Seismic interpretation:

The purpose of interpretation is to obtain depth map (structural map) of the surveyed area. These maps are given to the geologist to locate:

1- Exploration wells.
2- Delaines (evaluation) wells.
3- Development wells.

Type of seismic maps:

1- **Isochrones (Time) map**.
2- **Velocities map**.
3- **Depth map**.

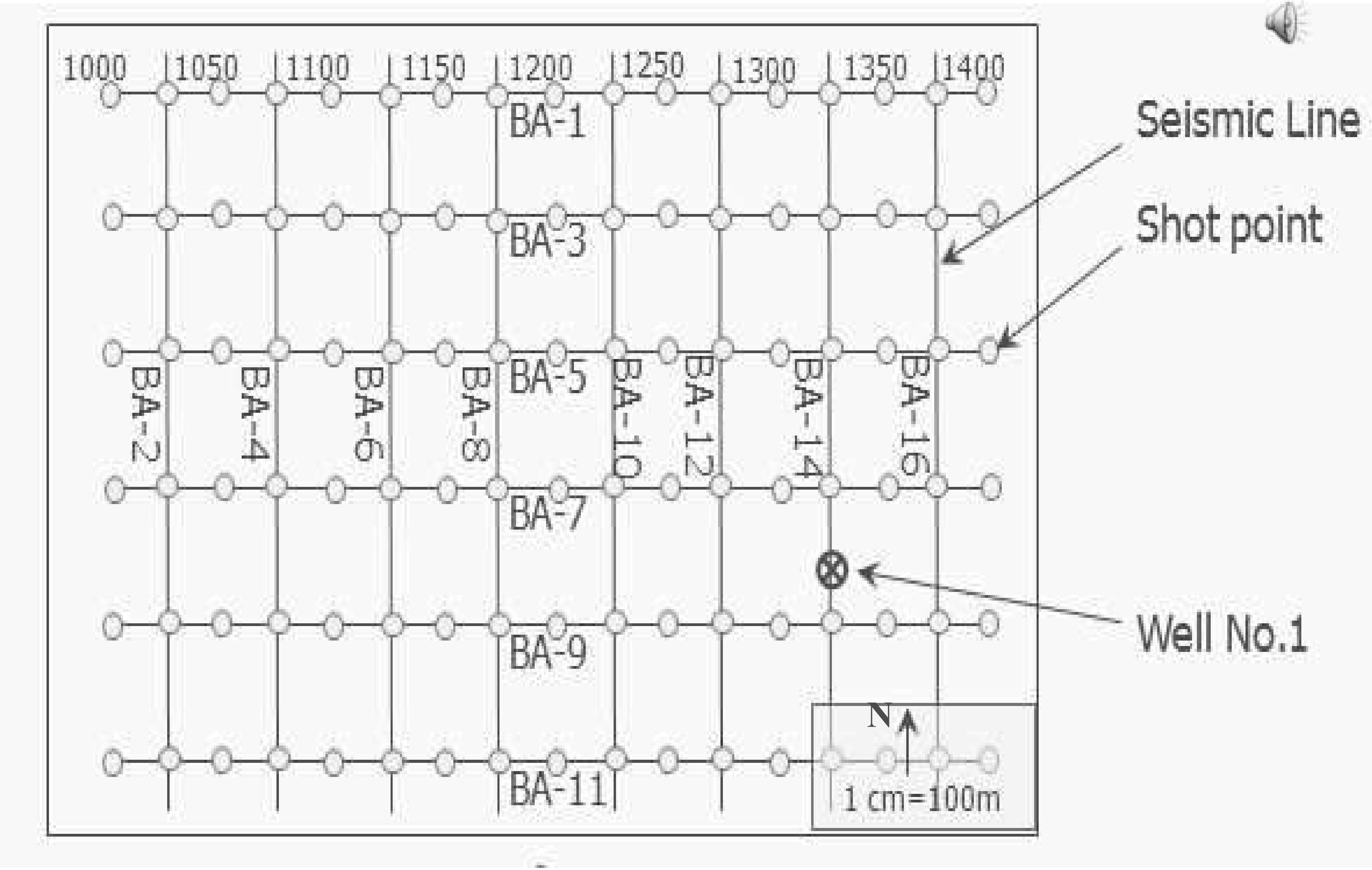
Construction of seismic maps:

The following tools are required

1- Base map.

It is a map consist the following elements:

a- Seismic lines.
b- Names and number of the seismic lines.
C- Shot point number.
d- Location of wells.
e- Scale and north symbol.



Base Map of Study Area

The direction of seismic lines depend on:

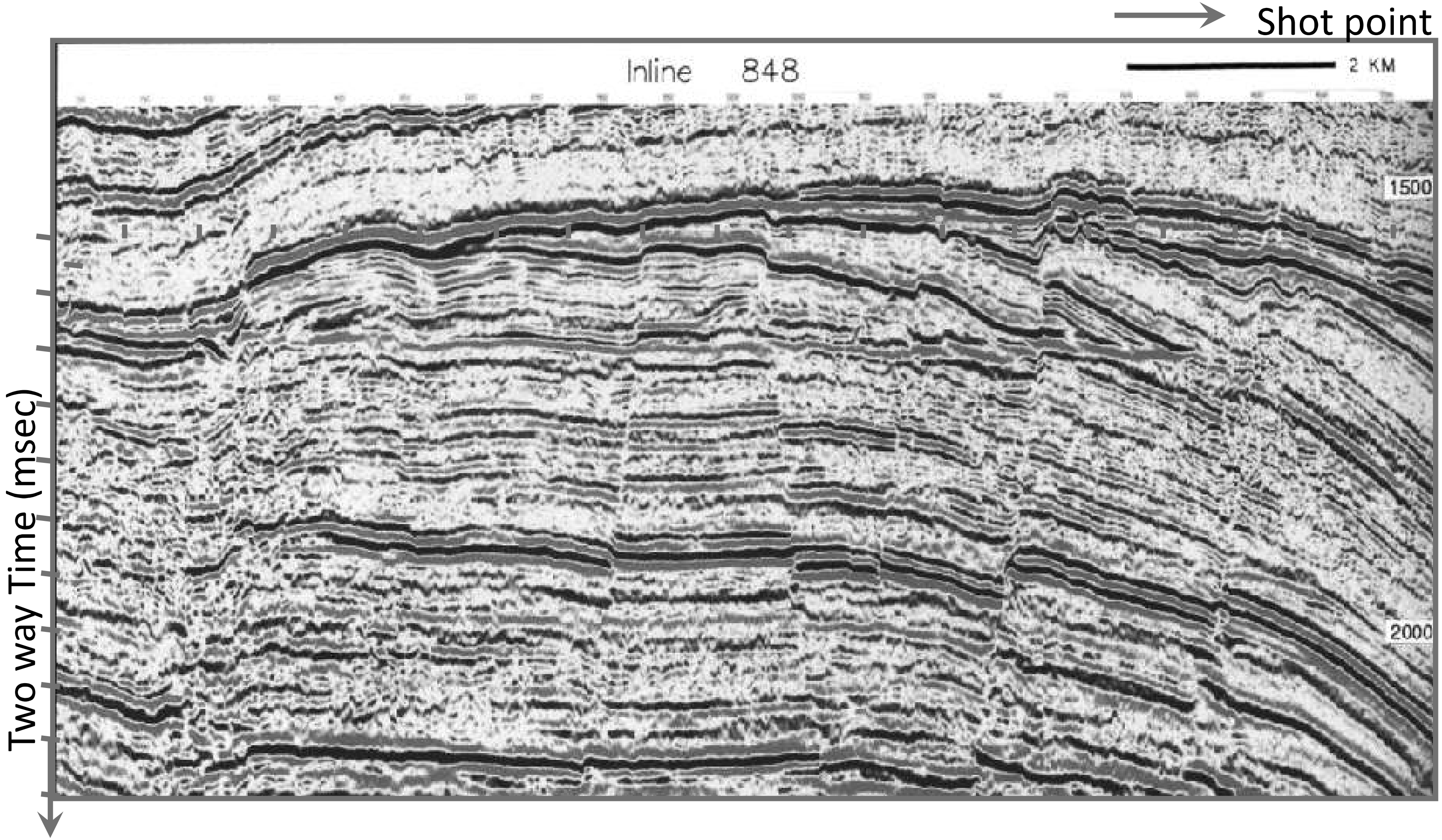
1- Strike and dip of the outcrops.
2- General trend of the structures.
3- General strike.

The following information must be known:

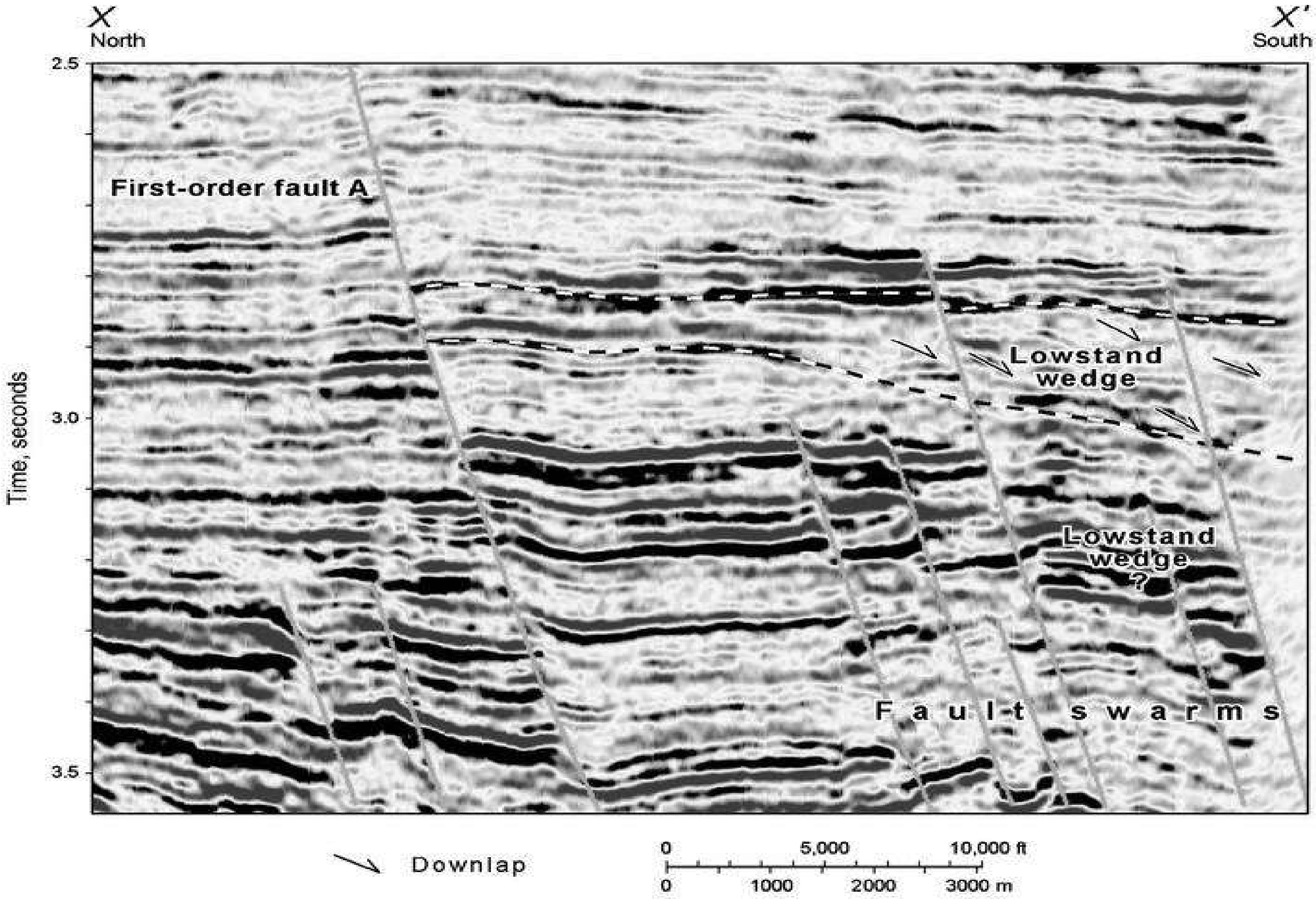
1- Whether the seismic lines from different survey.
2- Fold of coverage.
3- Energy source.
4- Elevation of datum plane.
5- Different processing operation.

2- Seismic sections.

It is a product of a final stage of data processing.

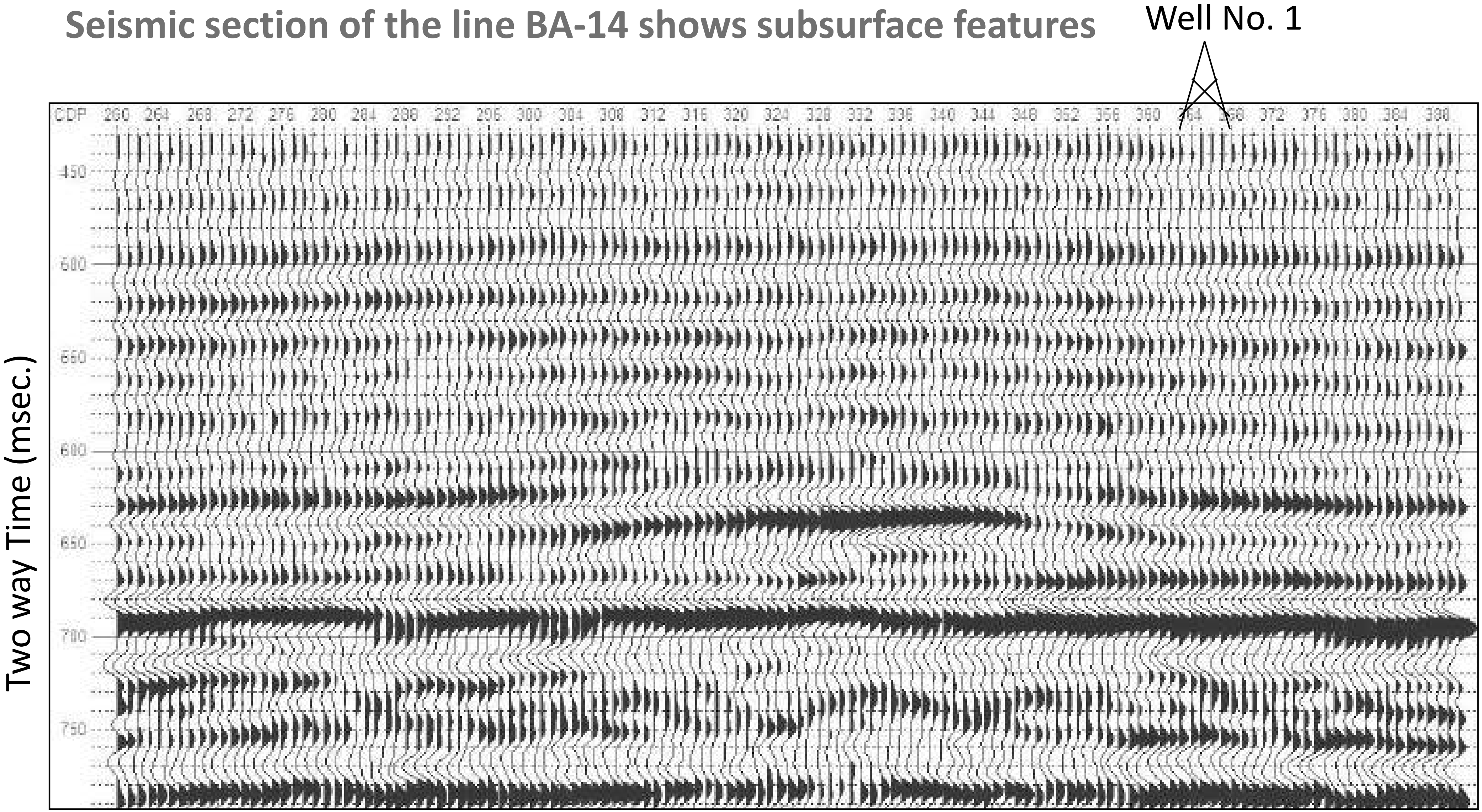


Seismic section of the line BA-3shows subsurface layers



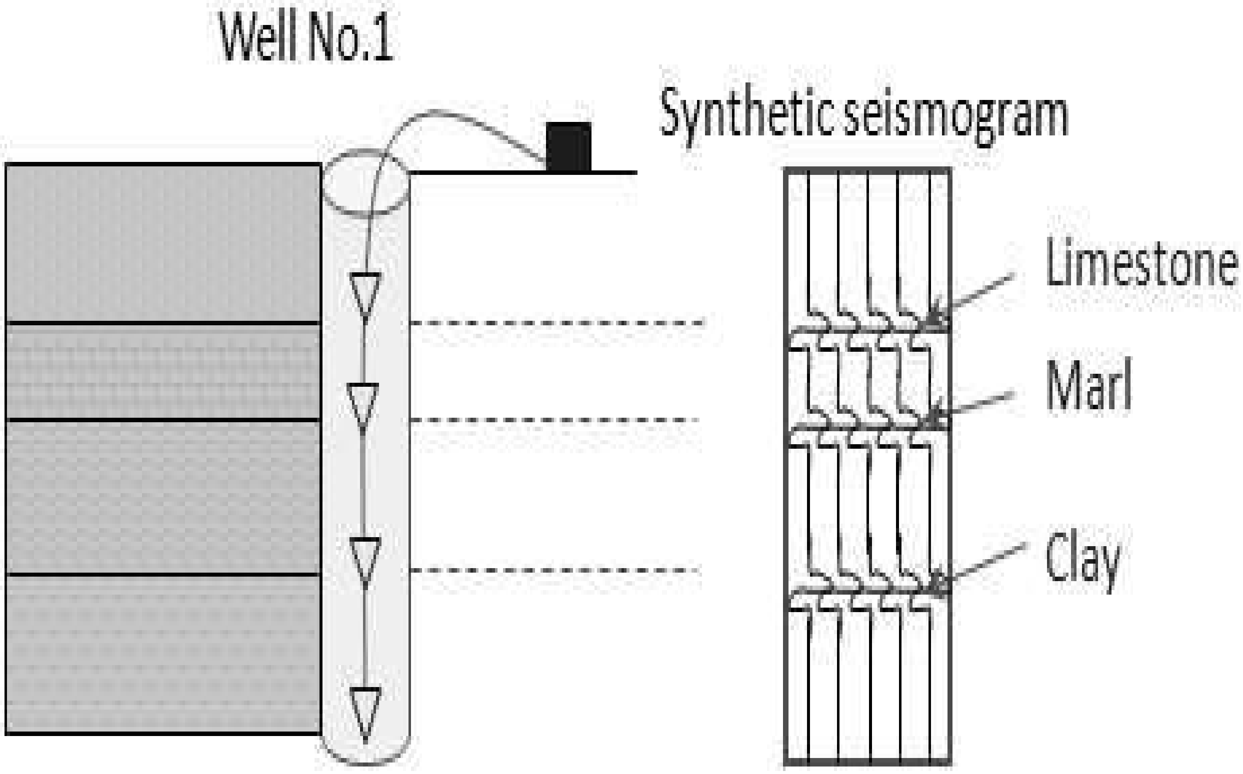
Vertical seismic slice along profile XX́ showing faulted stratigraphic features.

