North Sea Oil Exercise

This practical exercise about North Sea oil was originally produced by Richard Swarbrick (Swarbrick, 2000) and was created for a workshop at the 1999 ESTA Annual Course and Conference that was held at Durham University. Although the exercise has been used for undergraduate teaching at Durham, it is also suitable for use with A-Level Geology students to introduce the principal elements of the petroleum system (source rock, reservoir, trap etc). Illustrations and web links have been added to provide useful background information and the original activity has been updated.

Introduction

North Sea oil is a mixture of hydrocarbons (liquid petroleum and natural gas) produced from petroleum reservoirs beneath the North Sea. The highest annual production was seen in 1999, when 407×106 m^3 (398 million barrels) of offshore oil was produced in that year. After more than half-a-century of development, the North Sea continues to produce crude oil and gas. Approximately 24bn barrels could still be available for extraction and there may be between 30 to 40 years of production remaining.

This exercise aims to remind you of the principal geological elements which are necessary for the accumulation of oil and gas deposits in sedimentary basins. The main aim of the practical is to help you see how temperature history is important in the relative timing of basin processes.

The major elements (definitions)

- Source rock - organic rich sediment, often shale/mudrock which when heated will generate petroleum liquids and gases.
- Reservoir - sedimentary rock (usually) in which there are spaces (pores) in which the oil and gas can be stored.
- Trap - set of circumstances (often fine-grained seal such as a shale or salt horizon) which prevent the buoyant oil and gas from escaping as it migrates to the Earth's surface.
- Timing - sequence of events which allows trapping of petroleum in the reservoir en route from the source rock to the surface.

When were the oil and gas generated?

Source rocks start to generate oil when the temperature reaches about 100°C, and gas at temperatures above about 160°C. The actual temperature depends on the age of the source rocks, their type and the rate of heating.

There are various computer models or simulations, backed up by experimental data, which can be used to "predict" when a source rock matures. Input to the model includes a reconstruction of the source rock's burial history, which might include periods of uplift and/or hiatus (non-deposition) as well.

To estimate the temperature history, the present-day geothermal gradient must be known and an estimate of how it may have varied in the past is needed. For example, in the Gulf of Mexico, offshore Texas, the temperature increases at about 25°C/km from the surface which is at about 20"C. So, the temperature of 120°C (onset of oil generation in this region) is reached at a depth of 4.0 km (20°C surface temperature + (4 x 25°C). In the Gulf of Thailand the geothermal gradient is 48°C/km so the depth of generation is at 2.0 km (24°C surface temperature + (2 x 48°C). Both Gulf of Mexico and Gulf of Thailand sediments are young, i.e. less than 10 My old. In the older North Sea sediments, the gradient is 35°C/km now, and was likely higher in the past, following rifting 150 My ago. The onset of oil generation is at about 90°C, i.e. about 2.5 km allowing for a 5°C surface temperature.

Timing of the trap

If the trap is formed after the generation and migration of the oil and gas, then there will be none found when a trap is drilled. To assess the time when the structure, and circumstances for trapping, took place, it is necessary to create a visualisation or picture of the sedimentary layers (geological cross section).

