Table 1.1 Seismic Reflection Data Used for Base Map

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Chapter 1: Introduction

Sanghar Trough

Sanghar trough is an important hydrocarbon-producing area. It extends from the Khairpur-Jacobabad High to the northeast and Umerkot High to the southeast and merges into the Thar Slope in the east. (Kazmi 1997).Kadri (1995) defines Kandhkot-Mari Horst as the northern boundary of the Sanghar Trough in the south, with Kirthar Foldbelt as the western margin and Indian Shield as the eastern margin.

Introduction to the Study Area

The Khairpur area lies in district Khairpur, upper Sindh. It is located on the border of central and southern Indus basin, near the Jacobabad High. This area is highly complex due to varying tectonic activity and contains a complex system of horsts and grabens. According to Raza et al. (1988), a number of oil and gas fields are present in this area. Khairpur block includes Chak 66 oil field, which is the easternmost oil field in Pakistan.

Figure 1.1: Map showing the location of the study area

Accessibility

The study area is about 50 km from Sukkur city. The nearest airport is Sukkur International Airport. It is connected with Khairpur through the National Highway N-5, and other metaled roads also provide good access.

Objectives

The main objectives of this study are:

- Structural and stratigraphic interpretation of seismic sections.
- Generation of synthetic seismogram.

- Preparation of time and depth contour maps.
- Identification of reservoir lithology through facies analysis.
- Gassmann fluid substitution to evaluate fluid effects on velocity and density.

Data Used

The following seismic and well data were used:

- Seismic lines: 2001-KH-30, 2003-KH-44, 2003-KH-39, and 2003-KH-35.
- Well data: Bilal-01, Naimat Basal-01, and Siraj South.

Methodology

The methodology included loading seismic and well data into Kingdom 8.4, generating synthetic seismograms, marking horizons and faults, preparing fault polygons, constructing time and depth maps, carrying out facies analysis, and applying Gassmann fluid substitution.

Smt Kingdom 8.4

SMT Kingdom Suite is an integrated geoscience interpretation software used for seismic interpretation, geological mapping, well correlation, and reservoir characterization. It enables the interpreter to load seismic SEG-Y data, well logs, formation tops, and navigation information. It also provides tools for horizon and fault picking, gridding, contouring, cross plotting, and fluid substitution.

1.8.1 Seismic Data Loading

Navigation data and SEG-Y files were imported into Kingdom software. The line locations were checked on the base map, and the seismic data quality was reviewed before interpretation.

1.8.2 Well Data Loading

Well headers, formation tops, sonic logs, density logs, gamma ray logs, and resistivity logs were loaded. The well locations were checked relative to the seismic lines.

1.8.3 Interpretation

Synthetic seismograms were generated to tie well tops with seismic reflectors. Horizons and faults were then picked on the available dip and strike lines. Fault polygons and time and depth maps were generated to understand the subsurface structure.

Chapter 2: General Geology

2.1 Introduction to Area

Pakistan is geologically located at the junction of the Indian, Eurasian, and Arabian plates. The Indus Basin is the main sedimentary basin of Pakistan and is divided into Upper, Middle, and Lower Indus basins. The study area lies near the boundary between the Middle and Lower Indus basins. It contains thick sedimentary sequences ranging from Precambrian basement to recent deposits.

The geological history of the region is controlled by rifting, subsidence, sedimentation, and later tectonic deformation. The Indian Plate separated from Gondwana and moved northward before colliding with the Eurasian Plate. This movement influenced the development of the Indus Basin and its structural framework.

2.2 Tectonic Setting

The Indus Basin is bounded by the Indian Shield to the east, the fold and thrust belts to the west, and the Himalayan ranges to the north. The study area lies in an extensional tectonic regime. Normal faults form horst and graben structures that provide potential structural traps for hydrocarbons.

The Jacobabad-Khairpur High separates the Upper Indus Basin from the Lower Indus Basin. The area contains several basement-related faults that influenced sedimentation and structural development. These faults were reactivated during different tectonic phases.