Seismic section of the line BA-14 shows subsurface features

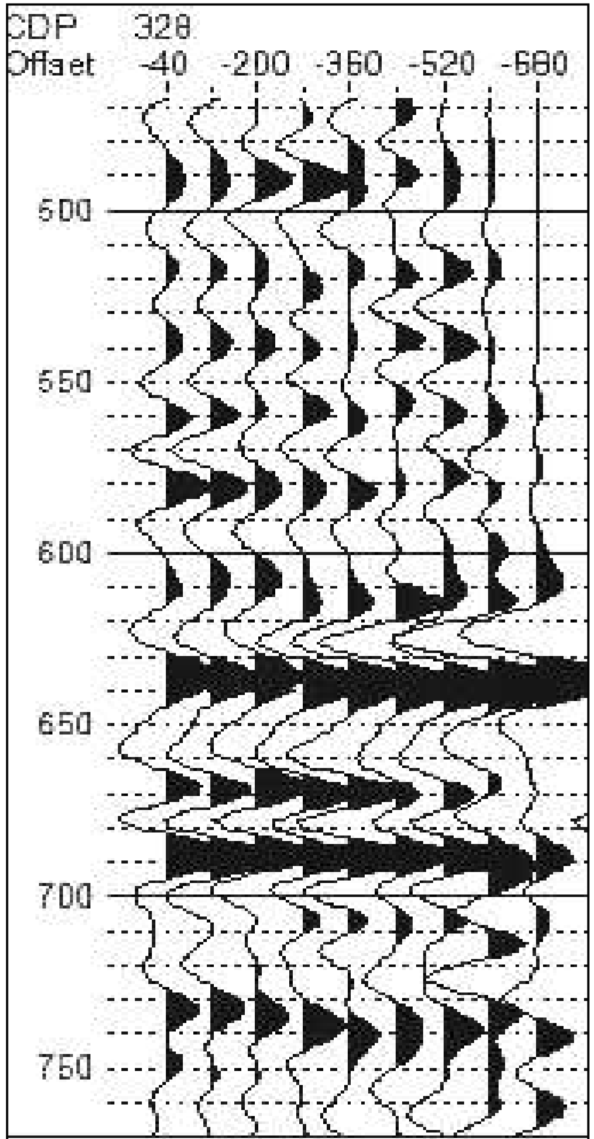


3- Synthetic seismogram.

It is a theoretical seismic response model for assumed geological situation



Actual Synthetic seismogram



Notes:-

A- When there is a well and the well has synthetic seismogram.

1-The synthetic seismogram of the well is prepared.

2- The depths of the different geological unit obtained from the geological column of the well.

3- The velocity of different geological unit (or formation) calculate from the well survey.

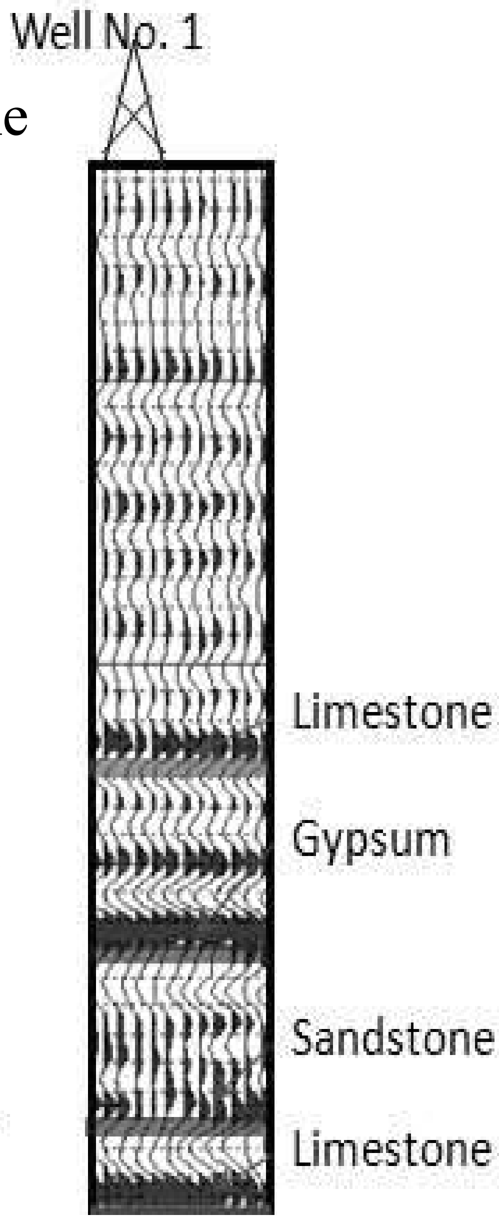
4- The two way time is calculate for each layer by:

TWT = Depth/ Velocity

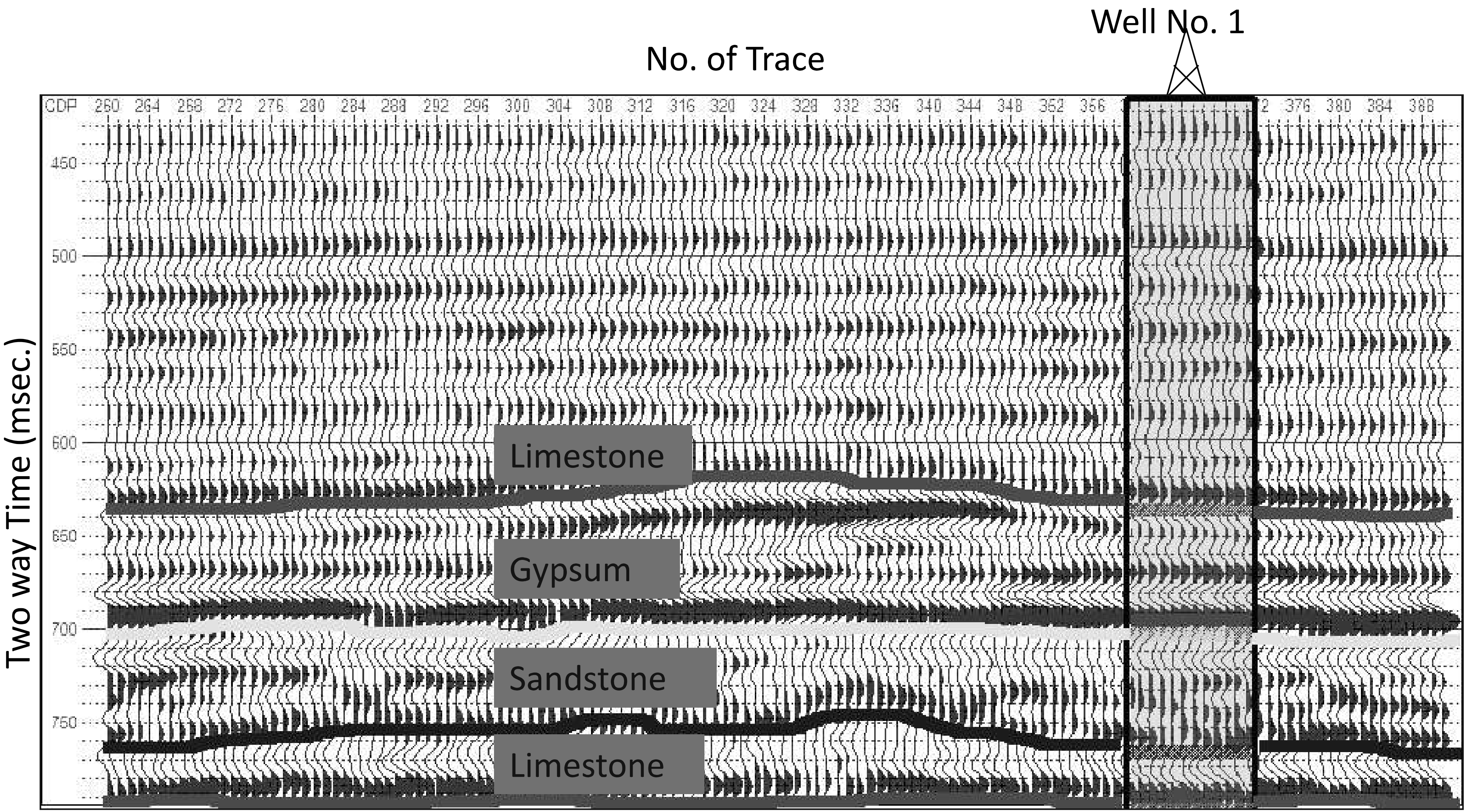
5- From the calculated TWT different reflectors on synthetic seismogram were picked.

6- Then the synthetic seismogram is coincide with the seismic section No. BA-14 at its proper location

7- The reflectors will pick on this seismic line and then on other lines using the intersection points ……………



Seismic section of the line BA-14 shows subsurface features



8- Measurements of TWT were taken for each reflector and on each seismic section.

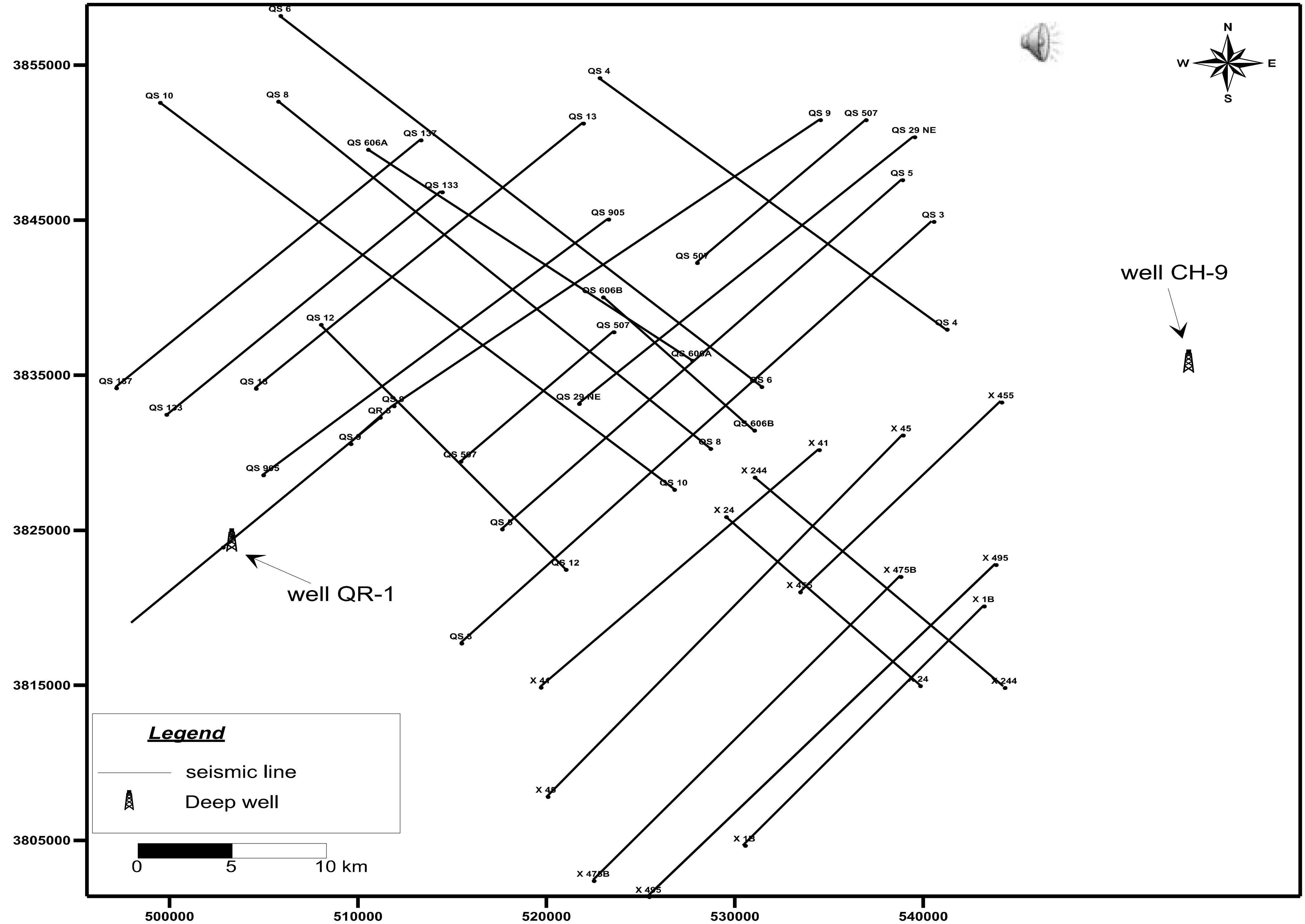
9- The measurements are plot in the following table:

Shot point No.	Two way time (msec) Reflector-1	Reflector-2	Reflector-3	Reflector-4
1000	223	345	556	654
1050	229	356	535	667
1100	243	367	542	679
1150	245	365	552	689
1200	254	376	578	690
1250	269	381	587	700

10- The measurements of TWT for each reflector are plotted on the base map of the area for drawing isochrone map

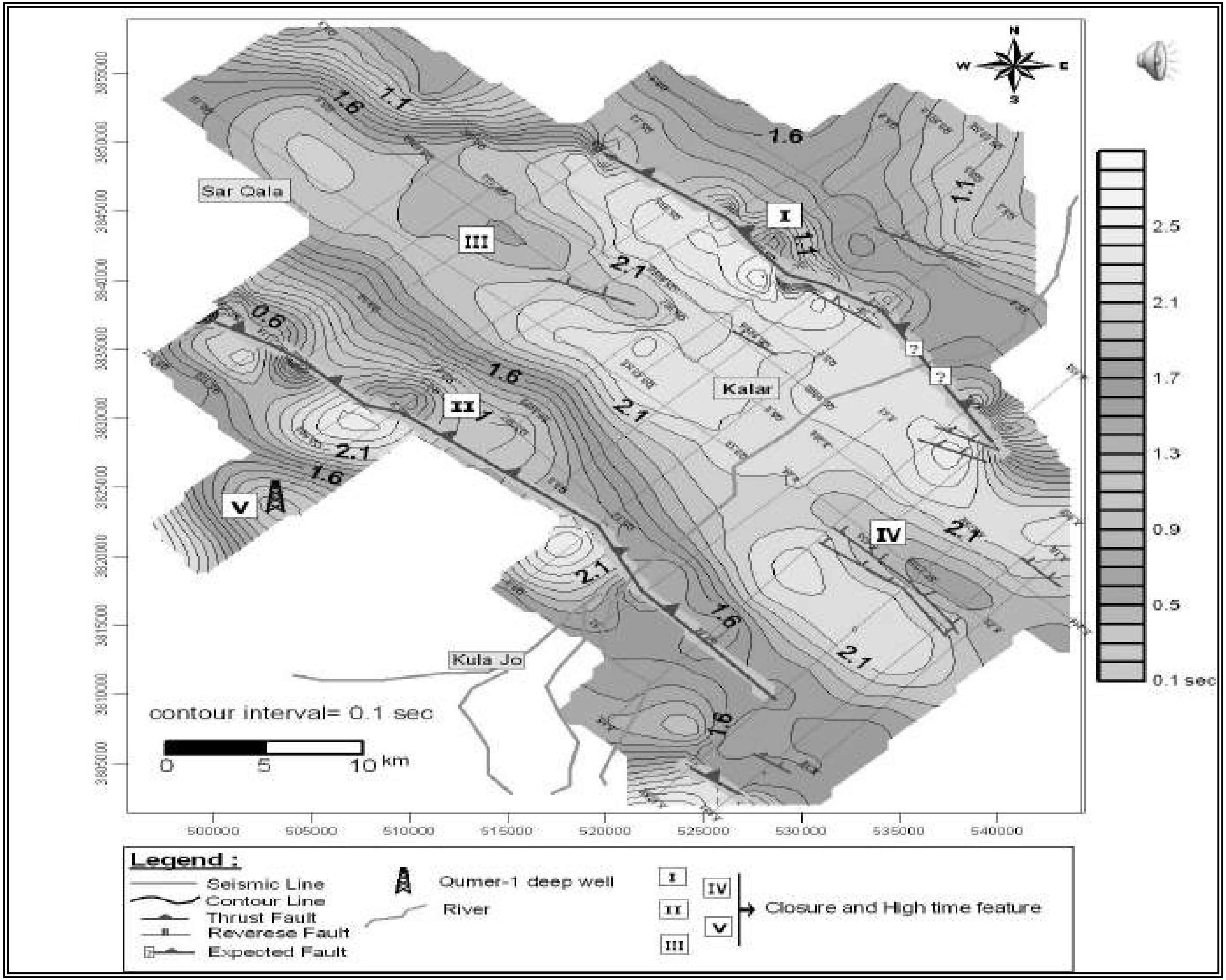
11- From velocity analysis the average velocity map for each reflector is drawn also.