Exercise

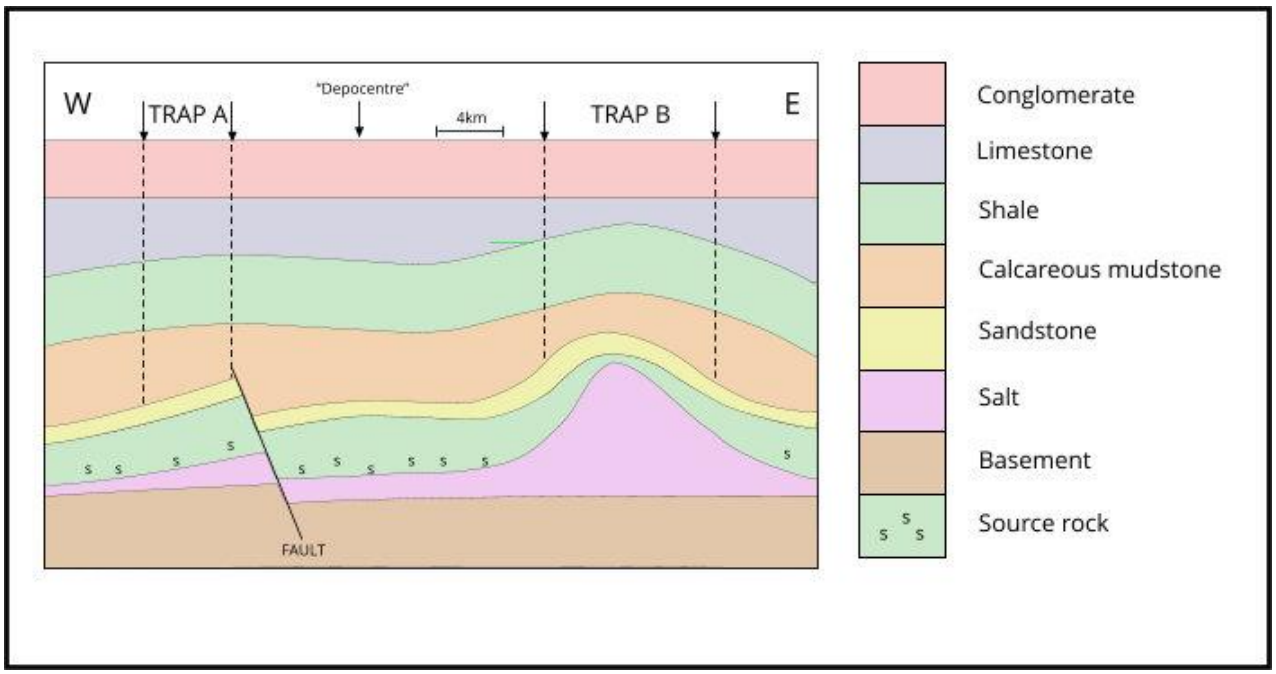

Figure1 Geological cross section. (Note: In traps A & B the sandstone reservoir is sealed by calcareous mudstone)

