1.022	1.020
Resistivity m at 60°F	0.463	0.404	0.296	0.226	0.300	0.229	0.642	0.513	0.317	0.252
pH	8.3	7.8	10.0	10.2	11.3	11.5	7.9	7.4	8.5	7.9
Mg/L										
Sodium	61600	5244	11990	9620	12070	8990	4600	4120	9240	8145
Potassium	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Calcium	870	815	740	608	670	666	650	626	1690	1600
Magnesium	385	342	9.2	101	2.1	28	28	32	80	51
Barium	0.3	N.D.	0.2	N.D.	0.2	N.D.	0.8	N.D.	1.0	N.D.
Strontium	4.1	3	8.9	13	4.4	8	5.1	7	31	41
Total Iron	700	0	4.6	0	14	0	14	0	47	0
					(3.0)*		(0.2)*		(20)*	
Chloride	8690	8640	12730	12745	11700	11609	6380	6195	14070	13753
Sulphate	4440	1875	9320	4400	10410	4150	2490	1675	4410	2200
Bi Carbonate	350	909	130	146	160	0	185	220	280	311
Carbonate	-	0	130	114	295	276	-	0	29	0
Hydroxide	-	0	-	0	-	63	-	0	-	0
Viscosity at 107°F										
Centistokes	0.73	0.716	0.71	0.693	0.76	0.708	0.68	0.675	0.72	0.712
Cp	0.72	0.707	0.69	0.676	0.74	0.690	0.67	0.670	0.70	0.698

N.D. Not determined

* Dissolved iron

TABLE I/8.3