12- Then by coinciding the velocity map over isochrone map the depth maps for each layer are drawn.

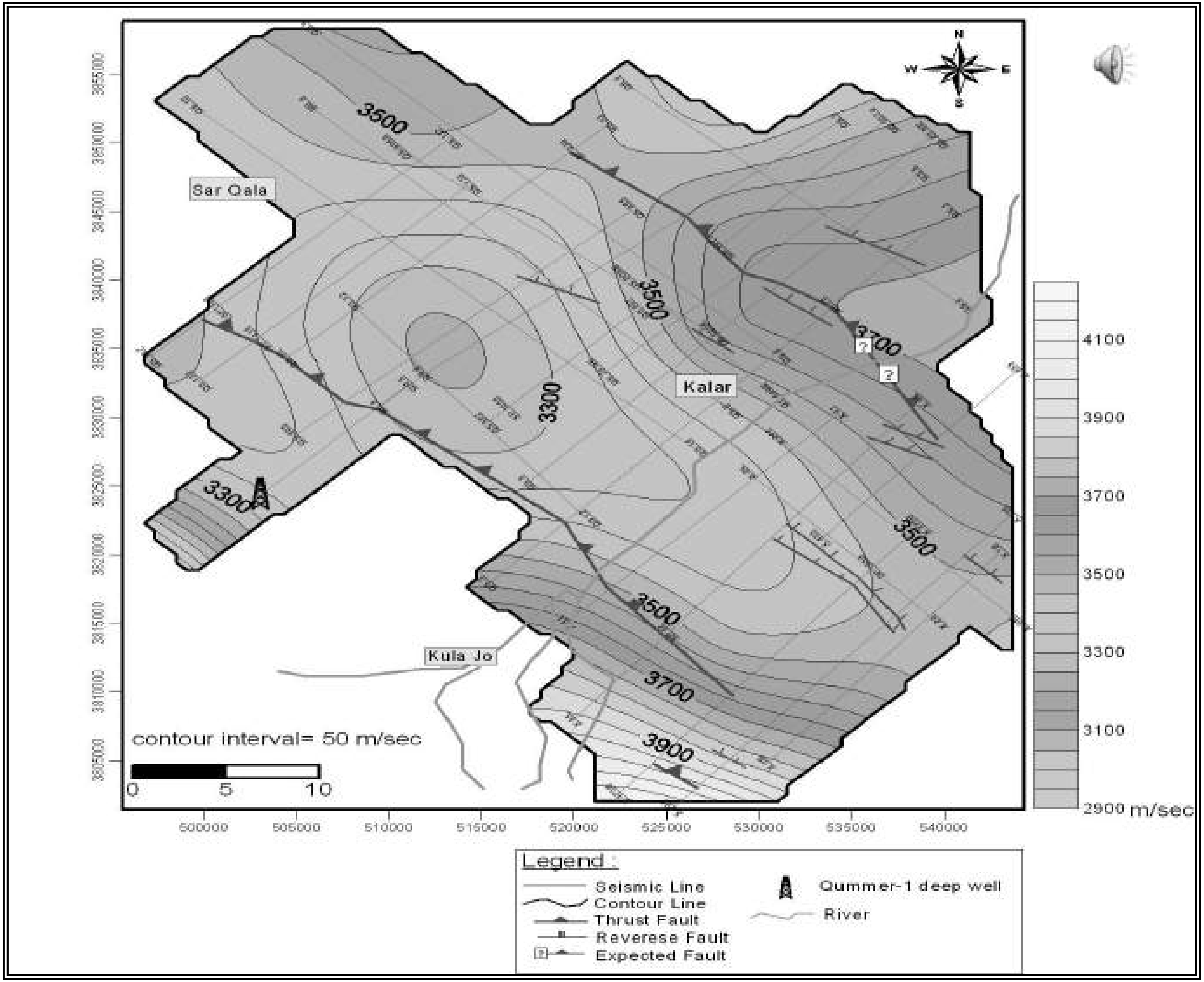


N
S
W
E
well CH-9
well QR-1
QS 6
QS 4
QS 10
QS 8
QS 13
QS 9
QS 507
QS 29 NE
QS 137
QS 606A
QS 133
QS 5
QS 905
QS 3
QS 606B
QS 12
QR 5
X 455
X 45
X 41
X 244
X 24
X 475B
X 495
X 1B
3855000
3845000
3835000
3825000
3815000
3805000
500000
510000
520000
530000
540000
Legend
seismic line
Deep well
0
5
10 km

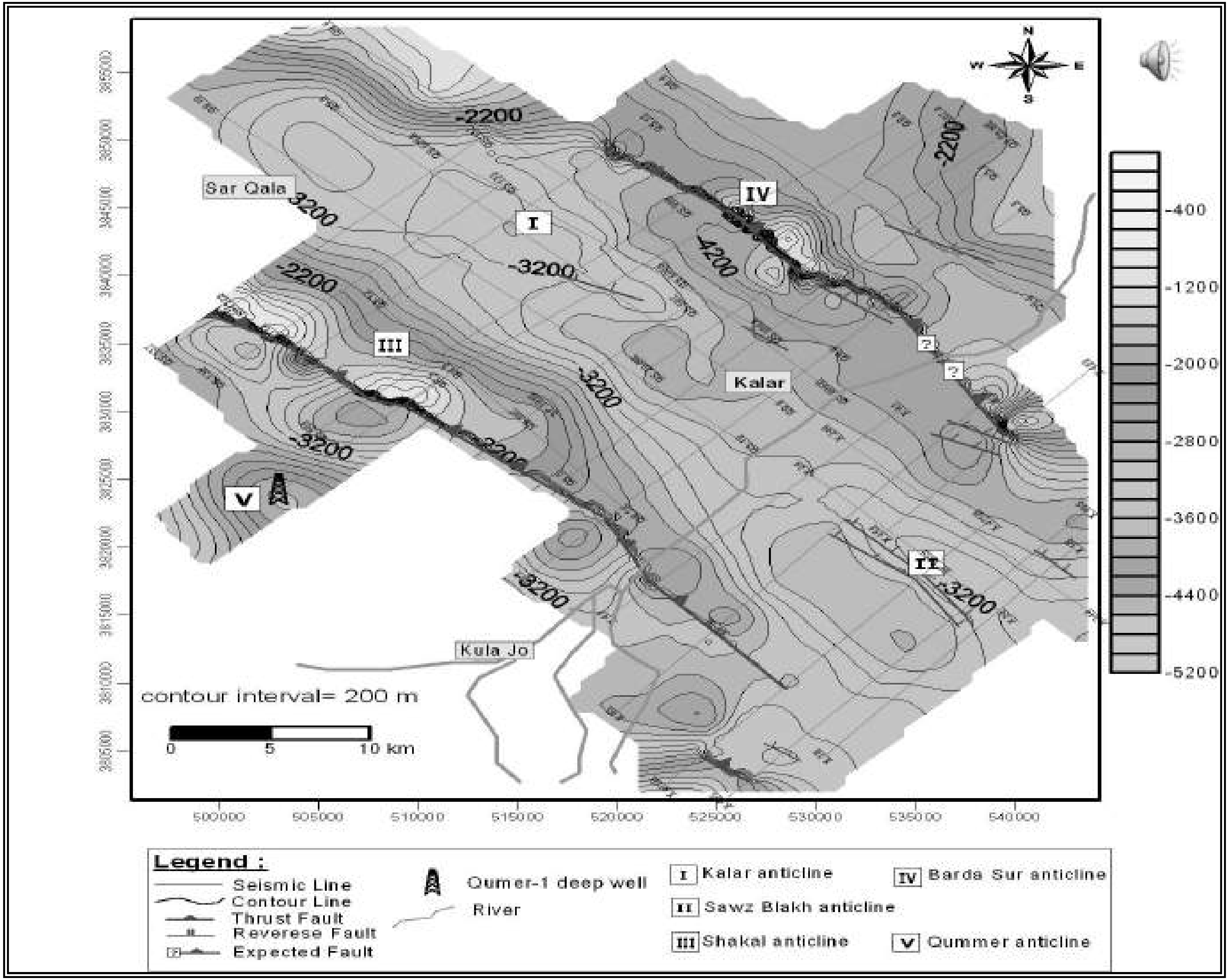
Base map



Isochrone map of reflector-1



Average velocity map of reflector-1



Depth map of reflector-1

B- When there is a well and the well has no synthetic seismogram or there is no well.

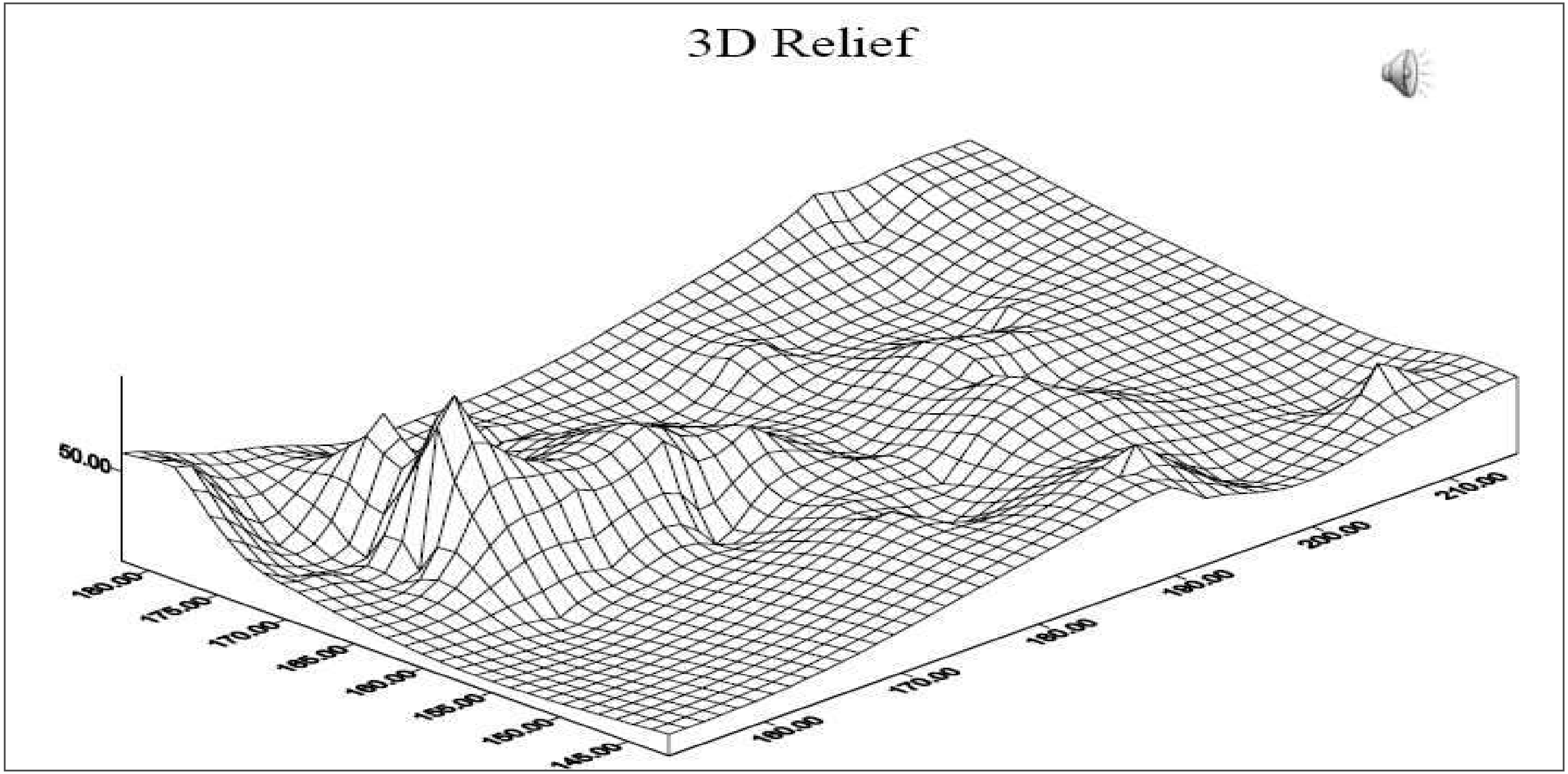
1- The study area is connected with a well located out side the area.

2- The studied area connected with an adjacent interpreted area.

3- The same steps described before followed for interpretation.

Seismic maps:

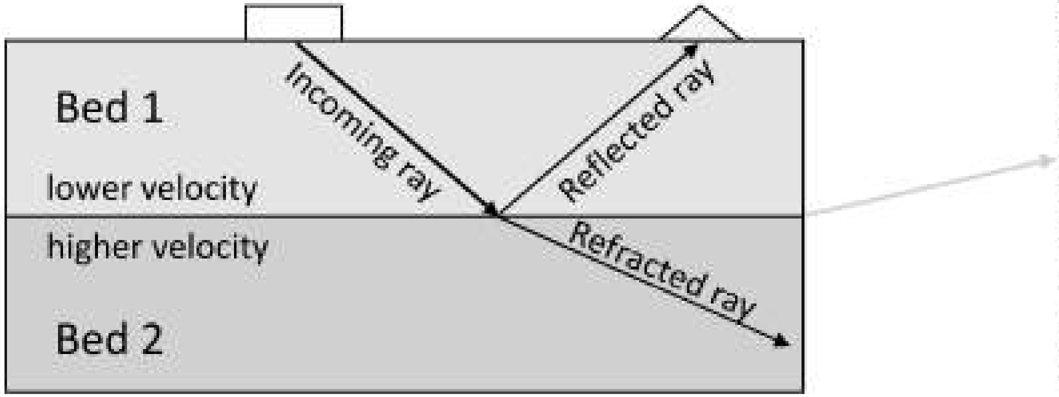
Isochrone map	x	Velocity map	=	Depth map
Isochrone map(H1)	-	Isochrone map(H2)	=	Interval Time map
Interval Time map	x	Interval velocity map	=	Isopach map
Depth map (H2)	-	Depth map (H1)	=	Isopach map

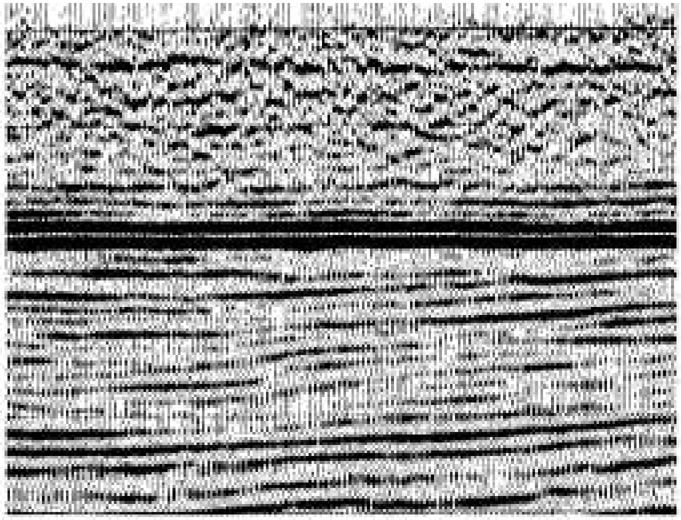


THE END

What is a reflector?

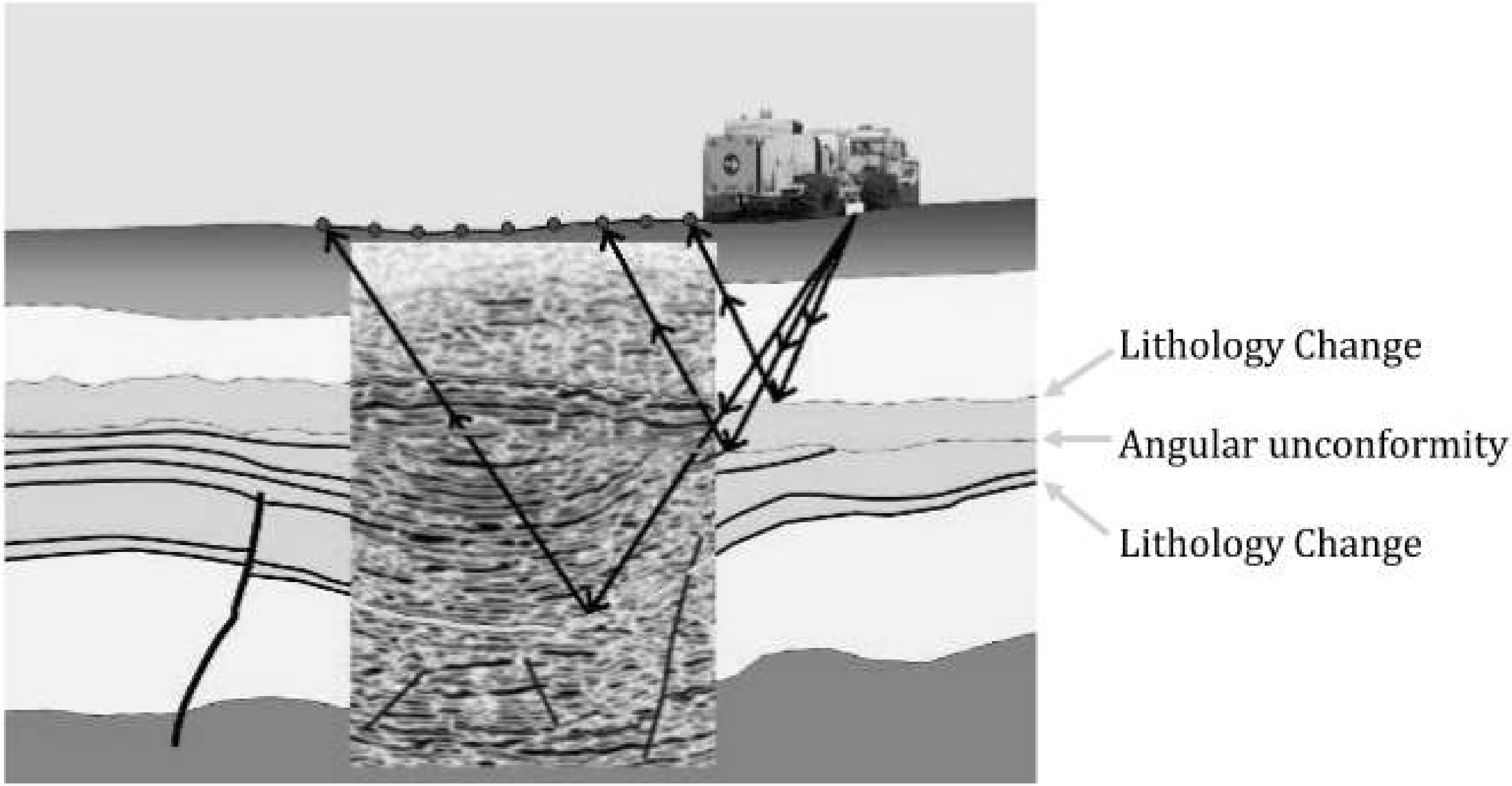
- A seismic reflector is a boundary between beds with different properties. There may be a change of lithology or fluid fill from bed 1 to bed 2.
- These property changes cause some sound waves to be reflected back towards the surface.
- Major changes in properties usually produce strong, continuous reflectors as shown by the arrow





Seismic acquisition onshore (1)

- Seismic horizons represent changes in density and allow the subsurface geology to be interpreted.