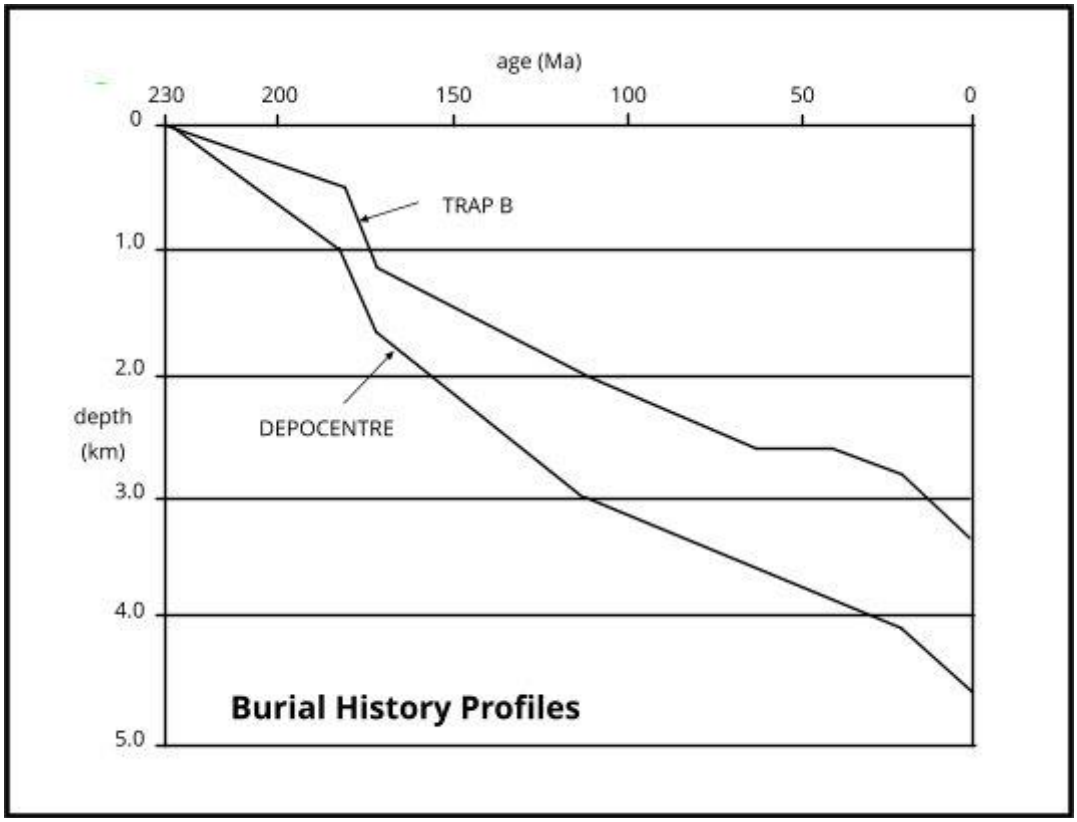

Figure 2 Burial history profiles for the base of the source rock, reconstructed for (a) the depocentre and (b) trap B.

Notes

(i) Depocentre is the area between traps A and B where the source rock will be first mature for generation of oil and gas.

(i) Trap B is structurally higher than the adjacent depocentre. Note the "hiatus" (non-deposition) - this is a time when the salt moved to create trap B.

Assumptions

I. Oil generation occurs between 90°C to 130°C.
Gas generation occurs between I7O°C to 210°C.

2. Surplus of oil and gas to fill the traps.

3. Migration from source to trap is instantaneous with no major loss en route.

4. Reservoir is present at both traps.

5. Geothermal gradient is 40°C/km and has remained constant through time

6. Surface temperature is 10°C.

7. Time is in millions·of years (My).

- The limestone unit was deposited between 20 and 60 My ago.
- The calcareous mudstone was deposited between 110 and 170 My ago.
- The reservoir was deposited between 170and 180 My ago.
- The source rock was deposited between 180 and 230 My ago.

What do you need to do?

a) Draw the temperature lines onto Figure 2 (remember to include the surface temperature).
b) Estimate the timing of oil generation and gas generation for the source rock in the depocenter (use the burial history for the depocentre).
c) Compare these with the timing of the trap formation. (Use the burial history for trap B in Figure 2 and the cross section shown in Figure 1)
d) Predict the likely fluids present in traps A and B.

Solution to the North Sea Oil Exercise

a) Horizontal depth lines on Figure 1 can be annotated with temperature as follows:

Depth (km)	Temperature (°C)
Surface	10
1.0	50
2.0	90
3.0	130
4.0	170
5.0	210

b) Using the 'depocentre' burial history profile in Figure 2 (as a simulation of the source rock where it first matures, because it reaches the necessary temperatures earlier), oil generation starts at 90°C (i.e. 2.0 km and 157 My ago) and finishes at 130°C (i.e. 3.0 km and 112 My ago). Gas generation starts at 170°C (i.e. at 4.0 km and 27 My ago) and is continuing to the present day.

c) Hence the timing of oil generation is 157 - 112 My, and gas generation from 27 My to the present. (Figure 3)

