BP Exploration Company Limited

Geological Division

Report No. U.K. 345.

(APT.10)

COUSLAND NO. 6
GEOLOGICAL COMPLETION REPORT

by

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1) WELL DATA

Location:	Latitude 55° 54' 04.9"
	Longitude 02° 59' 09.8"
R.T.E:	556.58 ft. above O.D.
Rig:	T.20 Jack-knife
Drilling commenced:	15.11.59.
Drilling completed:	9.1.60.
Final depth:	1910 ft.
Completion:	Plugged back to surface with cement.
Hole sizes:	14.3/4" - Surface to 307 ft.
	8.5/8" - 307 ft. to 1910 ft.
Casing:	11.3/4" cemented to surface at 301 ft.
Cored Intervals:	1173 - 1186 ft.
(see graphic log	1195 - 1215 ft.
for recovery figures)	1224 - 1263 ft.
	1365 - 1466 ft.
	1493 - 1568 ft.
	1613 - 1661 ft.
	1735 - 1779 ft.
	1820 - 1910 ft.

A directional deviation survey was made on January 9th - 10th with the following results:-

Depth	Deviation	Direction
500'	$\frac{1}{2}^\circ$	S. 45° W.
600'	1°	S. 23° W.
700'	$\frac{1}{4}^\circ$	S. 37° W.
800'	$\frac{1}{4}^\circ$	S. 42° E.
900'	1°	S. 16° E.
1000'	$1\frac{1}{2}^\circ$	N. 72° W.
1100'	$\frac{1}{2}^\circ$	S. 87° W.
1200'	$2\frac{1}{2}^\circ$	S. 67° W.
1300'	3°	S. 60° W.
1400'	$2\frac{1}{2}^\circ$	S. 53° W.
1500'	$3\frac{1}{4}^\circ$	S. 20° W.
1600'	$3\frac{1}{2}^\circ$	S. 20° W.
1700'	4°	S. 12° W.
1800'	5°	S. 15° W.
1900'	$6\frac{1}{2}^\circ$	S. 20° W.

Electrical, Gamma Ray and Caliper Logs were run on 10th January by Schlumberger, Walsall:-

Electrical Log:	1/200	301 - 1911 ft.
	1/500	301 - 1911 ft.

Gamma Ray Log:	1/200	20 - 1911 ft.
	1/500	20 - 1911 ft.
Caliper Log:	1/200	301 - 1908 ft.
	1/500	301 - 1908 ft.

(No Microlog was obtained).

2) DRILLING HISTORY (for details see Weekly Boring Logs)

Drilling was slow because of the hardness and abrasiveness of the formations. It was found impossible to keep the hole straight below 1200 ft.

All of the major sand units below 1100 ft. were cored and seven drill stem tests were carried out (see section 8).

A bentonite - base drilling mud was used throughout the drilling operations. CMC was used to condition the mud for a water loss figure of 5 cc. No mud losses were experienced.

The decision to terminate drilling was made when 370 ft. of beds beneath the lowest sand at 1493 - 1540 ft. had been penetrated without encountering any further reservoirs.

3) GENERAL INTRODUCTION

Six boreholes have now been drilled by BP Exploration Co. Ltd. on the D'Arcy - Cousland Anticline. Two of these, Nos. 5 and 6, were drilled for the Gas Council. The reasons for choosing the Cousland culmination and the results of the first three wells are given in U.K. Report No. 62. Cousland No. 1, which was drilled in 1937/38 found a little oil and considerable quantities of gas in sands of the Calciferous Sandstone Series. Cousland No. 2, drilled about half a mile down the west flank of the dome, and No. 5, drilled 1000 ft. south of No. 1, found only water and small quantities of gas. No. 3 and No. 4 were drilled on other culminations of the anticline, also without success, although No. 4 had several gas sands, one of which produced at a rate of 100,000 cu.ft./day.

