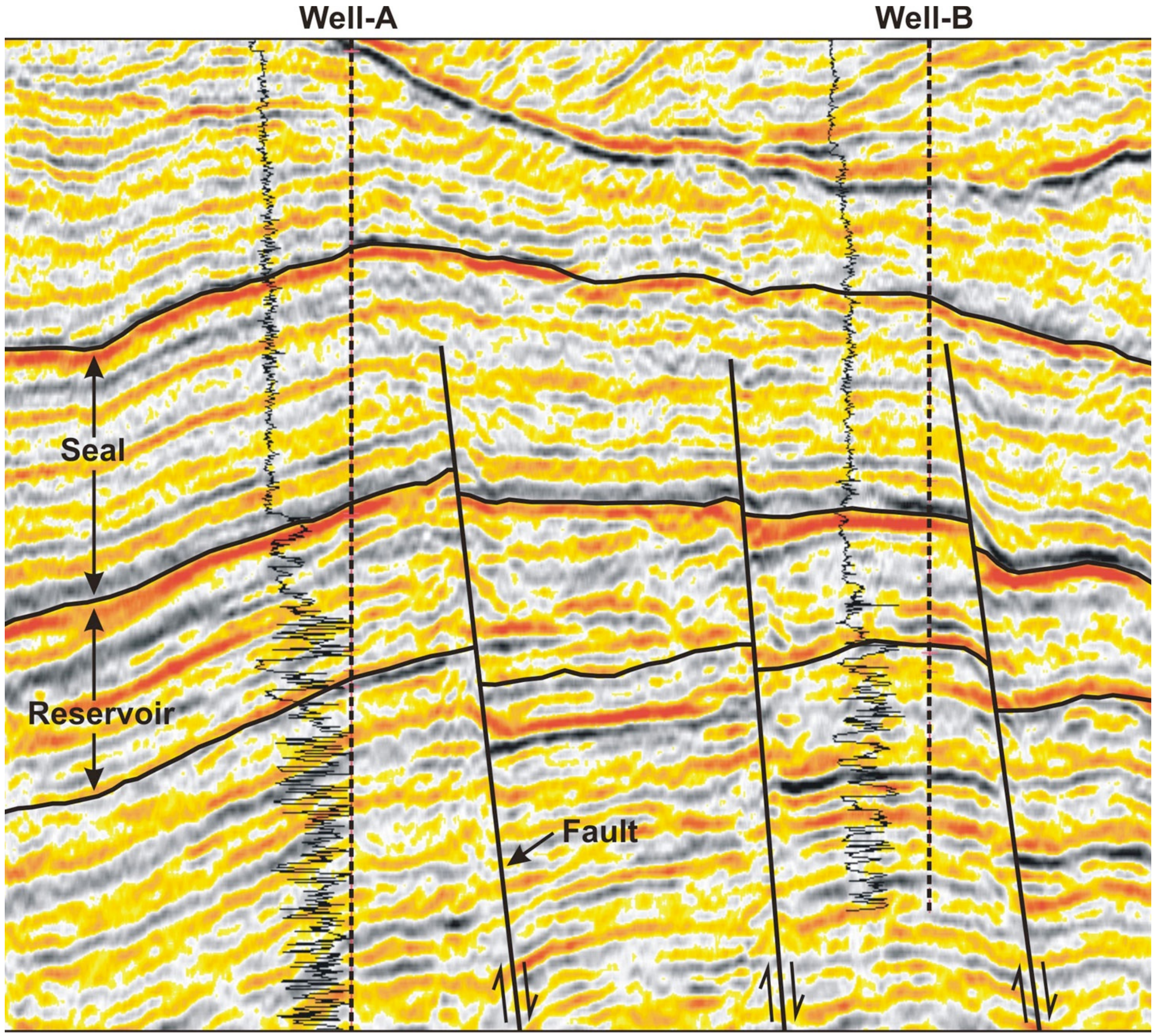
GEOS 3102

Global Energy & Resources



TRISTAN SALLES, DIETMAR MULLER & AMY I'ANSON

Setting up the environment

Using USYD computer

Open the **Kitematic** application and go directly to the **Kitematic** section below.

Installation on your Mac or PC

If you want to install the environment on your own computer you will need to download the Docker Toolbox which is an installer to quickly and easily install and setup a Docker environment on your computer.

Kitematic

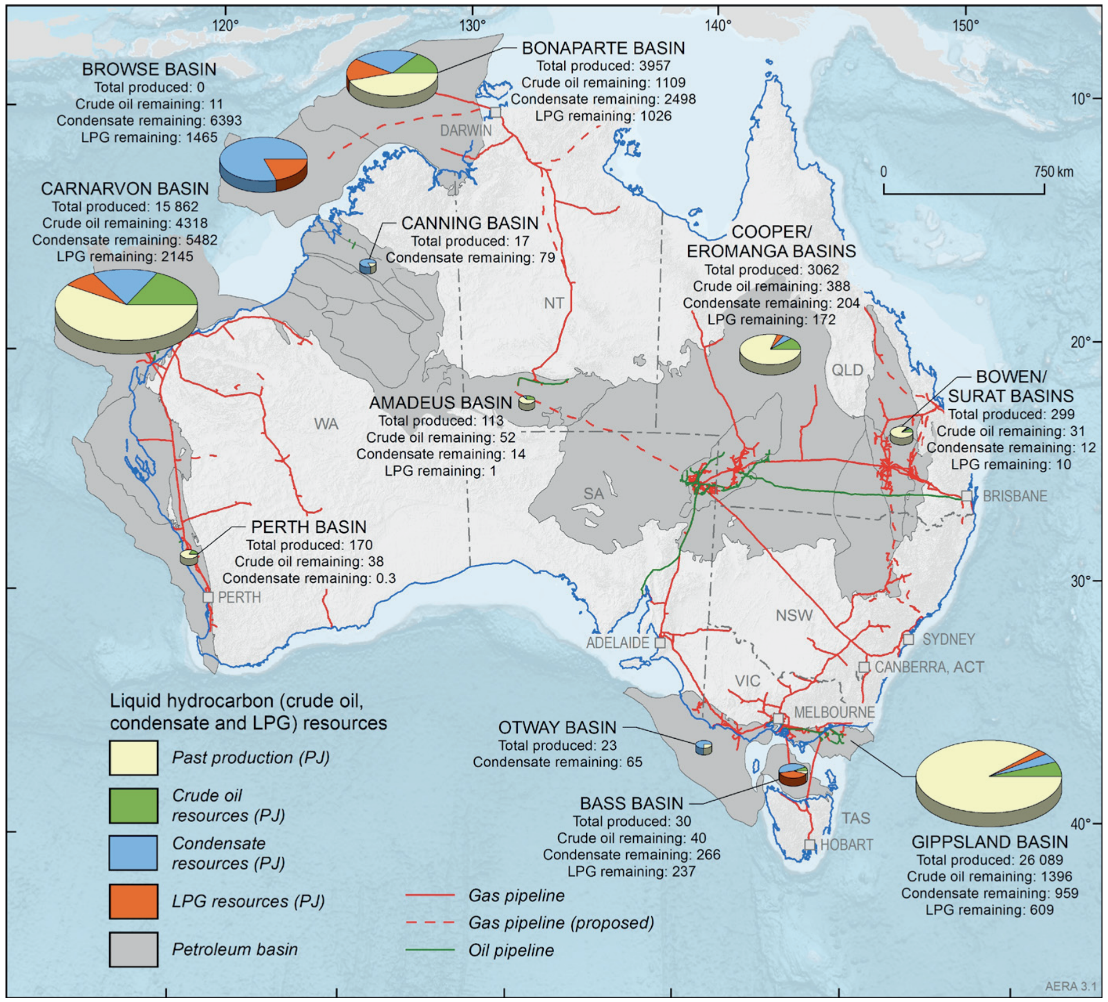
Once it's installed you will need to log to the Docker Hub through the **Kitematic** application (which is shipped within the Docker Toolbox installation). For a guide on own to use **Kitematic** follow this link.

To connect to **Kitematic** and the **DockerHub** you will be required to get a login access. We have made one for you:
- name **usydgeos** (not required but in case: usydgeos@gmail.com)
- password **madsenf09**

Once the **Kitematic** window is active, search for the lab Docker image called **geos3102** from the DockerHub and click create. It will emulate a virtual machine with the IPython notebooks that we will use during these labs.

When the download has finished click on the right icon (square and arrow sign) on the right panel facing the Web Preview. It will fire-up a webpage which contains everything we need.

Mapping of resources



Overview

Global distribution of mineral & oil resources and reserves are essential to understand not only the economic wealth of specific countries but also some of the major conflicts taking place in different regions of the World.

Australia has an abundant and diverse range of energy resources. It has very large coal resources that underpin exports and low-cost domestic electricity production, more than one third of the world's known uranium resources, and substantial conventional gas and coal seam gas resources. These can support Australia's domestic needs and exports for many years to come. Identified resources of crude oil, condensate and liquefied petroleum gas are more limited and Australia is increasingly reliant on imports for transport fuels.

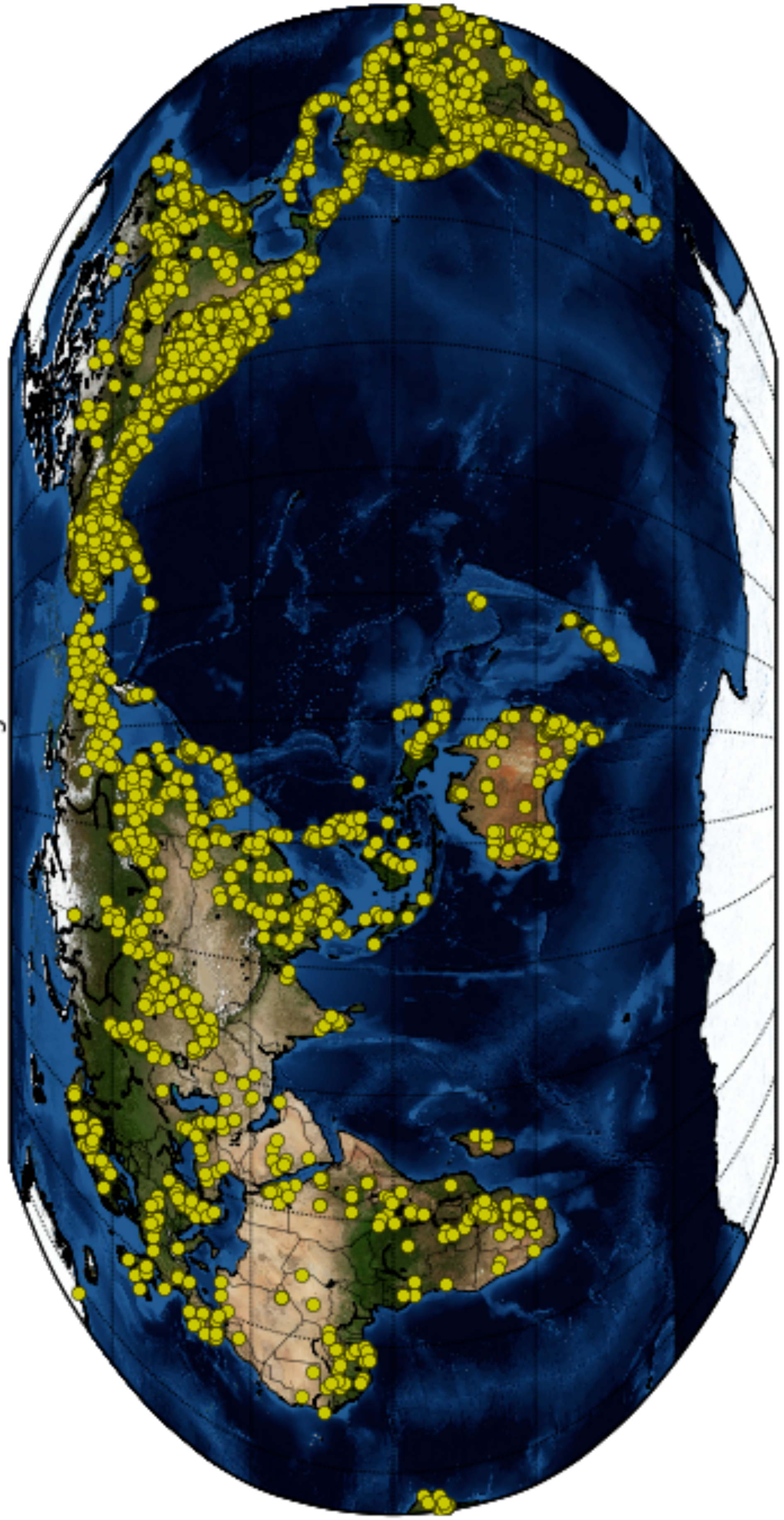
Instructions

The main goal of this lab is to help you get comfortable with IPython notebooks. We will use it throughout the 6 first weeks of the UoS GEOS3102. In part 1, you have 2 questions, provide solution for both of them.

In this first part we will introduces the Basemap library part of the python suite. This library can be used to create maps and plot geographical datasets. If you follow along with the associated ipython notebook, you'll end up making the map on page 2.

Making a simple map

Let's start out by making a simple map of the world. If you run the following code, you should get a nice map of the globe, with good clean coastlines.



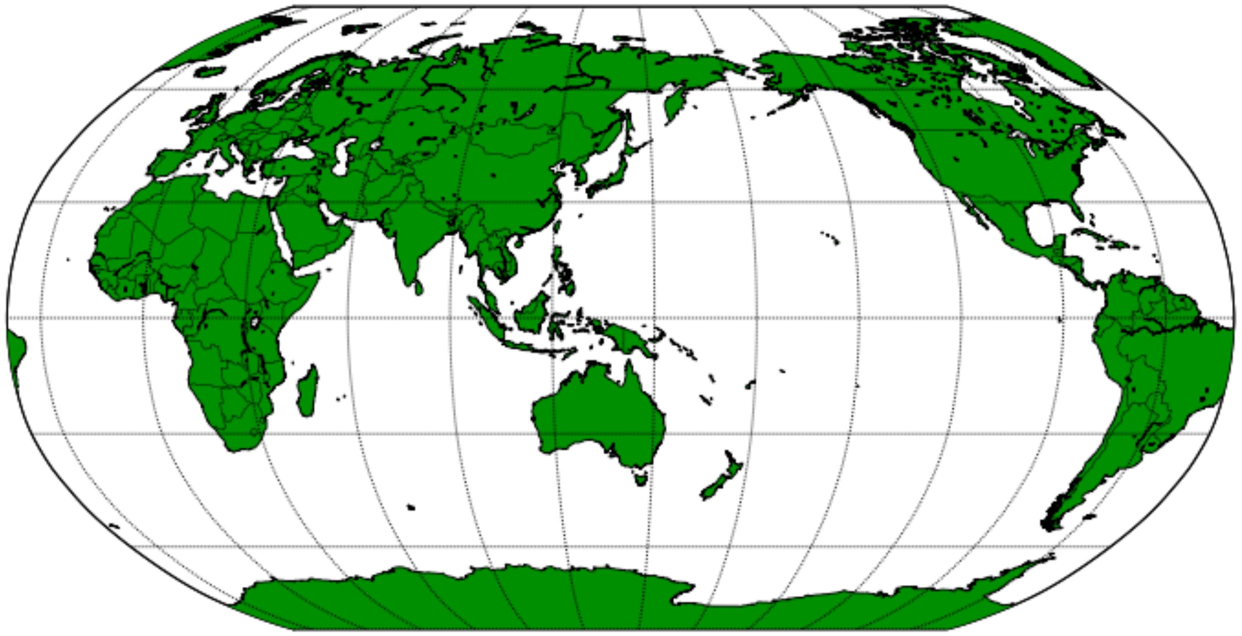
Gold mineral resources around the globe from USGS MRDS dataset

Let's add some more detail to this map, starting with country borders and the latitude and longitude lines.

Before plotting data on this globe, we will start by adjusting the perspective. Change the latitude and longitude parameters in the original Basemap definition to 0 and -100. You should see your map centered along the equator.

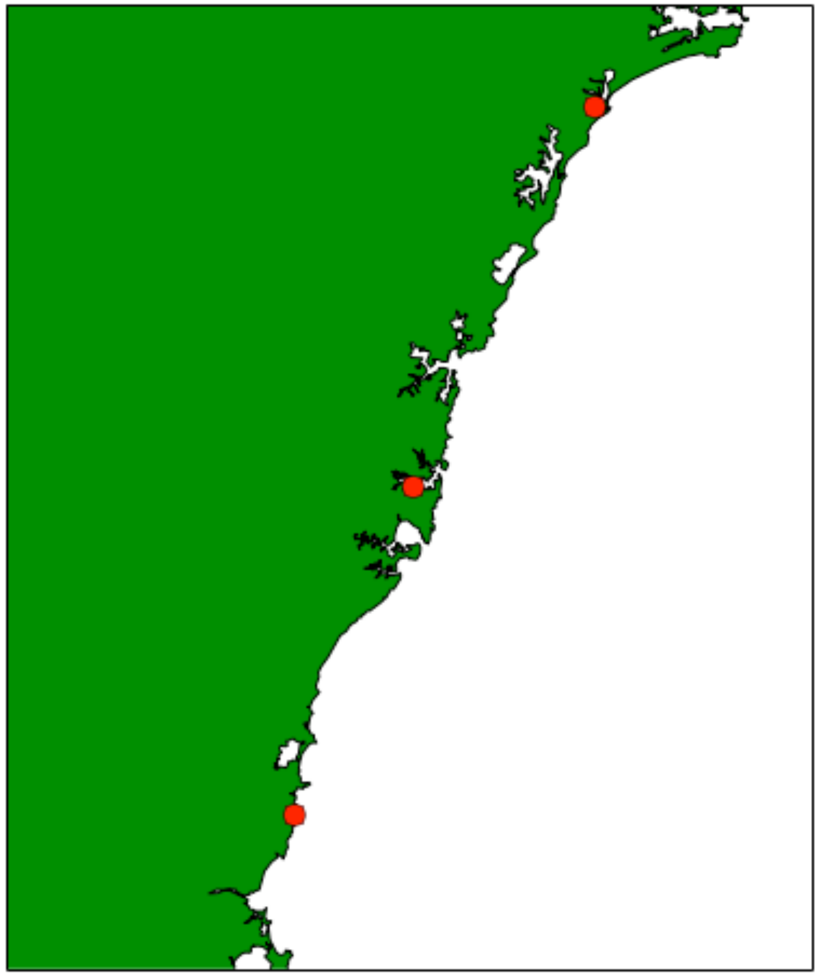
Now let's change the kind of map we're producing. Change the projection type to 'robin'.

For a review of common map projections follow this link.



Zooming in

Before we move on to plotting points on the map, let's see how to zoom in on a region. This is good to know because there are many data sets specific to one region of the world, which would get lost when plotted on a map of the whole world. Some projections can not be zoomed in at all, so if things are not working well, make sure to look at the documentation.



