Exam GEO4 – 1437 – Sustainable and unconventional resources

27 May 2014 – 13:30 - 16:30

In total 15 questions are asked, grouped in 4 subjects. The weighting of all questions is equal. Write all your responses on separate sheets. You may draw and explain directly on the Figures, but do not forget to hand in these figures with the response sheets. Please indicate your name on every page.

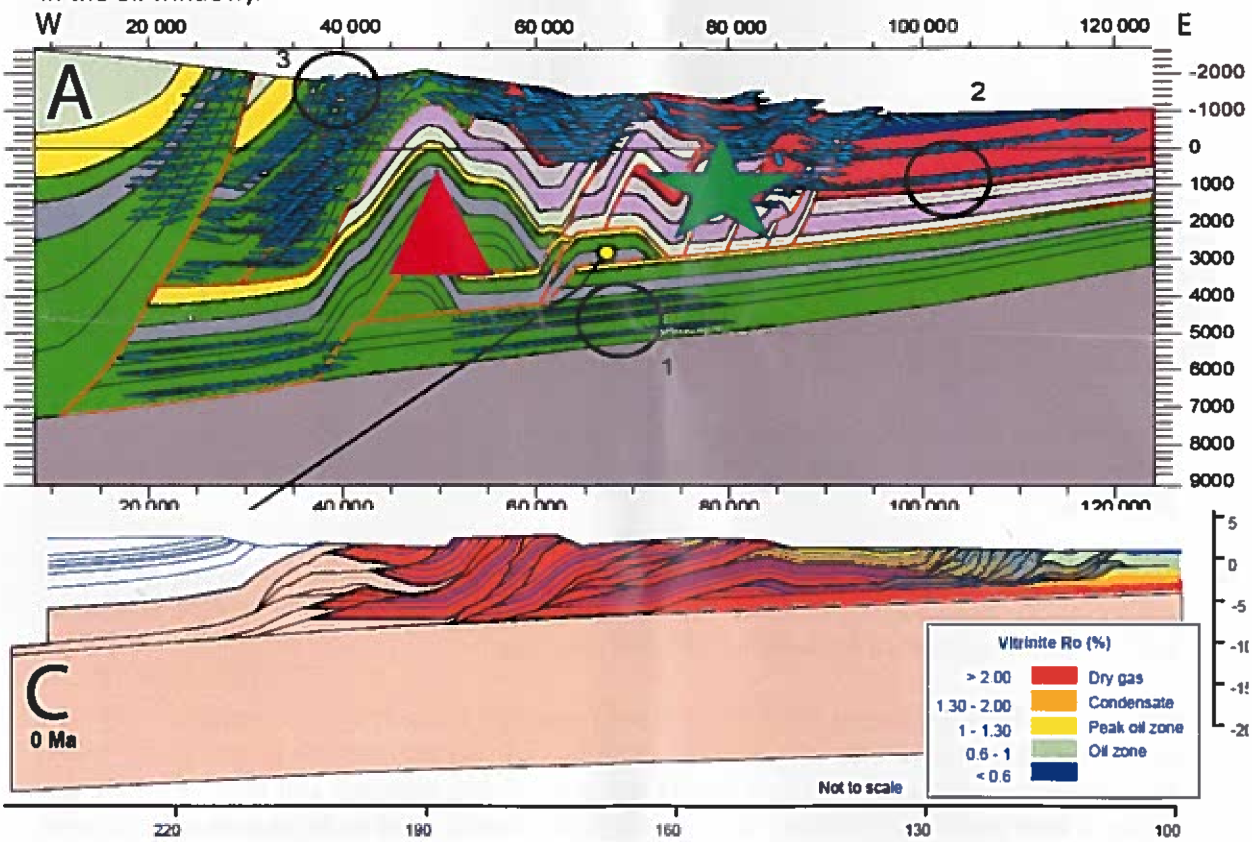
Subject 1 – Thermal structure of sedimentary basins. 30 minutes, 3 points

