

COMBINED EXERCISE 2

Objectives

Your task is to produce an interpretation of the reservoir succession penetrated by a single well. To do this you will need to include:

1. An analysis of the various lithologies present, marking the major stratigraphic boundaries.
2. An analysis of the geological depositional environment.
3. Zonation of the well for reservoir calculation purposes.
4. Calculation of STOOIP and STGOIP if relevant.
5. Produce a short summary report for management, including (a) very briefly the methods used, (b) clearly stated equations that you have used, (c) clearly stated input parameters for the equations, (d) logical structure, (e) key geological characteristics of the reservoir succession, and (f) a balanced assessment of the oil reserves in place, giving approximate error bounds in the calculation.

Resources

You are provided with:

1. A log suite for a single well in the northern North Sea that intersects a Middle Jurassic reservoir. Two copies are given such that one can be used as a rough copy. Note that the gamma ray log is reading slightly low in depth so you may have to take this into account in the assessment of the logs, and use the depths from the neutron-density log for readings of absolute depth to a given lithology boundary.
2. The trap in this reservoir is a tilted fault block.
3. Both the seal and the likely source of the oil in an unconformable Upper Jurassic Kimmeridge Clay formation.
4. Seismic analysis of the area reveals off-lapping horizons that suggest the reservoir sequence may be part of a progradational delta.
5. Seismic analysis also reveals that the best approximation currently to the extent of the reservoir is 2023.5 ha.
6. PVT tests in the laboratory reveal that the oil formation factor $B_o = 1.65$.
7. The mean price of Brent crude in 1996 and 1998 was 20.16 and 13.42 \$/bbl., respectively.

Deliverables

1. The annotated logs for the well indicating clearly all useful parameters and construction lines. This includes (i) a shaded depth scale for lithology, (ii) if present, shaded mudcake, caving, washout, neutron-density separation (positive and negative), (iii) GR sand and shale lines, (iv) Neutron and Density sand and shale lines, (v) the position and coding of your zonation of the well together with codes for their fluid content and indication qualitatively of their permeability, (vi) facies information including fining-up (FU) and coarsening-up (CU) profiles, (vii) the depth of main

- fluid interfaces (i.e., at least an OWC), (viii) boundaries between the main depositional environments.
2. A separate diagram summarizing the lithologies penetrated with an indication of likely grain sizes and grain size changes (i.e., a sedimentary log).
 3. Tables: (i) The first, identifying all zones and calculating the respective physical parameters therein contained, and (ii) the second, which takes only the reservoir zones and progresses the calculations to a final value of OOIP.
 4. A summary report including: (i) A brief description of the methods that you have used, including equations where appropriate, and indicating the type of mud used and the type of formation waters present, and the values of the various cut-offs and sand and shale lines that you have used. (ii) The key geological characteristics of the reservoir succession including an interpretation of the depositional environments present (quote depths and reference to the wireline logs and your drawn sedimentary log to illustrate the points you make). (iii) An assessment of oil reserves in place, including the net-to-gross ratio for (a) sands and (b) all lithologies, (iv) an assessment of the gross worth of extractable oil in the reservoir in 1996 and then in 1998. Do not comment upon the economic viability of the field.
 5. Ensure that your name appears on every item submitted, and informally bind the document in a holder or docket.

Suggested Procedure

- Do a basic lithology interpretation and qualitatively locate porous and permeable intervals and reservoir fluid type. Shade the depth scale for the lithologies, and place codes for the qualitative porosity, permeability and hydrocarbon content in the right-hand margin (e.g., +, ++, and +++ for permeability; 0, L, H, VH for the porosity; and the symbols for water oil and gas for the fluid content). Mark on the relevant log obvious FU or CU sequences with arrows. Work from obvious large packages of rock to smaller ones. Highlight with shading (i) positive neutron-density separations, negative separations, (iii) between the medium and deep resistivity tools where deep resistivity > medium resistivity, (iv) mudcake etc. Note that; (a) small +ve neutron-density separations indicate shaly sand not shale, (b) where medium resistivity \approx deep resistivity, but greater than the MLL (very shallow resistivity) you have an interval of high permeability but NO hydrocarbons.
- Locate the mudstones on the gamma ray log, and use a 30% cut-off to separate the shaly sandstones (which you will ignore in any reservoir oil calculations as not productive) from the cleaner sandstones (which you will keep). To define the shale line use values in the interval 9760' to 9880' in the upper part of the log, and values in the interval 10050' to 10140' in the lower part of the log. The sand line definition is the same throughout the log. Choose to switch between the two shale lines at some appropriate depth in the middle of the log at a lithology boundary. Use a 80% cut-off to locate the depths at which good shales occur.
- Zone the log. Define depth zones for what is reservoir and non-reservoir rock. Give each zone a code (e.g., A, B, C, D etc) in the left-hand margin with lines to indicate the depth extent of each zone (so that you can easily measure their thicknesses later). Every depth in the log should be in a single zone or exactly on an interface between two zones. You will use some of these zones as reservoir zones later, so we must take into account various properties in carefully defining them. In the zoning process, therefore, take account of :
 1. The lithology (e.g., good shales ($V_{sh} > 0.8$) and evaporites are not reservoir rock).

2. The shale volume (rock with $V_{sh} < 0.3$ (in this exercise) is not reservoir rock).
3. The presence of hydrocarbons (rock with no hydrocarbons is not reservoir rock).
4. The permeability (rock with low permeability is not reservoir rock).
5. No zone should be thinner than 5 ft.