A global mineral resources data-set

The USGS maintains a **Mineral Resources Data System** (MRDS) on its website. MRDS is a collection of reports describing metallic and nonmetallic mineral resources throughout the world. Included are deposit name, location, commodity, deposit description, geologic characteristics, production, reserves, resources, and references.

You can also choose from a variety of formats. In this first example, we'll look at how to parse a file in the **csv** format (comma-separated value). There are more convenient formats to work with such as **json**, but not all data sets are neatly organized.

Parsing the data

If we examine the first few lines of the text file of the dataset, we can identify the information that's most relevant to us.

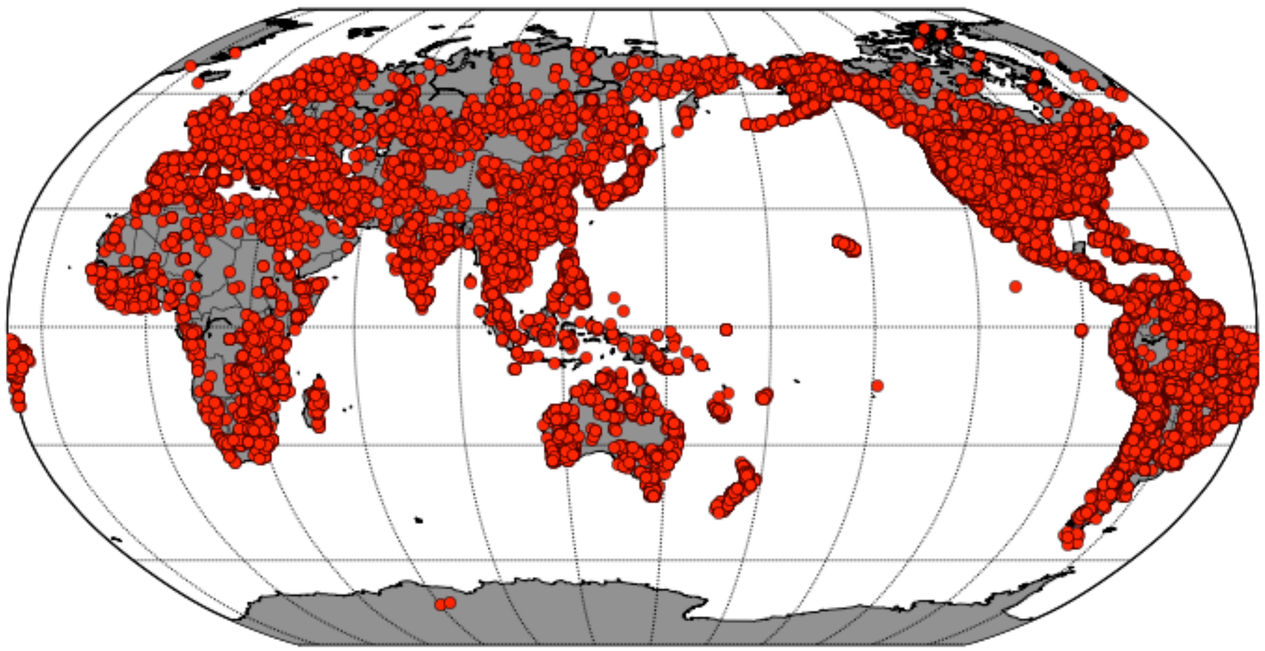
Using Python's csv module to parse the data

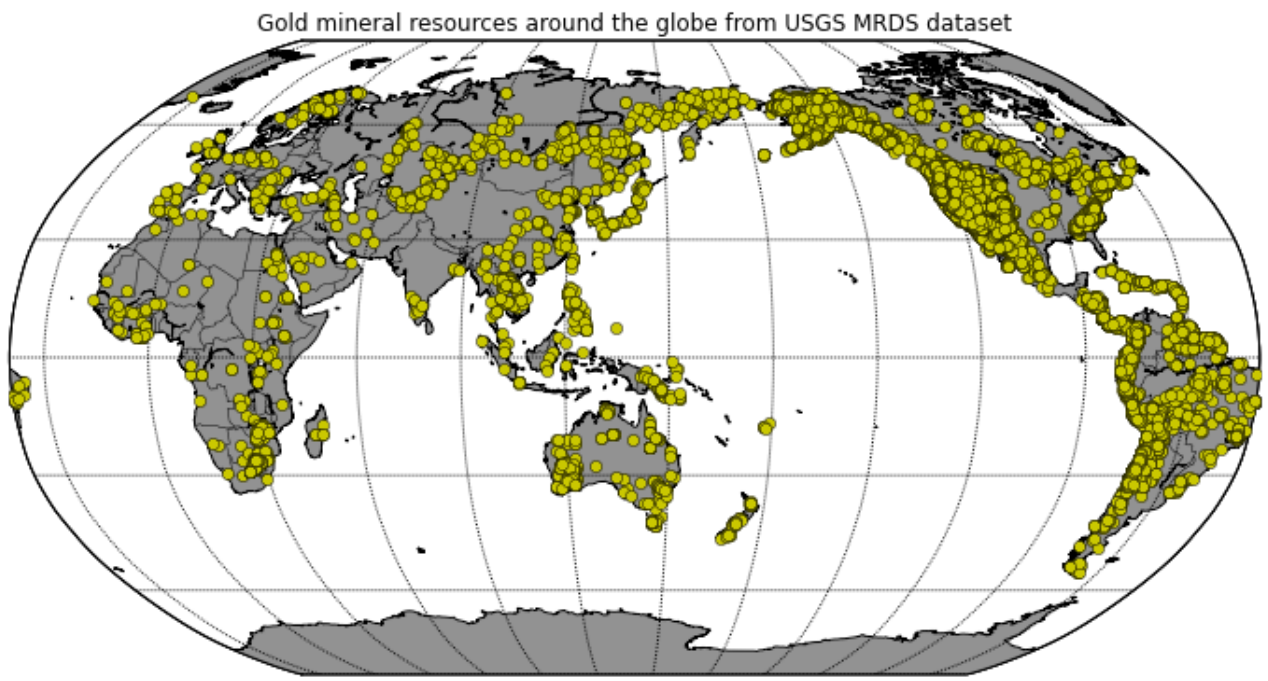
We'll process the data using Python's csv module module, which simplifies the process of working with csv files.

Plotting minerals location

Using what we learned about plotting a set of points, we can now make a simple plot of these points.

Extracting gold resources from the datasets





Q1. Using the IPython notebook *MappingGlobalResources.ipynb* and the associated MRDS dataset you will map the global distribution of iron (FE). You will need to provide the same kind of map as the one produces for gold resources.

Q2. In addition to the MRDS dataset we have provided you with another dataset containing the Australian offshore Oil & Gas database from GA. Based on what you have learnt, you will provide a map illustrating the distribution of Oil & Gas offshore Australia. The datasets is located in the same folder as the MRDS one and is called **OilGas.csv**.

Visualise in NbViewer

Follow this link to see the IPython notebook that we are going to use for the Part 1 of lab 1.

LAB1 Part 1 IPython material : nbviewer link

Instructions

Using IPython we will quantitatively estimate the relationship between submarine channel sinuosity, valley slope & latitude. There are 5 questions labeled Q, some with multiple parts. Provide solutions for all of them.

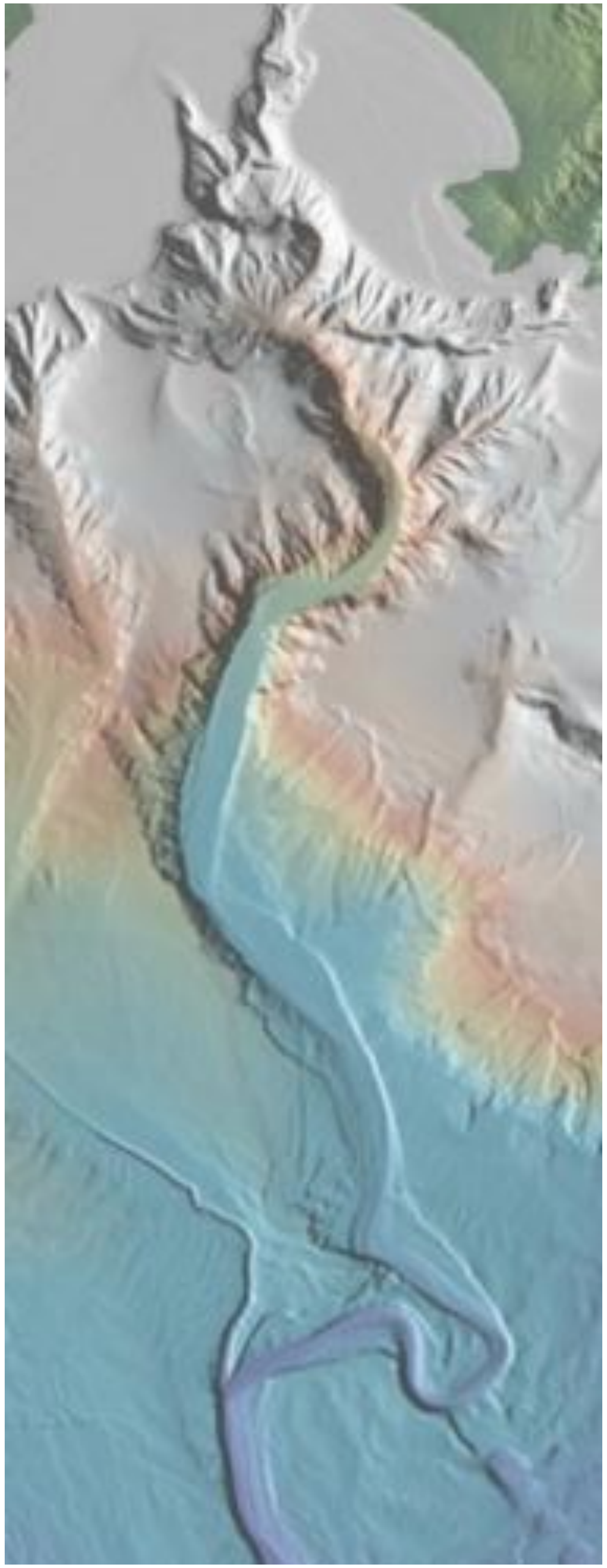
A note on submarine sedimentary systems

Submarine fans receive sediment through canyon-channel systems and are the largest detrital accumulations on Earth.

Submarine fans are prolific hosts for oil and gas resources. Approximately 58 billion barrels of oil equivalent have been discovered in water depths >500 m from 18 basins on six continents as of 2002. However, only ~25% of the discoveries were developed or under development, and <5% were produced as of 2002.

Most resources have been found in the Gulf of Mexico, offshore Brazil, and offshore West Africa. Exploration and development of the world's resources hosted in submarine fans and related turbidite systems are at relatively immature stages as a result of infrastructure and economic limitations, but destined to become a major future focus.

For an overview of submarine sedimentary systems it is recommended to read the following article from Covault (2011) link.



Context

In 2011, Peakall et al. (see ref below) proposed that submarine channel sinuosity was in part induced by Coriolis force. They based their findings on a quantitative comparison of slope versus latitude for different submarine channel systems.

In 2013, Sylvester et al. (see ref below) took a closer look at the data provided by Peakall et al. and highlighted the importance of the nature of slope and sediment supply as the major factors controlling the development of submarine channel sinuosity.

Using their dataset and IPython, you will make your own analyses of the dataset.

References:

Peakall, J., Kane, I. A., Masson, D. G., Keevil, G., McCaffrey, W., & Corney, R. (2011). Global (latitudinal) variation in submarine channel sinuosity. Geology, 40(1), 11–14. [doi:10.1130/G32295.1]
Sylvester, Z., Pirmez, C., Cantelli, A., & Jobe, Z. R. (2013). Global (latitudinal) variation in submarine channel sinuosity: COMMENT. Geology, 41(5), e287–e287. [doi:10.1130/G33548C.1]

Note:

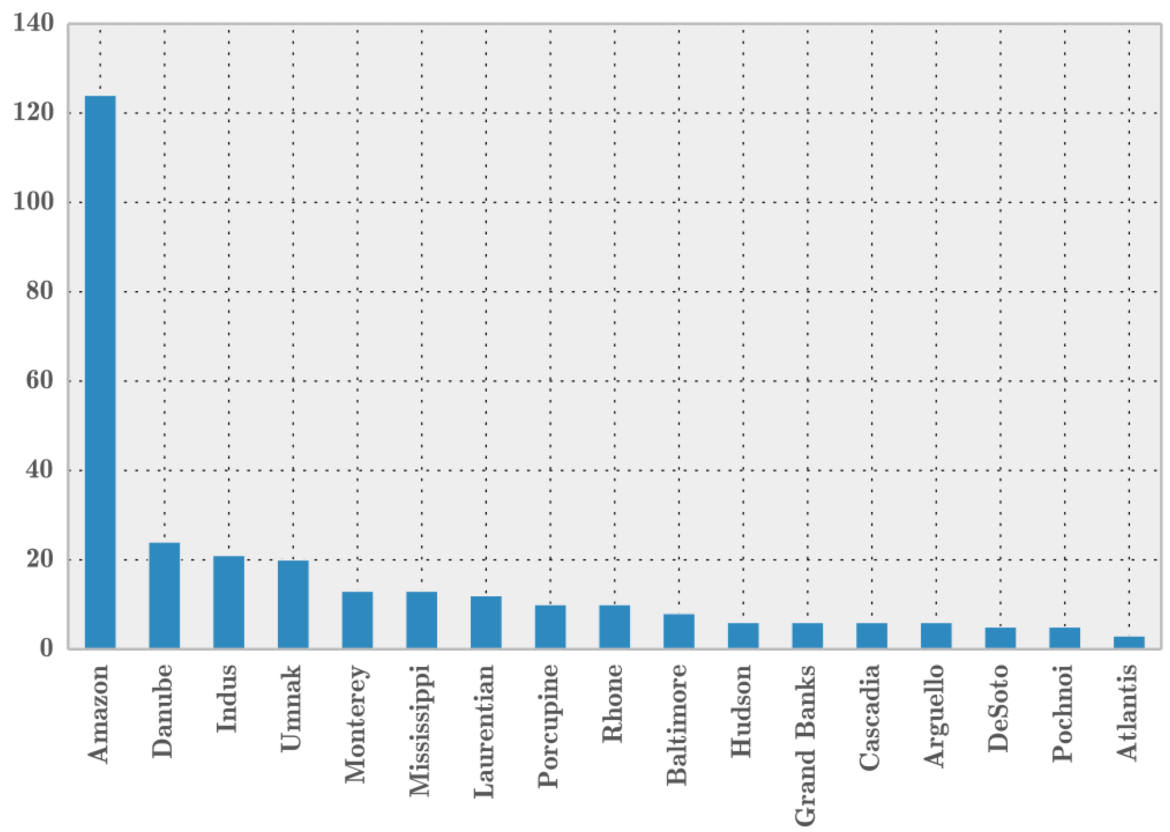
This lab is based on the notebook and associated dataset from Sylvester, Z. (blog).

Dataset:

The majority of the data comes from the book by Clark and Pickering (1996), which also forms the basis of the analysis by Peakall et al. (2011). Data for the Amazon Channel comes from Pirmez and Flood (1995); and Popescu et al. (2001) (centerline digitized from map in paper and half-wavelength sinuosities calculated from centerline). See full references in papers.

Quantitative analyses with IPython

Q1. What is the Coriolis force, and how it varies with latitude?

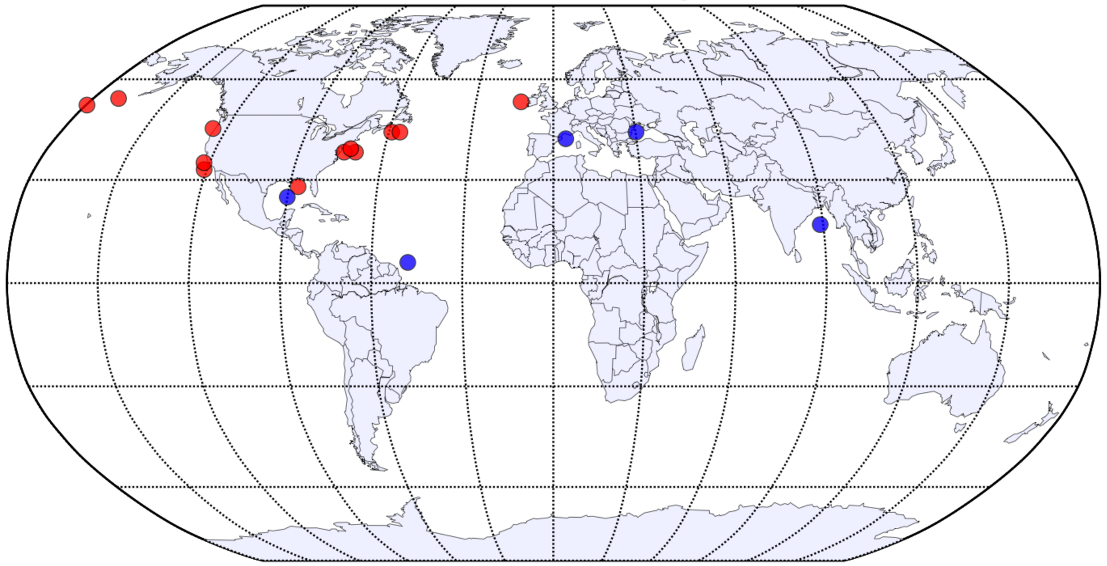


Open the ipython notebook *SubChannelSinuosity.ipynb* in a new web page. To work with the dataset we will use Pandas. **Pandas** is an easy-to-use data structures and data analysis tools for Python.

We first read the channel sinuosity dataset (csv file) and we plot the number of measure for each submarine channel system.

Q2. Explain why there are several measures for each submarine system?