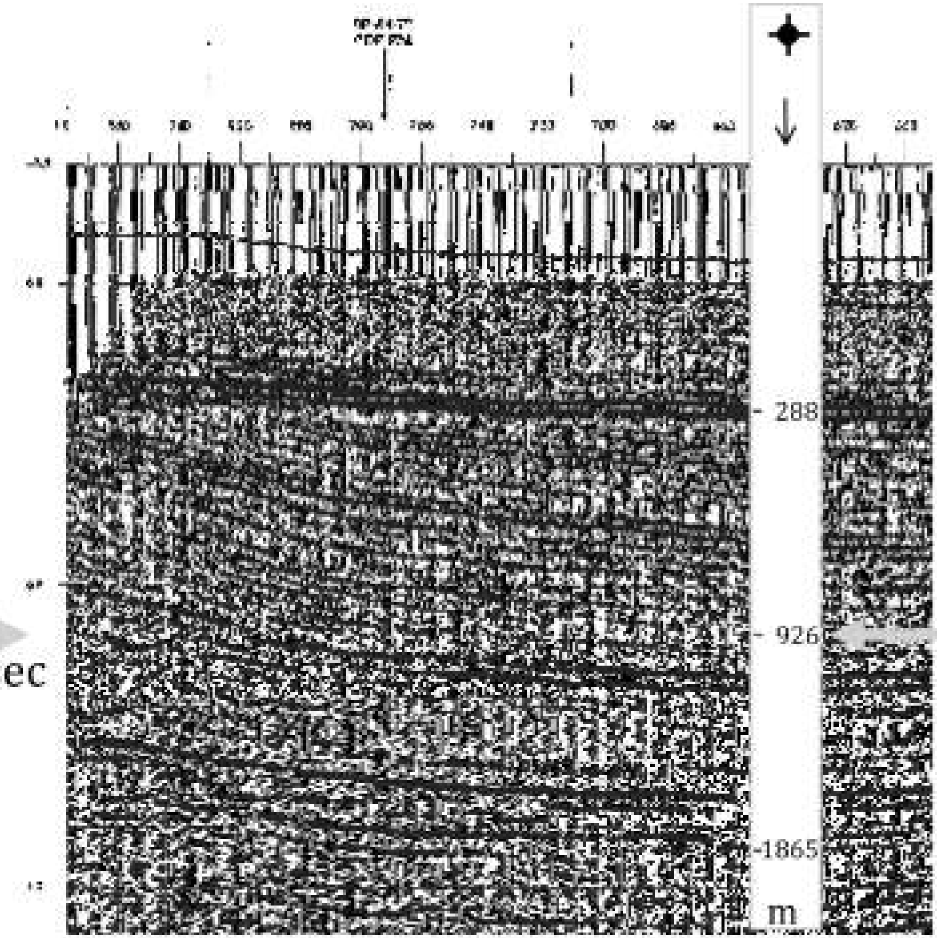


Time *versus* depth

- Two way time (TWT) does not equate directly to depth
- Depth of a specific reflector can be determined using boreholes
- For example, 926 m depth = 0.58 sec. TWT

- Two Way Time (TWT) does not equate directly to depth

- Depth of a reflector is determined by boreholes



Well Logs Versus Seismic

- Well logs
  - Great vertical resolution
  - Delimit bounding surfaces
  - Establish lithology of sediments penetrated
- Seismic
  - Great lateral continuity and resolution
  - Define gross sediment geometry

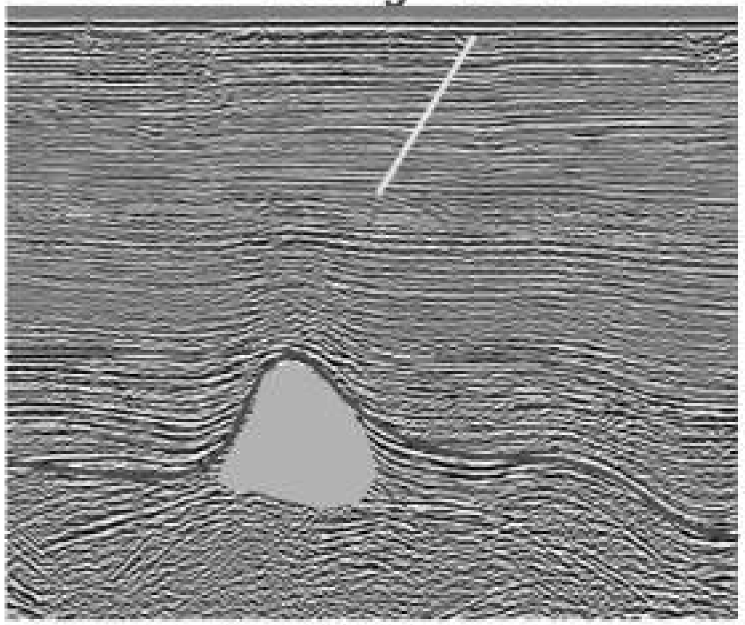
Seismic Data Interpretation is more than picking

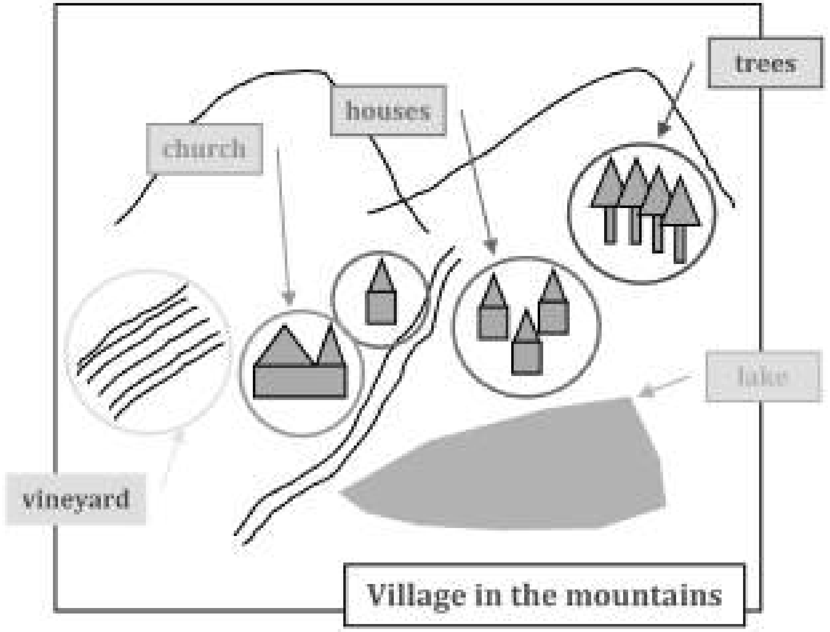
Seismic Interpretation

=

Understanding the geology of the subsurface

Seismic Data Interpretation is a Data Analysis Problem





High Level

Low Level

Seismic interpretation	Data analysis
Building the geological model	**Understanding the system** Explaining the system.
Giving geological meaning to the features	**Identifying information** Giving a meaning to objects
Picking the features	**Finding information** Segmenting information into objects

Seismic Interpretation and Subsurface Mapping

Seismic Interpretation and Subsurface Mapping

1. Introduction
2. Basic principles

Seismic Data Interpretation is more than picking

Seismic Interpretation

=

Understanding the geology of the subsurface

1. Introduction

- Seismic interpretation and subsurface mapping are key skills that are used commonly in the oil industry

- This teaching resource introduces the basic principles of seismic interpretation and then, if time permits, they can be applied in a practical exercise

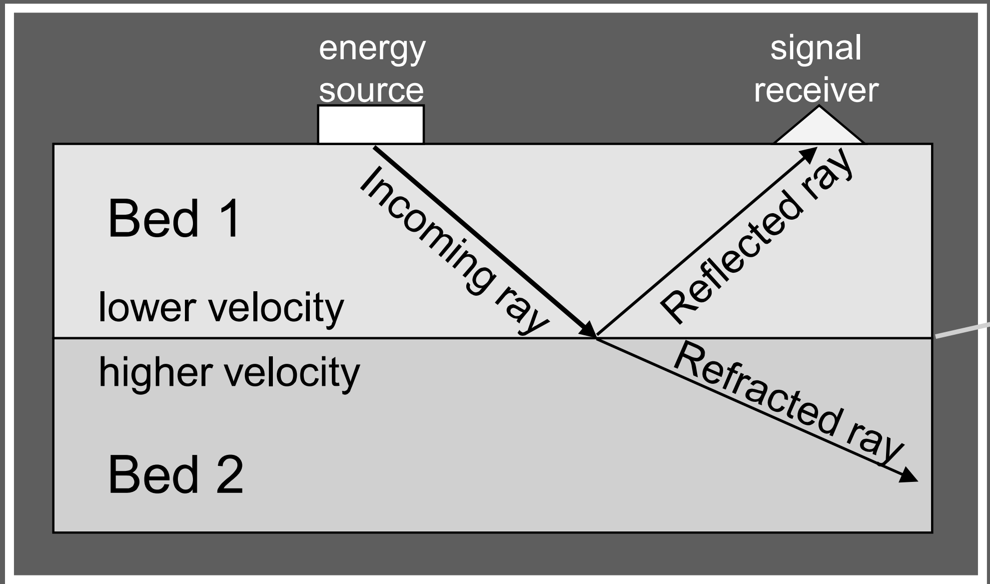
2. Basic principles

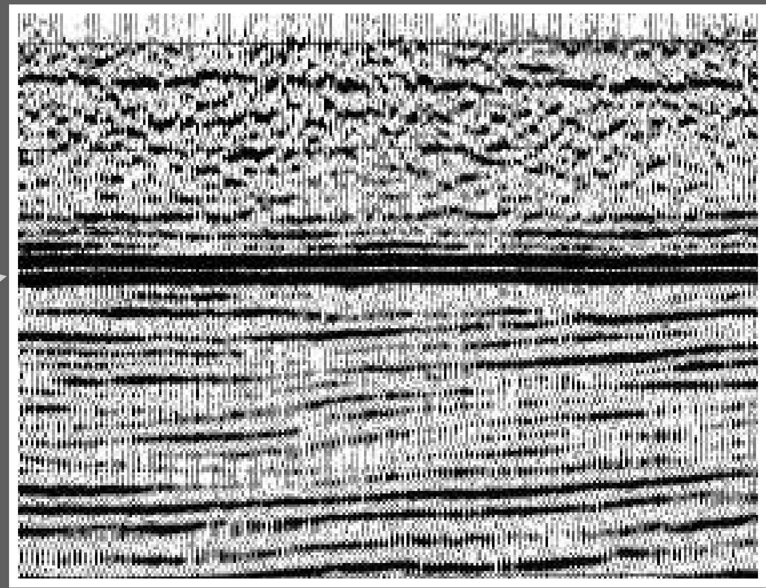
- Understanding the data
- Seismic interpretation

What is a reflector?

A seismic reflector is a boundary between beds with different properties. There may be a change of lithology or fluid fill from Bed 1 to Bed 2. These property changes cause some sound waves to be reflected towards the surface.

There are many reflectors on a seismic section. Major changes in properties usually produce strong, continuous reflectors as shown by the arrow.





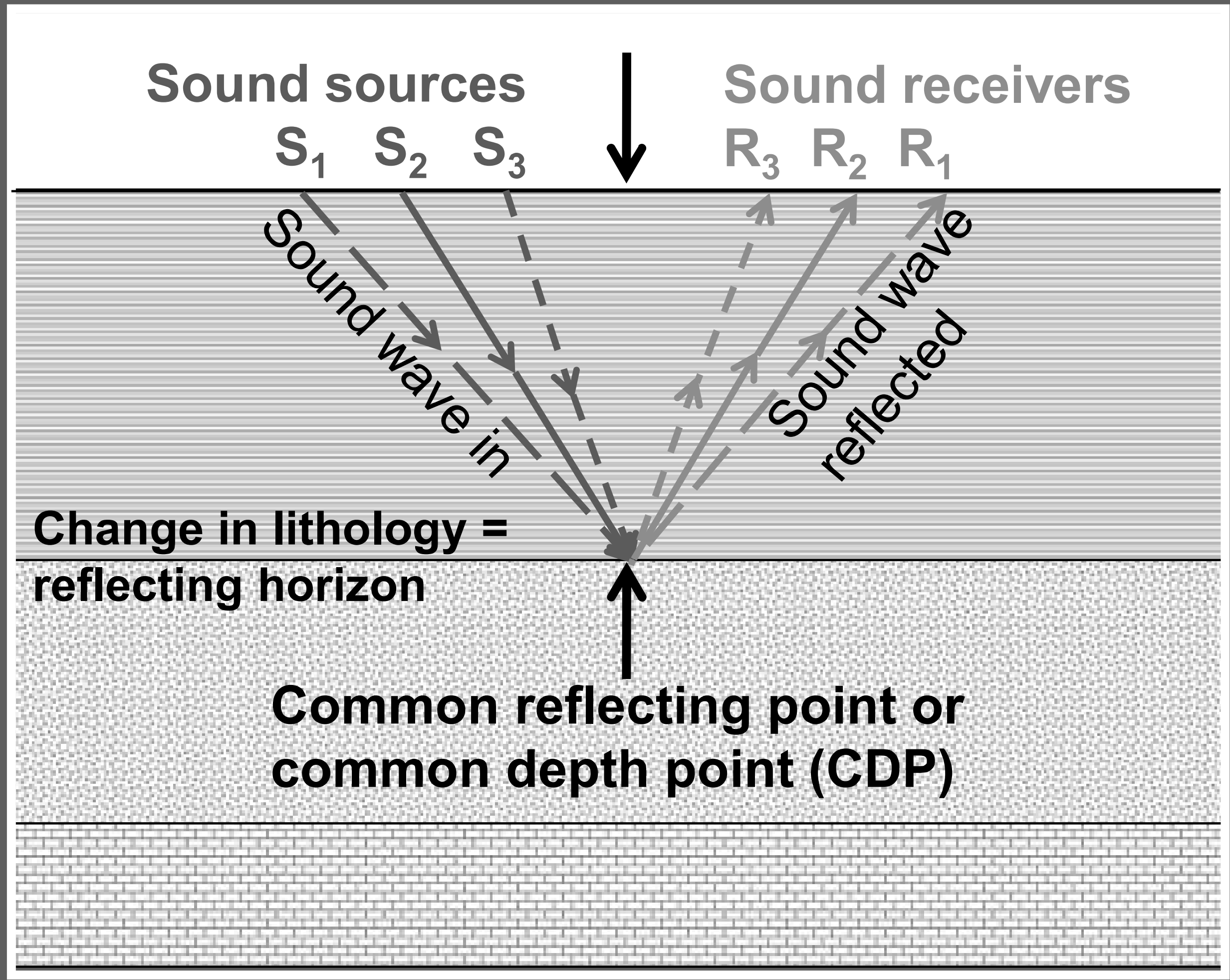
Understanding the data

- Common Depth Points (CDPs)
- Floating datum
- Two way time (TWT)
- Time *versus* depth

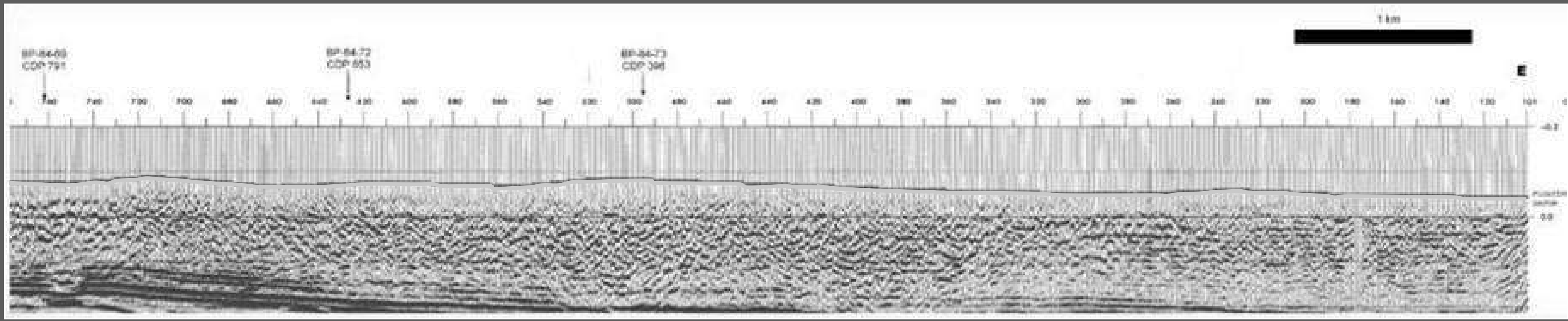
Common Depth Points

CDPs are defined as 'the common reflecting point at depth on a reflector or the halfway point when a wave travels from a source to a reflector to a receiver'.