2.3 Stratigraphy

The stratigraphic succession includes rocks from Precambrian to recent age. Important hydrocarbon-bearing formations include the Sembar Formation, Lower Goru Formation, and Upper Goru Formation. The Lower Goru Formation is the principal reservoir unit in many fields of the Lower Indus Basin, while the Sembar Formation is regarded as a major source rock.

2.3.1 Sembar Formation

The Sembar Formation consists mainly of shale with subordinate sandstone and siltstone. It is considered the primary source rock in the Lower Indus Basin because of its organic-rich marine shale and suitable maturity in many areas.

2.3.2 Lower Goru Formation

The Lower Goru Formation is composed of alternating sandstone, shale, and siltstone. Its basal sand units form important hydrocarbon reservoirs. Reservoir quality varies laterally due to changes in depositional environment, grain size, sorting, and diagenesis.

2.3.3 Upper Goru Formation

The Upper Goru Formation is dominated by shale and acts as a regional seal over the Lower Goru reservoirs.

2.4 Petroleum System

A complete petroleum system requires source rock, reservoir rock, seal, trap, migration pathway, and suitable timing. The Sembar Formation provides the source, Lower Goru sandstones provide the reservoir, and Upper Goru shale provides the seal. Normal faults and horst structures form potential traps. Hydrocarbons generated in the deeper parts of the basin migrate along faults and carrier beds into suitable structural and stratigraphic traps.

2.5 Depositional Environment

The Lower Goru sediments were deposited in shallow marine to deltaic environments. Sand bodies may represent channels, bars, shoreline deposits, or turbidite systems. Lateral facies variation strongly controls reservoir continuity and quality.

2.6 Structural Style

The structural style is dominated by extensional faulting. Normal faults create tilted blocks, horsts, and grabens. Some faults may act as migration pathways, while others may provide lateral seals depending on shale smear, displacement, and juxtaposition.

Chapter 3: Seismic Interpretation

3.1 Seismic Surveying

Seismic reflection surveying is one of the most widely used methods in petroleum exploration. It provides information about subsurface structures and stratigraphy by recording reflected seismic waves generated at or near the earth’s surface. Seismic energy travels through the subsurface and is reflected at interfaces where acoustic impedance changes.

Acoustic impedance is the product of density and seismic velocity. A strong contrast in acoustic impedance produces a strong reflection. Seismic records are processed to improve the signal-to-noise ratio and generate interpretable seismic sections.

3.2 Seismic Reflection Method

In the seismic reflection method, energy is generated by a source such as dynamite, vibroseis, or an air gun. The reflected energy is recorded by geophones or hydrophones. Travel times are used to estimate the depth and geometry of subsurface reflectors.

3.3 Seismic Data Processing

Seismic processing typically includes editing, geometry assignment, deconvolution, static correction, velocity analysis, normal moveout correction, stacking, migration, and filtering. The objective is to enhance true geological reflections and suppress noise.

3.4 Seismic Interpretation

Seismic interpretation is the process of converting seismic reflection data into geological information. The objective is to identify horizons, faults, structures, stratigraphic relationships, and possible hydrocarbon traps.

The basic technique is to find coherent reflectors and follow them across the seismic area. The picks are timed by reading the reflection times. These times can then be plotted on a map and contoured to show locally high places or other features that may be prospects for drilling.

3.5 Types of Seismic Interpretation

There are two types of seismic interpretation

- Stratigraphical Interpretation
- Structural Interpretation

3.5.1 Stratigraphical Interpretation

According to Telford et al. (1990), stratigraphy analysis involves delineating the seismic sequences, which present the different depositional units, recognizing the seismic facies characteristic with the suggested depositional environment, and analysis of the reflection characteristic variation to locate both stratigraphy change and hydrocarbon depositional environment. 3-D work is especially important in recognizing the stratigraphic features with distinct shapes. The amplitude, velocity, frequency, or change in wave shape indicates hydrocarbon accumulation. Variation of the amplitude with the offset is also an important hydrocarbon indicator. Unconformities are marked by drainage patterns that help to develop the depositional environment. Reef, lenses. An unconformity is an example of a stratigraphic trap (Telford et al., 1990).