Position of submarine channels from the dataset: blue markers for larger river & red markers for smaller ones

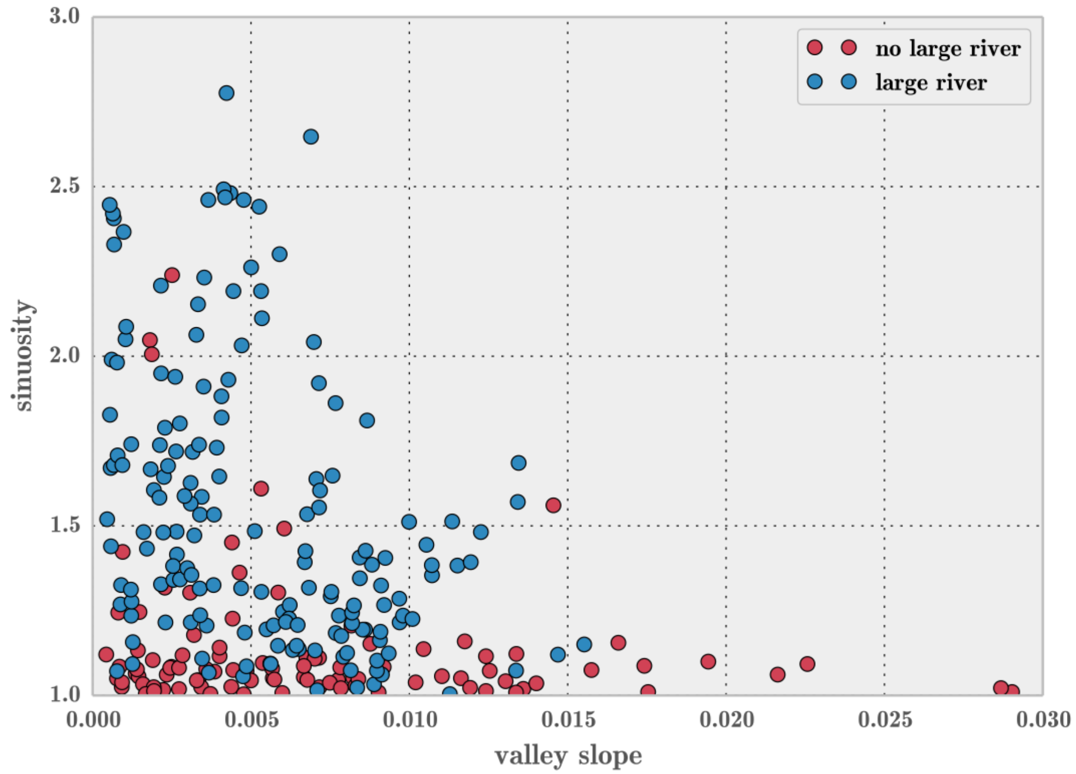


We then load the second dataset containing the global coordinates of each of these systems (*canyon_loc.csv*).

From the combined dataset we will use **Basemap** library (remember the first part of this lab?) to visualise the global distribution of the dataset.

Q3. In the notebook the proposed script has been modified to plot only the large river systems. Find a way of plotting both types and to get the same map as the one above. Explain.

Sinuosity vs valley slope/latitude



From the dataset, we will first try to find if there are any variability in channel sinuosity with valley slope.

Q4. From the graph above, do you find any trend in the dataset that could help to understand the variability in sinuosity?

Q5. Using the script provided for the sinuosity versus valley slope write a new one to look at sinuosity versus latitude.

a. Do you find any trend in this new chart?

b. According to Peakall et al. (2011) what process could explain it?

Global river discharge dataset

In Sylvester et al. comment (2013), it is argued that another explanation could be that no significant sediment volumes reach deeper waters at higher latitudes due to the lack of large rivers that would provide the source.

Using the dataset from Dai and Trenberth Global River Flow and Continental Discharge Database we will plot a world map of the discharge of largest rivers in the world using Basemap.

Once the dataset has been loaded into IPython we will work with only 4 columns:

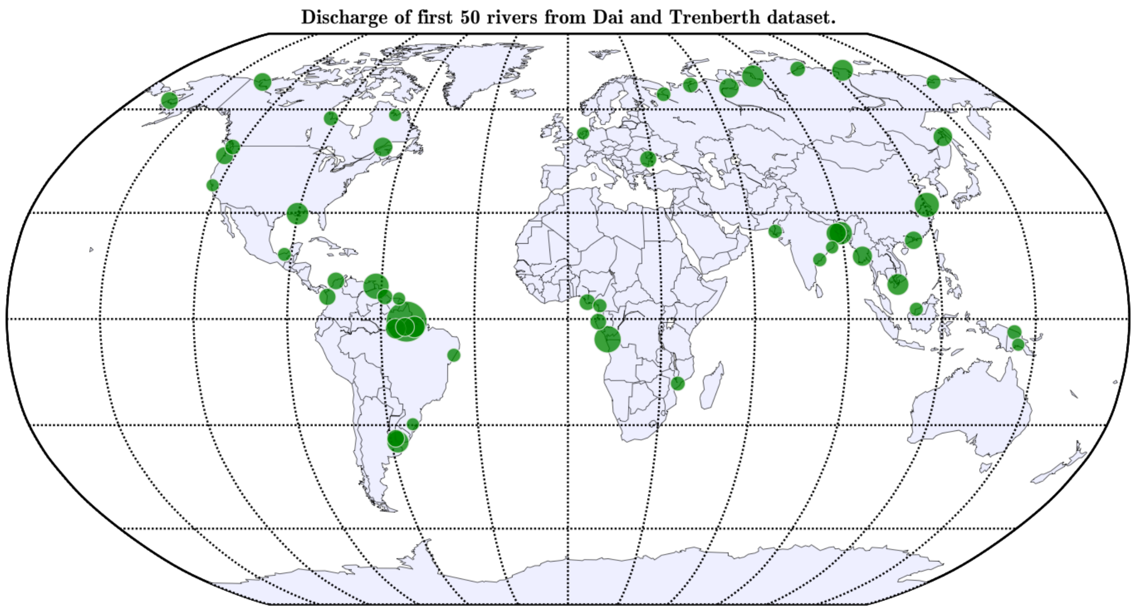
- **lonm**: longitude
- **latm**: latitude
- **m2s_ra**: river mouth to station ratio of flow rate times 10,000
- **Vol**: station annual flow rate (km3/yr)

In order to get the river discharge we need to perform a simple manipulation of the dataset. The discharge D is given by:

$$D = \sqrt{Vol\frac{m2sra}{10000}}$$

Q6. Knowing that the squared root $\sqrt{\ }$ in IPython is given my **np.sqrt()** write the previous equation in the IPython cell. Copy/paste your python equation in your report.

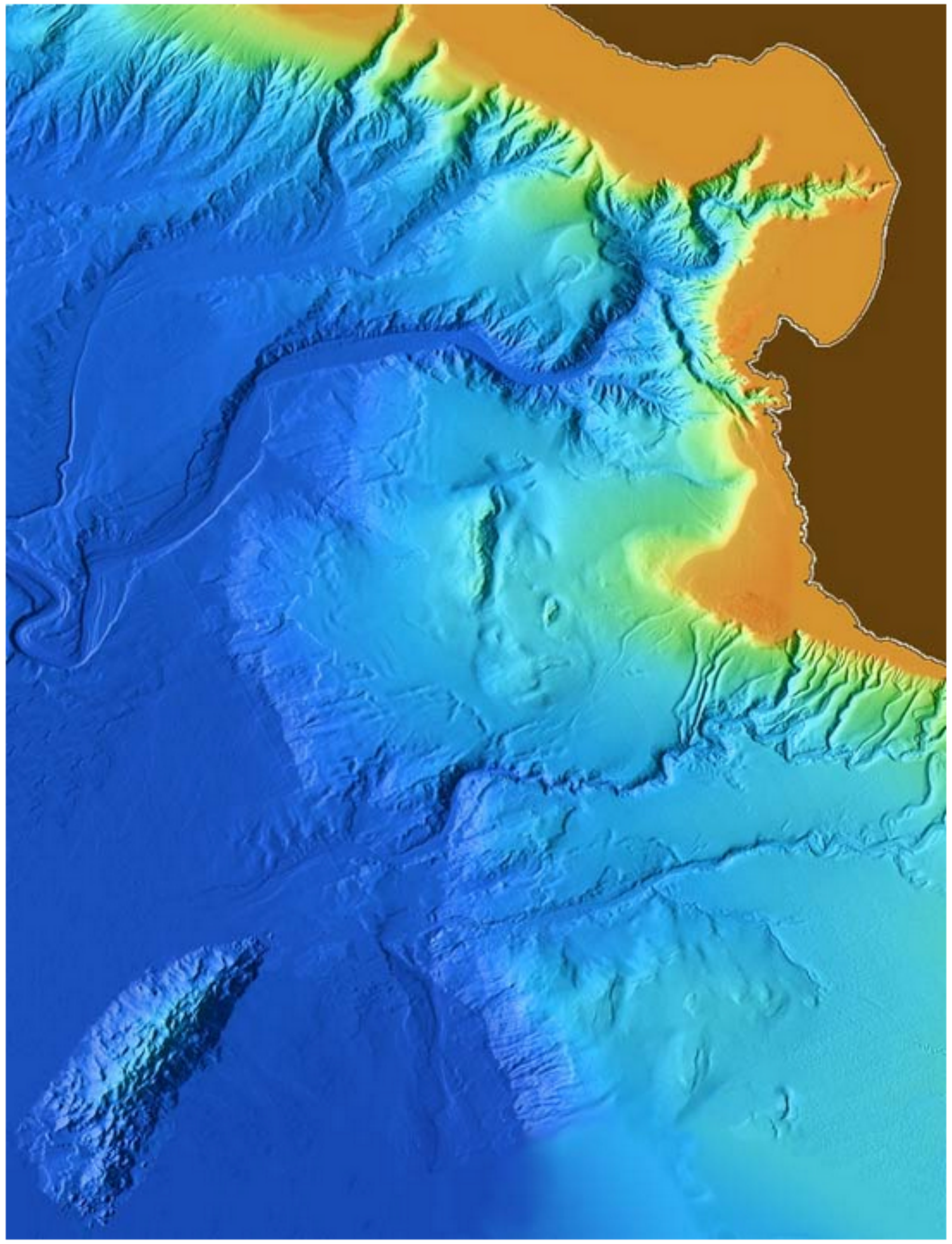
We then map the 50 biggest rivers discharge using Basemap.



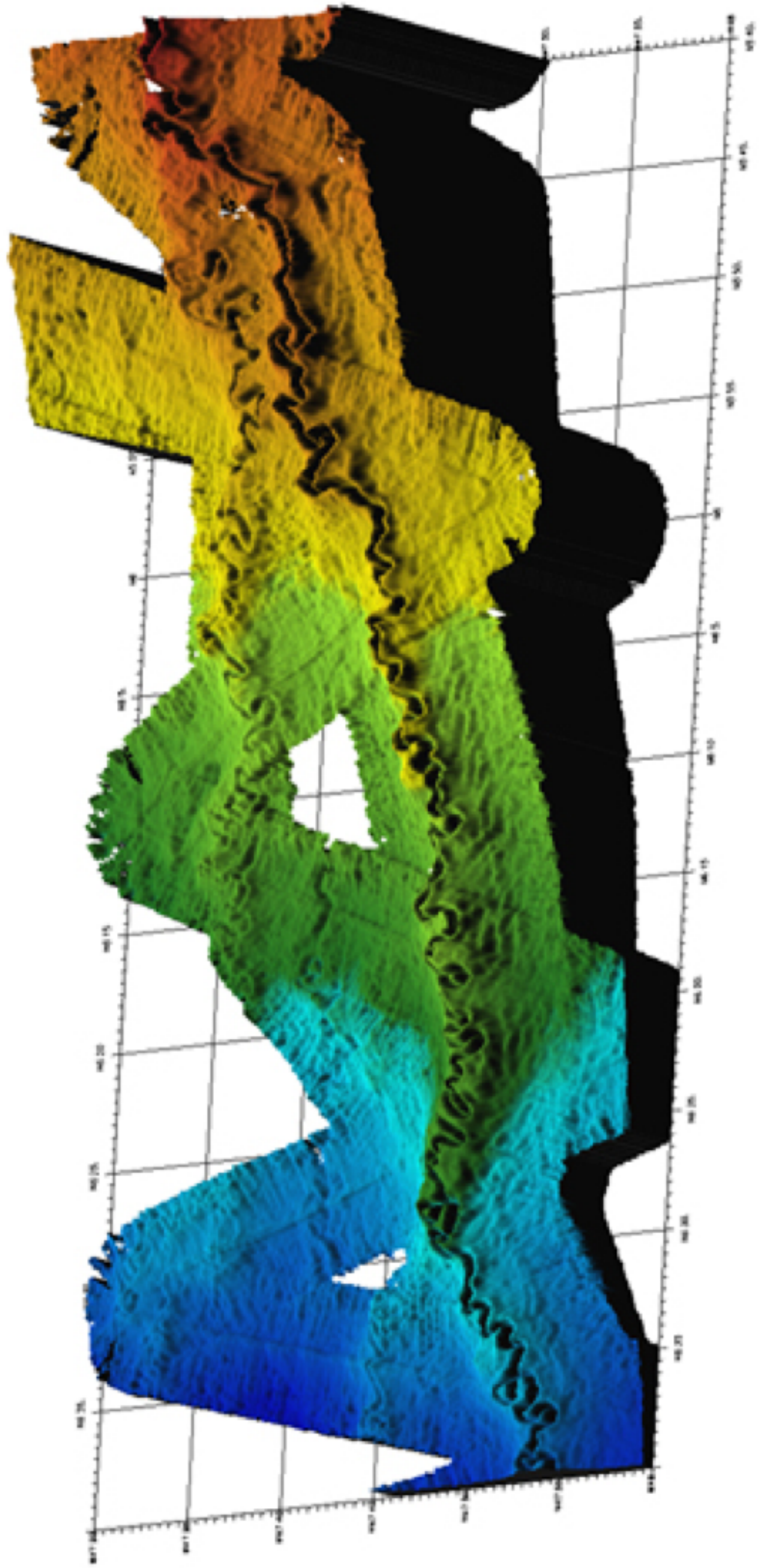
Q7. In regards to Sylvester et al. comment (2013) and this last plot, can you see a relationship between river discharge and sinuosity variability?

Interpreting: submarine channel morphologies

Q8. Based on what you have learn in this notebook and from both Peakall et al. (2011) and Sylvester et al. (2013), you might be able to have an initial guess on the most likely place where you might find these 2 types of channel systems. Explain.



Submarine channel system 1



Submarine channel system 2

Visualise in NbViewer

Follow this link to see the IPython notebook that we are going to use for the Part 2 of lab 1.

LAB1 Part 2 IPython material : nbviewer link

Seismic stratigraphy & interpretation

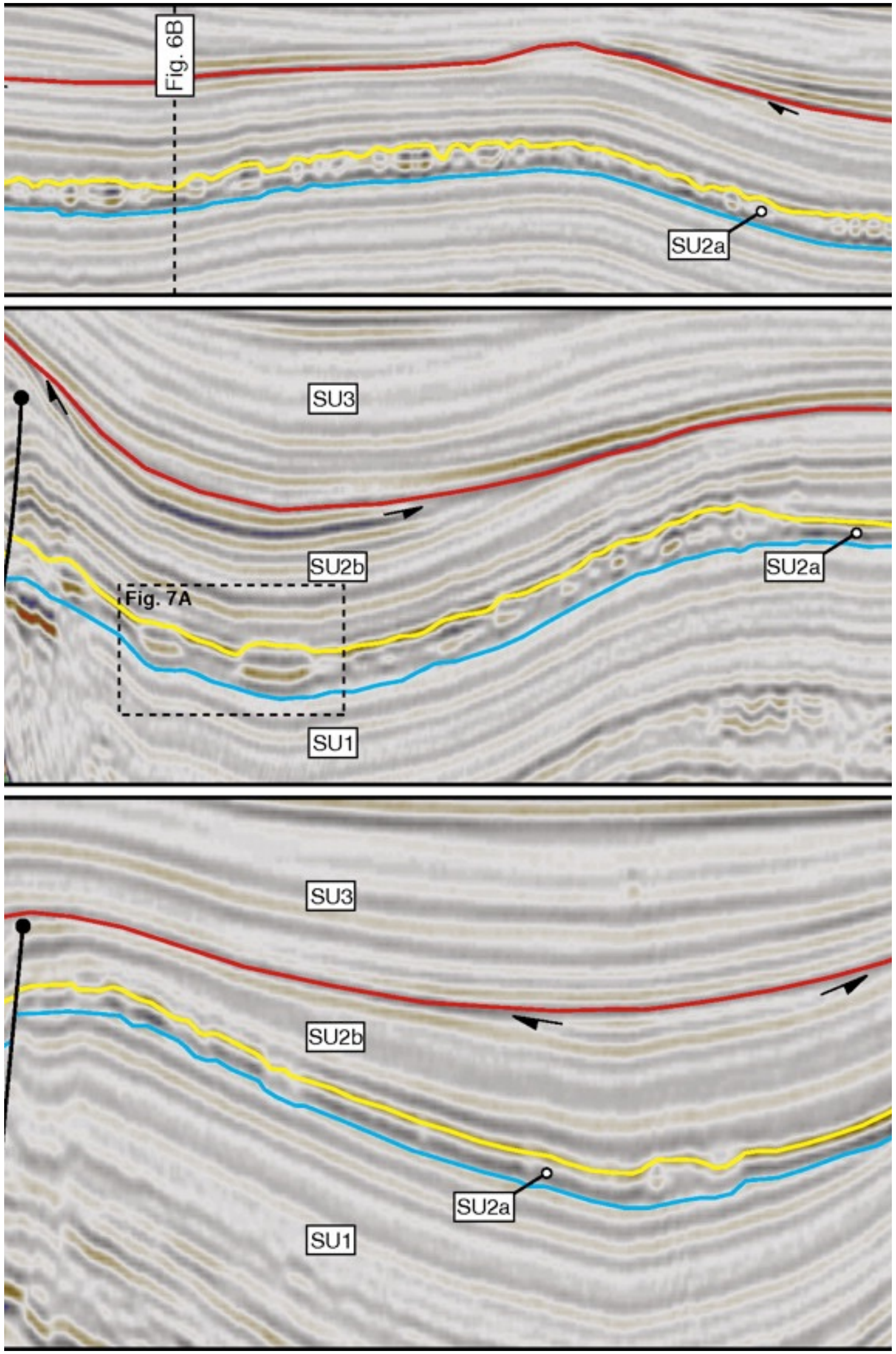
Overview

Seismic stratigraphy deals with interpretation. It is the study of seismic data for the purpose of extracting stratigraphic information.
Seismic stratigraphy is often divided into several sub-areas:

- **Analysis of seismic sequence**
  Separating out time-depositional units based on detecting unconformities or changes in seismic patterns;

- **Analysis of seismic facies**
  Determining depositional environment from seismic reflection characteristics;

- **Analysis of reflection character**
  Examining the lateral variation of individual reflection events, or series of events, to locate where stratigraphic changes occur and identify their nature; the primary tool for this is modeling by both synthetic seismograms and seismic logs.



Data Set

In this lab, you have:

- 6 seismic lines,
- a location map and
- a synthetic seismogram from the *Genoa 1* well.

Data comes from the **Cooper Basin**, and all lines are 2D. The vertical scale is **~15cm/second** which is okay for general petroleum work. You will need to provide answers to the following questions as well as your interpreted seismic sections.

Instructions

Q1. Review all the lines first and use the base map to work out the orientation of the lines. The SP (shot point) numbering convention is used, the line name is near the top of the section, above that are the intersections. Notice that the 1977 line has not been reprocessed, it was considered good quality at the time. Compare the SP spacing and vertical resolution of the old with the new.

