Three-Dimensional Visualization of Geologic Structures using a Seismic Data Cube

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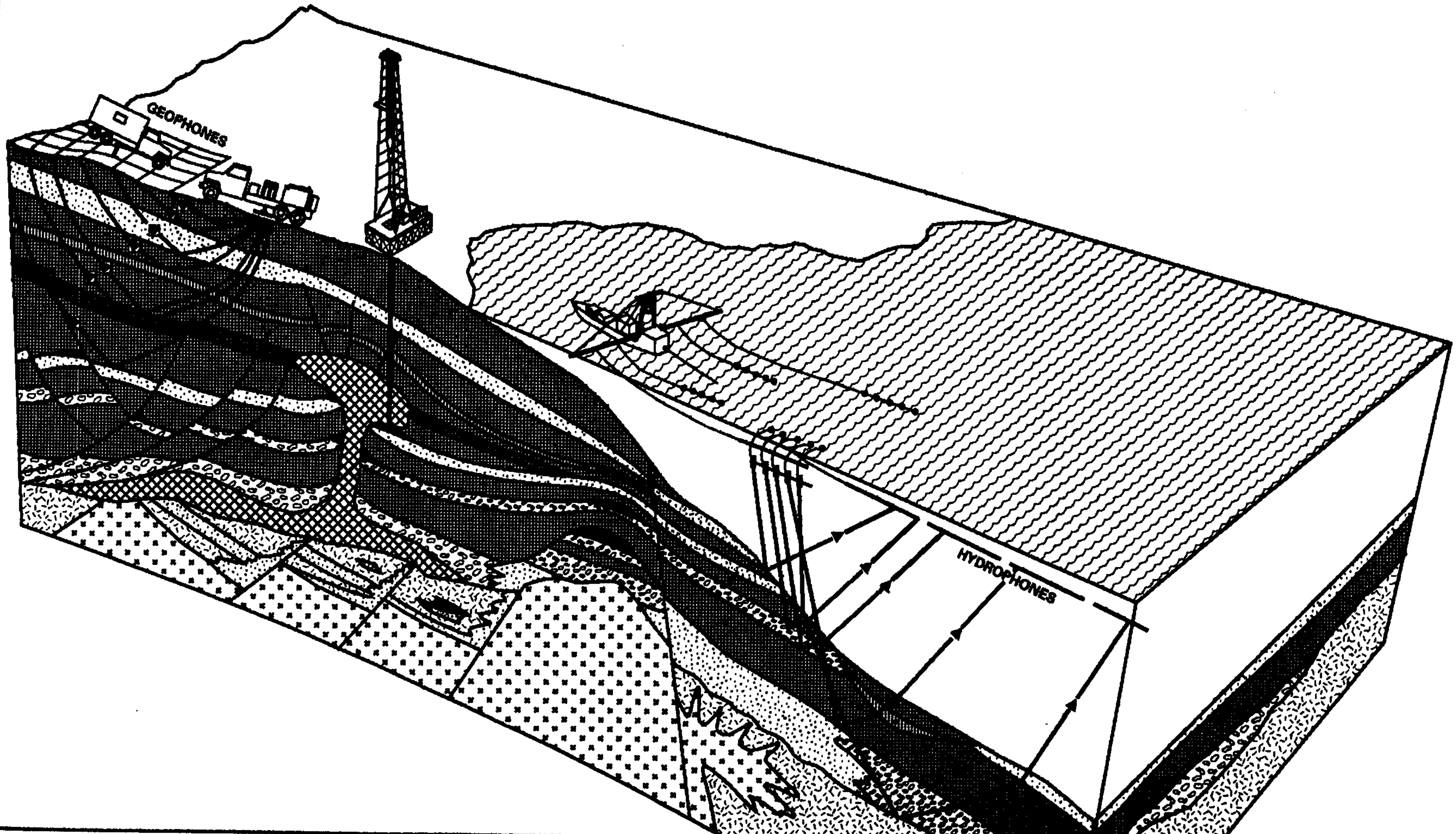
SEISMIC ACQUISITION



After National Geographical Society

Figure 1

Introduction

Mountains, rivers, valleys, hills, and shorelines seen while driving or flying cross country are also present many miles inside the earth. To image and map these buried geologic structures, geoscientists often use a technology called **reflection seismology.** Sound waves that are projected downward will bounce or reflect from rock interfaces and return to the earth's surface (Figure 1). Hundreds of very sensitive listening devices called **geophones** listen for and receive the reflected acoustic waves, and relay their soundings via electronic signals to a computer for storage.