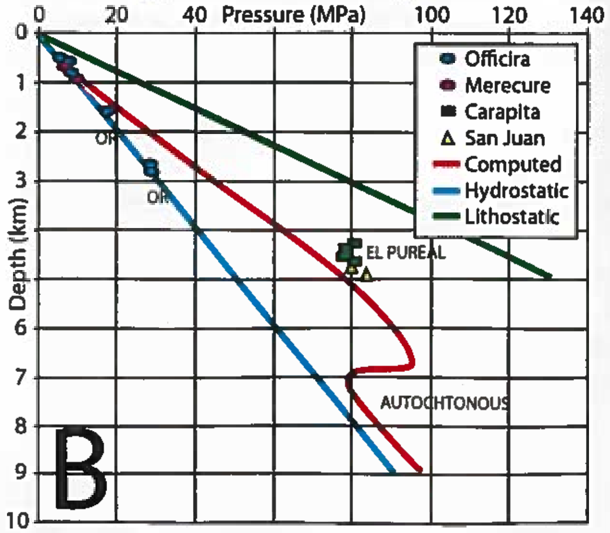
The images below represent a regional transect in the Canadian Rockies, with:

A. Red triangle - gas accumulations in Paleozoic carbonates, Green star - oil accumulation in Cretaceous sandstones. Current fluid flow regime: 1 – E-ward flow of compaction water without meteoric signature; 2 - westward flow with meteoric signature; 3 - downward and upward flows with meteoric signatures.

B. Overall distribution of pore fluid pressures in thrusted reservoirs, with: blue - hydrostatic trend, green - the lithostatic trend, red - domain of overpressures.

C. Current maturity ranks of source rocks (Paleozoic sources in the gas window, Cretaceous sources in the oil window).





Questions:

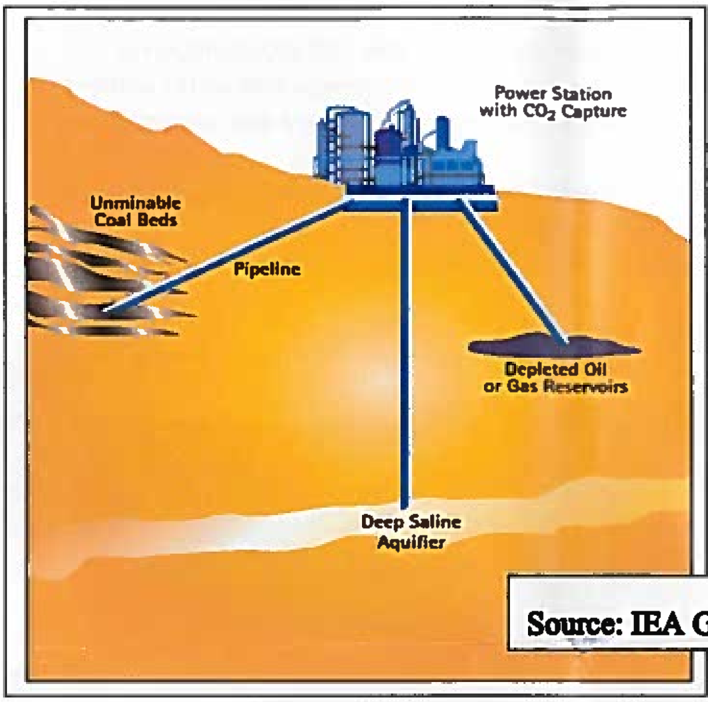
a. Where would you look for hydrothermal springs in the Canadian Rockies?

b. Where would you look for oil derived from Cretaceous source rocks?

c. Assuming rapid and important un-flexing and erosion, how would it impact the overall pore fluid pressure regime? Would it be possible to get locally underpressures (reservoirs with a pore fluid pressure lower than the hydrostatic pressure)?

Subject 2 - Geological storage resources and carbon dioxide sequestration. 40 minutes, 4 points.

As you know from the course, carbon dioxide capture from point sources, such as fossil fuel power stations or steel plants, coupled with geological storage of CO_2, forms a component of almost all IPCC scenarios for reducing emissions to the atmosphere. The main types of geological reservoirs are shown schematically in the figure below. Address the questions posed.