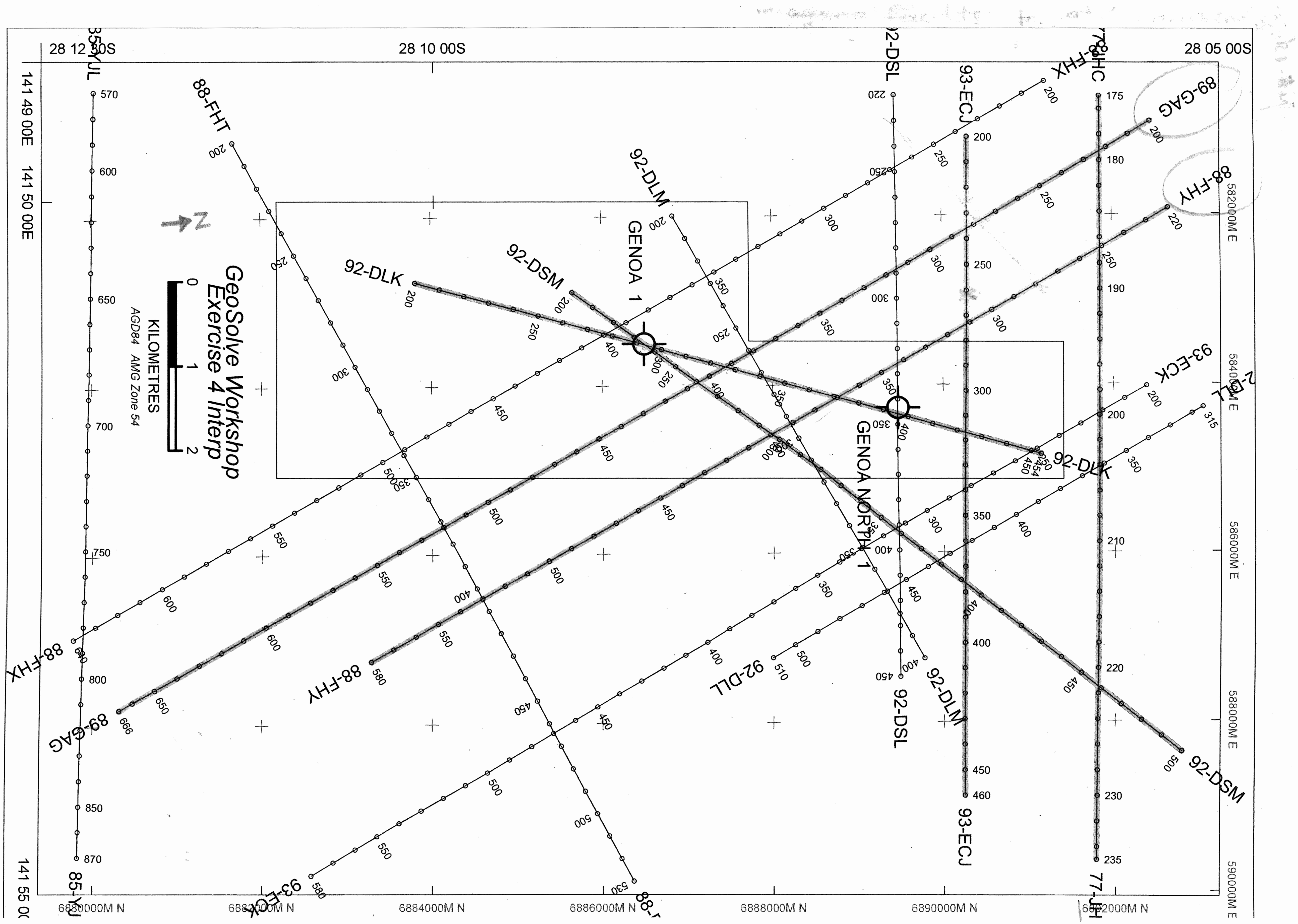
Q2. Line intersections can be compared by folding the paper. Identify 2-3 reflectors that are suitable for interpretation. Let the data dictate which surfaces you interpret. Trace the reflectors across the seismic lines, colored pencils are best used here.

Q3. Using the synthetic seismogram at *Genoa 1*, identify which formations your chosen reflectors are from. Label them on your seismic sections. In Lab 4, we will learn how this is constructed

Q4. Identify the *Yanko Fault* in the North of the grid and show the fault trace on the map.

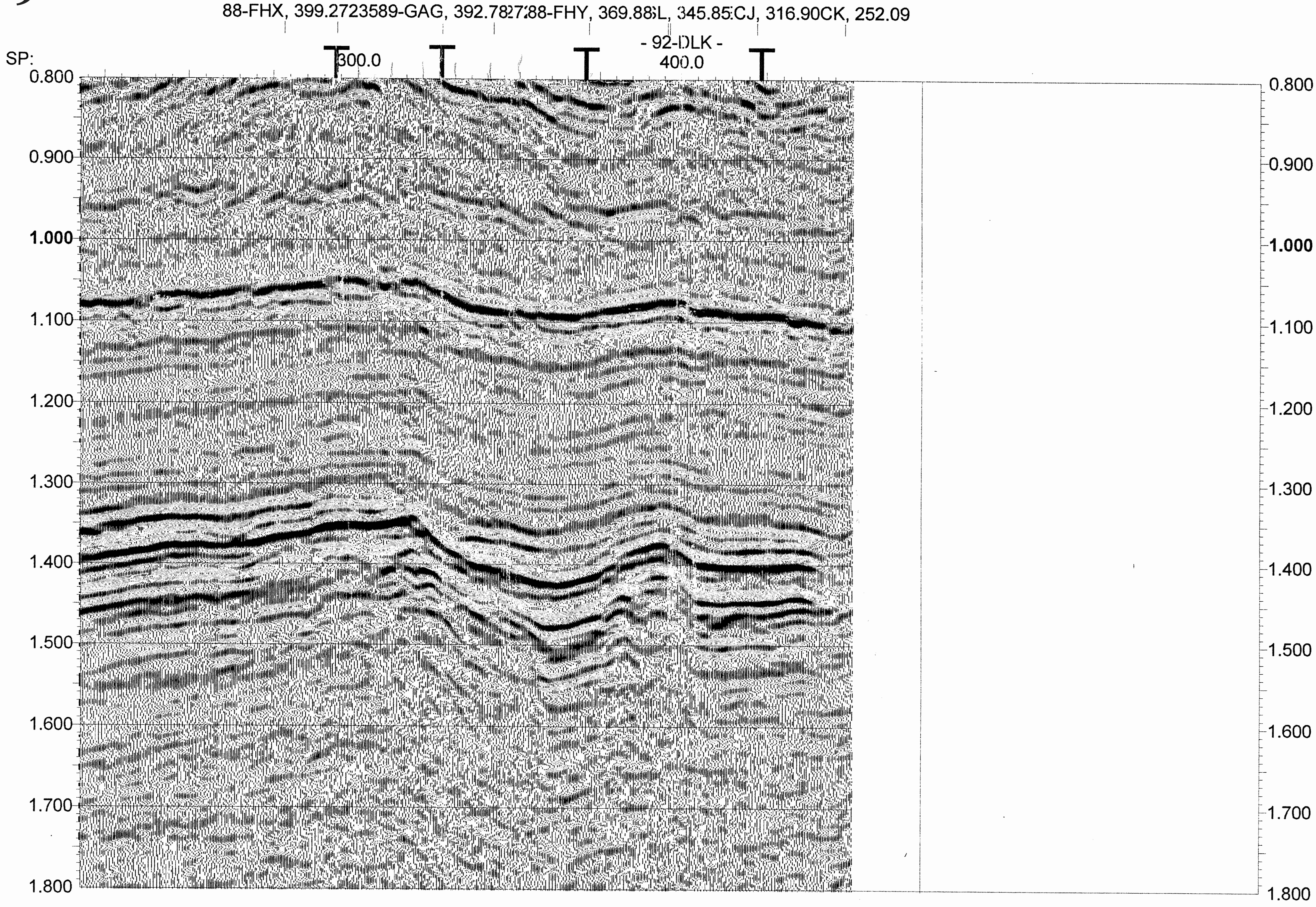
Q5. Estimate the Throw of the *Yanko Fault*, use a Velocity (average) value of **3000m/s**. This is a typical velocity used for Jurassic-Permian aged sediments in Eastern Australian basins during a first pass analysis.

$$Throw(m) = \frac{\Delta TWT(ms)}{2000 \times V(ave)}$$



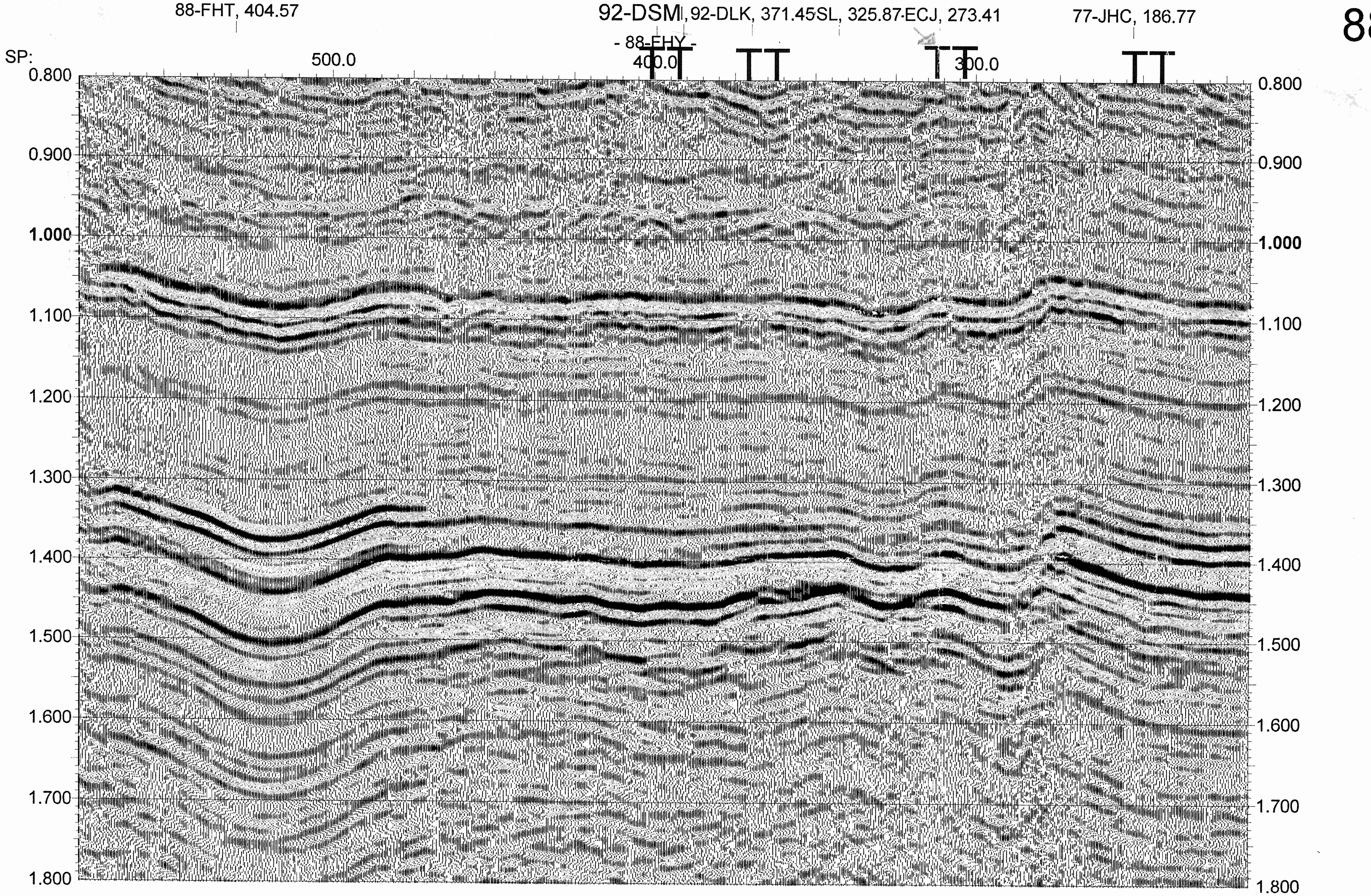
GeoSolve Workshop
Exercise 4 Interp
KILOMETRES
AGD84 AMG Zone 54
GENOA 1
GENOA NORTH 1
28 12 30S
28 10 00S
28 05 00S
141 49 00E
141 50 00E
141 55 00
6880000M N
6882000M N
6884000M N
6886000M N
6888000M N
6890000M N
6892000M N
5820000M E
5840000M E
5860000M E
5880000M E
5900000M E
88-FHT
92-DLM
92-DSL
93-ECJ
88-FHX
77-JHC
89-GAG
88-FHY
92-DLK
92-DSM
93-ECK
92-DLL
85-YJL

92-DLK

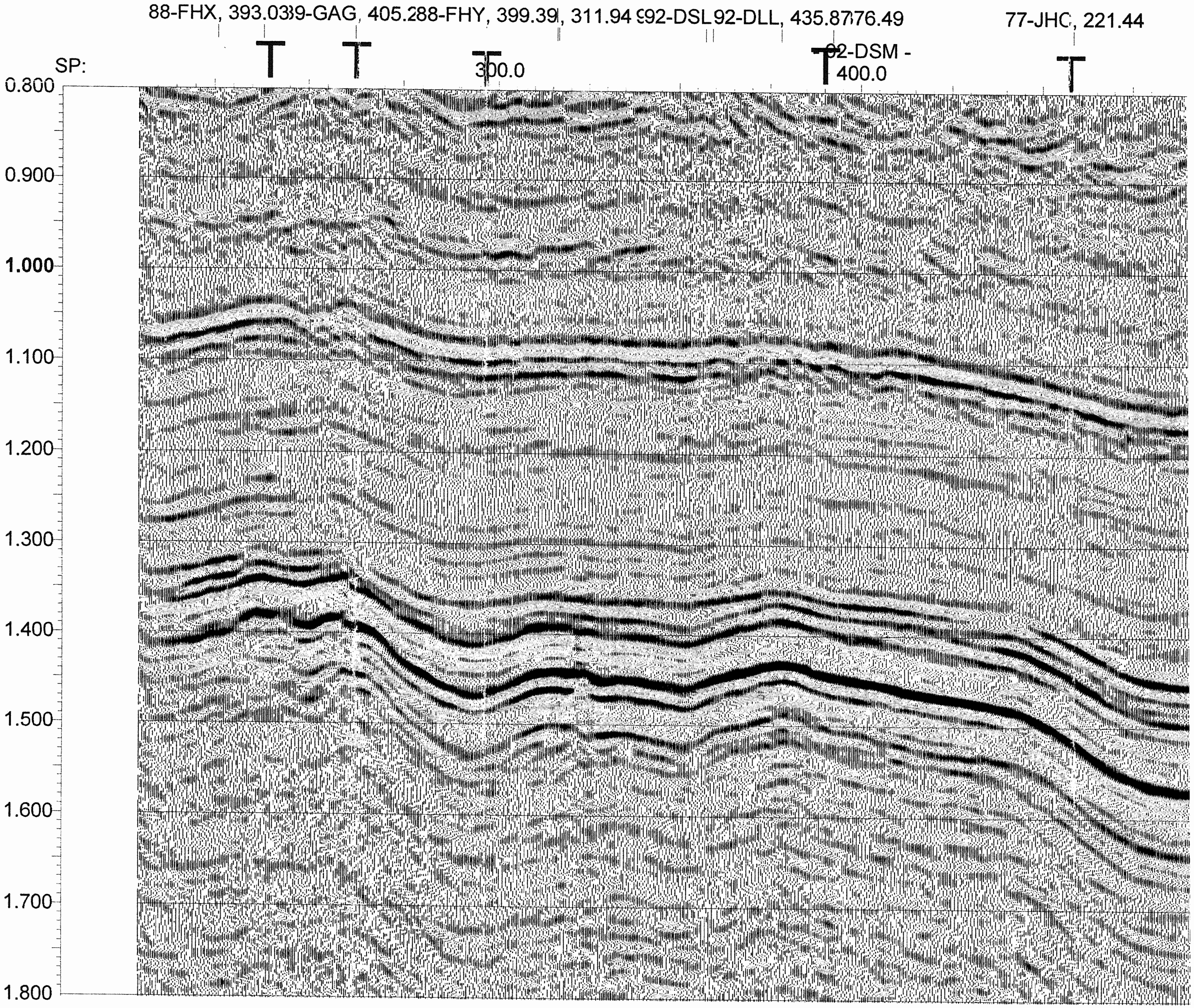


88-FHX, 399.2723589-GAG, 392.7827288-FHY, 369.883L, 345.85CJ, 316.90CK, 252.09
SP:
300.0
- 92-DLK -
400.0
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800