The recorded signals are called **seismic data** or **seismic field records.** These recordings are made on land using explosive charges or trucks with heavy vibrators to create the acoustic shock waves. In the oceans, compressed air is used to generate a pressure pulse that is reflected back to pressure sensitive listening devices called **hydrophones.**

The volume of recorded seismic data is enormous and involves billions of numeric data points. Compiling this data into a useful format requires the most powerful computers available. The computer analysis is referred to as **seismic data processing** and can require several months of complex mathematical calculations in order to render a 3-dimensional picture of the earth. Figure 2 shows a 3D seismic data cube that images a 2 x 3 x 1.5 kilometer volume of the earth.

The process of using this 3D data cube to image and map geologic structures is called **seismic interpretation.** The seismic data show light and dark contrasting bands that represent the travel time and spatial position of rock interfaces several miles inside the earth. It requires a highly skilled geoscientist to predict the depth of these rock interfaces and to determine what type of rock caused the reflection event. Geophysicists and geologists do this by combining information from

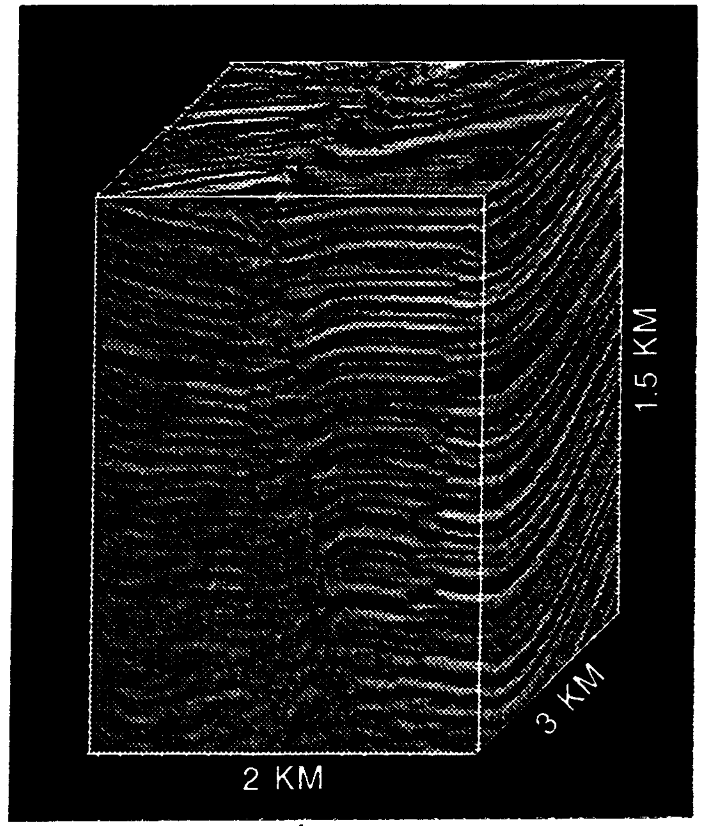


Figure 2

the computer processing with data taken from the inside of oil wells that have penetrated the subsurface rock layers. Wireline log data obtained at the well is combined with the seismic data to determine if hydrocarbon reservoirs are present, and if so, how extensive the accumulation of hydrocarbon reserves may be.

