Problem Set Lecture 3: Temperature and heat flow

1. Name the two primary reasons why the thermal conductivity of sediments may change below the seafloor?

2. At a porosity of 60%, and fully saturated with sweater, what is the thermal conductivity of A) a deep sea carbonate ooze, B) a clean quartz sand and C) a glaciomarine silty-clay (composed mainly of mixed-layer clays)? Calculate these using both the linear and geometric relationships between porosity and matrix conductivity. Assume a thermal conductivity for seawater of 0.6 W/mK

3. A 10 cm needle probe with a heating power of 12.5 $Wm^{-1}s^{-1}$ is used to measure the thermal conductivity of a core in the laboratory. The needle probe is inserted into the core and measurements taken of the temperature for 200 s. Plot the heating curve and determine which interval is best suited to calculate the thermal conductivity. Using the equation from the lecture notes what is thermal conductivity of this sample?

Time (s)	Temperature (^{o}C)
0	20.967
10	21.379
20	21.746
30	21.911
40	22.003
50	22.068
60	22.121
80	22.203
100	22.268
120	22.321
140	22.366
160	22.405
180	22.439
200	22.470

4. Outrigger temperature probes were placed on a 16 m piston core and 4 in-situ temperature measurements were acquired. The results are shown below.

Depth (mbsf)	Temperature (^oC)
1.5	1
5.5	1.18
10.5	1.41
15.5	1.57

A. Based only on the shallowest and deepest measurements, what is the geothermal gradient ($^oC/km$)?

B. A better approach is to plot the data and perform a linear regression on it. Using this method, what is the geothermal gradient and the Pearson Correlation Coefficient (R^2)?

C. On the recovered core, thermal conductivity measurements are made at a vertical resolution of 1 meter. The results are given below. What is the average thermal conductivity for these sediments?

Depth (mbsf)	Thermal Cond. (W/mK)
.05	1.1
1.5	1.14
2.5	1.12
3.5	1.36
4.5	1.25
5.5	1.18
6.5	1.38
7.5	1.41
8.5	1.34
9.5	1.25
10.5	1.41
11.5	1.45
12.5	1.42
13.5	1.53
14.5	1.51
15.5	1.48

D. Using Fourier's Law, calculate the heat flow at this station

E. Now calculate the thermal resistance profile using the conductivity measurements and add them in the table below.

Depth (mbsf)	Therm. Cond. (W/mK)	Therm. Res. (Ω, m^2K/W)
.05	1.1	
1.5	1.14	
2.5	1.12	
3.5	1.36	
4.5	1.25	
5.5	1.18	
6.5	1.38	
7.5	1.41	
8.5	1.34	
9.5	1.25	
10.5	1.41	
11.5	1.45	
12.5	1.42	
13.5	1.53	
14.5	1.51	

F. Use the Thermal Resistance profile and the temperature measurements to construct a Bullard Plot. Based on the Bullard Plot, what is the Heat Flow? Is the coefficient of determination using this method better or worse than the linear regression performed on the temperature versus depth data?

G. In the seismic data across this station, there is an enigmatic reflector found 200 meters below the seafloor. You think it may be a diagenetic reaction front that is controlled by temperature. Therefore, you want to know what the temperature is at this depth. If you extrapolate the geothermal gradient (from B) what is the predicted temperature at 200 mbsf?

H. You are concerned that the near surface measurements of thermal conductivity are not representative for the entire upper 200 meters of the sediments. Due to compaction and porosity loss, you believe that the average thermal conductivity is actually much higher. Drilling in a near-by location shows that an average thermal conductivity for the upper 200 m is actually 1.8 W/mK. Using Fourier's Law and the Heat Flow from the Bullard Plot, re-calculate the temperature at this depth.

5. In a 1 km sediment column with an average bulk density of 2.0 g/cm^3 and a typical shale composition, what is the radiogenic heat contribution to the surface heat flow?

6. As organic rich sediments are heated, they *mature*, first producing $C0_2$ and organic acids, and then oil and finally gas. How deep does a source rock, deposited on oceanic crust with an age of 45 million years, need to be buried to reach the middle of the oil window? Assume a bottom water temperature of 4^{o}C, and calculate the approximate depth using an average thermal conductivity of a) 2.0 w/mK and b) 3.0 W/mK