3.5.2 Structural Interpretation

Seismic data interpretation is mainly done on the basis of available information and stratigraphy of the area. Seismic is correlated with the formation tops penetrated in the wells using well tops if available. In this study, seismic interpretation is done by picking horizons in Kingdom suit, and the reflector is continued in all other seismic lines. Major faults are picked on the dip lines, and their parts are correlated across the strike lines to map the structures throughout the area. Two-way time (TWT) maps are generated using fault polygons to describe the structural inclination at different levels. The study area is in extensional regime, horst and graben structures are present in the area. The horizons that are marked on the seismic section show normal faults.

3.6 Seismic Interpretation Workflow

The procedure adapted for interpretation is given in Figure 3.1. The base map is prepared by loading navigation data and Seg-Y in the software Kingdom 8.4. Horizons of interest are marked manually with the help of a synthetic seismogram. In this process, faults are identified and marked in the seismic section. Faults polygons are generated, and horizons are contoured to find structural highs and lows. The different important steps involved in the interpretation workflow are discussed in Figure 3.1.

Figure 3.1: Workflow for seismic data interpretation

3.7 Synthetic Seismogram

Synthetic seismograms are artificial seismic traces used to establish correlations between local stratigraphy and seismic reflections. A sonic log is needed to produce a synthetic seismogram. Ideally, a density log should also be used, but these are not always available. With the help of Bilal-01 well, we construct the synthetic seismogram (Figure 3.3) in order to mark the horizons.

Synthetic seismograms provide a crucial link between lithological variations within a drill hole and reflectors on seismic profiles crossing the site. In essence, they provide a ground truth for the interpretation of seismic data. Synthetic seismograms are useful tools for linking drill hole geology to seismic sections because they can provide a direct link between observed lithologies and seismic reflection patterns (Handwerger et al., 2004). Reflection profiles are sensitive to changes in sediment impedance, the product of compression wave velocity and density. Changes in these two physical parameters do not always correspond to observed changes in lithologies. By creating a synthetic seismogram based on sediment petro-physics, it is possible to identify the origin of seismic reflectors and trace them laterally along the seismic line (Handwerger et al., 2004).

Figure 3.2: Showing Synthetic seismogram of Bilal-01 well

3.8 Picking of Horizons and Fault Identification

The primary task of interpretation is the identification of various horizons as an interface between geological formations. For this purpose, good structural as well as stratigraphic knowledge of the area is required. Thus, during the interpretation process, I mark both the horizons and faults on the seismic section (McQuillin et al., 1984). Using well data of wells Bilal-01, horizons are marked on dip lines 2001-KH-30, 2003-KH-44, and strike lines 2003-KH-39, 2003-KH-35. Bilal-01 is drilled on shot point 686 of line 2003-KH-39 and ties all available dip lines, and horizons are continued on all lines.

Finally, marked horizons are named Basal Sands and the Top of Lower Goru formation with the help of a synthetic seismogram of Bilal-01 well data on the strike line 2003-KH-39 (Figure 3.3).

Figure 3.3: Showing Synthetic Seismogram on Seismic section of line 2033-KH-39

The study area lies in an extensional regime dominated by normal faults and associated horst and graben structures. The identification of faults was difficult to some extent due to data quality. The average throw of the faults is observed to be about 15 – 20 ms. On the basis of discontinuity in time, seven normal faults have been marked on the seismic sections of the line 2001-KH-30 (Figure 3.4), forming the horst and graben features. Clues of normal faulting exist on all of the interpreted seismic lines.