The seismic imaging of hydrocarbon reservoirs is an essential aspect of modern oil exploration and production. Billions of dollars are spent each year by oil companies to acquire, process, and interpret seismic data. Geophysicists, geologists, computer specialists, mathematicians, and electrical engineers are all involved in supporting the technology of reflection seismology.

Interpreting the seismic data cube requires knowledge of geologic forms and processes. It also requires **visualization** or the ability to perceive the buried landforms in true 3-dimensional space.

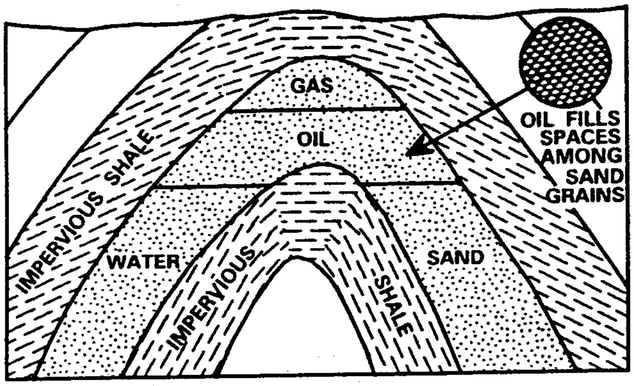


Figure 3

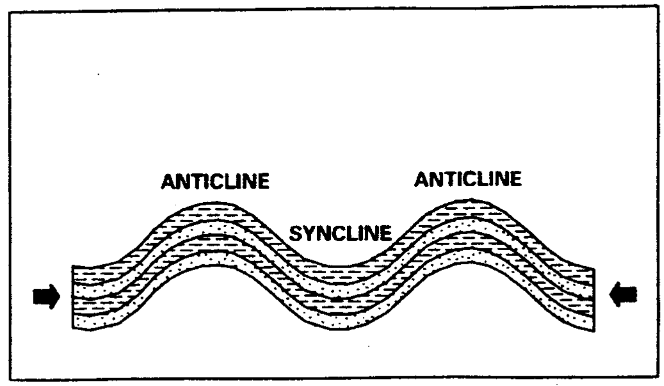


Figure 5

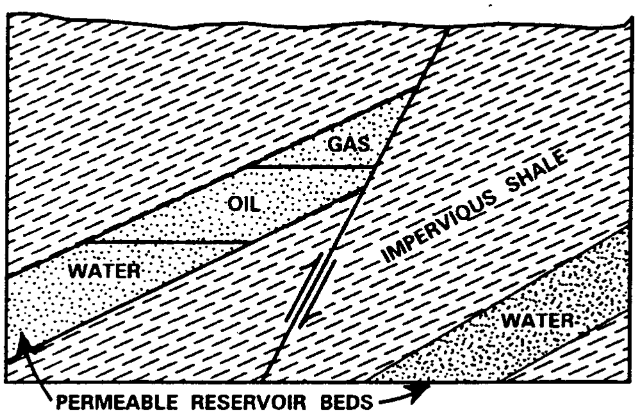


Figure 4

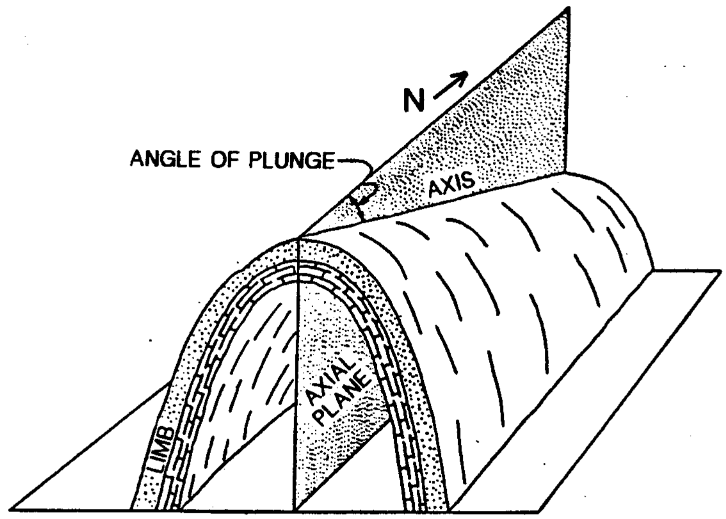


Figure 6

The accompanying exercise will allow you to visualize some basic geologic features using seismic data. You will construct a 3D data cube and then review the acoustic images to predict the shape of the geologic structures imaged by this seismic dataset.