Common midpoint above CDP



Floating datum



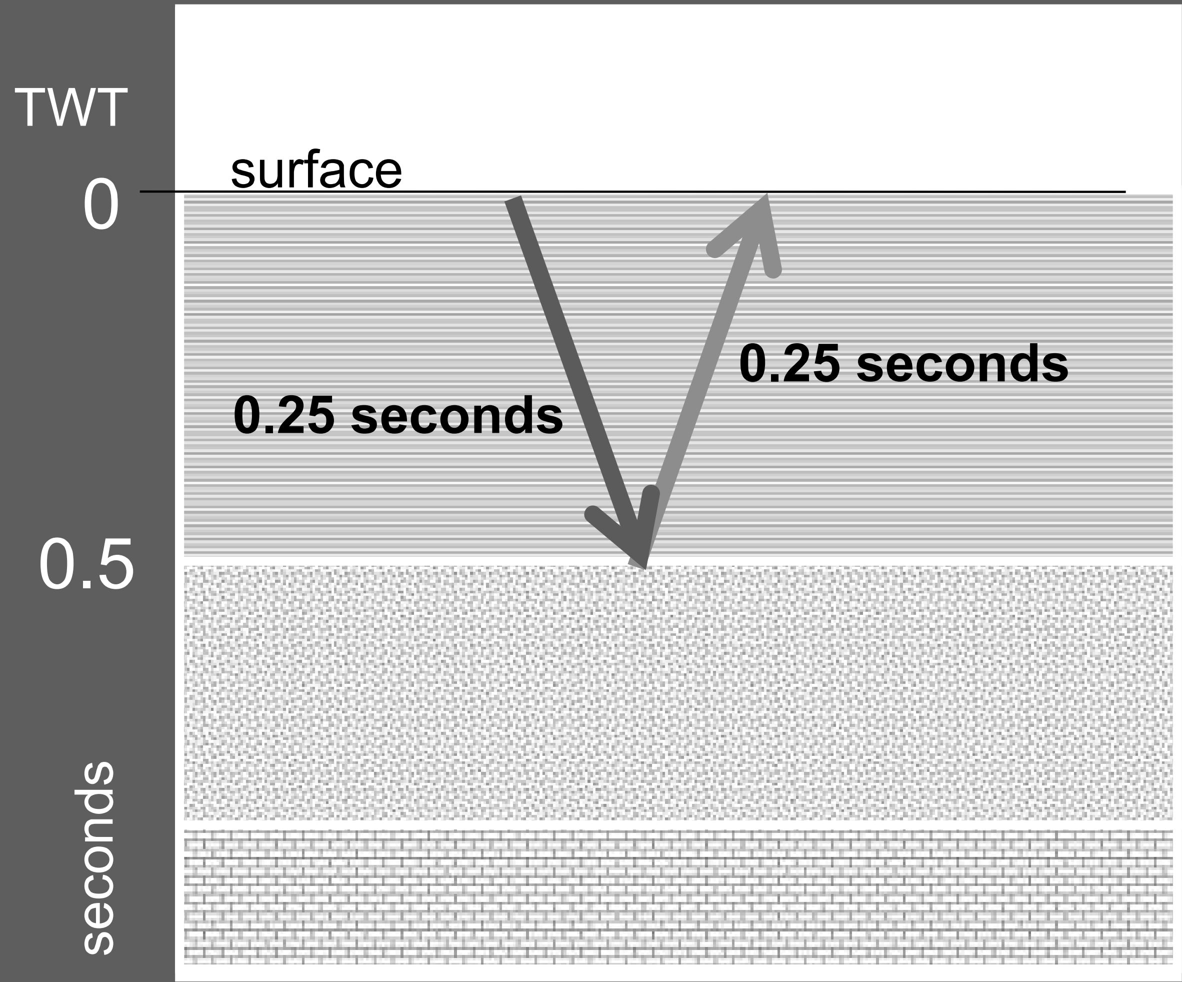
The floating datum line represents travel time between the recording surface and the zero line (generally sea level). This travel time depends on rock type, how weathered the rock is, and other factors.

The topographic elevation is the height above sea level of the surface along which the seismic data were acquired.

Two way time (TWT)

Two way time (TWT) indicates the time required for the seismic wave to travel from a source to some point below the surface and back up to a receiver.

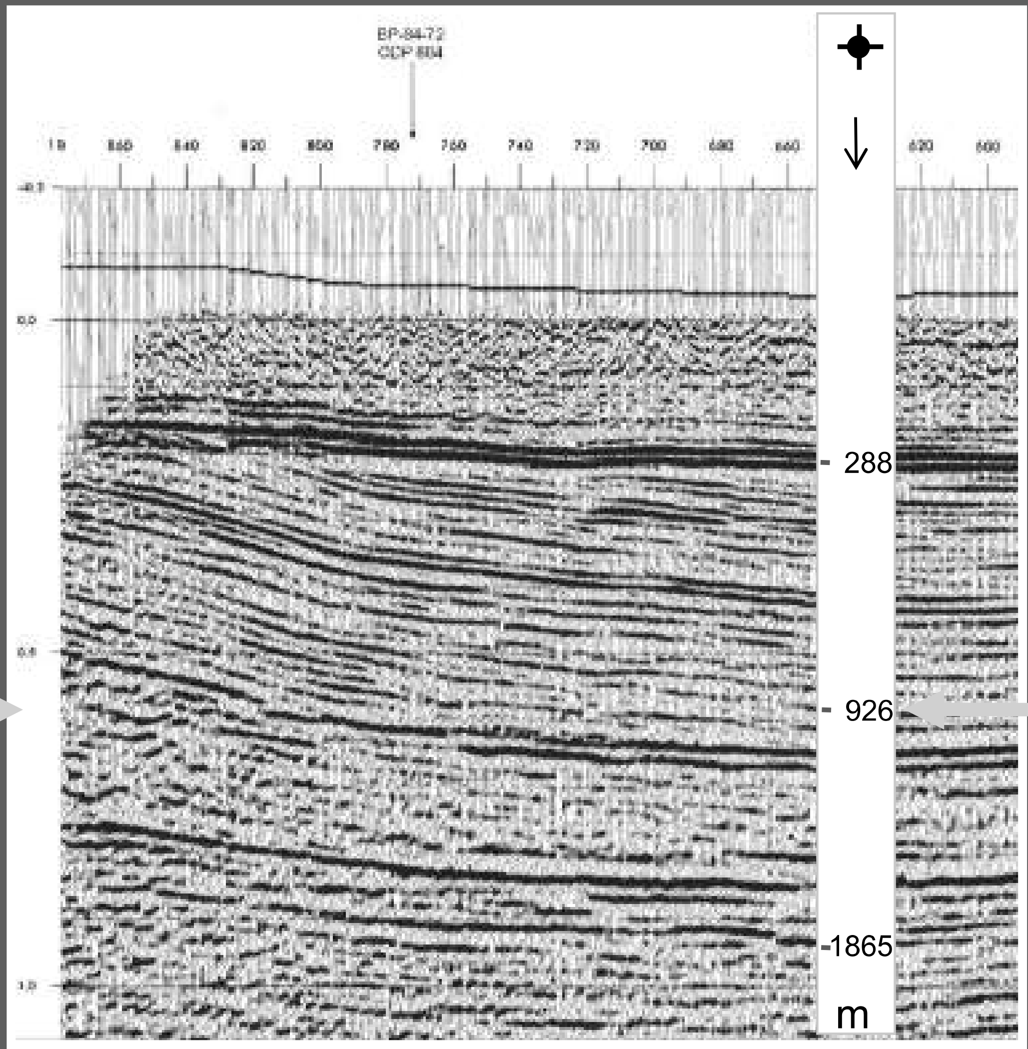
In this example the TWT is 0.5 seconds.



Time *versus* depth

- Two way time (TWT) does not equate directly to depth
- Depth of a specific reflector can be determined using boreholes
- For example, 926 m depth = 0.58 sec. TWT

0.58 sec

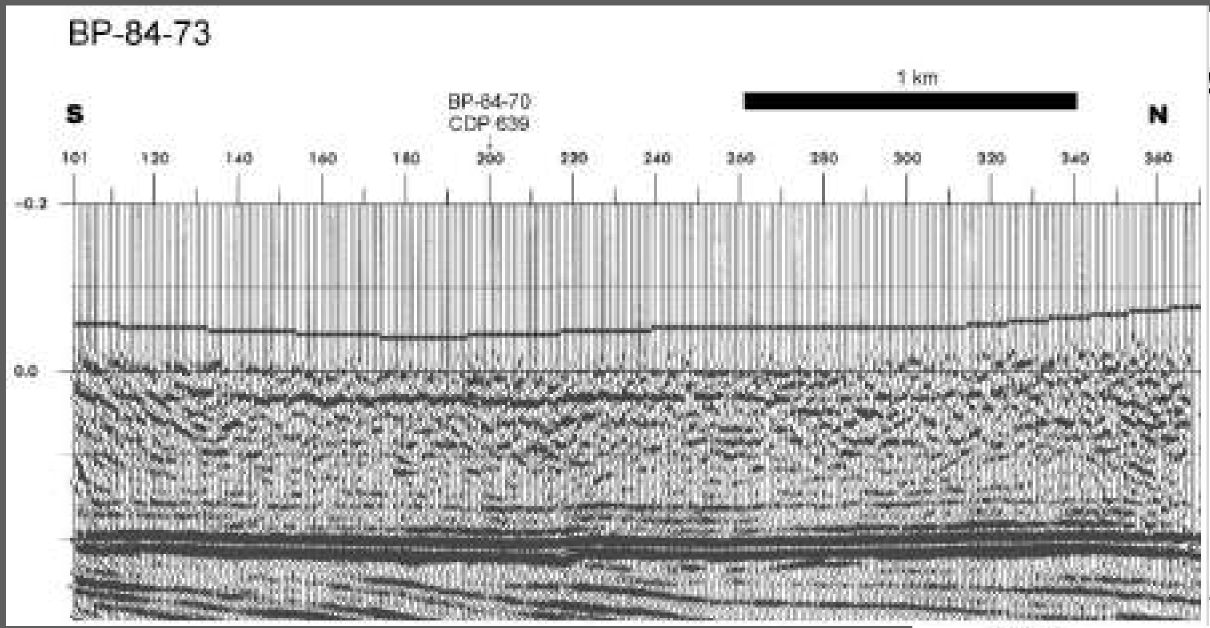


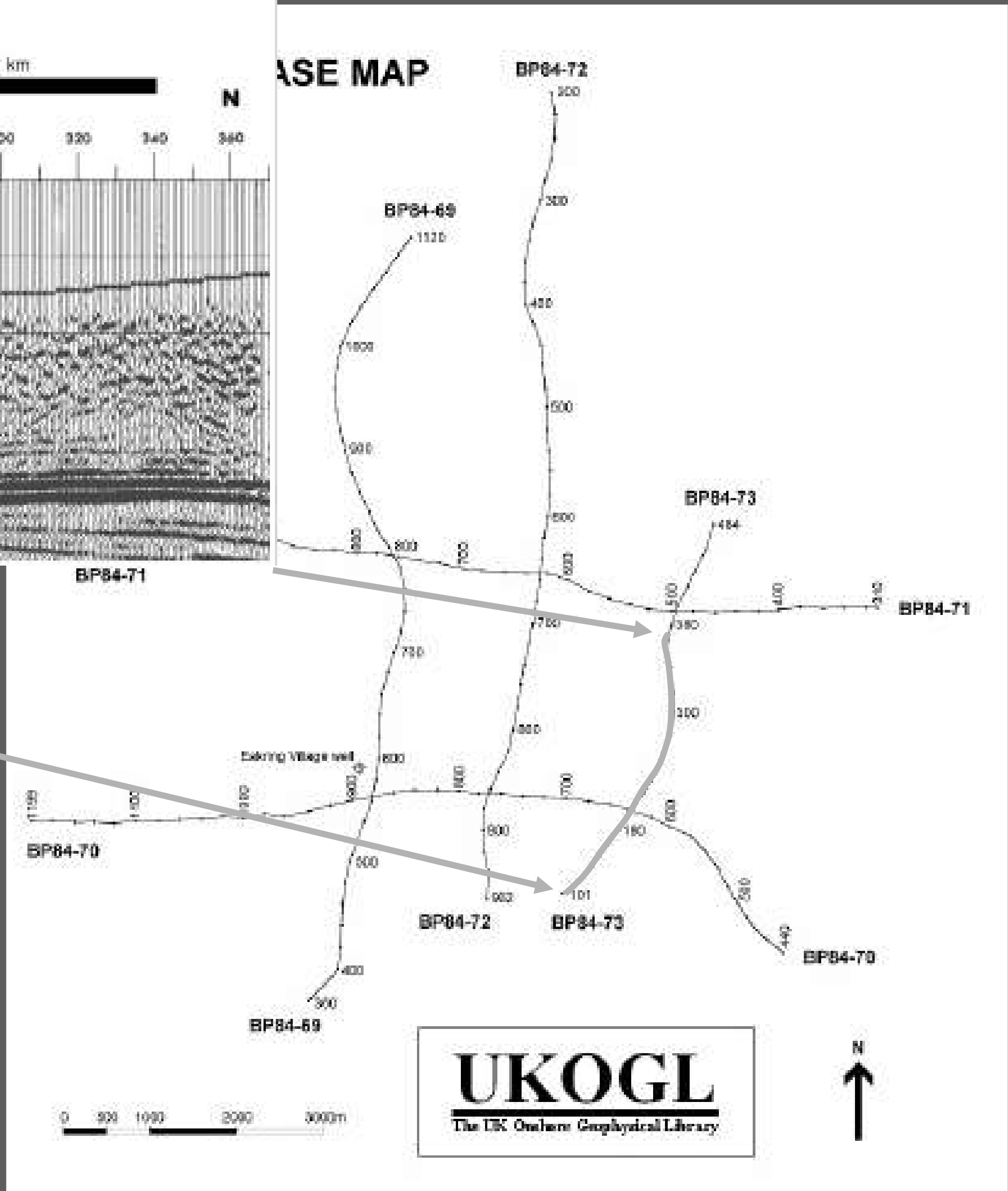
926 m

Seismic interpretation

- Check line scale and orientation.
- Work from the top of the section, where clarity is usually best, towards the bottom.
- Distinguish the major reflectors and geometries of seismic sequences.

Scale and orientation

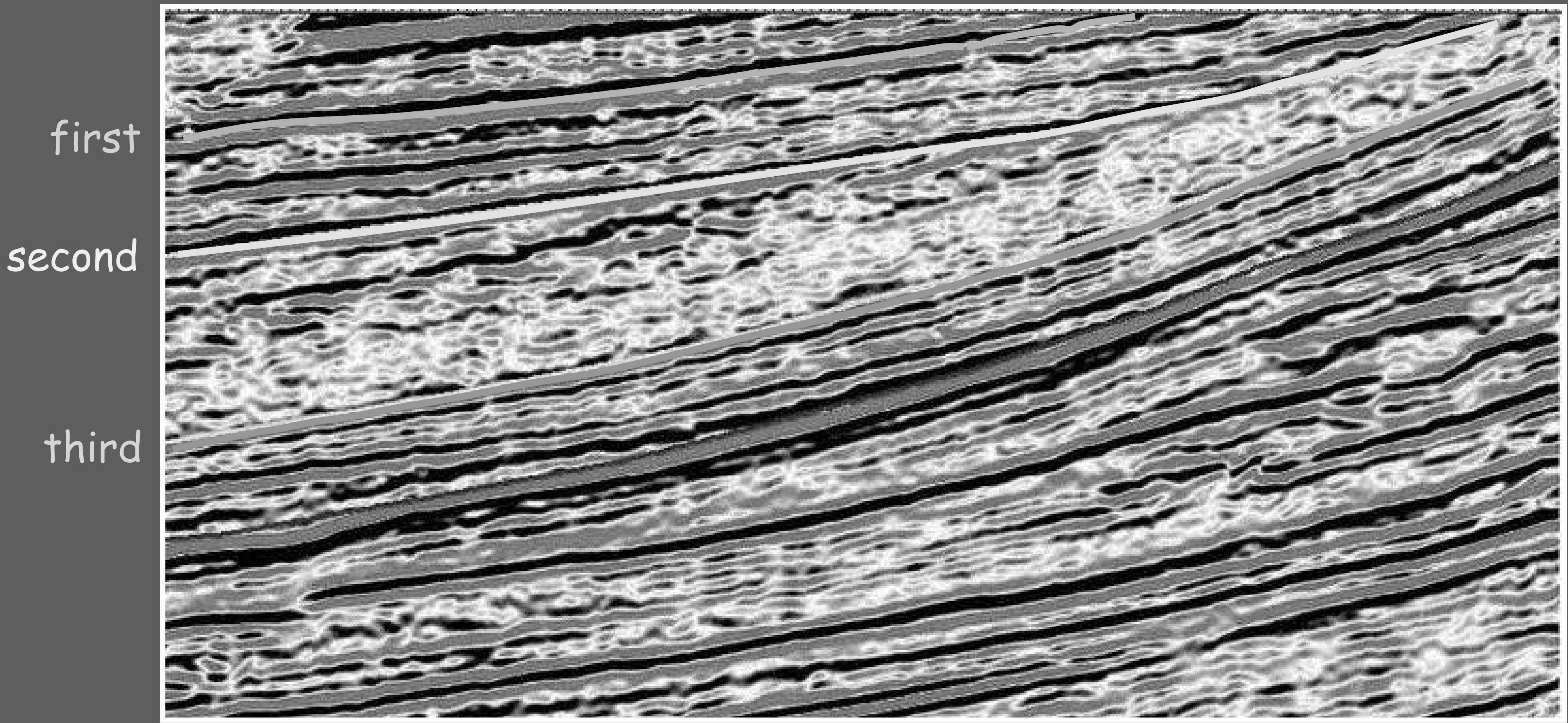




- Use the scale bar to estimate the length of the line
- Use CDPs to check the orientation of the line on the accompanying map