After Cousland No. 5 had been drilled in 1954, the Gas Council suggested that BP should propose the next step in the exploration of the area. (PRO/20, 8.3.55.). Accordingly a geological appraisal of the D'Arcy - Cousland Anticline was made and two locations for boreholes were recommended (BP Technical Note GL-RGWB.5-U.K.-Scotland 10.5.55). One of these locations was on the Cousland culmination of the anticline, east of Cousland No. 1. A firm proposal to drill a well at this point was made by BP Exploration Co. Ltd., Eakring (Geol/A65/2183, 25.3.59.) and the location was approved by Chief Geologist of BP and by Professor V.C. Illing, geological adviser to the Gas Council (Geol/A65/2382, 6.8.59.).

The well, called Cousland No. 6, was drilled in November 1959 - January 1960, approximately 1900 ft. east of Cousland No. 1. The object of the well was to investigate the sands known to be gas bearing in No. 1. On the evidence then available the location was considered to be structurally higher than No. 1 at the horizon of the 1582 ft. sand and in what was believed to be the general direction of sand improvement (see the Technical Note referred to above).

4) SUMMARY OF THE STRATIGRAPHICAL SUCCESSION
(details are to be found on the graphic log)

Lower Limestone Group of the Carboniferous Limestone Series

Sandstone and siltstone	Surface to 27 ft.	27 ft.+
Limestone and shaly limestone	27 to 57 ft.	30 ft.
Sandstone and siltstone with coals	57 to 159 ft.	102 ft.
Limestone and calcareous shale (considered to be the No. 1 Gilmerton or Upper Crichton Limestone).	159 to 184 ft.	25 ft.

Calciferous Sandstone Series

Sandstone	184 to 200 ft.	16 ft.
Shale with impure coal	200 to 229 ft.	29 ft.
Sandstone, silty at base	229 to 253 ft.	24 ft.
Mudstone and shale	253 to 278 ft.	25 ft.
Limestone and calcareous shales	278 to 318 ft.	40 ft.
Shales with ironstone	318 to 450 ft.	132 ft.
Sandstone	450 to 645 ft.	195 ft.
Shales and siltstones with ironstone and two thin limestones	645 to 805 ft.	160 ft.
Sandstone	805 to 854 ft.	49 ft.
Sandstone and shale, interbedded	854 to 887 ft.	33 ft.
Shales, siltstone, oil shales	887 to 1032 ft.	145 ft.
Sandstone	1032 to 1066 ft.	34 ft.
Sandstones, siltstones and shales, interbedded	1066 to 1190 ft.	174 ft.
Sandstone with shale partings	1190 to 1241 ft.	51 ft.
Silty shales with sandstone and oil shale at base	1241 to 1300 ft.	59 ft.
Limestone, calcareous sandstone and mudstone	1300 to 1358 ft.	58 ft.
Sandstone with shale partings	1358 to 1425 ft.	67 ft.
Shales	1425 to 1493 ft.	68 ft.
Sandstone	1493 to 1540 ft.	47 ft.
Siltstone and shale	1540 to 1610 ft.	70 ft.
Fossiliferous limestone and calcareous shale	1610 to 1625 ft.	15 ft.
Shales, siltstones with occasional thin sandstones and limestones	1625 to 1910 ft.	285 ft.+

5) CORRELATION AND THICKNESS OF STRATA

Lower Limestone Group, Surface to 184 ft.

The borehole begins 9 ft. above a limestone which is mapped by the Geological Survey as the No. 2 or North Greens Limestone of the Lower Limestone Group (Edinburgh geological sheet 32 and Geological Survey Memoir "The Geology of the Midlothian Coalfield" Plate II).

The second limestone at 159 - 184 ft. in Cousland No. 6 appears to be equivalent to the upper leaf of the limestone group found in Cousland No. 1 at 165 ft. This consists of two limestones separated by shales and sands which are referred to collectively in Company Reports (UK.62 p.11, UK.195 p.7) as the No. 1 or Gilmerton Limestone. In the latest Survey Memoir (op. cit. fig. 5), however, only the upper limestone leaf is regarded as the equivalent of the Gilmerton (= Hurlet) Limestone and the lower leaf is included in the Calciferous Sandstone Series. These two limestones are also referred to by the Survey as the Upper and Lower Crichton Limestones, from the locality 4 miles south of Cousland.