Several basic geologic features are present in this data and include **faults, anticlines,** and **synclines**. As illustrated in Figures 3 and 4, anticlines and faults can serve to entrap oil and natural gas. The hydrocarbons are lighter than the rocks and associated water, and therefore rise toward the surface. (Recall that a drop of oil floats in a beaker of water.) A roll-over anticlinal structure (Figure 3) or a fault (Figure 4) may stop the natural upward migration of hydrocarbons if an impervious rock like shale is juxtaposed to a porous reservoir rock like sandstone. Geoscientists will use the seismic data to identify areas where known sandstone rock layers have taken the form of anticlines or fault blocks.

The difference between an anticline and syncline is shown in Figure 5. The beds forming the fold frequently have a third dimension of structural dip that is perpendicular to the axis of the anticline or syncline. Figure 6 shows how the axis of an anticline can also **plunge** downward into the earth. A north plunging anticline is one whose axis plunges down-to-the-north.

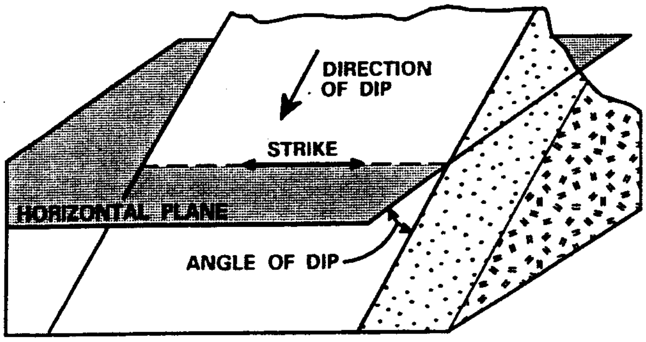


Figure 7

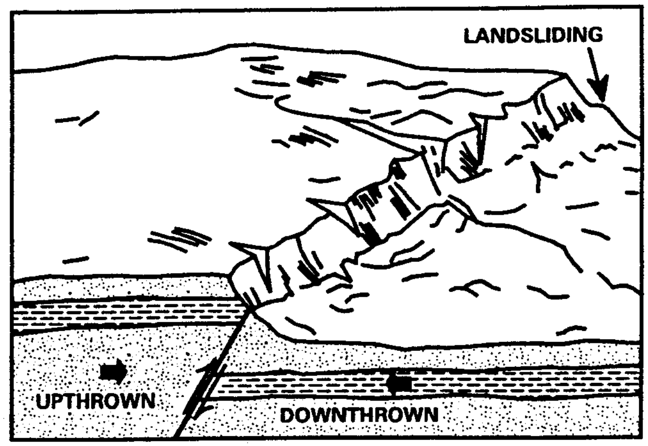


Figure 9

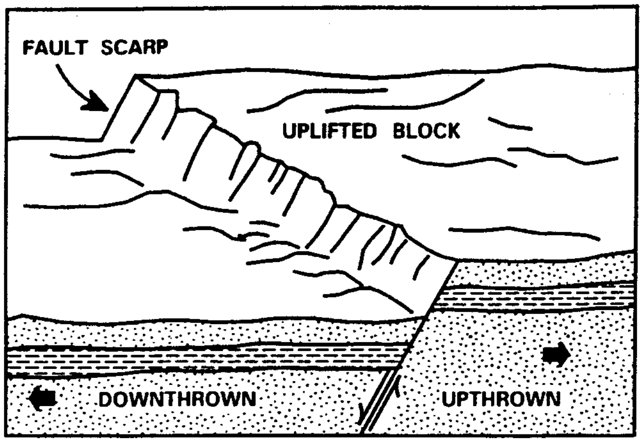


Figure 8

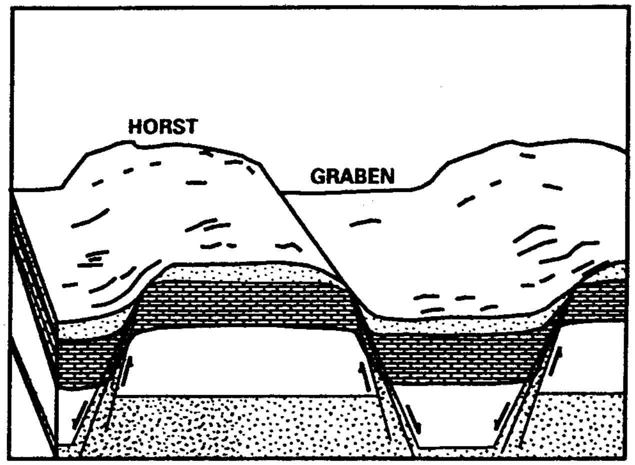


Figure 10

The terms **dip** and **strike** are used to describe the spatial orientation of rock layers and fault planes. Figure 7 illustrates how dip refers to the direction that a drop of water would run downhill if placed on the top of the rock layer. Dip is quantified by the number of degrees of dip and the direction of that dip (i.e. 10° N, 3° SW, etc.). Strike is the perpendicular direction of dip and represents a line that has no change in depth. Therefore, strike is referenced by direction only (i.e. SE-NW, N-S, etc.).

Faults are often found in conjunction with tightly folded rocks. Whenever beds are no longer able to bend or flex, they tear and slip across themselves forming a fault. Figure 8 shows a **normal fault** that can offset bedding planes by hundreds of feet.