Top down approach

- Start at the top of the section, where definition is usually best
- Work down the section toward the zone where the signal to noise ratio is reduced and the reflector definition is less clear

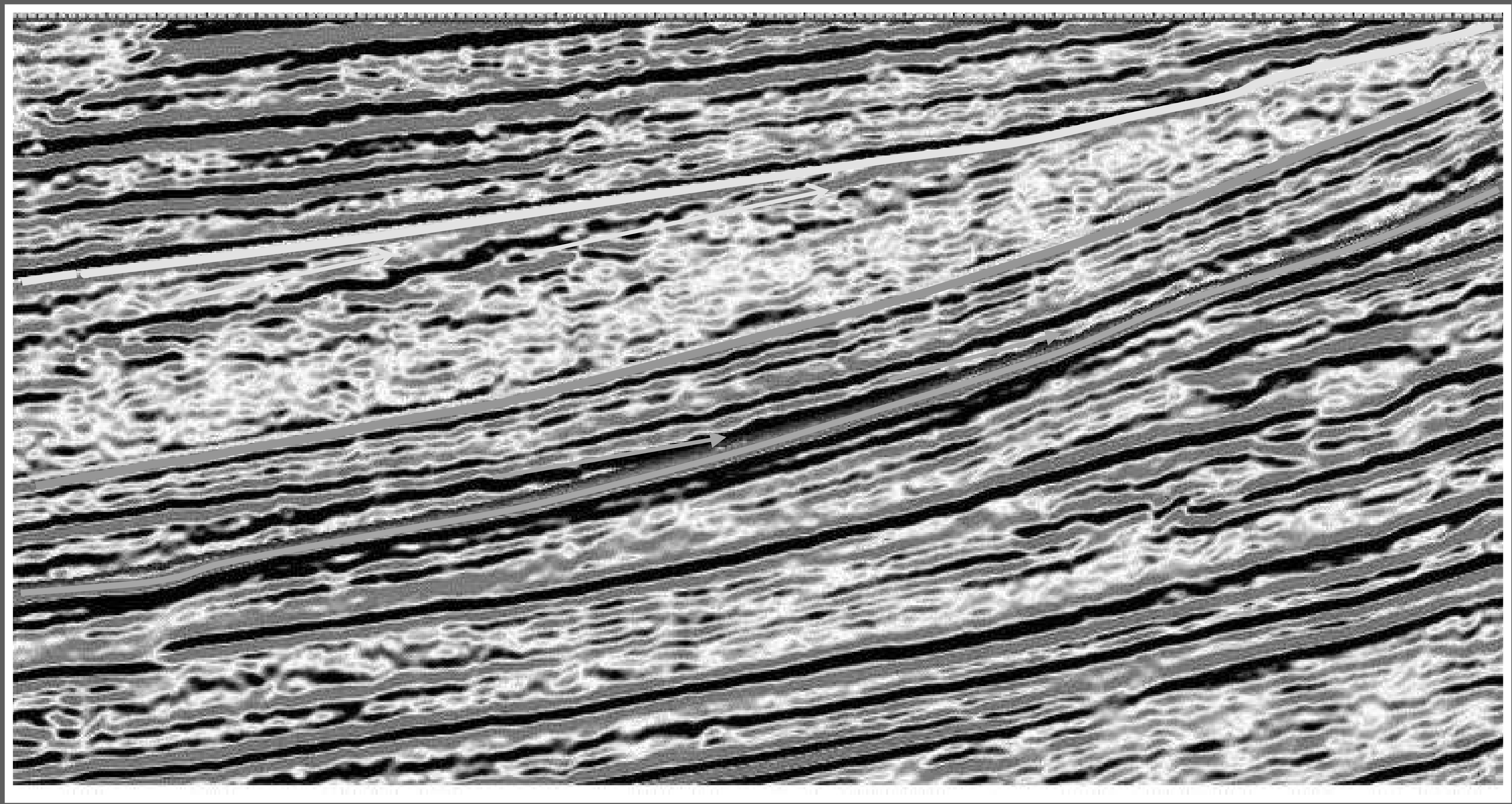


Reflector character and geometry

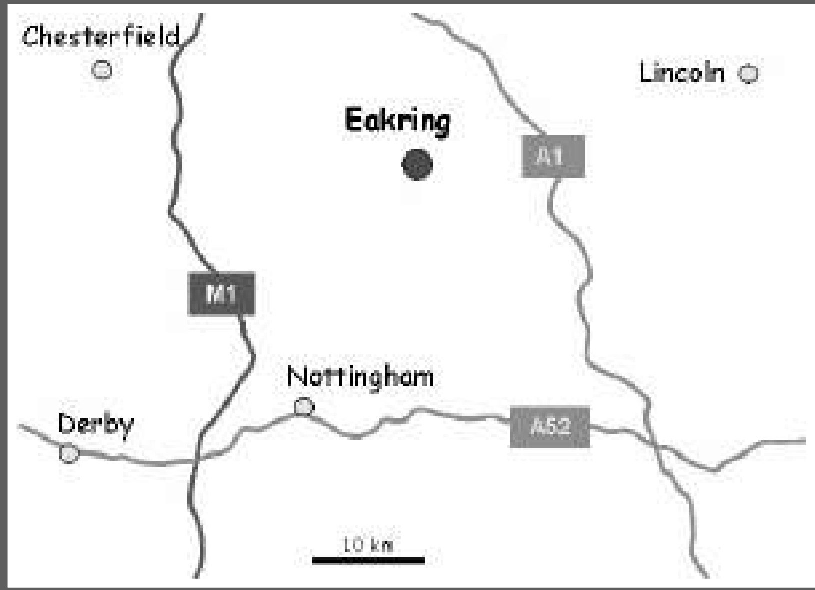
Continuous reflector truncating short ones

Next continuous reflector

Reflectors onlapping continuous one



Background information



Oil exploration in the East Midlands has a long history.

Eakring and the neighbouring Dukes Wood oil fields were discovered in the 1930s. Most oil wells at Dukes Wood date from World War II, though this 'nodding donkey' or oil pump may be a little younger.

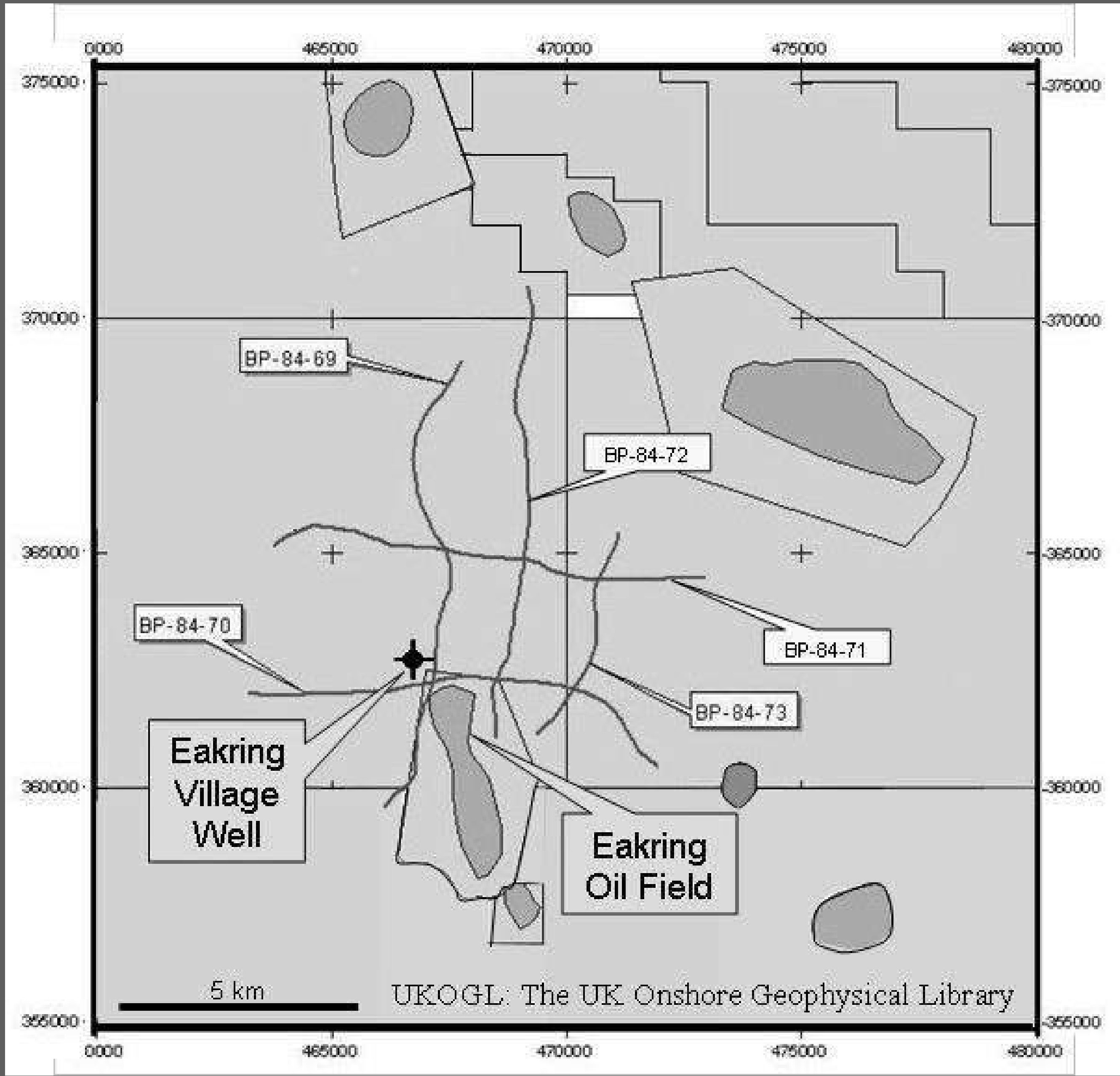
Production at Eakring and Dukes Wood was important to the war effort in Britain. Oil production at Dukes Wood stopped in 1966, but it continued in Eakring until 2003.

Project data

Map showing the location of the 5 seismic lines

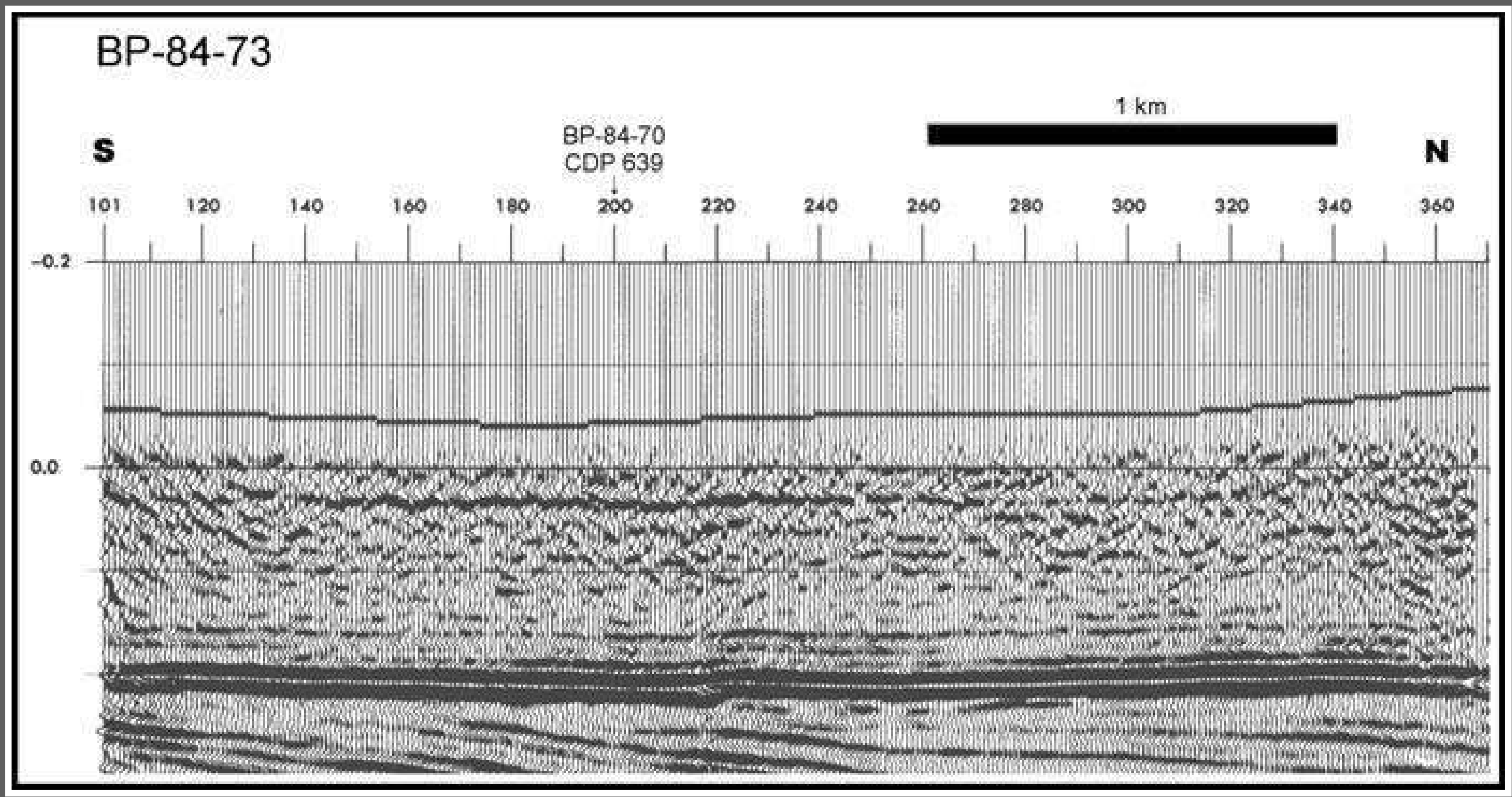
The seismic data were acquired in 1984 (hence the prefix “84” to each line number)

Notice also the Eakring Village well and the location of oil fields in the area



Understanding the data (1)

CDPs are typically marked at intervals along the top of seismic lines and they are regularly spaced to form a horizontal scale. Here, 80 CDPs represent about 1 kilometre (km).

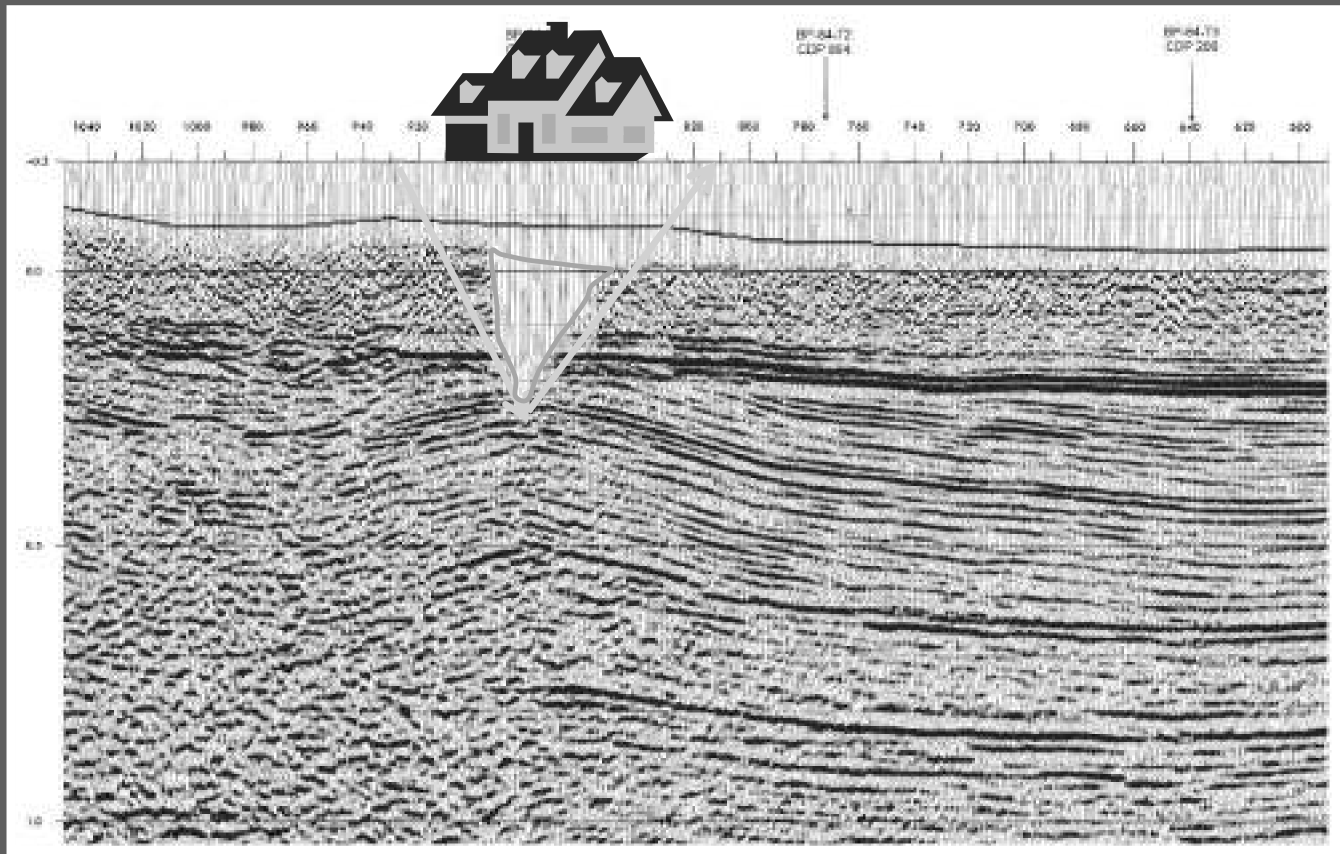


Understanding the data (2)