Source: IEA GHG R&D Programme

a. What are the trapping mechanisms associated with each of these types of storage reservoirs and how do they work? Explain your answers in terms of the relevant physical and chemical processes.

b. What special resources does the Netherlands have with regard to implementing geological storage of CO_2 and what are the potential economic benefits? Present your analysis as a list of points, explaining in detail the reasoning behind each point.

c. Imagine you have graduated and have just been awarded a job at an oil company. Your first assignment is to evaluate the CO_2 storage capacity of a specific reservoir typical of the Dutch situation and to evaluate the likely effects and risks of CO_2 injection and long term storage. Design a brief workflow covering the main issues that would need to be considered and what action would need to be taken on each point. Illustrate your answer with any sketches or equations that might be useful. Define the terms in any equations you use.

d. In you new job you are required to attend a public hearing to explain your company's strategy for CO_2 storage. It is commonly believed by the public that

i) CO_2 will generate acid that will attack quartz dominated reservoirs and impair reservoir-seal containment capacity, and

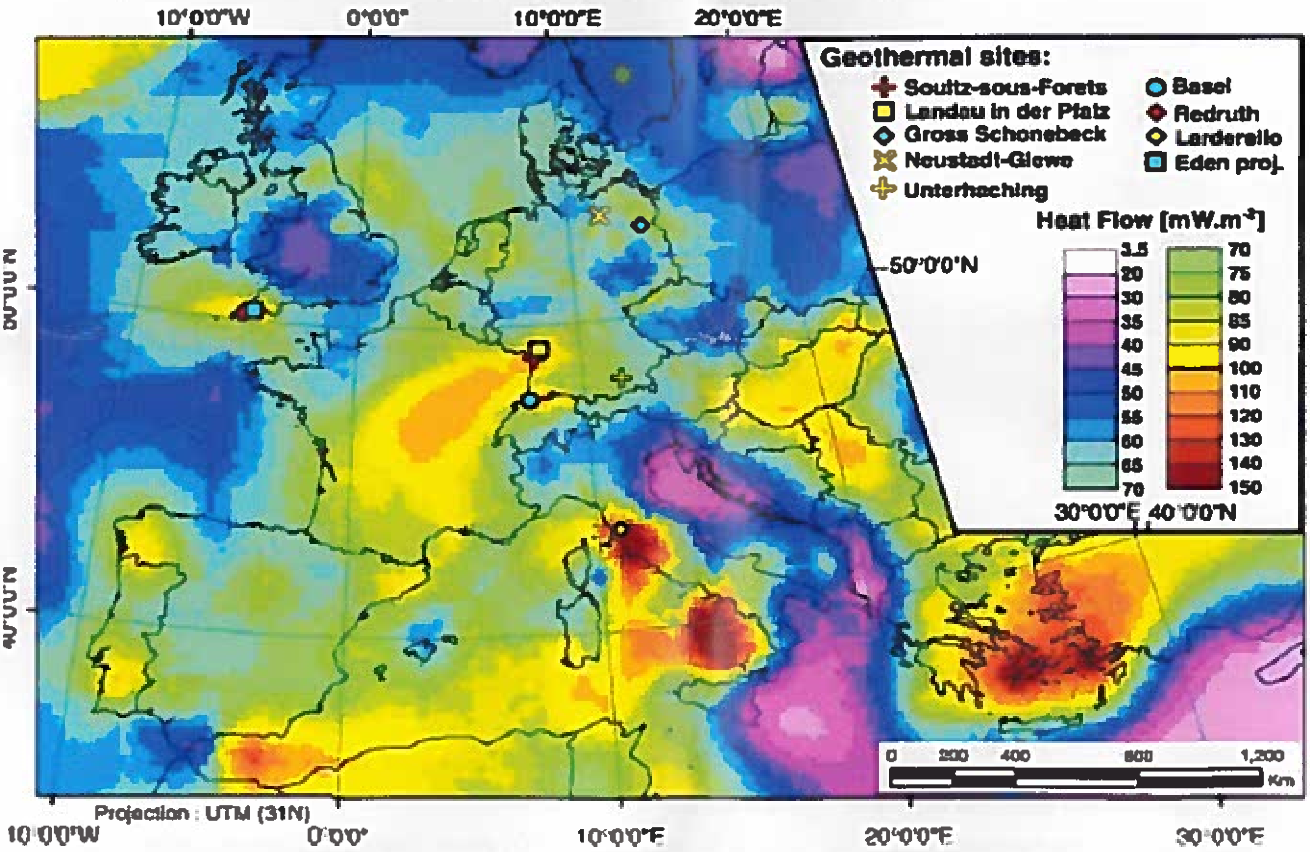
ii) that unmineable coal would be a better place to store CO_2 than a sandstone reservoir or aquifer because the CO_2 will adsorb to the coal and cannot therefore leak or escape.