The fault **throw** is the amount of offset or displacement along the fault between any two common rock layers. In Figure 8, the left side of the normal fault would be **downthrown** and the right side would be **upthrown**. In Figure 9, the fault thrown is reversed forming a **reverse fault.** Here the left side is upthrown compared to the downthrown right side. When multiple faults occur concurrently, it is possible to form structures called horsts and grabens (Figure 10). The horst and graben in Figure 10 are bounded by normal faults.

Geologic features like grabens, normal faults, dipping beds, anticlines, and synclines are easily visualized using 3D seismic data as will be illustrated in the following exercise.

3D Seismic Data Cube
Exercise

Objective: Construct a three-dimensional seismic data cube and interpret basic geologic features found therein.

Materials:

- 8 seismic sections
- 3 colored pencils or erasable pens (red, green, blue)
- clear tape
- scissors

Procedure:

(1) Organize the seismic data in the following order: Line 1, Line 2, Line 3, Trace 4, Trace 5, Trace 6, bottom horizontal slice, and top horizontal slice. You will do interpretation on these sections individually before constructing the data cube.

(2) On Line 1, observe the shape of Fault F3. The location of two other faults have been marked by F1 and F2 labels. Finish marking the position of these faults by making a broad colored swath top-to-bottom. Don't be afraid to extend the fault traces as far as you can. Use **blue** for F1 and **red** for F2. These fault trends should be generally smooth. Be sure and interpret the faults on **both sides** on Line 1.

(3) Repeat the interpretation of F1 and F2 on Lines 2 and 3. Use **blue** for F1 and **red** for F2 on both sides of each line.

(4) Interpret Fault F1 on Trace 6. Note that Line 1 and Trace 6 intersect at letter d. Lay Line 1 against Trace 6 and check the position of F1 at the intersection. If F1 is not coincident, adjust your interpretation on one or both sections.

(5) On Trace 4, interpret the location of bedding plane (horizon) H1 by shading a **green** swath below the dark band that is just above the H1 label. Carry this interpretation from edge-to-edge, and repeat for the opposite side of Trace 4.