Gaps in land seismic data are due to omissions where data could not be acquired

For example, it is not always possible to transmit the signal above pipes, in sensitive areas and above buildings

Signals from farther away will provide information for deeper horizons



Understanding the data (3)

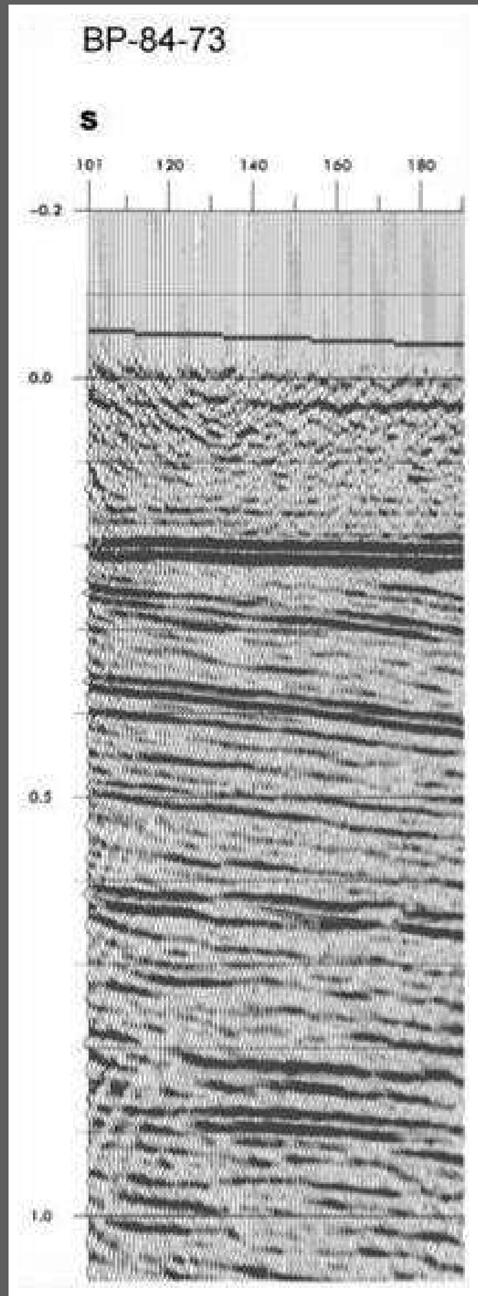
Two way time (TWT) is recorded on the vertical axis of the seismic line in fractions of a second. Sometimes it is more convenient to express time as milliseconds.

TWT is the time required for the seismic wave to travel from the source to some point below the surface and back up to the receiver.

0.0 seconds or sea level →

0.5 seconds or 500 milliseconds →

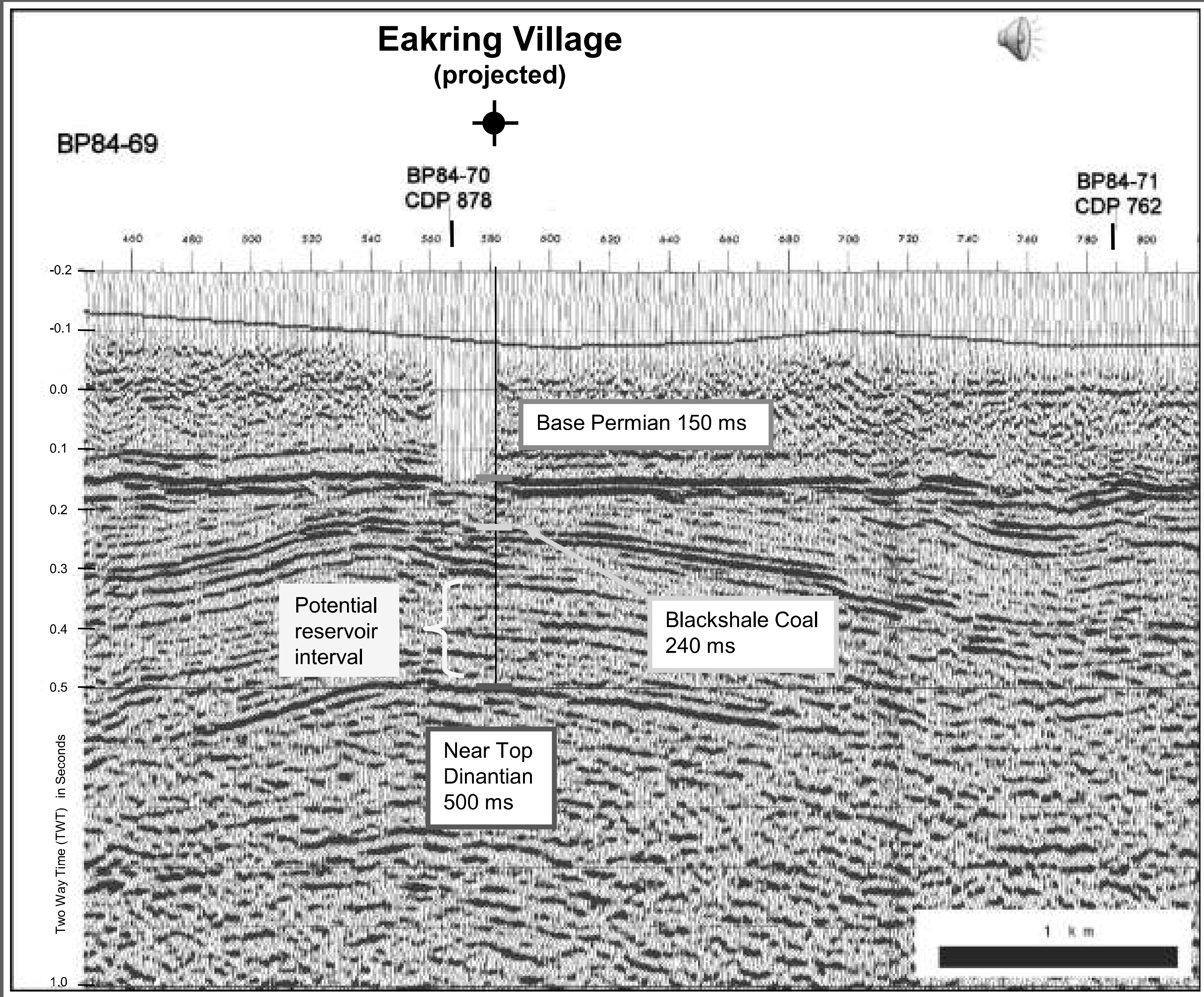
1.0 seconds or 1000 milliseconds →



Correlating well and seismic data

- Use the Eakring Village well, which is located near the intersection of lines 69 and 70, to tie seismic reflectors to known geological horizons identified in the well:
  - Base Permian at 150 milliseconds
  - Blackshale Coal at 240 milliseconds
  - Near Top Dinantian at 500 milliseconds
- The potential reservoirs are Namurian and Westphalian (Upper Carboniferous) sandstones that occur below the Blackshale Coal and above the Near Top Dinantian (Lower Carboniferous) horizon

Well tie to seismic



Correlating reflectors

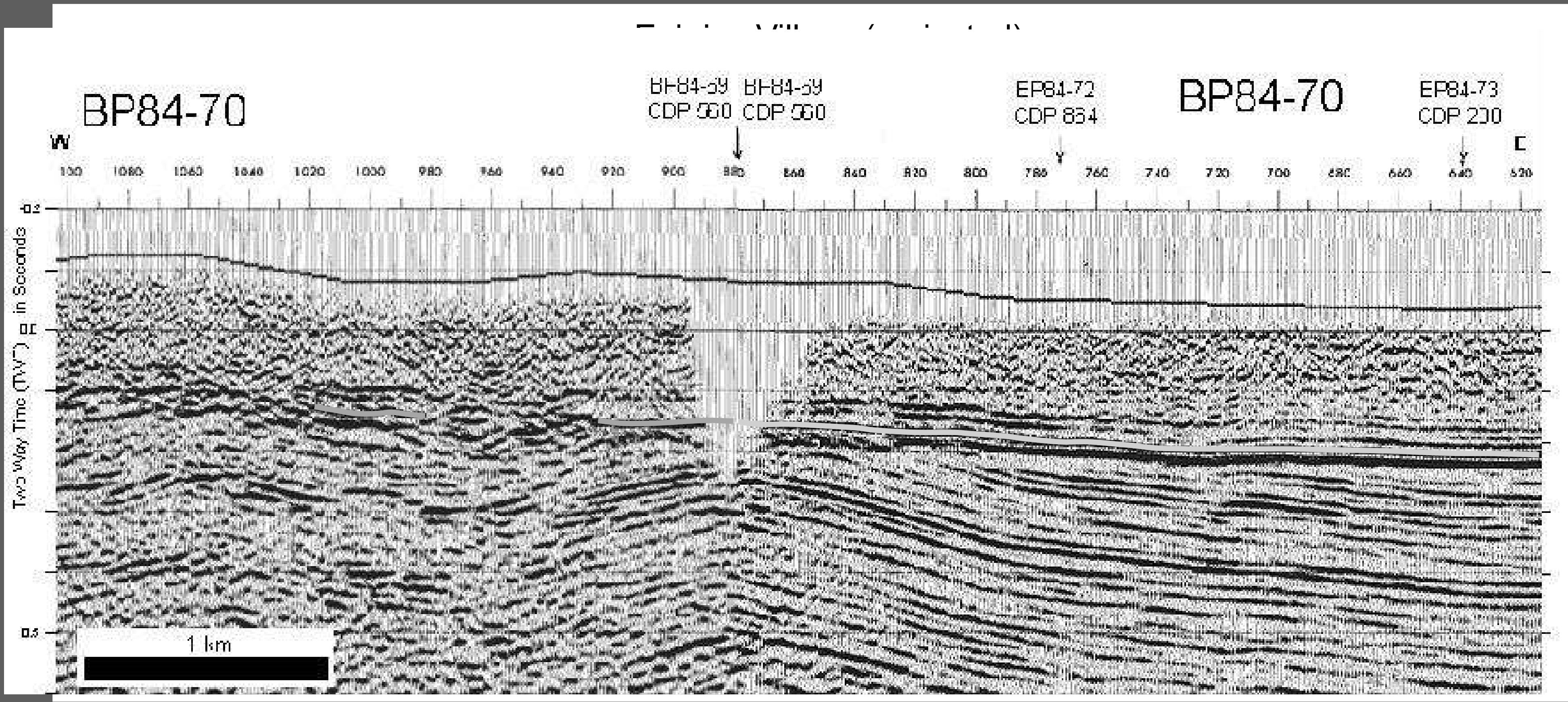
Starting at the top of the section, interpret the Base Permian unconformity away from the well on line 69 and correlate it with intersecting lines 70 and 71.

Continue this process around the 'loops' formed by lines 72 and 73, ensuring that your interpretation is consistent and geologically reasonable.

Repeat this process for the Blackshale Coal and Near Top Dinantian reflectors, accepting that in some areas the data quality is quite poor and a 'best-guess' interpretation is necessary.

It may be helpful to annotate the lines to highlight where possible faults disrupt the gentle dip of the Blackshale Coal.

Correlating the Base Permian unconformity

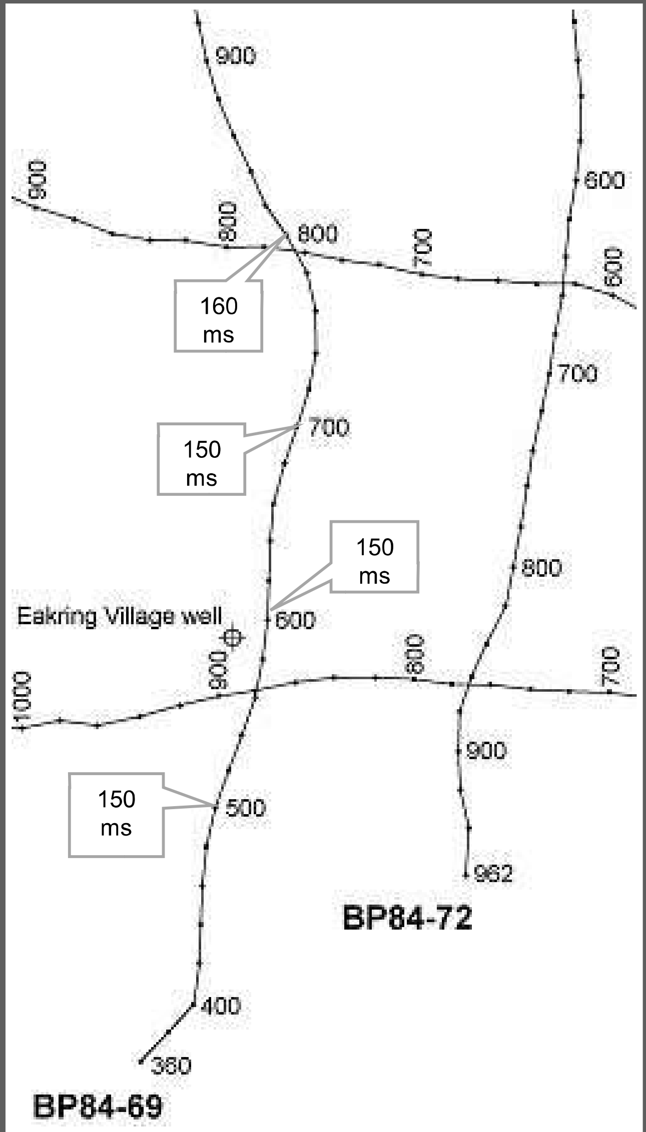


Start by interpreting the Base Permian unconformity away from the well on line 69.

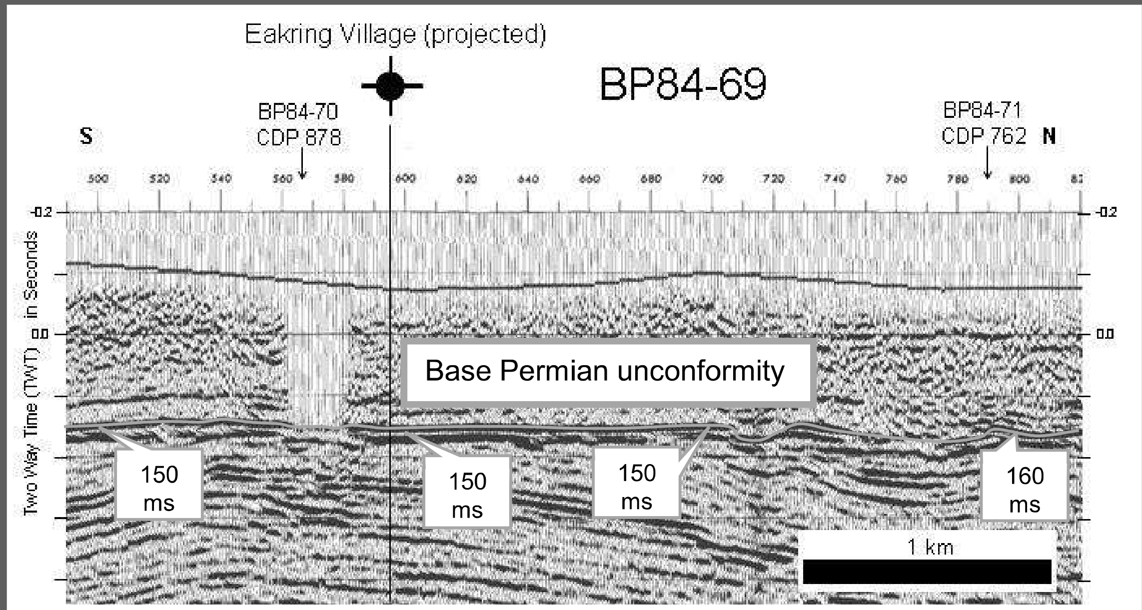
Next fold line 70 at the intersection with line 69 and match them up. Find and interpret the Base Permian unconformity.

Finally, unfold line 70 and finish the interpretation.

Plotting the Base Permian data



Determine the time values (in milliseconds) for the Base Permian at an appropriate CDP interval and plot those values on the map. For example, on line 69 you could start by plotting values at CDP 500, 600, 700, 800 and so on.