Figure 3.4: Showing normal faulting on Interpreted seismic dip line 2001-KH-30

Here is the Seismic section shown (Figure 3.4) on which seven faults are marked on the basis of continuity of reflectors, and two formations of Basal sand and the Top of Lower Goru are marked with the help of a synthetic seismogram. After marking the horizons and faults, we got good horst and grasped geometry structures, which matched our previous geological information.

Figure 3.5: Seismic Section of dip line 2003-KH-44 showing horst and graben geometry

The seismic section of line 2003-KH-44 shown in Figure 3.5 also shows the bookshelf geometry as the previous section (Figure 3.4) shows. As the extension of this line is comparatively smaller than the others, only five faults are marked on the section.

3.9 Construction of Fault Polygons

The construction of fault polygons is very important as far as the time contouring of a particular horizon is concerned. Fault polygons show the extension of faults on the base map, which I mark on seismic lines. So, it gives us a quick view of the structural disturbance in the area. Any mapping software needs all faults to be converted into polygons prior to contouring. The reason is that if a fault is not converted into a polygon, the software doesn't recognize it as a barrier or discontinuity, thus making any possible closures against faults represent a false picture of the subsurface structures.

Figure 3.6: Fault polygon at the Top of Lower Goru level showing normal faulting

In Figure 3.6, the color variation along both sides of the polygon depicts the change in time of seismic reflected waves due to the presence of faults. If the time is noticed along the boundaries of fault polygons, it comes to the result that the normal faulting of the area also confirms the horst and graben geometry.

Figure 3.7: Fault polygon at Basal Sand level

The fault polygon formed at the Basal Sand level, as shown in Figure 3.7, also shows alternate colors due to time changes along both sides of the polygon, showing a normal faulting pattern. Shape in nature of fault polygons almost similar with polygons formed at Top of Lower Goru level.

3.10 Contour Maps

Contouring is the essential constituent of the interpretation of the seismic data. Seismic interpretation actually displays the essential information extracted during interpretation in the form of time and depth contour maps. The contours are the lines of the same time or depth roving about the map as dictated by the data (Coffeen, 1986).

3.10.1 Time Contouring

After completing horizons and fault interpretation, time contour maps are constructed. There are some reasons for making time maps. The times are read directly from the sections and are immediately available for mapping. The pattern of the Time Contour map confirms the shape of the subsurface structure. Time contour maps of these formations show 2D variations with respect to time, and the hydrocarbons probably accumulate at those places where contour values are low.

Figure 3.8: Time contour at the Top of the Lower Goru level showing the change in time on the base map

The top of the Lower Goru grid (Figure 3.8) shows alternate colors along the boundaries of fault polygons. If we notice the time values, we can clearly see the presence of normal faulting with horst and graben geometry. The zone surrounded by the seismic line 2003-KH-39 is the shallower zone in the base map, so there is a maximum chance of accumulation of hydrocarbon in that elevated zone.

Figure 3.9: Time contour at Basal Sand level showing color variation in time along polygons

Time contour map of Basal Sand also shows the same pattern of variation in time through the base map as the Lower Goru formation. This alternate color variation is the sign of horst and graben geometry and time variation proves that it is normal faulting. The n-E region is found to be an uplifted area as compared to the S-W region.

3.10.2 Depth Contouring

When we read the time of a horizon from the section, it tends to show the structure of the horizon in the subsurface; it does not show us the structure directly. Depth conversion and depth contour maps are constructed to see the horizons in the subsurface at their true positions. Depth must be calculated over time to make a map that is more truly related to the subsurface shapes because the structure is a matter of depth. The idea of converting the times into depths is very reasonable in the case of showing the subsurface structures.

Figure 3.10: Showing Variation in depth of the Basal Sand in the base map

As Basal sand is recognized as a good reservoir rock of the Lower Indus Basin, a depth contour map of this formation is constructed, shown in Figure 3.10. The contouring pattern shows the N-E region as a relatively uplifted area. The structural pattern of the area is also confirmed by contouring as the horst and graben geometry. The region shown in blue color is the shallowest horst with low values of depth. It might be a good zone for the accumulation of hydrocarbons because hydrocarbons move towards pressure areas.