(6) Repeat the interpretation of H1 on the remaining traces and remaining lines. On Trace 6 and Lines 1 to 3, it will be necessary to **break** the horizon coloring at Faults F1 and F2. The green color should stop at the upthrown side of each fault, and continue at the downthrown fault-horizon intersection. Note that each fault has a different offset or throw.

(7) Begin assembly of the data cube.

(a) Place Line 1 next to Trace 4 so that letter **a** is visible on **both** sections. The horizons should line up at the intersection with **a**. If not, slide one section up or down **slightly** until they do blend. Tape along this seam in 3 places with **short** 1-2" strips of clear tape. Tape so the letters **a** are on the inside of the cube.

(b) Place Trace 6 next to Line 1 so that letter **d** is visible. Align the horizons and tape as before.

(c) Place Line 3 next to Trace 6 so that letter **c** is visible on both. Align the horizons and tape.

(d) On Line 2 cut the center white strip from **top-to-midway-down**. **Do not** cut beyond half-way. Attach Line 2 to Trace 4 with letter **f** visible on both sections.

(e) Fold Line 1 and 3 and Trace 4 and 6 into a cube and tape along letter **b**. It will be easier to tape on the outside (opposite side) of letter b.

(f) Set the cube upright and in 3 places tape Line 2 to Trace 6 at letter **e**.

(g) Cut from **bottom-to-midway-up** on Trace 5. Intersect Trace 5 with Line 2 by slipping the notched sections across each other. Check to see that letters **g** and **h** are juxtaposed on Lines 1 and 3. If they are not, reverse the direction of Trace 5. Tape as needed on Lines 1, 2, and 3 to secure and stabilize the cube.

(8) Set the cube onto the "bottom horizontal slice" so that letters **a** through **h** are aligned. Using the blue and red pencils respectively, mark the intersection of Faults F1 and F2 on the horizontal section. There should be 6 total points of contact for these two faults on Lines 1, 2, and 3.

(9) Repeat the process of marking the fault intersections for the "top horizontal slice".

(10) Finish connecting and coloring the fault intersection line for F2 and/or F1 on both the top and bottom horizonal slices. Use your intersection points from (8) and (9) to determine the trend of each fault.

Questions

With the cube realigned on the bottom horizontal section, answer the following questions.

___ 1. Given the "apparent dip" of Fault F1 on Line 1 and on Trace 6, which best describes the dip direction of F1 in the top SW corner of the cube? (a) NW (b) NE (c) SW (d) SE

___ 2. What is the dip direction of horizon H1 at letter P on Line 1?
(a) ENE (b) S (c) NW (d) E

___ 3. At which corner of the cube is horizon H1 the shallowest (highest)?
(a) NE (b) SE (c) SW (d) NW

___ 4. On Line 1, which best describes the layers between F1 and F2?
(a) anticline (b) syncline (c) horst (d) rotated fault block

___ 5. Between F2 and F3 on Lines 1, 2, 3, and Trace 5, is horizon H1 shallowest (highest) to the
(a) North (b) South (c) East (d) West

___ 6. On Lines 1, 2, and 3, which best describes the feature between F2 and F3?
(a) horst (b) north plunging syncline
(c) east plunging anticline (d) north plunging anticline

___ 7. Using the bottom horizon slice, which statement is valid?
(a) F3 extends from Line 1 to Line 3
(b) F2 strikes E-W
(c) F1 is very linear and straight
(d) F2 and F3 converge near Line 1

___ 8. Using Lines 1, 2, and 3, which statement is valid?
(a) F3 has more throw than F2
(b) F1 is downthrown to the east
(c) F3 is downthrown to the east
(d) F1 has more throw than F2

___ 9. On the bottom horizon slice at letter Q, are these arcuate horizons reflecting a
(a) north plunging anticline (b) north plunging syncline
(c) east plunging anticline (d) west plunging syncline

__ 10. At letter R on the bottom section, are the arcuate horizons most reflecting a
(a) east plunging syncline (b) west plunging anticline
(c) rotated fault block (d) north plunging syncline