Hydrocarbon maturation and trapping

You are provided with a seismic reflection profile from the southern North Sea basin (Figure 1). Simplified well-log information from two exploration boreholes **P** and **Q** is provided in Figure 2.

1. Note that the vertical coordinates of both the seismic profile and the well-logs are expressed as *Two Way Travel Time* (TWTT), i.e. the time taken for a seismic wave to travel down to the layer in question and back up again. Assuming that the rocks have a uniform seismic velocity of $3\,\mathrm{km\,s^{-1}}$, calculate the vertical exaggeration of the seismic profile.

2. Using coloured pencils, mark and label the positions of the geological horizons given for wells **P** and **Q** on the seismic section. Correlate the reflectors across the section and label each horizon at the side. Identify significant faults and unconformities and mark them clearly on the section.

3. On the graph paper in Figure 3, plot the depth below the sediment surface of the base of the red sandstone layer as a function of time for well **P** only. You will need to convert the TWTT values given in Figure into depth in kilometres using the same seismic velocity as before. Assume that the top of the gneiss layer was at sea-level at time 290 Ma (million years before present) and ignore the effect of compaction of the sediment. Repeat this process to plot the depths of all the other layer boundaries to provide a *stratigraphic growth plot* for well **P**.

4. The relationship between heat flux F through the bottom of a basin and the temperature as a function of depth below the sediment surface $T(z)$ is given by

$$F = k\frac{\mathrm{d}T}{\mathrm{d}z} \tag{1}$$

   where k is the thermal conductivity. Integrate this expression to find an expression for $T(z)$, assuming that k does not vary with depth. Given that $k = 1.5\mathrm{W\,m^{-1}\,{}^{\circ}C^{-1}}$ and $F = 60\,\mathrm{mW\,m^{-2}}$ and that the surface temperature is zero, draw a temperature scale down the right hand side of your stratigraphic growth plot in Figure 3. Oil is generated at temperatures between ~ 80 and $\sim 120^{\circ}$C; mark the oil generation window on Figure 3.

5. On Figure 2, the rock-type deposited between times 255 and 245 Ma and marked with a question mark is *rock-salt*, composed mainly of the mineral *halite* (NaCl). Halite is a sedimentary deposit formed by evaporation of sea-water under the hot, arid conditions that prevailed across the North Sea region during the Permian time period (Ireland and Britain were situated close to the Tropic of Cancer at this time). Determine the density of the halite using the following information. The seismic reflection coefficient R for any interface depends on rock density ρ and seismic velocity v according to

$$R = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} \tag{2}$$

   where subscripts 1 and 2 indicate values for the rock above and below the interface respectively. The velocity and density of the overlying sandstone layer are $3.0\,\mathrm{km\,s^{-1}}$ and $2400\,\mathrm{kg\,m^{-3}}$ respectively. Detailed analysis of the seismic profile shows that the velocity of the halite is $5.7\,\mathrm{km\,s^{-1}}$ and that $R = +0.25$ for the boundary between the halite and the overlying sandstone.

6. Note that the top of the halite layer is domed but its base is flat. It seems unlikely that the doming occurred in response to regional tectonic shortening of the type we looked at last week, as such shortening would have deformed both boundaries. Both regional seismic evidence and observations from halite deposits forming at present suggest that halite is originally deposited as a flat, laterally extensive sedimentary layer. It thus appears that the halite layer has deformed to its present shape by ductile flow. This idea is consistent with the fact that halite is a very soft, weak mineral. Based on your answer to the question above, what force drove ductile flow of the halite layer?

7. At the time when the halite layer was flowing, growth of the dome structure we see today would have caused thinning and/or erosion of the sedimentary layers overlying the dome. Based on the geometry of the sedimentary layers imaged on the seismic profile, how many million years ago did the halite dome form?

8. You are an exploration manager with a major oil company. Your servile minions tell you that there are 2 potential source rocks in the area. The first is within rocks of Carboniferous age which are sometimes encountered between the gneiss and the red sandstone (aged 290 Ma) and the second consists of black shale layers within a younger sandstone layer (aged 235Ma). Use your stratigraphic growth plot to determine the time periods during which each of these potential source rocks lay in the oil window. Could either of the two source rocks have produced oil which might have been trapped in this area? State with reasons if and where you would drill to find the oil.