In this report the Survey's classification has been adopted and the limestone at 159 - 184 ft. in well No. 6 is correlated with the No. 1, Gilmerton or Upper Crichton Limestone. The boundary between the Lower Limestone Group and the Calciferous Sandstone Series is taken at its base.

Oil Shale Group of the Calciferous Sandstone Series, 184 - 1910 ft.

Below the Upper Crichton (= Gilmerton or No. 1) Limestone the succession in Cousland No. 6 is bradly similar to that found in the earlier wells, consisting of rhythmic sequences of coal, shale with ironstones, limestone, oil shale, sandstones and seatearths. The limestones are mostly non-marine with ostracods and *Spirorbis*, but there are some marine bands with crinoids. The latter would seem at first sight to be the most useful marker beds for correlation but although five marine bands were recognised in No. 1 and four in No. 6 only one near the top of the series appears to be common to both wells. In fig. 3 it has been assumed that the major sand units in the succession are lithologically continuous within the area covered by the wells and the tracing of these sands forms the basis of the correlation. It is supported by a few other points of lithological similarity which are apparent when the well logs are compared.

Most of the limestone - sandstone section between 222 and 315 ft. in No. 1 and between 252 and 375 ft. in No. 5 appears to be missing in No. 6. This cut-out could either be due to an unconformity at the base of the Upper Crichton Limestone or to faulting. Faulting seems the more likely explanation as a similar cut-out was recorded at a slightly different horizon in No. 1 (UK.195 p.9).

Below the Crichton Limestones the next important marker in No. 1 and No. 5 is an ostracod limestone correlated with the Burdiehouse Limestone. This bed cannot be recognised in No. 6, but an 82 ft. sandstone section at 805 ft. in No. 6 is thought to be equivalent to the sand found at 923 ft. in No. 1 and at 1026 ft. in No. 5 (see fig.3).

A 34 ft. sandstone was encountered at 1032 ft. in No. 6. If this sandstone is regarded as the equivalent of the 1248 ft. sand in No. 1, the underlying succession down to and including the two main sands at 1358 ft. and 1493 ft. can be matched more or less bed for bed with that of No. 1 (see fig. 3). The interval between the 805 and 1032 ft. sand in No. 6, however, is about 100 ft. less than the corresponding interval in No. 1 and No. 5.

The absence of sandstones below 1600 ft. in No. 6 which could be considered the equivalents of the 2000 ft. and 2094 ft. sandstones of No. 1 suggests that either faulting or lateral facies change has taken place in these lower beds. The steep dips in this part of the succession in both wells can in any case be expected to interfere with correlation.

If the correlation illustrated in fig. 3 is correct, the stratigraphic interval between the top of the Series and the top of the 1248 ft. sand of No. 1 varies by as much as 270 ft. in the four wells, being thickest in No. 2 and thinnest in No. 6. The difference in thickness between No. 1 and No. 2 on the western flank of the structure was attributed to westerly depositional thickening (UK.62 p.20). An apparent northerly reduction in thickness between No. 5 and No. 1 was later ascribed to normal faulting (UK.195 p.2). The easterly thinning from No. 1 to No. 6 seems more likely to be a depositional feature as it takes place at the expense of the shales (see sand/Shale ratios, fig. 2). The first interpretation shown in fig. 4* shows the thinning from No. 2 to No. 1 well continuing eastwards at a slightly decreasing rate to No. 6.

Although this easterly thinning is accompanied by a general increase in the proportion of coarser material (fine to medium sand) the actual quality of the individual sands seems to deteriorate, for they are finer grained, more micaceous and split up by shale partings

* The two sections of fig. 4 should be regarded as the stratigraphic and structural "end members" of a number of possible interpretations.

in No. 6. It is not possible to say whether this is a genuine trend or just a local feature. A petrographic study of the sands and their cementation should throw some light on the problem.