Note that: (i) ALL of the above need to be good for the zone to be a reservoir zone, but non-reservoir zones will exist and have a code, where the points above are only partially fulfilled. (ii) Your zones may differ from that of your colleagues (petrophysical interpretation is petrophysicist-dependent). (iii) It is also possible to implement a cut-off on porosity by also saying that porosity must be greater than 5%, say, for a reservoir zone. I have not asked you to carry out this procedure in this exercise as it does not affect the final zonation greatly.

Zonation hint: Start with the obvious shales on the neutron density log, check against the gamma ray log. Then find major clean sandstones from the neutron-density and gamma ray logs. Then find indications of fluid type and permeability from the caliper, resistivity and SP logs. What is left is shaly sand or other lithologies. Iterate back and forth, finding progressively thinner units until a minimum thickness of about 5 feet, then stop. Adjust the zones to ensure that the remaining intervals less than 5 feet are included in other zone, such that the log is completely zoned. If in doubt in a particular interval, leave it and come back to it later.

[In this log there is only one small interval below the OWC that may be not shaly sand, clean sand or shale. You can give this a zone of its own if you like, but it is irrelevant to the main purpose of the analysis as it is below the OWC. We do not know the lithology of this zone, but its recognition and analysis may be useful for correlation with other wells.]

- Construct a sedimentary log on a separate sheet of paper (at a scale of 1" to 100' or 2 cm to 100') showing interpreted approximate grain size (e.g., sand-silt-clay), marking on your interpreted zone codes. Work out the depositional environment by thinking about the nature and variation in the packages of sediment, and remembering that this is a progradational delta sequence. Group the zones where the depositional environment is consistent with a given depositional sequence. Boundaries between these groups show where the depositional environment has changed suddenly by a large amount, and may indicate unconformities. Expect about 4 or 5 groups. Each group is a well defined depositional environment.
- Complete Worksheet 1 for every coded zone.
 1. **Depths and Thicknesses.** Note that the gamma ray log is reading slightly low in depth so you should take this into account in the assessment of the logs, and hence use the depths from the neutron-density log for readings of absolute depth to a given lithology boundary.
 2. **Hole Condition.** Comment; OK, dodgy, bad. These are highly technical assessments!
 3. **Lithology.** SST, SH-SST, or SH is sufficient.
 4. **Neutron Porosity.** Correct the neutron porosity read from the log (f_N) to that valid for sandstone for all depths (f_{Ncorr}) using the correction chart supplied.
 5. **Density Porosity.** Read the porosity from the density log (r_b), then calculate the porosity (f_D) from this value. Use $r_{ma} = 2.65$ for quartz throughout, $r_f = 1.10$ for water in a water zone and $r_f = 0.81$ for oil in a hydrocarbon-bearing zone. The porosities obtained will not give exactly the same porosity as that corrected from the neutron log. Why not? It is possible to back-calculate from the resistivity logs a value for S_w and S_h to allow the two fluid densities to be linearly mixed to give a value closer to the actual mean fluid density. Do not attempt to do this, as it is long-winded and boring, and will overcomplicate the exercise.

6. **Sonic Porosity.** Ignore the “Sonic” columns in the table.
 7. **Resistivity.** Write down the value of R_t for each zone.
 8. **Gamma Ray Log.** Write-down the gamma ray value for each zone, and calculate the shale volume for each zone using the relevant sand and shale lines.
 9. **Fluid Type.** Indicate the type of fluid originally present in the virgin zone.
- Complete Worksheet 2 for only those zones that are reservoir zones (i.e., fulfill the lithology, permeability, fluid type, shale volume, and thickness criteria given during the zoning step above. The resistivity log in this particular example has not been corrected to 24°C/75°F, therefore we must either correct every value from the log value to that at 24°C/75°F, or correct the water resistivity from the value given to that at reservoir temperature. We will do the easier, latter, process.
 1. Calculate the reservoir temperature in °F using:

$$T_{res}(\text{°F}) = 227 + (\text{mid.-depth} - 10,000) \times 0.01975$$
 2. Calculate the water resistivity at reservoir temperature using:

$$\log_{10}(R_w) = 1.2245 - 0.9492 \times \log_{10}(T_{res})$$
 3. Copy R_t from Worksheet 1, and use mean porosity of f_{Ncorr} and f_D .
 4. Calculate the formation factor using the Humble equation:

$$F = 0.62 \times f^{2.15}$$
 5. Calculate the water saturation using the Archie equation:

$$S_w^2 = (F \times R_w) / R_t$$
 - Calculate the OOIP for each zone. Sum them up to give an OOIP for the reservoir. Calculate the STOOIP for the reservoir. Give all answers in Mbbl. to two places of decimals.
 - Given that the producible fraction of the oil is 0.20, calculate the gross value of the reserves in the field in 1996 and in 1998.

Detailed log interpretation - pore fluids worksheet 1

Name:

Zone No.	Top Depth	Base Depth	Thick-ness	Hole Cond.	Lithology	Neutron		Density		Sonic		LLD	Gamma-ray		Fluid type
						ϕ_N	$\phi_{N_{corr}}$	ρ_b	ϕ_D	δt	ϕ		R_t	γ_{log}	

Detailed log interpretation - water saturation worksheet

Name:

Zone no.	Mid-point Depth (ft)	Temp-erature °F	Calculated R_w	R_t from worksheet 1	Porosity: average of $\phi_{N_{corr}}$ ϕ_D , ϕ	Formation Factor, F (Humble)	Calculate S_w
E	9907	225.16	0.0981	100	0.265	10.7749	0.1028