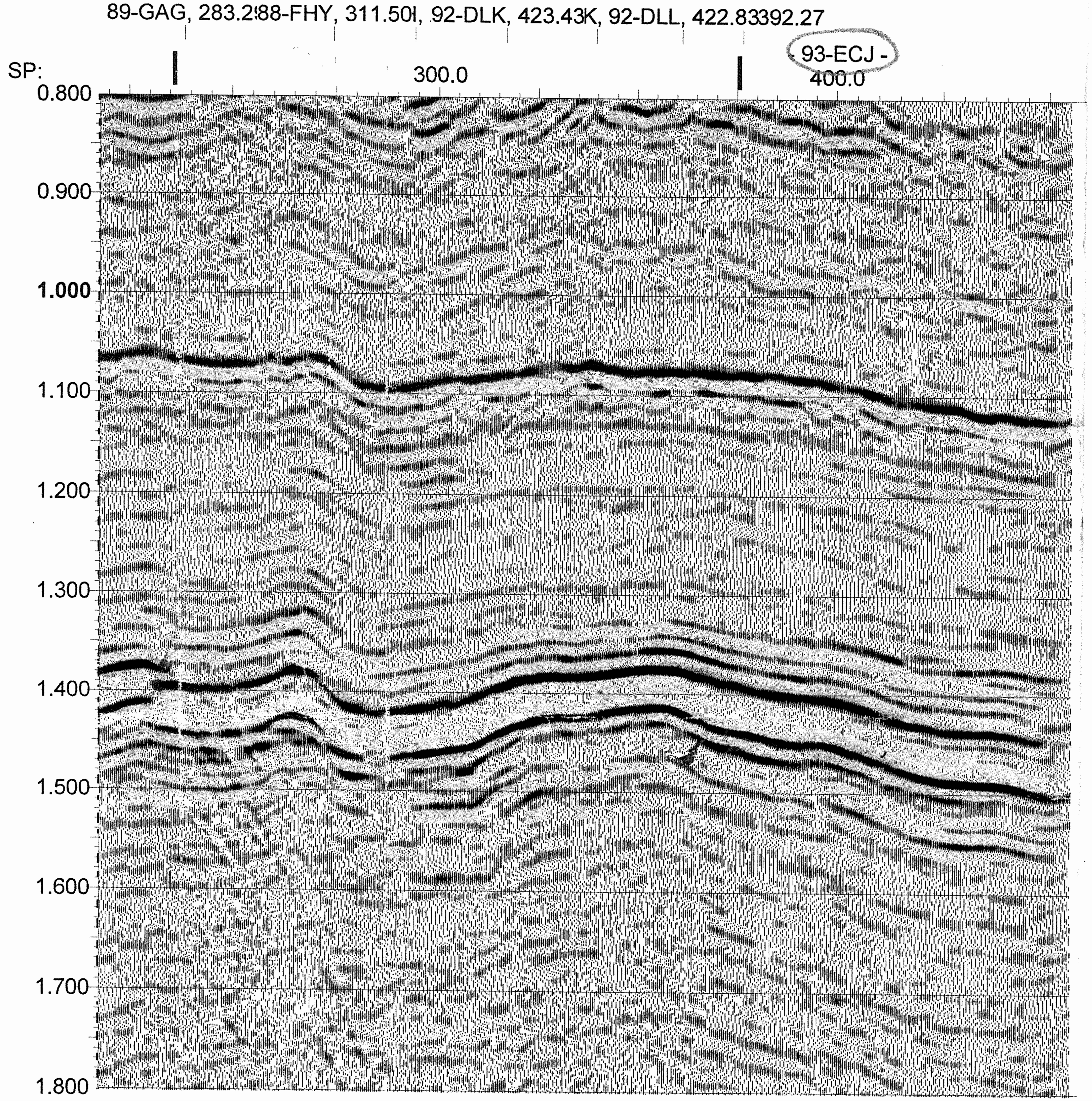
88-FHY


88-FHT, 404.57
92-DSM
, 92-DLK, 371.45
SL, 325.87
ECJ, 273.41
77-JHC, 186.77
88
- 88-FHY -
SP:
500.0
400.0
300.0
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800

92-DSM

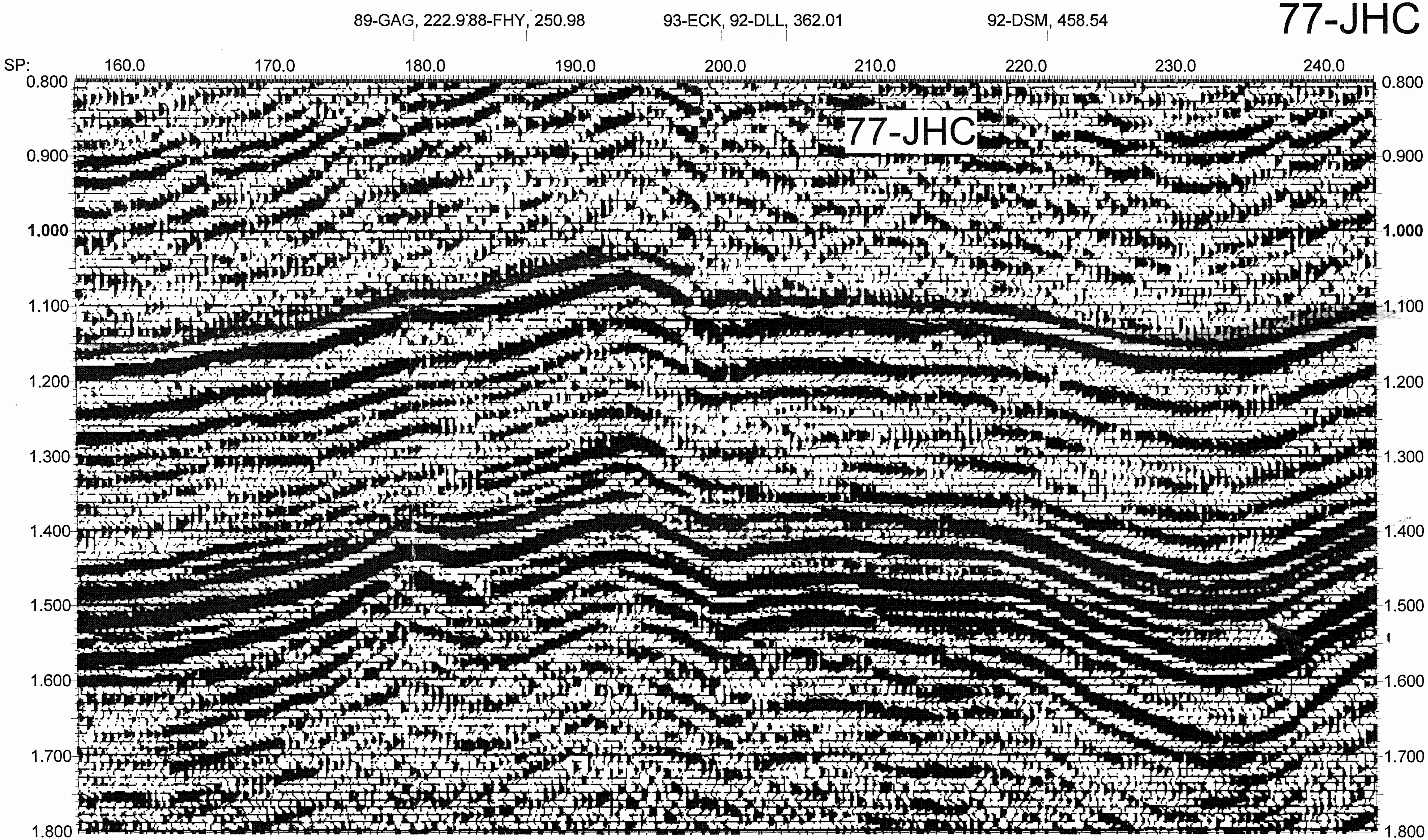

88-FHX, 393.0389-GAG, 405.288-FHY, 399.39, 311.94 92-DSL 92-DLL, 435.87776.49
77-JHC, 221.44
SP:
300.0
92-DSM -
400.0
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800

93-ECJ



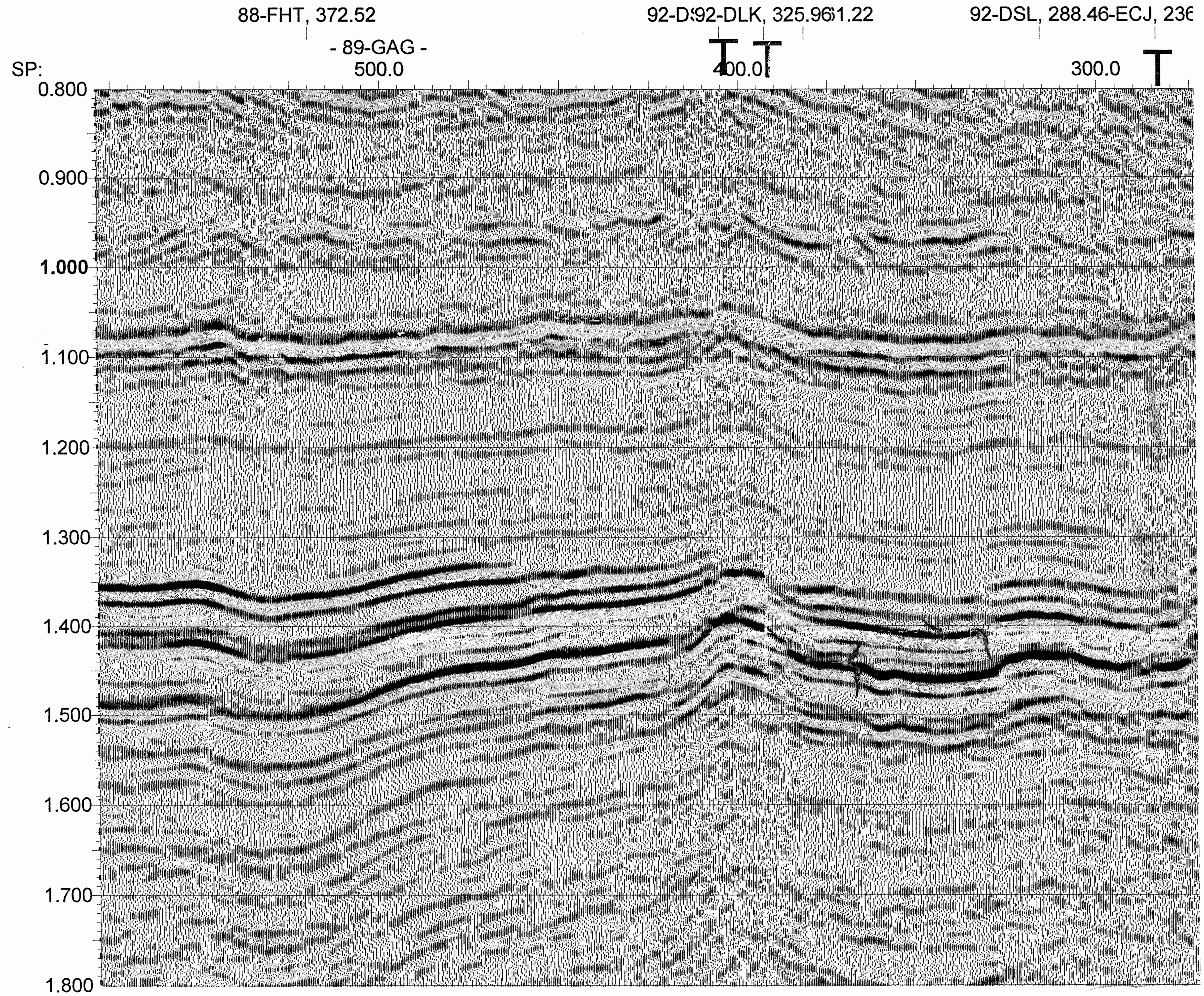
89-GAG, 283.2!88-FHY, 311.50l, 92-DLK, 423.43K, 92-DLL, 422.83392.27
93-ECJ -
SP:
300.0
400.0
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800

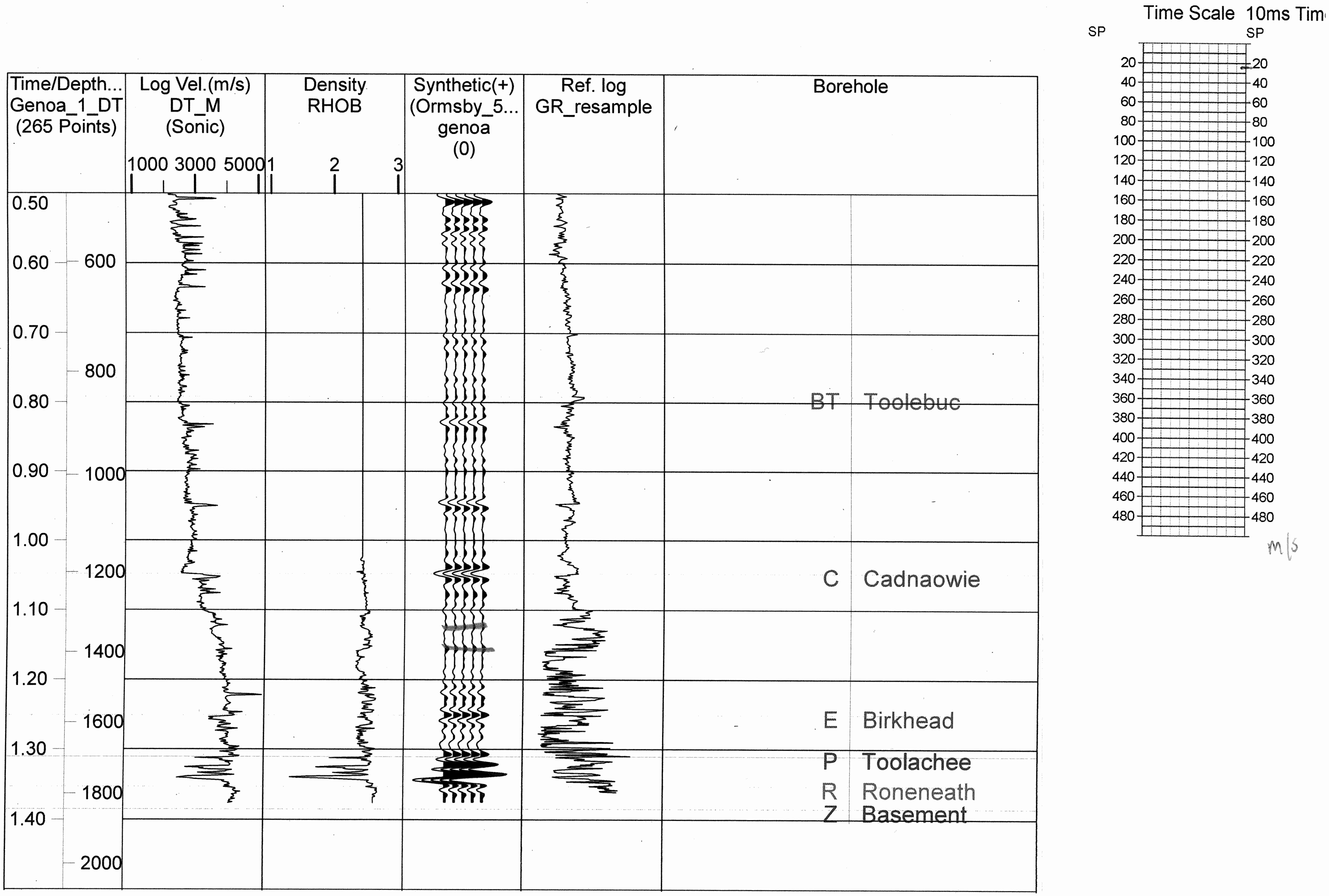
77-JHC


89-GAG, 222.9
88-FHY, 250.98
93-ECK, 92-DLL, 362.01
92-DSM, 458.54
77-JHC
SP:
160.0
170.0
180.0
190.0
200.0
210.0
220.0
230.0
240.0
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800
77-JHC

1977

89-CAG


88-FHT, 372.52
92-D?92-DLK, 325.96?1.22
92-DSL, 288.46-ECJ, 236
- 89-GAG -
SP:
500.0
400.0
300.0
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800


Time/Depth...
Genoa_1_DT
(265 Points)
Log Vel.(m/s)
DT_M
(Sonic)
1000 3000 5000
Density
RHOB
1 2 3
Synthetic(+)
(Ormsby_5...
genoa
(0)
Ref. log
GR_resample
Borehole
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
600
800
1000
1200
1400
1600
1800
2000
BT Toolebuc
C Cadnaowie
E Birkhead
P Toolachee
R Roneneath
Z Basement
Time Scale 10ms Tim
SP
SP
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
m/s

Surface processes & sea-level

Overview

The Sedimentary Record of Sea-Level Change is about how we can detect past changes in sea- level from an analysis of the sedimentary record. In particular, it concentrates on the concept of sequence stratigraphy.

This concept has changed the way in which many sedimentologists and stratigraphers examine sedimentary rocks because it provides a framework for how entire sedimentary systems evolve through geological time and places emphasis not only on the sediments themselves, but also on gaps between sedimentary units (hiatus). In addition, sequence stratigraphy incorporates two long-standing observations: first, that the sedimentary record shows repetitions or cycles; and secondly, that some sedimentary units can be traced over long distances.

In this lab we will analyse the influence of sea-level fluctuations on the development of stratigraphic sequences in deltaic environments, based on the results from a surface process model (badlands).

Instructions

Four different models with varying sea-level inputs have been ran with Badlands. You will use IPython to analyse and interpret the results of these models. There are 4 questions labeled Q. Provide solutions for all of them.

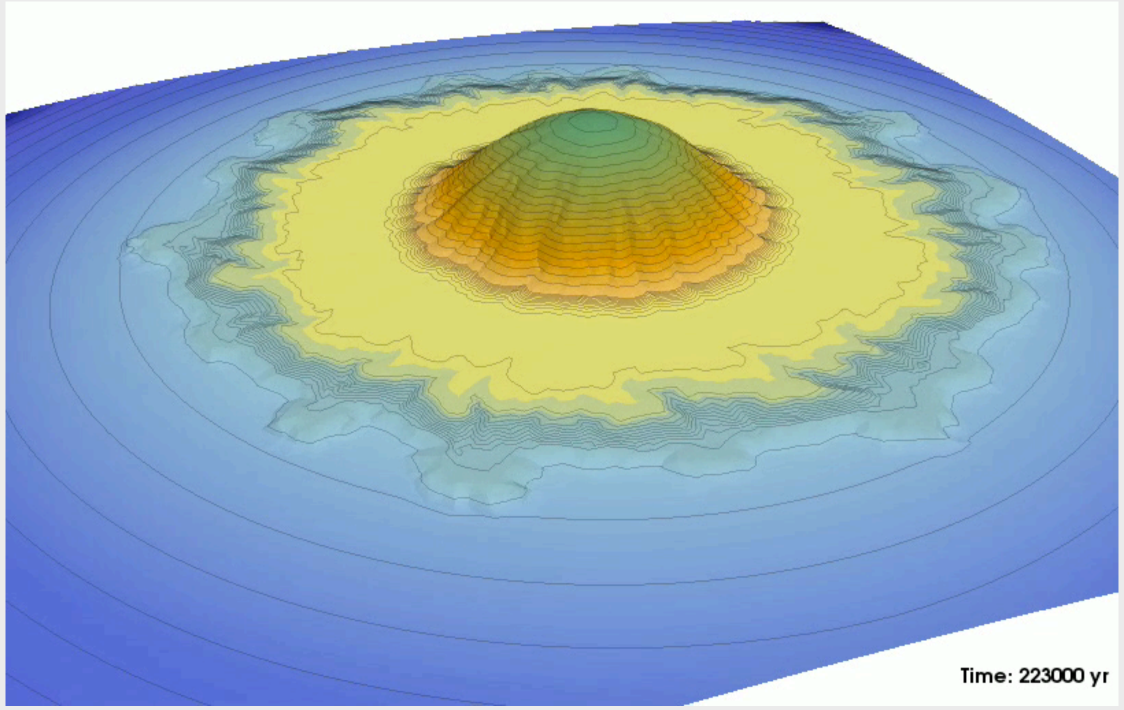
Models initial conditions

Badlands model simulates the erosion, transport and deposition of sediments by rain under geological time scale. For an overview of the code capability and implementation follow this link.