6) STRUCTURE

Dip evidence in No. 6 is available only from those intervals that were cored between 1173 and 1910 ft. The following measurements were recorded:-

1173 - 1179 ft.	Dip 40°
1195 - 1215 ft.	Dip up to 50°, average 30 - 40°
1224 - 1229 ft.	Dip 30°
1229 - 1241 ft.	Dip up to 50°
1244 - 1252 ft.	Dip 30°
1365 - 1382 ft.	Dip 20 - 30°
1436 - 1438 ft.	Dip 70°
1455 - 1466 ft.	Dip 25°
1532 - 1552 ft.	Dip 35°
1552 - 1568 ft.	Dip 40°
1615 - 1645 ft.	Dip 40 - 60°
1820 - 1840 ft.	Dip 25°
1840 - 1871 ft.	Dip 35°
1871 - 1894 ft.	Dip 35 - 50°

The more obvious primary depositional dips have not been included, so that the dips listed above are for the most part apparently structural.

Indirect evidence of the amount and direction of dip is provided by the deviation measurements. Above 1100 ft. the deviation is negligable. Below 1100 ft. the deviation increases steadily from ½° to 6½° at 1900 ft. The direction of deviation below 1100 ft. is consistently to the S.W. These facts imply low dips down to about 1100 ft. and steeper dips, possibly to the N.E., below that depth. Zones of steep dips also occur below the 1720 ft. sand in No. 1 and No. 2 wells. They could be due to primary depositional structures, to faulting or to local disharmonic folding. The fact that a correlation between No. 1 and No. 2 can be made in spite of these dips has been taken as evidence that there are no large faults in those two wells. (U.K. 62 p.16).

The structural elevations of the key beds penetrated in the wells are tabulated in fig. 2. Down to the base of the Lower Limestone Group there is very little difference in elevation between Well No. 1 and well No. 6. At the level of the 1248 ft. sand of No. 1 and below it, No. 6 is over 200 ft. higher than No. 1. This could be due to gradual easterly thinning of the beds, to unconformities in the sequence or to structural cut-outs. In the lower section of fig. 4 two normal faults downthrowing west have been postulated to account for the absence of these beds; one cutting out the Lower Crichton

Limestone and most of a thick sand beneath it, the other cutting out about 100 ft. of beds between the 805 ft. and 1032 ft. sands. Other faults may be present but undetected. The dip of the faults has been arbitrarily drawn as 70° to the west; in fact neither the dip nor the trend is known. Such faults have not been mapped at the surface but this is not surprising as exposures are poor and both the North Greens and the Crichton Limestone groups are about 100 ft. thick and are underlain by thick sandstones.

The base of the North Greens or No. 2 Limestone is known accurately at 10 points in the vicinity of Cousland in the four deep wells and in six Associated Portland Cement Manufacturer's boreholes. Some dip measurements have been recorded in the limestone quarries (see U.K.195, fig. 1). Tentative contours on the base of the limestone have been drawn on fig. 2. The structure at the top of the Calciferous Sandstone Series is probably similar, but there is the possibility of an unconformity at this horizon (fig. 4). Interpretation of the structure below this becomes very speculative because of uncertainties regarding thickness changes, possible unconformities and faulting. Cousland No. 6 was drilled on the crest of the inferred structure at the level of the 1582 ft. sand of No. 1. This was derived by adding the contour lines on the base of the Crichton Limestone and isopachytes on the interval between these two beds. Drilling confirmed that the 1582 ft. sand is structurally higher at No. 6 than it is at No. 1 but the difference between the amount of structural rise predicted (90 ft.) and that actually found (over 200 ft.) requires an explanation. The most likely one is a combination of faulting at the base of the Upper Crichton Limestone in No. 6 and stratigraphic thinning between that horizon and the top of the 1032 ft. sand.

There is no information on the structure at depth north of a line through No. 2, No. 1 and No. 6 wells. Two shallow boreholes have been drilled on the northern half of the surface anticline (APCM Nos. 6 & 7) but neither of these reached the Calciferous Sandstone Series. As it is quite possible that the structure at the level of the gas sands rises or maintains its elevation for some distance north of No. 1 there is justification, on structural grounds alone, for a fifth well on the Cousland culmination.

7) GAS, OIL AND WATER SHOWS

Gas was produced from one interval only, namely the 1493 - 1540 ft. sand, in very small quantities (see below).

Oily or bituminous sands were recorded at six levels (see well log), confirming an earlier suggestion that oil residues are more concentrated at structurally higher levels (UK.62 p. 27).