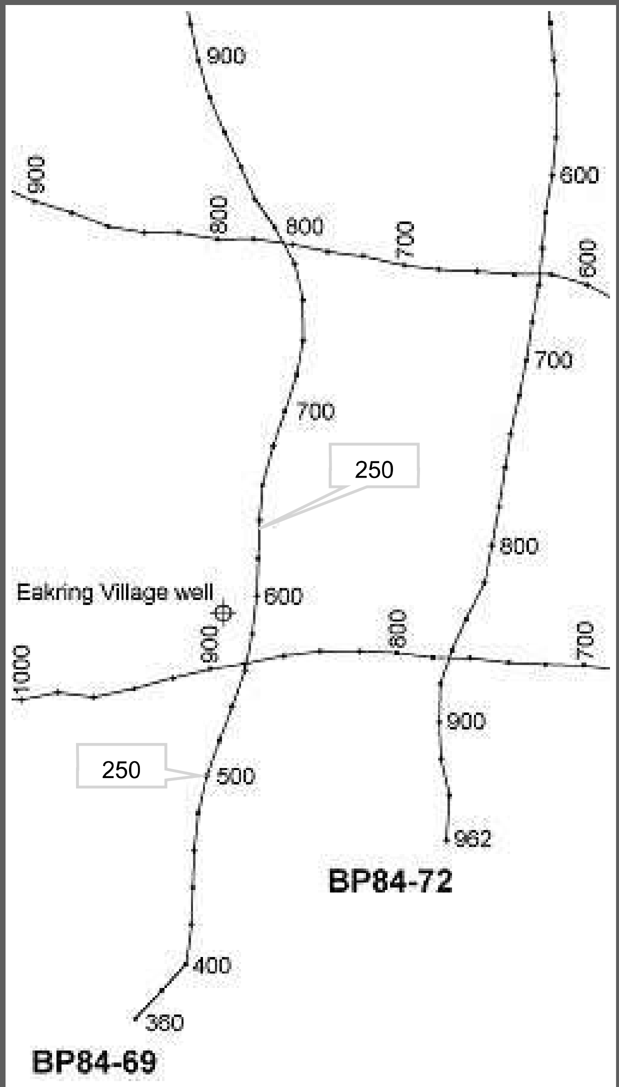


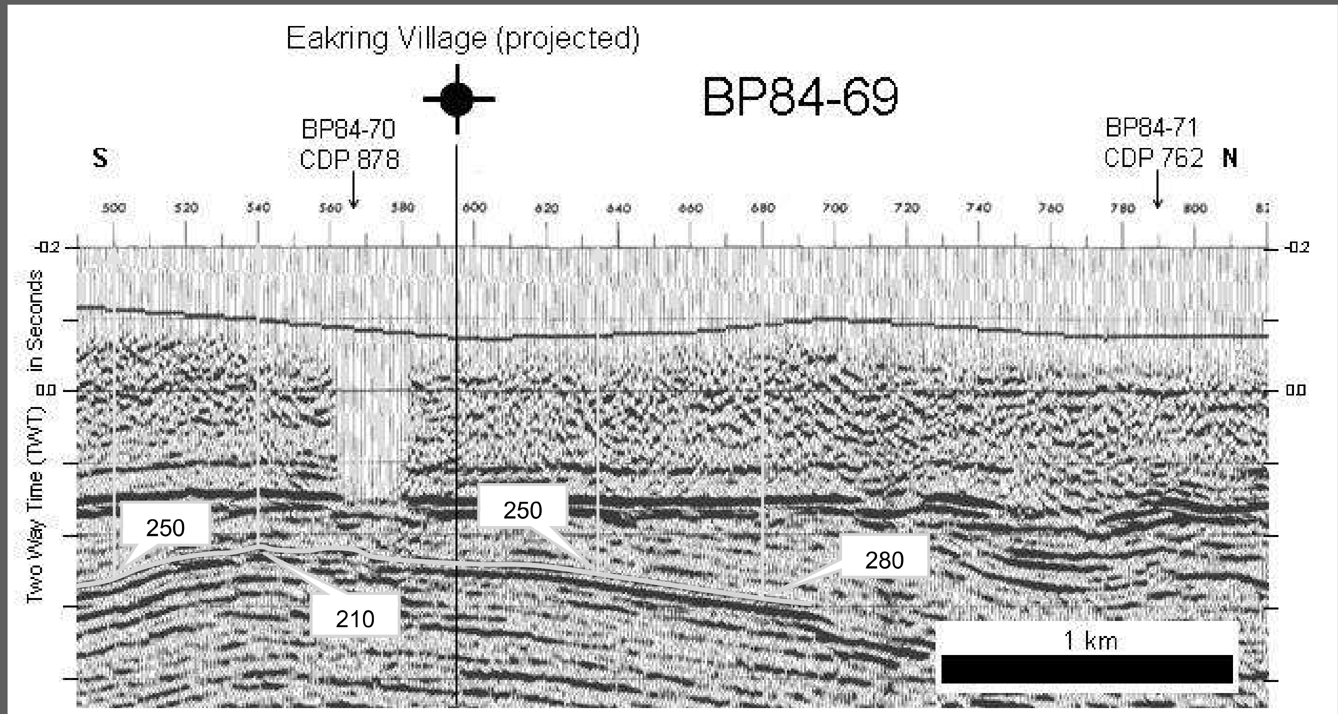
Mapping the Blackshale Coal

- Because the potential reservoir interval is poorly imaged (the reflectors are weak and discontinuous) the closest and most prominent reflector to map is the overlying Blackshale Coal.
- Determine the time value (in milliseconds) for the Blackshale Coal at an appropriate CDP interval and plot that value on the map. For example, on line 69 you could start by plotting values at CDP 500, 600, 700, 800 and so on. In some areas it may be necessary to infill with data at a finer scale.
- Contour these values to make a time map. Take particular care to recognise where faults may complicate the interpretation.
- Normally, a time map is converted into a depth map using velocity functions, but for the purpose of this exercise the time/depth pairings at the top of each seismic line give an adequate representation of the depth to a given horizon.

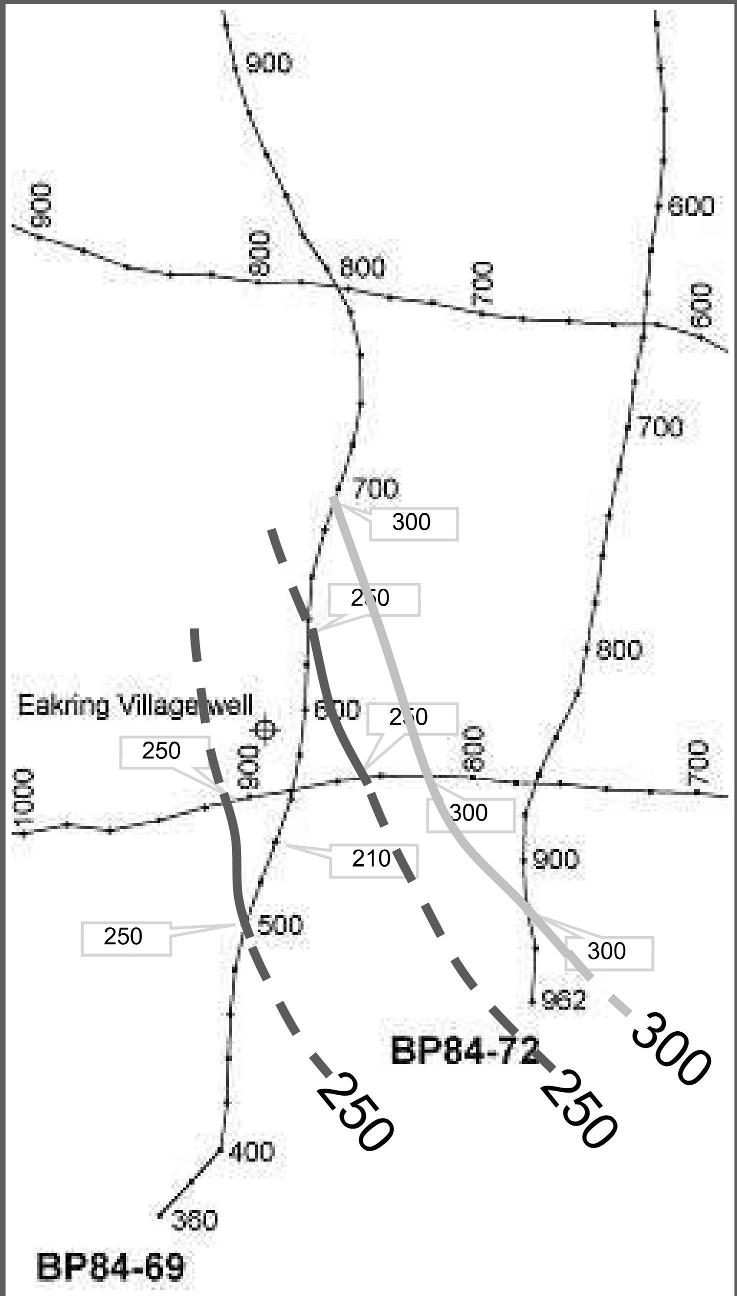
Plotting data for the Blackshale Coal

In some cases it may be easier to choose convenient time values for contouring (say, 250 ms, 300 ms, 350 ms, etc.) and plot these against the appropriate CDPs.





Contouring the data



Use the time values to produce contours.

Label them in milliseconds to create a subsurface time structure map.

Chapter 1
Seismic Wave Propagation and Rock-Fluid Properties

Abstract Seismic waves propagating through different rock layers in the earth suffer loss of energy. The different types of energy losses and their mechanisms need to be understood for their geologic significance.

The intrinsic properties of a seismic wave, – amplitude and velocity, are influenced by the properties of rocks through which it travels. The clasticity and density of rocks primarily determine the seismic amplitude and velocity, though other properties such as porosity, texture, fractures, fluid saturation and viscosity, pressure and temperature also affect seismic properties.

Focusing on geologic interpretation of seismic data before introducing fundamentals of seismic principles and rock physics can be something like putting the cart before the horse. Therefore, this chapter is a revisit to the basics of seismic wave propagation and related rock physics. It answers briefly some of the important questions, as given below, which ultimately guide interpretation.

- *How do seismic waves propagate through rocks?*
- *How is seismic energy attenuated?*
- *What are fundamental wave properties?*
- *What are rock-fluid properties and how do they affect seismic response?*

Seismic Wave Propagation

A seismic wave is an elastic wave traveling through a solid rock. When a rock is subjected to a pressure wave, its particles get displaced, transferring energy to the adjacent ones causing a seismic wave to propagate onwards in the rock through particle motions. There are two types of seismic body waves that travel in solid rocks; longitudinal (primary or compressional) waves and transverse (secondary or shear) waves. In fluids, however, only the longitudinal waves can travel.

A seismic wave propagating in the earth encounters several discontinuities (boundaries) between rock types of different physical properties and produces wave phenomena such as reflections, diffractions, absorptions, scatterings and transmissions (refractions). At each boundary or interface between two different rocks, a

N.C. Nanda, *Seismic Data Interpretation and Evaluation for Hydrocarbon Exploration and Production*, DOI 10.1007/978-3-319-26491-2_1

part of the incident energy is reflected back to the surface and the rest of energy is transmitted to the underlying rocks. Seismic methods for exploration of hydrocarbons mostly use the reflected energies of primary or compressional waves returning to the surface. Shear waves reflections are also recorded and are used in specific cases, to provide valuable subsurface information. Chapter 9 (Shear Wave Seismic) provides more detailed discussion on shear seismic.

Also as the wave of energy (seismic pulse) travels downwards in solid media, it undergoes gradual loss of energy (attenuation) depending on the rock-fluid properties. Attenuation, a natural phenomenon, comprises of several types of losses and understanding the process behind each loss can be useful in interpreting the rock type.

Energy Losses

Absorption

The seismic source wave, generated at the surface, as stated earlier, propagates through a rock by transferring energy from one particle to another. In the process, a part of the energy is attenuated due to conversion of mechanical energy to heat energy through frictions at grain contacts, cracks and fractures and fluids present in pores of a rock. The frictional loss primarily due to motion between rock particles at the point of grain contacts is known as *absorption*. Frictional loss is also sensitive, though to a lesser extent, to fluid properties like saturation, permeability and viscosity as the wave travels through the rock. Absorption in rocks is believed to be related to the first power of frequency whereas in liquids it is related to square of the frequency (Anstey 1977).

Absorption is anelastic, frequency selective and cuts out higher frequencies progressively from the source pulse. This results in reduced energy with a wavelet of lower frequency and lower amplitude at deeper depths (Fig. 1.1). Absorption effects are severe within shallow weathering zones and decrease with depth. Magnitude of absorption (friction) loss in a hard rock is liable to be much higher than that in a fluid saturated rock as friction in fluid, considered as a slushy medium, is likely to be small (Gregory 1977). Seismic in offshore deep waters hardly shows low- frequency dominance supporting little energy-loss due to absorption in the water column. However, there can be some absorption loss in partially saturated hydrocarbon reservoirs due to viscous motion between the rock and the fluid.

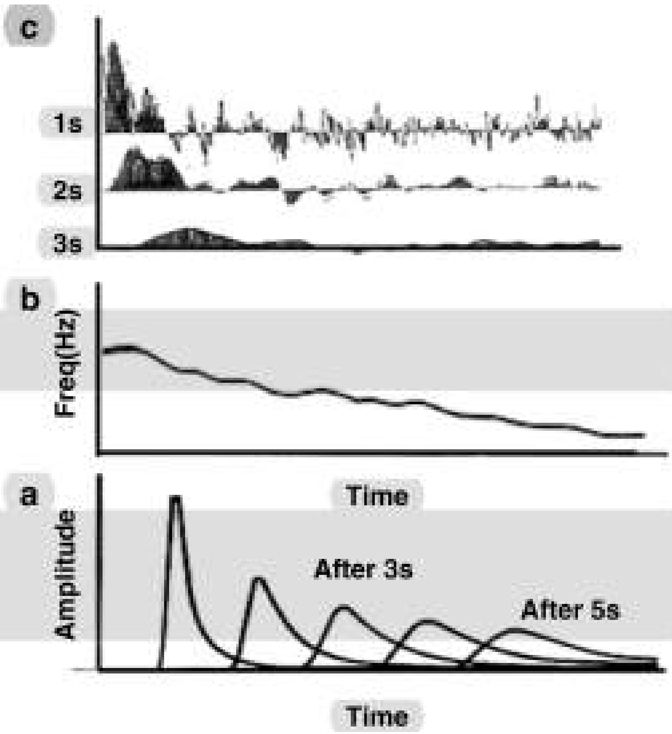


Fig. 1.1 A schematic showing the loss of energy due to absorption during wave propagation. (**a**) Shows a lowering of amplitude with time (**b**) the lowering of frequency with time and (**c**) the overall look of a seismic trace with time (Modified after Anstey 1977)

Scattering

Scattering loss is a frequency dependent *elastic* attenuation linked to dispersion, a phenomenon in which velocities in a rock measure differently with varying frequencies. Scattering losses are irregular dispersions of energy due to heterogeneity in rock sections, usually considered as apparent noise in seismic records. Scattering and absorption losses together are sometimes referred to as attenuation. Geological objects of very small dimensions tend to scatter wave energy and produce diffractions rather than continuous reflections. Highly tectonised shear zones with faults and fractures, very narrow channels, pinnacle mounds etc., are some of the geologic features, most prone to scattering effect.

Transmission

Transmission loss is loss of energy the wave undergoes at every lithologic boundary, as a part of the energy is reflected back to the surface allowing less to go deeper. The loss thus depends on the type and number of reflecting interfaces. It is often believed that a strong reflector like a limestone or an intrusive body reflects most of energy upwards and transmits less in the process, causing poor reflections or shadows below. However, Anstey (1977) has demonstrated that strong reflectors may not be the sole cause for large transmission losses. Instead, such effects may be caused due to large number of thin interfaces, even with small reflectivity, but with alternating signs of contrasts that cause many reflections to account for energy loss.

Transmission losses reduce amplitudes at all frequencies and are not frequency selective as in absorption. One positive spinoff of wave transmission through several thin beds can be the eventual constructive interference of peg-leg multiples from the interfaces of thin beds with reflections at times that aid in recording a reflection amplitude better. But addition of amplitudes tends to lower the frequencies giving an appearance of the pulse similar to the absorption effect. Prima-facie, it may be, hard to distinguish the effects on a seismic pulse due to absorption and transmission losses.

Spherical (Geometrical) Divergence

A seismic wave (usually considered travelling in the form of spherical wave fronts), suffers from reduction of energy as it continually moves away from source and spreads through the subsurface rocks with time (distance). This is also known as geometrical loss as it is linked to the wave-path geometry. The decay is dependent on distance from the source and increases with higher velocities due to greater distance travelled (Fig. 1.2).

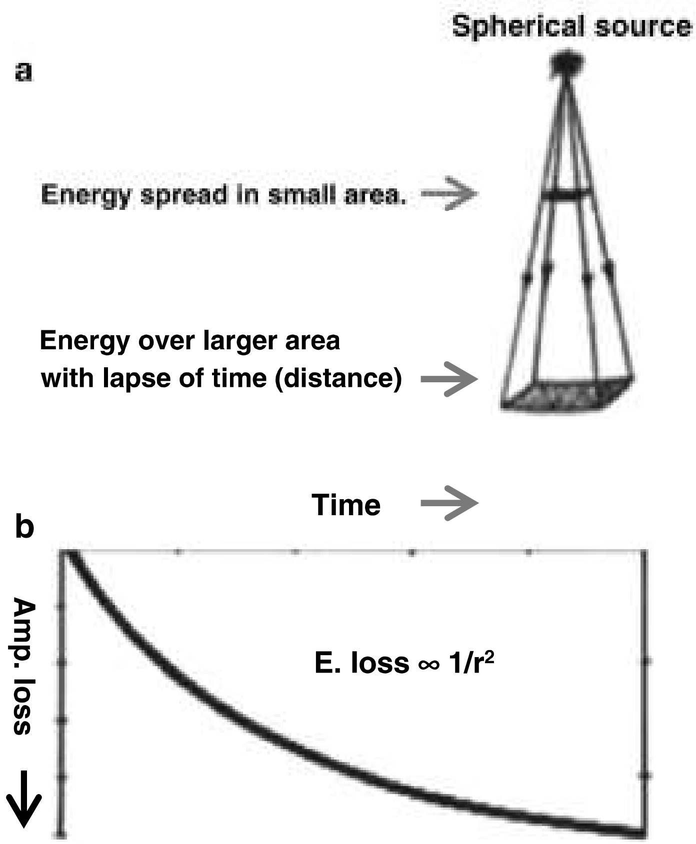


Fig. 1.2 Illustrating loss due to spherical divergence during propagation. (**a**) Spreading of spherical wave causes loss as the energy is distributed over larger area with time and (**b**) is proportional to distance travelled (Modified after Anstey 1977)