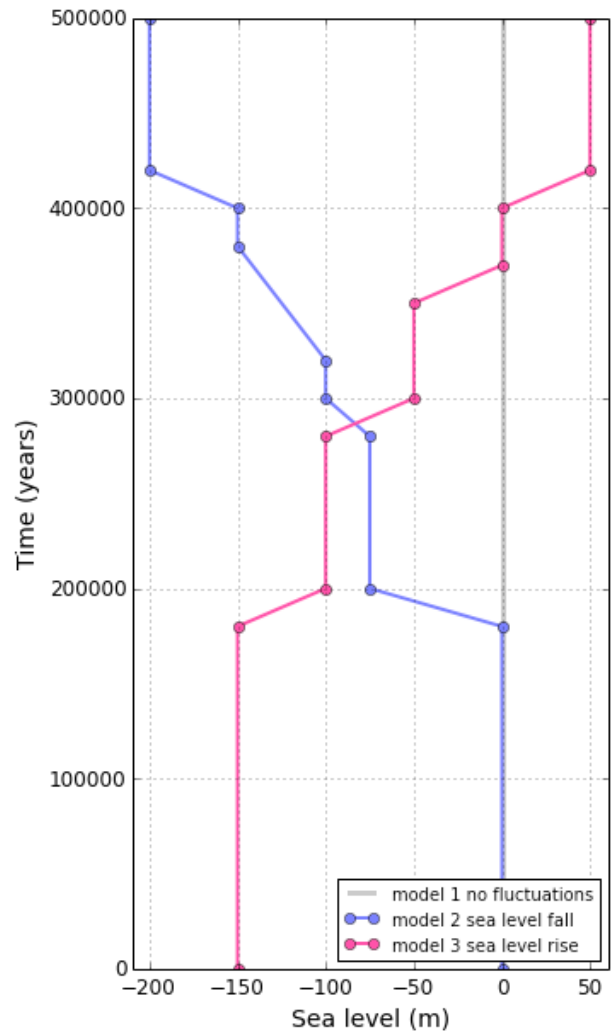
For the 4 models that we are going to analyse the initial surface represents a mount which is a half ellipsoid of 2000 m height and about 8 km large. An uniform precipitation rate of 1 m/yr is applied on the all area and the evolution of the surface is due to both hillslopes and overland flows. Two hillslope coefficient are defined for both the aerial and marine area.

The simulation runs for 500,000 years and for each models we impose different sea-level condition through time (values are defined in the plot on next page for the first 3 models).

In a nutshell, the first model simulates the erosion of the mount and the development of prograding deltas under a constant sea-level. For the second model, we impose in 5 steps a



Mountainous landscape evolution with sedimentation front evolving over time subject to sea-level fluctuations.



sea-level fall from 0 to -200m. For the third model, the sea-level rise from -150 to 50 m in 5 steps as well.

Example of badlands results

A link to the animation of one of the model result is available here.

Extracting the stratigraphic evolution

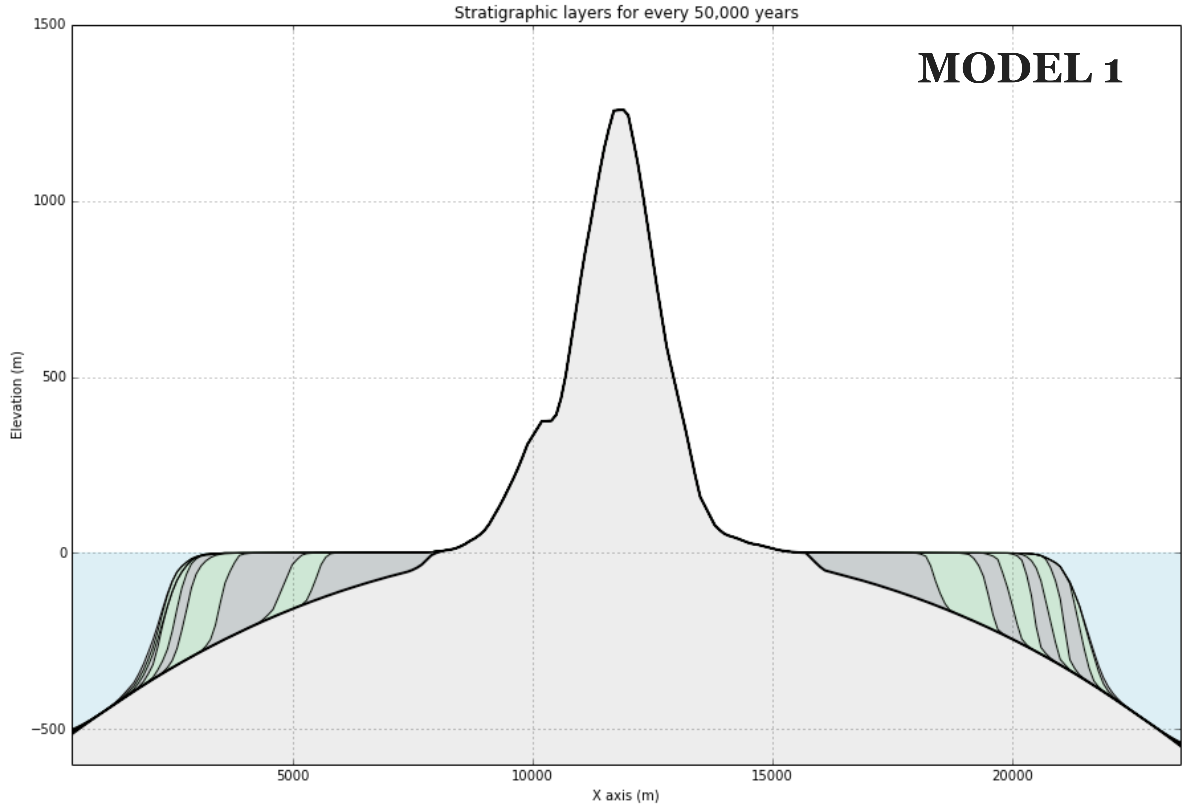
The last step of the 4 models (after 500,000 years) have been uploaded on the IPython server. The output produced by badlands are hdf5 files and we will need to open them in IPython before processing the dataset further.

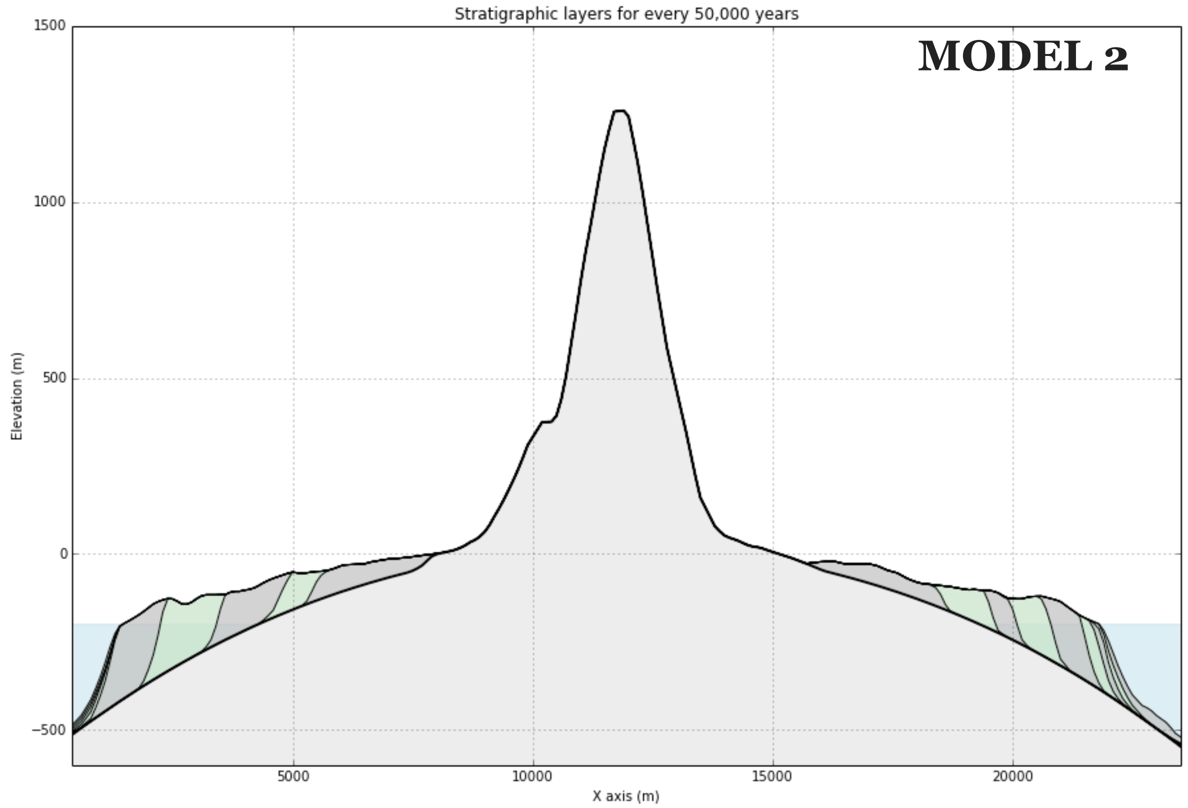
Open the notebook AnalyseModel1.ipynb and follow the different steps required to extract the stratigraphic layers for the final time steps along the X-axis.

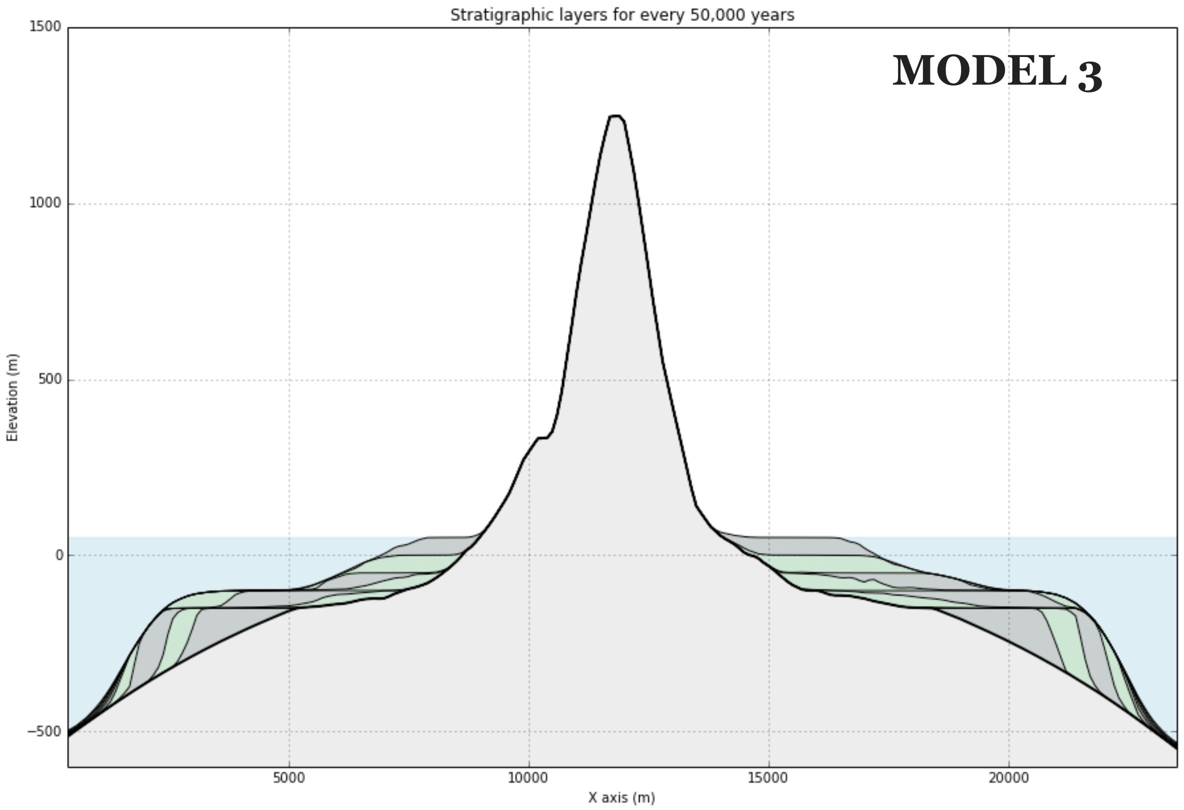
Q1. Using a similar approach plot the cross-sections for each 4 models along the X or Y-axis. You will need to include them in your report.

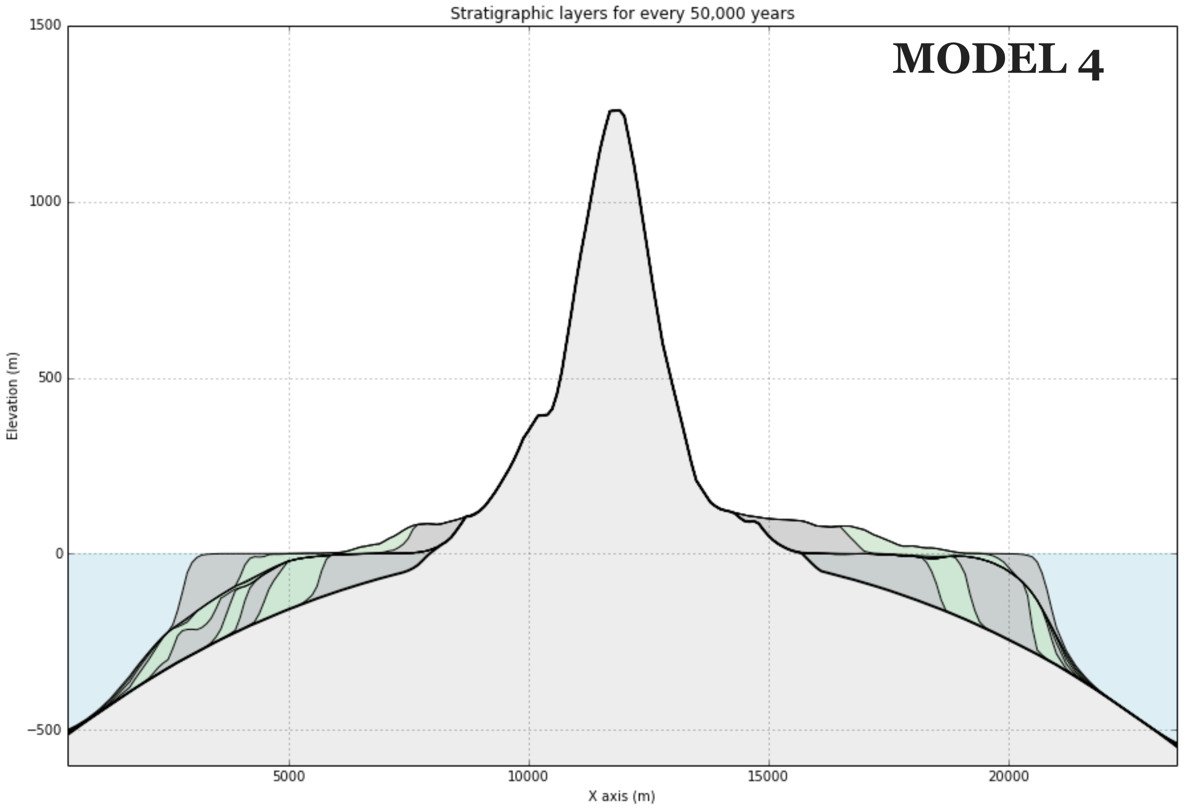
You will now use either the X-axis or Y-axis cross-sections you have extracted from the model output.

Q2. Explain the differences between the 3 first models (no sea-level fluctuations, sea-level fall and sea-level rise) in terms of stratigraphic sequences geometries.









Q3. Explain what is a transgressive system and a highstand system. In which case will you find progradational stacking? and regrodational one? Can you see associate any of these stacking types to the stratigraphy recorded in the 3 models you have just processed?

For model 4 the imposed sea-level fluctuations are not provided.

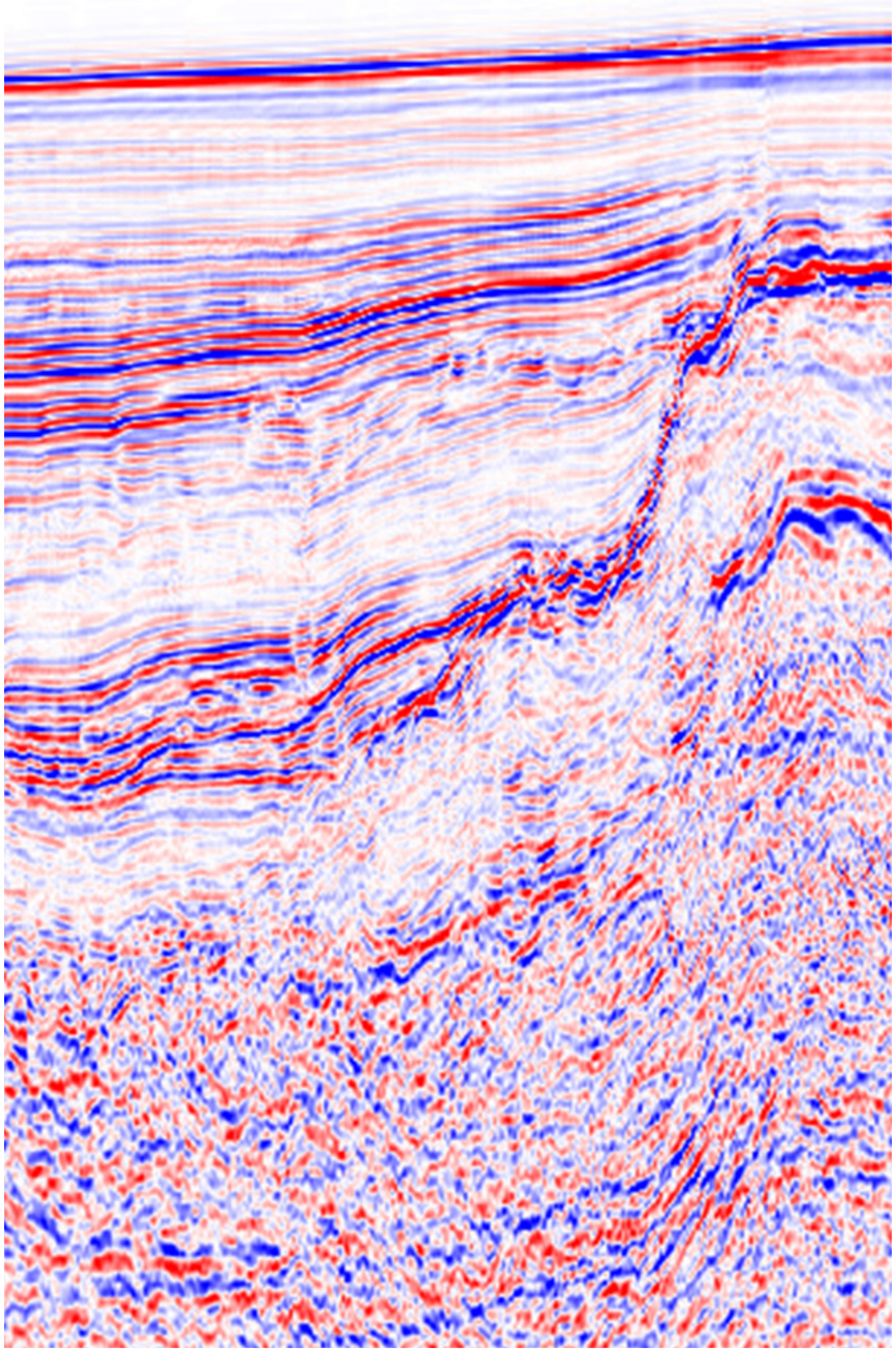
Q4. Give a possible sea-level fluctuation scenario which could produce a similar stratal pattern. Explain. On this model, can you show potential erosional surfaces based on the stratal geometries?