Chapter 4: Facies Analysis

4.1 Introduction

A rock or stratified body is distinguished from others by its appearance or composition.

OR

It can be defined as:
The characteristics of a rock or series of rocks reflecting their appearance, composition, and condition s of formation (Lucia. 1995).

4.2 Facies Types

4.2.1 Sedimentary Facies

Sedimentary facies are bodies of sediment recognizably different from adjacent sediment deposited in a different depositional environment

4.2.2 Metamorphic Facies

The sequences of minerals that develop during progressive metamorphism define a facies series.

4.3 Walther's Law of Facies

Walther's Law of Facies, or simply Walther's Law, states that the vertical succession of facies reflects lateral changes in the environment. Conversely, it states that when a depositional environment "migrates" laterally, sediments of one depositional environment come to lie on top of another. A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions. However, the law is not applicable where the contact between different lithologies is non-conformable (Lucia 1995).

4.4 Facies Analysis

Fundamental to all subsurface geologic studies is an analysis of depositional facies. Lucia (1995) describes the development of a facies classification scheme as a particularly challenging interplay between capturing enough information for environmental interpretation and remaining simple. Particularly important is the characterization of facies, as their recognition criteria relate to critical environmental thresholds such as sea level, normal wave base, and storm wave base. These physical environmental zones regulate sedimentary textures and biotic assemblages. A good understanding of paleoecology always strengthens the interpretation, and such studies should be included as part of all depositional facies studies. Depositional textures, in turn, affect porosity-permeability in carbonates. The vertical and lateral organization of facies is an exercise essential to sequence stratigraphic interpretations. (Lucia 1995).

4.5 Facies Analysis Procedure

From the KINGDOM software main window menu bar, choose Tools > Cross plot > New to open the Select Data dialog box. A window will appear, as shown in Figure 4.1.

Data for each axis

X =Rho b

Y =LLD

Z =Gr

Figure 4.1: Facies models showing different cluster points of lithologies

Figure 4.2: Facies model showing the Sand and Shaly Sand in Naimat Basal-01 well

4.6 Results of Facies Analysis

There are two clusters of data points in Figure 4.2. The high resistivity values and corresponding low gamma ray values indicate clean sands. High gamma ray values associated with low resistivity values indicate shale.

Chapter 5: Gassmann Fluid Substitution

5.1 Introduction

Fluid substitution is an important part of seismic rock physics analysis (e.g., AVO, 4-D analysis), which provides a tool for fluid identification and quantification in reservoirs. This is commonly performed using Gassamann's equation (Gassamann, 1951). Many authors (Batzle and Wang, 1992; Berryman, 1999; Wang, 2001; Smith et al., 2003; Russell et al., 2003; Han and Batzle, 2004) have discussed the formulations, strengths, and limitations of the Gassmann fluid substitution (Kumar 2006).

5.2 Gassmann's Fluid Substitution

Saturated porous reservoir rock contains fluid and rock matrix. Porous rock is called dry rock when there is no fluid in pores. Production of oil from a reservoir affects the fluid part and does not affect the solid part. Kumar (2006) describes these fluctuations as the elastic constants (bulk modulus (K), shear modulus ( ), density ( ), etc.), which affect the velocity of seismic waves. K of dry and water-saturated rocks (and   ) are more sensitive to water saturation than P wave velocity ( ) under the same condition of pressure (Batzle and Wang, 2004)). Furthermore, water saturation has slight effects on μ, as the shear modulus of fluid ( ) is zero.