Explain using fundamental scientific principles, relating to sandstone deformation and the phenomenon of sorption, what is wrong with these two beliefs.

Subject 3 (Engineered) geothermal systems for power production. 40 minutes, 4 points.

The figure below shows the surface Heat flow map of Western Europe. The plotted points are the location of (planned) European geothermal sites for power production, which correspond mainly to areas characterized by high surface heat flow values. Among these locations, Landau is located near the boundary of the Upper Rhine Graben. Here, a combined heat and power plant has been developed based on a doublet in a permeable fault zone at a depth of 3500m, reaching temperatures of ~150°C. The fault is hosted in the granites underlying Rhine Graben sediments. Fluids are produced from and re-injected in the fault zone. When compared with the planned production levels, the production and injection flow rates in Landau have been reduced at the start of production because of seismicity occurring at the injection well.

European Heat Flow map



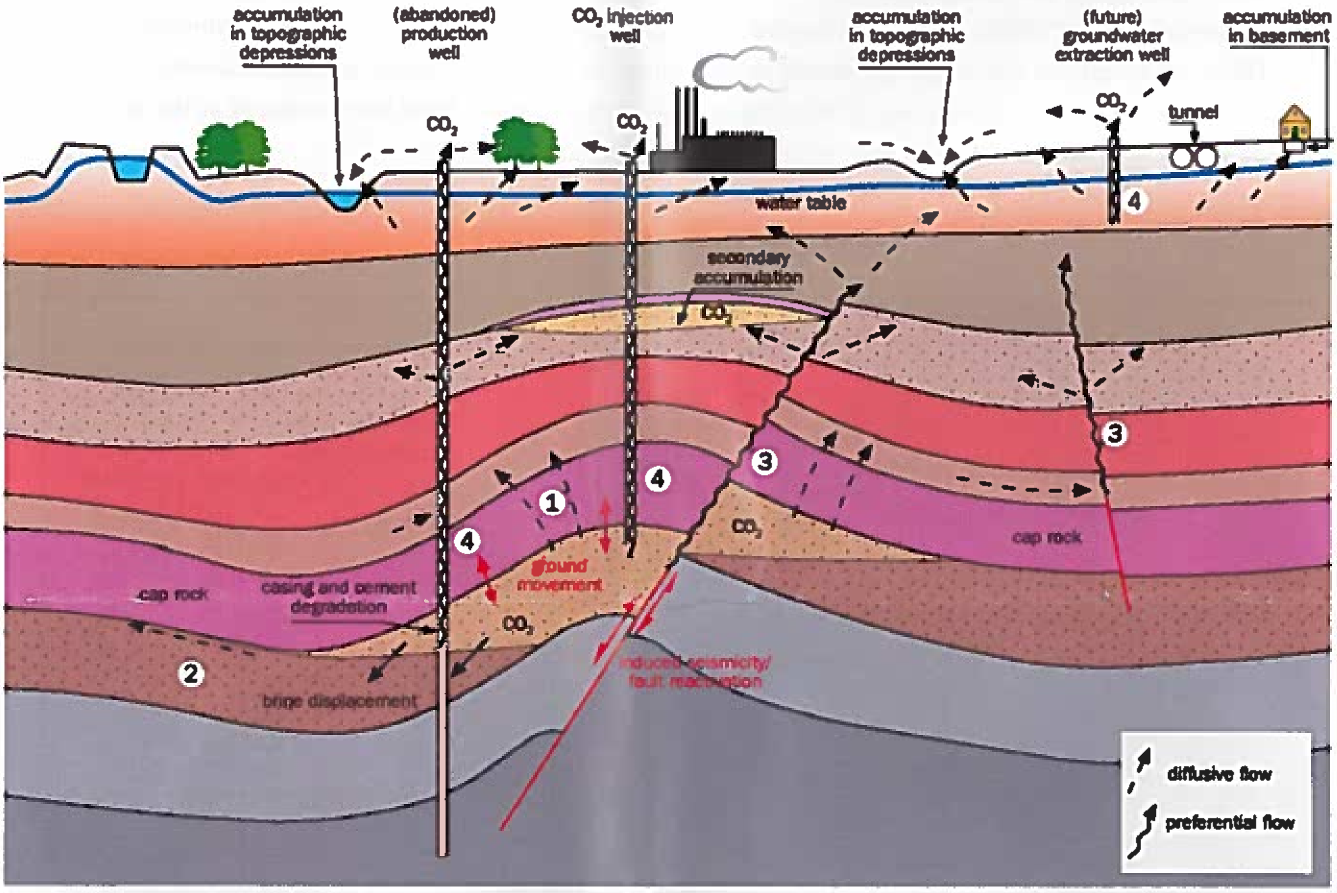
a. For a vertical thermal conductivity of 2 W m^{-1} K^{-1}, what is the thermal gradient [C km^{-1}] for Basel and Larderello? What is the expected temperature at these locations at 1 km depth, adopting a surface temperature of 15°C?