No formation water was produced in any of the drill stem tests.

8) DRILL STEM TESTS were carried out over five intervals, with the following results:-

1.	1179 - 1215 ft.	No production.
2.	1205 - 1263 ft.	No production.
3.	1357 - 1382 ft.	No production.
4.	1370 - 1455 ft.	No production.
5.	1483 - 1568 ft.	Gas at 150 cu.ft./day (Duration of test $4\frac{1}{2}$ hrs.)

The hole was plugged back with cement to 1540 ft. and the sand at 1493 - 1540 ft. which had produced a trace of gas during the fifth test was 'shot' to try to improve penetration. Two further tests of this sand were carried out; the first was mechanically unsatisfactory, the second obtained a production of 72 cu.ft./day of gas and 440 galls./ day of returned drilling fluid. The possibility that a sand at 803 - 866 ft. in the well was gas bearing was eliminated by a bailing test.

For further details see Eakring Pet. Eng. Dept. Report No. 334.

9) <u>CONCLUSIONS</u>

1) None of the sands penetrated by Cousland No. 6 yielded any significant amount of gas, oil or water. Although the two main gas sands of well No. 1 are probably represented in No. 6 only one (the 1720 ft. sand of No. 1) produced any gas and this was in very small quantities. No equivalent of the gas sand at 2094 ft. in No. 1 was found in No. 6.

2) Structurally No. 6 appears to be about 200 ft. higher than No. 1 at the level of the gas sands. It is not certain how much of this structural rise is due to faulting, unconformity or to depositional thinning in the upper part of the Calciferous Sandstone Series. Because of this uncertainty little more can be added to what has already been said about the size and structure of the reservoir. There is, however, still the possibility that the structure rises or maintains its elevation north or north-east of No. 1.

3) The apparent easterly thinning in the Calciferous Sandstone Series between No. 1 and No. 6 is associated with a general increase in the amount of sand in the succession. There is also an apparent deterioration in the quality of the sands in the same direction. Wells No. 4 and 5 showed that the gas sands of No. 1 also contain shale intercalations and are less permeable to the south of the discovery well.

4) Whatever its significance may be, the poor permeability of the sands in No. 6 detracts from the prospects of the eastern part of the structure. On the western and southern flanks the gas reservoir is limited by edge water, proved in wells No. 2 and No. 5.

5) Having regard to the possible extension of the structure at depth to the north or north east and also to the possibility of sand improvement in that direction it is recommended that before abandoning the Cousland culmination as a gas prospect a step-out well should be drilled 1000 ft. N.E. of No. 1.* This well should serve as a test for gas production and would also provide information on structure and reservoir conditions in that direction.

It should also be noted that the Falside - Carberry Hill culmination north of Cousland has yet to be tested for gas. A well on this structure has already been proposed (Tech. Note GL-RGWB.5-UK.-Scotland - 10.5.55.).

*Footnote:- Existing maps show this locality to be clear of limestone quarries, etc., but this should be confirmed by an examination of the ground.

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10) REFERENCES

Company Reports

Allison, A.	-.10.36.	Report on Cousland - D'Arcy Structure (Geol. Rep. A.A.4 U.K. 17)
Brunstrom, R.G.W.	10. 5.55.	The Prospect of finding more Gas in the Cousland Area. (TN-GL-RGWB.5-UK-Scotland)
Falcon, N.L.	1940	Cousland Geological Completion Report (Geol. Rep. NLF.15, U.K. 62)
Jones, W.D.V. etalia	1954	Reports on the Cousland Area, Midlothian, Scotland. (Geol. Rep. U.K. 195)
Martin, F.C.R. Taitt, A.H.	15.12.55.	The Gas Prospects of the Midland Valley of Scotland. (Geol. Rep. FCRM.3, U.K. 231)
Taitt, A.H.	-.12.38.	Cousland Shallow Boreholes. (Geol. Rep. AHT.23, U.K. 45)
British Petroleum Co.		U.K. Data Book - Scotland (U.K. 265)

Published Information

Tulloch, W. Walton, H.S.	1958	The Geology of the Midlothian Coalfield. (Geol. Surv. Scotland, 1958).