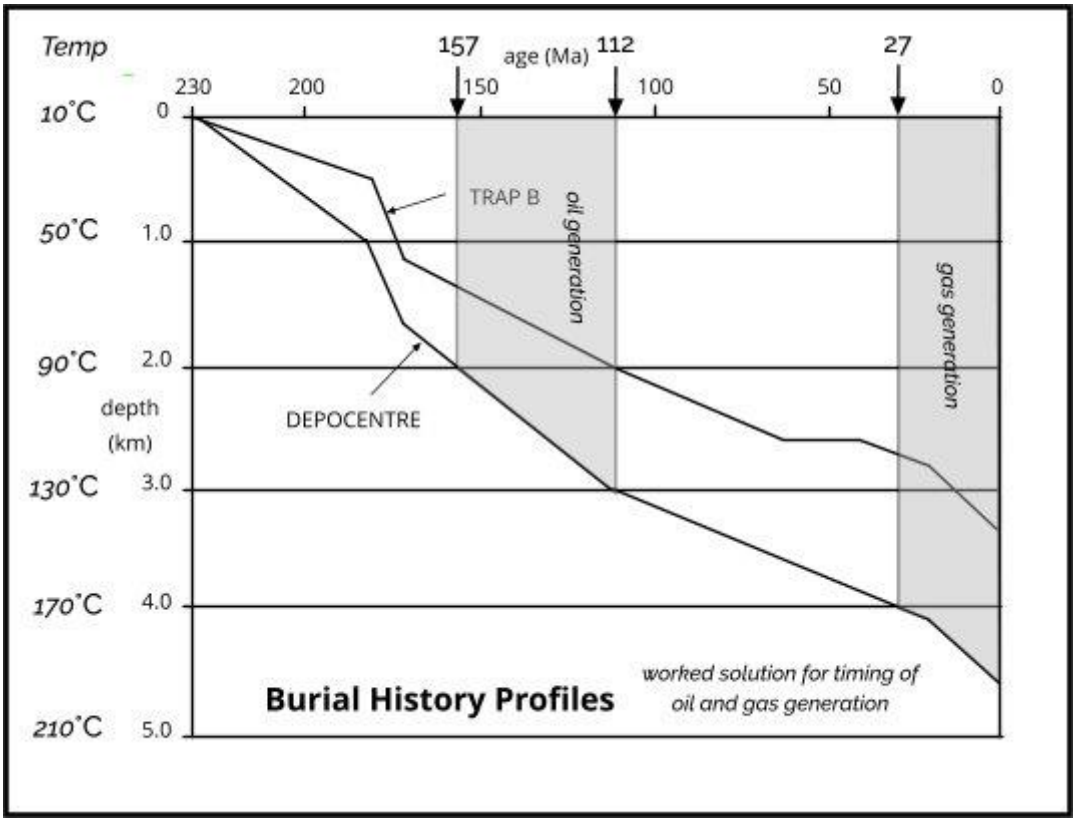

Figure 3. Worked solution for the timing of oil and gas generation

Trap A at reservoir level (see Figure I) was formed early in the history of the basin, prior to complete deposition of the calcareous mudstone caprock. It was created. By extensional faulting and block rotation and the fault dies out in the middle of the calcareous mudstone. Hence trap A was certainly available for filling by the end of deposition of the calcareous mudstone, i.e. 110 My ago but most likely by the middle· of its period of deposition, i.e. between 170 and 100 My, say 140 My ago.

References

Swarbrick, R. (2000) Workshop exercise: North Sea oil. Teaching Earth Sciences 25 (1), pp 23-25.

1. North Sea oil – history of exploration, licensing, reserves and production. https://en.wikipedia.org/wiki/North_Sea_oil
[Accessed November 2018]

2. Booklet - 'Quest for oil' produced by Maersk available at this site. https://www.maerskdrilling.com/~/media/qfo-section/files/educational-material/en/questforoil-themebooklet_uk.pdf?la=en
[Accessed November 2018]

3. Energy resources for schools from the Geological Society of London available at this site. https://www.geolsoc.org.uk/energyresources
[Accessed November 2018]

4. Site with links to various topics relating to oil and gas. https://geology.com/oil-and-gas/
[Accessed November 2018]

Maggie & Peter Williams, Department of Geology & Geophysics, University of Liverpool
hiatus@liverpool.ac.uk
tjpeter@liverpool.ac.uk