b. What is the most likely cause for natural permeability of the fault in Landau?

c. In Landau, reinjection of cooled fluids in the fault zone caused earthquakes. Why do these occur in the vicinity of the injection well and not in the production well?

d. A project developer claims an excellent prospectivity to develop a geothermal power system with a production and injection well (flow rate 50l/s) at 4 km depth in central southern Sweden (green dot in map) with a Levelized cost of energy below 150 EUR/MWh. The heat capacity of the fluid is 4MJ m^{-3} K^{-1}. The developer proposes a binary system (conversion efficiency of 10%) with a production temperature of 150C and reinjection temperature of 80C. Total investment is 25Mln EURO, the system is producing 8000h/y. Why is the claim of LCOE of 150 EUR/MWh not realistic? Hint: undiscounted payback time >10 y is not acceptable, you may assume variable and fixed OPEX is negligible.

Subject 4 - CO_2 storage. 40 minutes, 4 points.



a. What are potential migration pathways (name four) to be managed during risk management of CO_2 storage (see Figure above)?

b. Describe the "bow tie" approach for risk assessment with all components. Give one example using the well leakage scenario from the Figure above.

c. What is the most frequently used technique for monitoring CO_2 plum (see Figure above) in the subsurface (and geological structure of subsurface)? Describe possible variations of the technique (like different topography or components or modes in which it can be used) and the principles on which it is based (what do you exactly measure and how can you tell where CO_2 is)?

d. Scenario 1 in Figure above can be a consequence of leakage through fractured caprock. Consider a *radially* propagating fracture with no leakoff: the height is equal to the length, and the width reduces toward the fracture tip. The average width is related to the fracture radius according to the laws of elasticity: $\frac{w_{av}}{R} = \frac{8}{3\pi}(1-\nu)\frac{p_f - \sigma_3}{G}$ use G = 1 GPa, ν = 0.25; no leakoff to the formation; an injection rate of 2 m^3/min, and a propagation pressure $p_f = \sigma 3 + dP_n$; with constant overpressure dP_n = 0.1 MPa. What is the radius and the width versus time?