Visualise in NbViewer

Follow this link to see the IPython notebook that we are going to use for this lab.

LAB3 IPython material : nbviewer link

Basic seismic data analysis



Overview

When reflection seismic data are collected, a geophones are laid out, and a source (such as dynamite or a vibroseis truck) sends a wavelet into the subsurface. The wavelet reflects off interfaces separating units with differing acoustic impedances. A reflection seismic survey will consist of multiple shots over the survey area. For this lab, we will consider a 2D seismic line, where sources and receivers are positioned along a straight line.

Reflection seismology is the workhorse geophysical technique for oil and gas exploration. Seismic sections or volumes are interpreted for geologic structure and other geologic features. Each of the traces composing the volume is an ideal normal-incidence seismogram. In this lab, we will be investigating geologic factors that impact the character of a seismogram and walk through how a seismogram is generated from the collected data.

This lab and the associated IPython Notebooks are from Dominique Fournier from the University of British Columbia (Department of Earth, Ocean & Atmospheric Sciences).

Instructions

There are 5 questions labeled Q, some with multiple parts. Provide solutions for all of them.

Normal Incidence Seismogram

A normal incidence seismic trace simulates the time series you would observe if the source and receiver were coincident (matching). For horizontal layers, it simulates the response you would expect for a signal that travels vertically and is reflected off of the various interfaces it encounters.

The arrival time and amplitude of the signal depend on the density, ρ, and seismic velocity, v, of the layers it travels through.

Using the *SyntheticSeismogram.ipynb* , we will walk through how to construct a normal incidence seismogram.

Q1. Run the cells corresponding to Step 0 and Step 1 in the notebook and adjust the slide-bars to help answer the following questions. (Note: When "usingT" is off, which is the default, the reflectivity is simply the reflection coefficients at each interface.)

a. Start with equal density (rho1=rho2=rho3) for all 3 layers and adjust the velocity ($v1$, $v2$, $v3$) of the layers. What is required to have two reflection coefficients of opposite sign?

b. Create a simple 3 layered model as shown below, using the typical density and velocity parameters given in the script. Would you get a positive or negative reflection coefficient between the sandstone and coal?

c. Consider a 3 layered model that has a shale above a sandstone. What amplitude of reflectivity would result? How does this differ from the acoustic impedance value between the sandstone and the coal? Can you explain why this is the case?

d. Build a few models and turn the transmission coefficients on and off using the "usingT" toggle. When do you notice a large difference between the reflectivity series generated when transmission coefficients are ignored or included?

We now have a series that tells us the amplitudes of reflectivity measured at the surface interfaces at depth. The signal we input and the data we measure are in time. Knowing the layer thicknesses and velocities, we can convert from depth to time.

Q2. Execute the cell corresponding to Step 2 in *SyntheticSeismogram.ipynb* by clicking on it and using “Shift + Enter.” You can adjust the depth to the layer interfaces and the velocity of each layer.

If you adjust the velocities of the three layers, you will see that the depth-time curve is composed of 3 line segments with different slopes. What is the slope of each of the line segments in terms of the physical properties of each of the layers?

Using the depth-time conversion, we can describe the reflectivity series in time. We input a source wavelet and the measure a seismogram in time which is the convolution of the wavelet and the reflectivity series. Set the depth-time curve to the parameters shown on the right.

Q3. Execute the cell corresponding to Step 3/4 to define a wavelet and convolve it with the reflectivity series to construct a seismogram. For this example, the geologic model is the fixed model shown in figure 1.

a. Adjust the amplitude of the input pulse. How does this affect resulting seismogram?

b. Adjust the frequency of the input pulse. What causes the width of the pulse recorded on the seismogram increase? decrease?

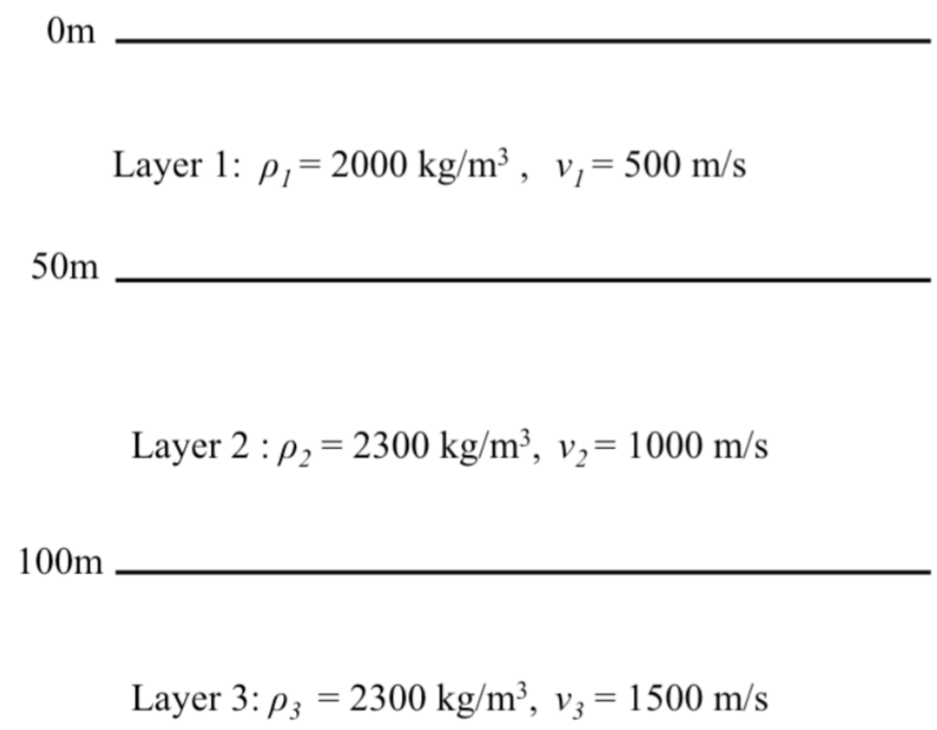


Figure 1: Fixed geologic model used in step 3.

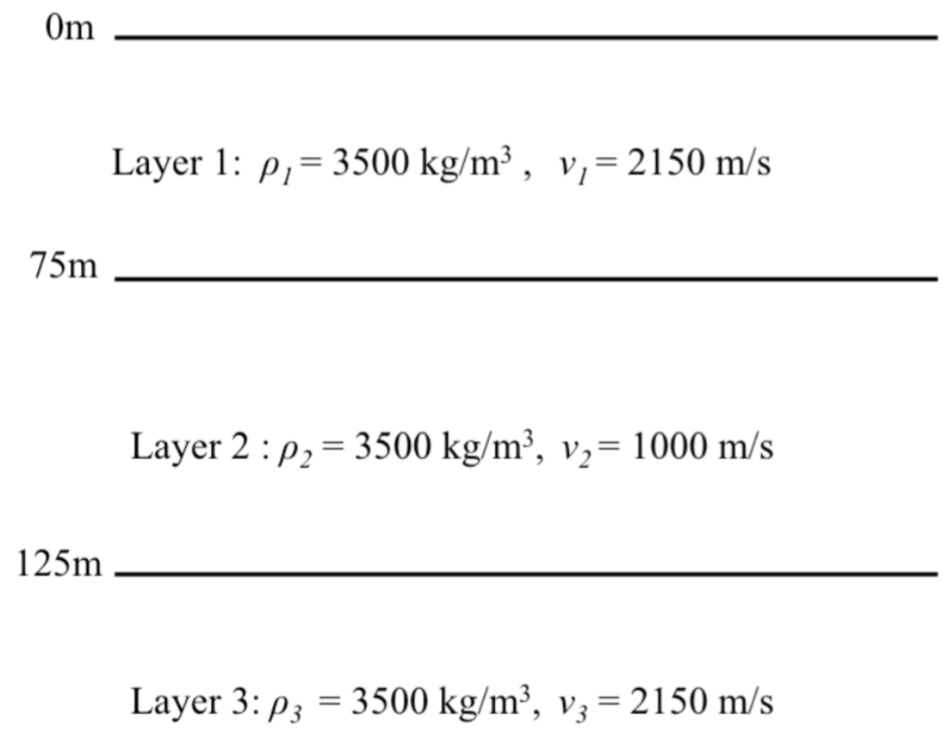


Figure 2: Geologic model for the seismic resolution investigation.

Q4. Run step 4. Now you can play with the geologic model and input wavelet frequency, as well as include noise. First, construct the model shown in Figure 2. You will need to adjust the value of v2. Set the amplitude of the input pulse to 1.

a. Here we will investigate the impact of the wavelet frequency on seismic resolution. One question that is always of interest is "how thick must a layer be before it is detectable?". Using the model in 4 as a starting point, we will fill in the following table. To compute the wavelength, λ, use the velocity of the second layer (v2) and the frequency of the input pulse. Adjust the thickness of layer 2 (h2) by adjusting the depth to the top of layer 3 (d3). For each of the frequencies listed, record the minimum h2 for which evidence of the top and bottom of the layer are visible in the seismogram.

f (Hz)	λ	Min h2 clean	Min h2 noisy
5			
10			
20			
50			
100			

b. Set the thickness of layer 2 to 1m. Set wavf = 100, and slowly decrease it. What happens to the amplitude of signal as the frequency is decreased?

Q5. In step 4, you can also build models and adjust any of the parameters.

a. Construct a model with two positive reflection events. Include an image when you hand in your lab (in the notebook, you can right click: copy and paste it into a word document).

b. Construct a model with two events with negative polarity. Include an image when you hand in your lab.

c. Construct a model with one positive and one negative reflection event. Include an image when you hand in your lab.

d. Using d2 = 75, d3 = 125, wavA = 1, construct a model which has variations in both density and velocity but does not show any evidence of the layer in the seismogram. Include an image when you hand in your lab.

Visualise in NbViewer

Follow this link to see the IPython notebook that we are going to use for the Part 1 of lab 4.

LAB4 Part 1 IPython material : nbviewer link

Instructions

There are 6 questions labeled Q, some with multiple parts. Provide solutions for all of them.

Constructing a Normal Incidence Seismic Trace

In previous part of LAB 4 we have investigated the impact of geologic factors on an ideal normal-incidence seismogram, we will now examine how such a trace is extracted from the seismic data.

Sketch the Problem

There are multiple ways to sort seismic data.
 - A **common shot gather** consists of the time-series recorded by the geophones for a single shot. The recorded time series are usually plotted with time on the y-axis and location on the x-axis.

- A **common midpoint gather** consists of the collection of traces that share the same midpoint between the source and receiver.

See SubSurf Wiki for further explanation.

Q1. On the figure below or a separate piece of paper, sketch 4 reflection ray paths, from source to receiver for a common shot gather.

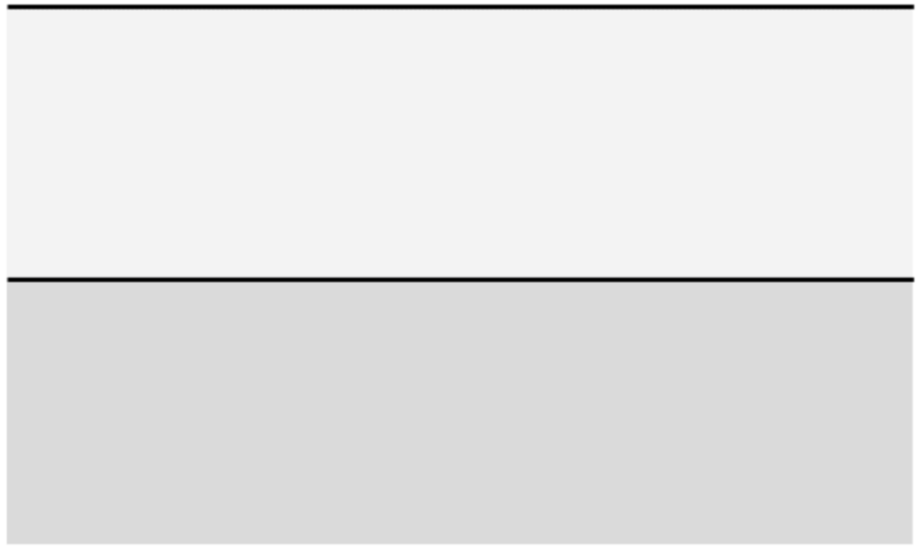


Figure 1: Common shot gather

Q2. On the figure below or a separate piece of paper, sketch the ray paths for the reflections recorded on 4 geophones for a common midpoint gather.

Figure 2: Common midpoint gather

From CMP gather to a Seismic Trace

Here, we will walk through how to construct a normal incidence seismogram from a CMP gather. We have two data sets for you to examine. One is a clean data set, and the other is noisy.

To perform this task, we will use the Seismic NMO notebook (*SeismicNMOapp.ipynb*). In the iPy Home tab of your web-browser, click on *SeismicNMOapp.ipynb* to open the seismic NMO notebook. If you closed your browser, follow the Instructions at the beginning of the lab to get the iPython notebook running again.

To estimate the geologic model and interpret structure from the seismic data, we want a single, normal-incidence trace. There are two challenges that must be considered when doing this from a CMP gather: 1. For different source-receiver offsets, the arrival time of the reflection event will be different, 2. The data are usually contaminated with noise. Challenge 1 will be tackled using a Normal Moveout correction (NMO), and challenge 2 will be addressed by stacking the NMO corrected traces to reduce the impact of random noise. If performed properly, the result will be a single normal-incidence trace.

Execute the cells corresponding to steps 0 and 1 in *SeismicNMOapp.ipynb* to import the necessary packages and plot the data.

Q3. The arrival time of a reflection event as a function of source-receiver offset is described by a hyperbola.

$$t(x) = \sqrt{\frac{x^2}{v^2} + t_0^2}$$

$$t_0 = \sqrt{\frac{4d^2}{v^2}}$$

The offset x is known for each trace, but we do not know the velocity v or thickness d of the first layer, so both v and *t0* must be estimated. Execute the cell corresponding to step 2.

a. By adjusting the intercept time *t0* and velocity v. Fit a hyperbola to the reflection event in the CMP gather. The panel on the right shows the NMO corrected data, that is, the data flattened on the hyperbola. Record the intercept time and velocity for the hyperbola you fit.

b. What happens to the NMO corrected reflection event when you use a velocity which is too small? too or too large?

Q4. In the cell corresponding to Step 2, enter the intercept time and velocity you used to fit the hyperbola in the previous question for the variables t0 clean and vstack clean and run the cell. This will produce a stacked trace.

a. Include the image of the stacked trace in your lab.

b. Assuming the input pulse has the same polarity as in the previous section (the maximum amplitude is a positive peak), what does the polarity of the event in the stacked trace tell you about the physical property contrast corresponding to that interface?

c. Compute the depth to this reflector.

Q5. Now we will work with the noisy data set. Since this data set is so noisy, we provide 3 hyperbolas for you to experiment with at a time. The panel on the right performs the NMO correction for the second hyperbola (red). Execute the cell corresponding to step 3 to find a possible hyperbola to fit the reflection event in the noisy data. You can also enter the intercept time and 3 velocities to generate stacked traces for each velocity.

a. By using the tools corresponding to steps 3 and 4, find the intercept time and velocity that correspond to the reflection event in the noisy data

b. Include an image of 3 traces, with v1 100m/s slower than the velocity you picked in (a), v2 equal to the velocity you picked in (a), and v3 100m/s faster than v2.

c. Estimate the depth to this reflector.

Q6. One approach to estimating the hyperbolas corresponding to the reflection events is to use a semblance analysis. For a semblance analysis, we select a number of hyperbolas, with intercept time t0 and velocity v, and sum up the coherent energy in a window along that hyperbola. Figures 3 and 4 show the semblance analysis for both the clean and noisy data you used in this lab. From these semblance images, which values of t0, v correspond to the reflection events in the clean and noisy data? Do these agree with the values you estimated doing "semblance by eye" in the previous questions?

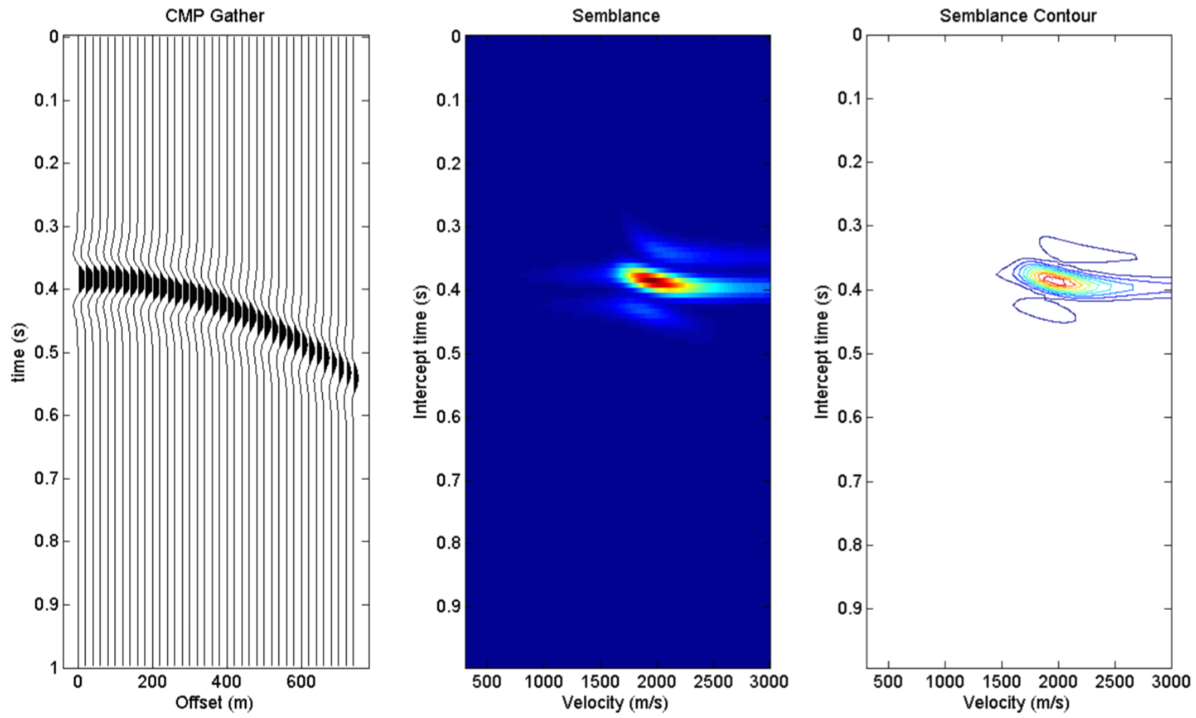


Figure 3: Semblance plots for the clean data

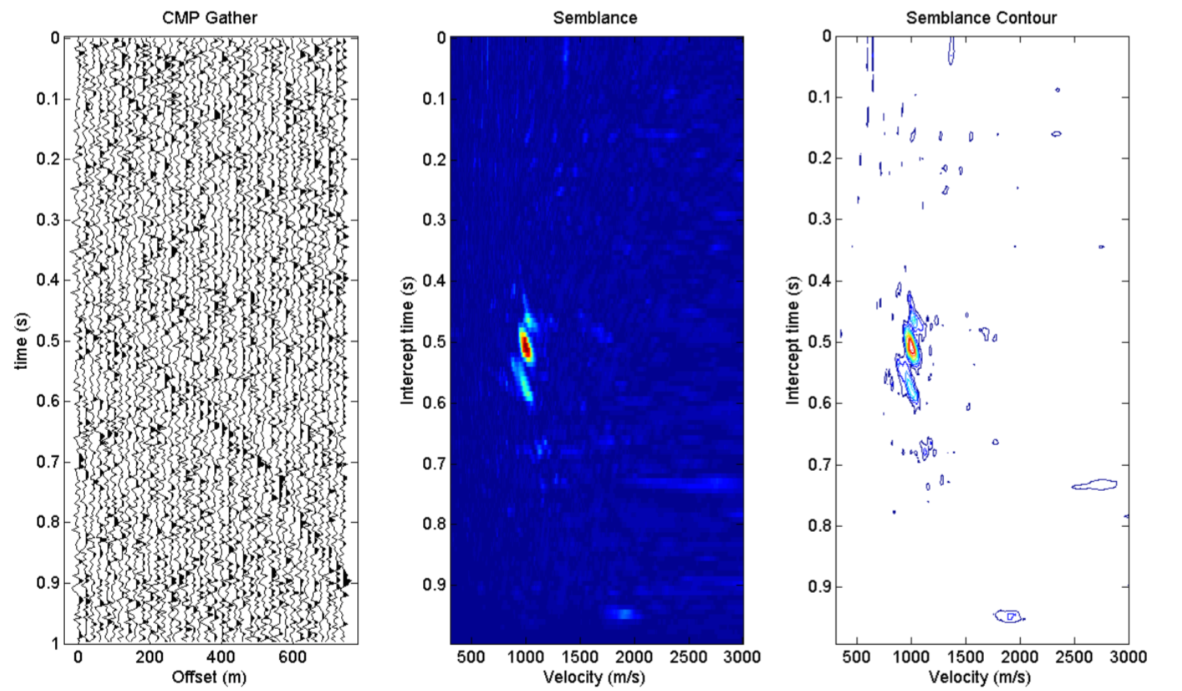


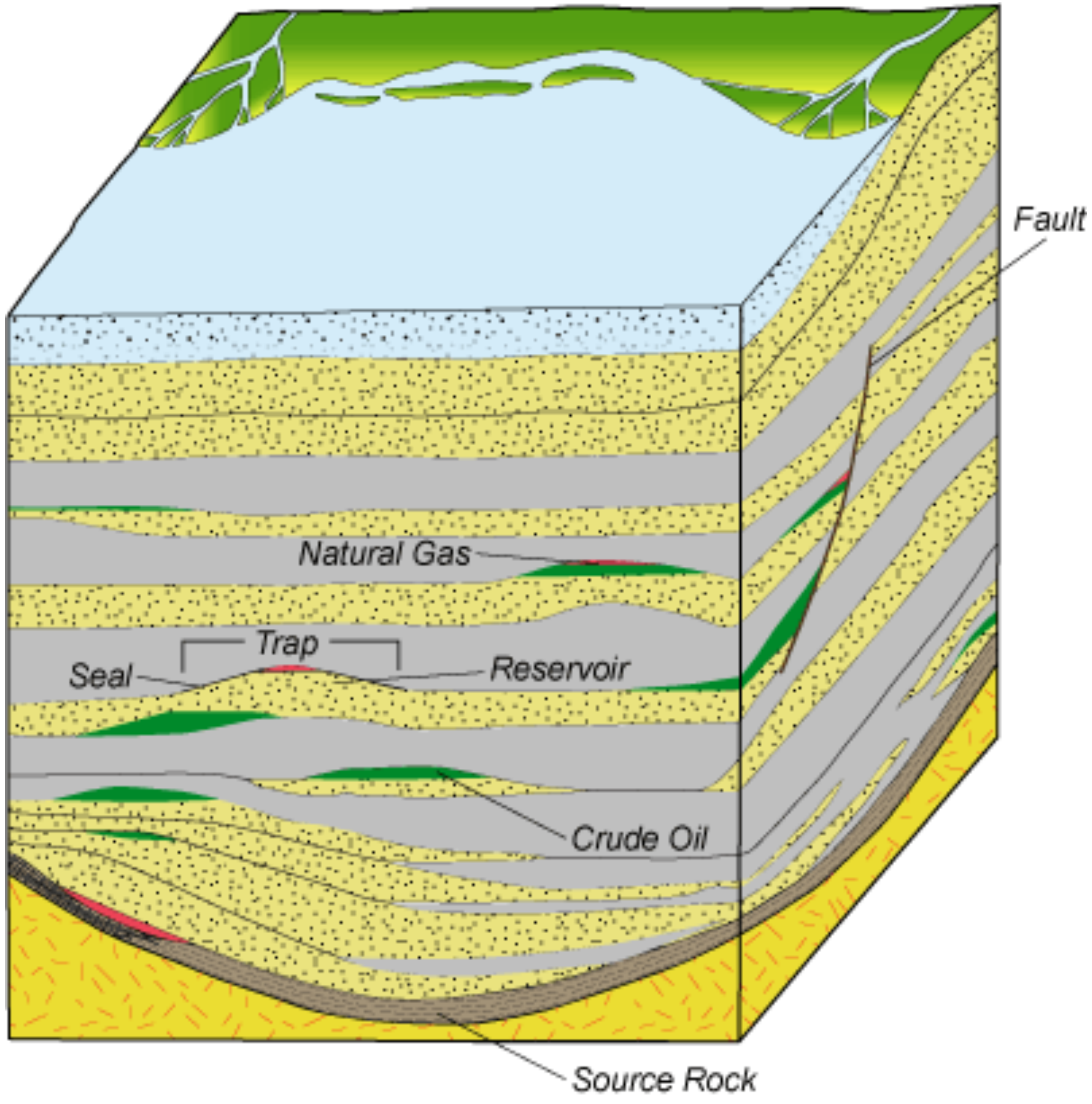
Figure 4: Semblance plots for the noisy data

Visualise in NbViewer

Follow this link to see the IPython notebook that we are going to use for the Part 2 of lab 4.

LAB4 Part 2 IPython material : nbviewer link

Modelling sedimentary basin tectonic subsidence



Overview

Back-stripping is a geophysical analysis technique used on sedimentary rock sequences. This technique is used to quantitatively estimate the depth that the basement would be in the absence of sediment and water loading.

This depth provides a measure of the unknown tectonic driving forces that are responsible for basin formation (otherwise known as tectonic subsidence or uplift). By comparing backstripped curves to theoretical curves for basin subsidence and uplift it is possible to deduce information on the basin forming mechanisms.

Report structure

Write a discussion of all your results. The structure of your report should follow the general pattern of *Introduction*, *Background*, *Methods*, *Results*, *Discussion* and *Conclusion*. You can save IPython images as jpg or png files and place them into an MS Word or Open Office doc). Include your IPython script as an appendix to this exercise. It should be neatly annotated with comments and all figures should have proper axis labels and titles.

Your report should have the following structure:

Title

The title must be concise and informative. It should state what the report is about, not simply the name of the assignment.

Introduction

This section presents the scope of the scientific problem. It should also provide a brief summary of the current state of knowledge. In a research paper this section would refer extensively to previously published material, but in this report that is not necessary. You simply need to reword/expand on the scientific problem stated above.

Methodology

This section describes the scope of the data you are presenting and how they were analysed. The writing style should be direct and matter-of-fact.

Data presentation and interpretation

This section presents the results of the exercise/study. You should still take care not to confuse fact with conjecture when you are writing this section.

Conclusion

Provide a brief summary of the results and then state the conclusions of the study in the context of the problems given. The conclusions should be direct statements, with appropriate qualification.

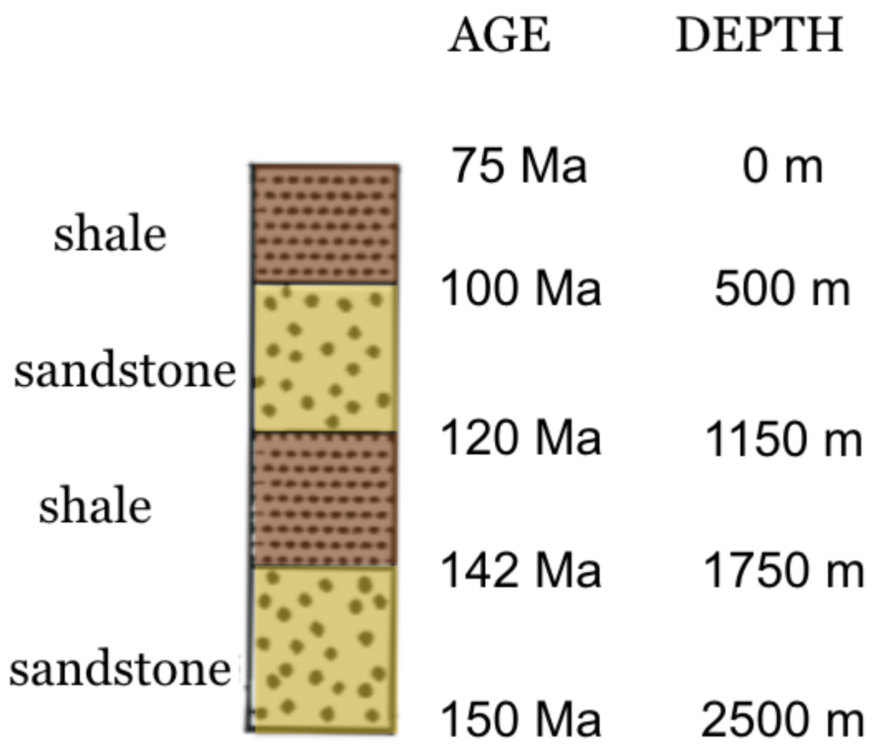
References

You should refer to publications that you used in your report following the Harvard System.

Report format

The text must follow the structure described above and is not page limited. However, part of the aim of the exercise is for you to write concisely and effectively. Any figures that you choose to include should be embedded in the text and should have captions. Figures should be referred to in the text in the appropriate manner.

You are given the stratigraphic section shown below to calculate the tectonic subsidence, or driving subsidence, of the basin. The section was measured on the side of a mountain, as the basin has undergone uplift after it formed. Fortunately for you the section has been corrected for bedding angle. The rocks are fully lithified with effectively 0% porosity at present. This shows that they were once buried several kilometers below the surface.



In order to calculate tectonic subsidence you must first decompact the sequence to its original thickness and density at the time after it was deposited. Thus, you need a porosity vs depth curve for sandstone and for shale. Fortunately for you we will cheat in this Lab and assume that porosity is a linear function of depth:

$$\phi = \phi_0(1 - z_{sd})/z_m \qquad (1)$$

Where ϕ_0 is the porosity at zero depth, z_{sd} is the decompacted sediment thickness, and z_m is the depth at which porosity is zero.

Lithology	**porosity at zero depth (%/100)**	**z_m (km)**	**grain density (g/cm3)**
sandstone	0.25	10	2.65
Shale	0.5	6	2.72

The mean porosity ϕ_{ave} of the decompacted sediment package is:

$$\phi_{ave} = \phi_0(1 - (z_1 + z_2)/2z_m) \qquad (2)$$

where:

- z_1 is the top of the sediment package

- z_2 is the base of the sediment package

The density of the decompacted sediment package is:

$$\rho_{sd} = \rho_{gr}(1 - \rho_{ave}) + \rho_w \rho_{ave} \qquad (3)$$

where:

- ρ_w is the density of water (1.03)

- ρ_{gr} is the fully lithified density (or grain density) of the sediment

- ρ_{ave} is the average density of the decompacted sediment package

Knowing that porosity ϕ is:

ϕ = (volume of water / (volume sediment + volume water)

= $z_w/(z_w + z_s)$

it can be shown that:

$$z_{sd} = z_s(1 + (\phi_{ave}/(1 - \phi_{ave}))) \qquad (4)$$

where

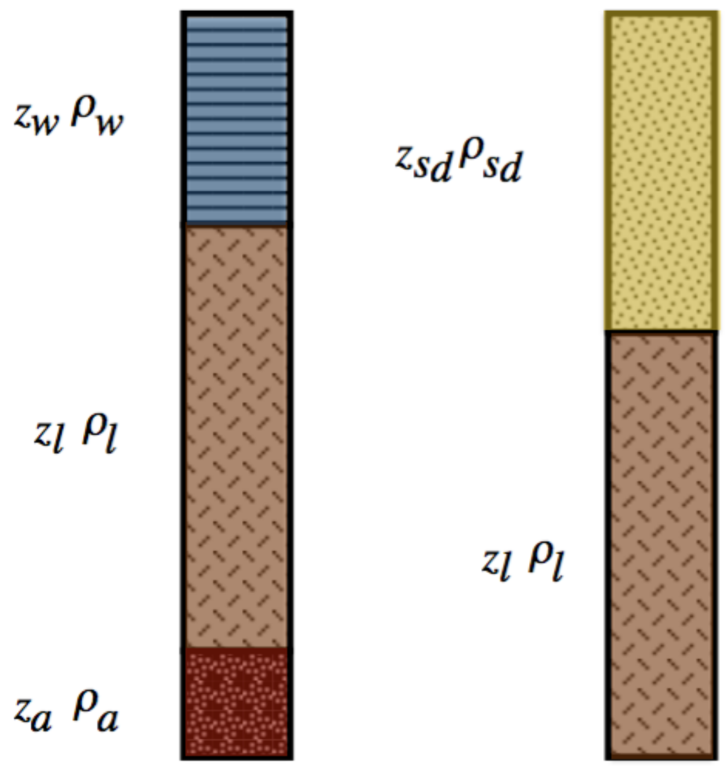
- z_{sd} is the decompacted thickness of the sediment

- z_s is the fully lithified thickness of the sediment

- ϕ_{ave} is the average porosity of the decompacted sediment package

Thus, you can obtain the decompacted thickness of each sediment package. But, if z_{sd} decompacted thickness of the sediment and z_s is the fully lithified (observed) thickness of the sediment package, then what is the porosity of the decompacted sediment package? **Explain**.

We define tectonic subsidence as the subsidence of the basement in sea water, but without the effects of sediment loading and compaction, and also removing the effects of water depth (w_d) during sedimentation and of eustatic sea-level changes (ΔSL). This allows us to easily compare the driving subsidence of a basin formed in stretched continental crust with the subsidence of ocean crust as it ages away from the mid-ocean ridge axis.



We isostatically balance the decompacted sediment column with a water loaded column (diagram above). The decompacted sediment thickness, z_{sd}, calculated, plus the underlying lithosphere (z_l in diagram) is in isostatic equilibrium with some thickness of water, zw, the underlying crust and lithosphere (z_l), plus some thickness of asthenosphere, z_a. In this case, we are not changing the thickness of the crust or upper mantle so they are the same in both cases and cancel out of the equilibrium equation. We assume zero water depth for our sedimentary basin and no sea level change for this isostatic balance. Therefore:

$$z_a + z_w = z_{sd}$$

or

$$z_a = z_{sd} - z_w \tag{5}$$

Balancing the two columns in the diagram above:

$$z_{sd}\rho_s = z_w\rho_w - z_a\rho_a \tag{6}$$

where

- ρ_w is the density of water (1.03)

- ρ_a is the density of the asthenosphere (3.2)

Solving for z_w, we obtain:

$$z_w = z_{sd}(\rho_a - \rho_{sd})/(\rho_a - \rho_w) \tag{7}$$

z_w is equivalent to the tectonic, water loaded subsidence. Why? **Explain**.

Calculate the tectonic subsidence for the stratigraphic section presented at the top of the page using a IPython script. You have a script called *backstrip.ipynb* and a function called *decomp*, which is called from within *backstrip.ipynb*. *decomp* based on equations 2, 3, 4 and 7 to make the calculations in for the decompaction. Estimating the decompacted thicknesses of each lithologic unit requires iterating. **Explain why** (see classnotes).

The notebook *backstrip.ipynb* plots the observed sediment thickness, decompacted sediment thickness and tectonic subsidence for the stratigraphic column at each of the 4 times for which you have data, starting at 150 Ma.

You will have to extend the IPython notebook which is given to solve the following questions:

You get a frantic phone call from the field geologist. She says that she has just heard from her paleontologist friend that the fauna in the youngest sandstone indicates that these sediments were deposited in 150 m of water. Also, her colleague at SHELL just told her that there was a eustatic sea level fall between 100 Ma and 75 Ma of 67.8 m relative to the land. What was the tectonic subsidence at 100 Ma? What was the tectonic subsidence at 75 Ma? You need to study the relevant portion of the class notes to understand how to tackle this problem and then you need to use your knowledge of IPython to add these computations to the script. Plot these new values on the previous graph (use hold command). Can you say anything about the driving mechanism for tectonic subsidence (flexure, extension, other mechanisms)? Think about this very carefully (don't mix up causes and consequences) and include an explanation in your discussion. Which factor introduces the largest uncertainty into such basin history models? **Explain**. In this context it would be worthwhile to have a look at some of the papers which have been provided, especially the papers by Kominz and Bond, Celerier, and Steckler and Watts.

A second hole that was drilled in a nearby basin yielded four units with the same thicknesses, but the lithologies are quite different. Instead of sandstone, limestone was recovered, and instead of shale, anhydrite was found. This means these sediments were deposited in a small, isolated rift basin due to evaporation. What was the tectonic subsidence history in this basin? How does it differ from the first basin you analysed? Is there more or less tectonic subsidence in the second basin, and how does this relate to having sediments with higher densities in the second basin? **Discuss**.

Lithology	porosity at zero depth (%/100)	z_m (km)	grain density (g/cm3)
Anhydrite	0.4	6	2.96
Limestone	0.4	6	2.7

Visualise in NbViewer

Follow this link to see the IPython notebook that we are going to use for these 2 labs.

LAB5&6 IPython material : nbviewer link