Gassmann's model calculates and of saturated rock by computing K, μ, and ρ for saturated reservoir rock in order to efficiently replicate the effects of fluid substitution. The objective of fluid substitution is to model the seismic properties (seismic velocities) and density of a reservoir at a given reservoir condition (e.g., pressure, temperature, porosity, mineral type, and water salinity) and pore fluid saturation such as 100% water saturation or hydrocarbon with only oil or only gas saturation (Kumar, 2006). The seismic velocity of anisotropic material can be estimated using known rock moduli and density. P- and S-wave velocities in isotropic media are estimated as,

respectively, where and are the P- and S-wave velocity, K and are the bulk and shear moduli, and is the mass density. The density of a saturated rock can be simply computed with the volume averaging equation (mass balance). Another parameter required to estimate seismic velocity after fluid substitution is the moduli, which can be computed using Gassmann's equations.

5.3 Gassmann's Equations

Gassmann's equations relate the bulk modulus of a rock to its pore, frame, and fluid properties as

where, and are the bulk moduli of the saturated rock, porous rock frame (drained of any pore-filling fluid), mineral matrix, and pore fluid, respectively, and φ is porosity (as a fraction). In the Gassmann formulation, the shear modulus is independent of the pore fluid and is held constant during fluid substitutions. Bulk modulus ( ) and shear modulus (μ) at in-situ (or initial) conditions can be estimated from the wireline log data (seismic velocities and density) by rewriting equations 1 and 2 as

5.4 Gassmann Fluid Substitution Wizard via Kingdom Software

The Gassmann Fluid Substitution Wizard uses Gassmann's theory to create new velocity and density logs. Gassmann's theory describes seismic wave propagation in a fluid-saturated porous solid using mathematical relationships between various properties of the rock skeleton (the solid material) and the fluid filling the pore space.

There are three steps to completing Gassmann's wizard:

Step 1.

Select a well, borehole, and porosity source (Figure 5.1).

Figure 5.1: Window of Gassmann's Substitution First step

As the Siraj South is producing well, so we selected that well for Fluid Substitution.

Step 2.

Select the density/porosity and velocity logs, define the skeleton and fluid parameters, and digitize the substitution regions (Figure 5.2).

5.4.1 Gassmann Fluid Substitution Fluid Parameters as Water and Gas

Figure 5.2: Window of Gassmann's Fluid Substitution second step

As mentioned earlier, in this step, we input the density and velocity log of the Siraj South well. Then, I mark the probable prospective zone (Lower Goru formation thickness), which acts as a reservoir for hydrocarbon accumulation. After that, we define the parameters (density and bulk modulus) of the skeleton and the types of fluid present in reservoir rock.

By clicking<Next> in the windows, we get the computed density and velocity log (Figure 5.3).

Figure 5.3: Input and computed velocity and density logs (for fluids such as water and gas)

Step 3.

Save the resulting density and velocity log curves.

5.4.2 Gassmann Fluid Substitution Fluid Parameters as Water and Oil

Figure 5.4: Window of Gassmann's Fluid Substitution second step (for fluids such as water and oil)

The second step of Gassmann fluid substitution for oil and water as fluids is shown in Figure 5.4

Figure 5.5: Input and computed velocity and density logs (for fluids such as water and oil)

Variation in density and velocity is shown in Figure 5.5 due to Gassmann Fluid Substitution theory.

5.5 Results of Gassmann Fluid Substitution

We can clearly see that after applying Gassamann's fluid substitution, there is a decrease in density and velocity in the marked zone. When fluid parameters are water and gas, there is a greater decrease in density and velocity (Figure 5.3) than when fluids are water and oil (Figure 5.5). This is because the density of gas is less than oil, so the velocity of waves is low in a gas medium. We can generate more computed curves by changing the water saturation level, and other fluids in the reservoir zone can estimate the amount of hydrocarbon present in the reservoir at different water saturation levels. These log curves help drill development wells. These new logs can also be saved and used to generate a new synthetic seismogram, which shows better results.

Discussion and Conclusions

Seismic reflection surveying is the most widely used and well-known geophysical technique, and it is specially used for hydrocarbon exploration. By this technique, we can extract information about geological structures on scales from the top tens of meters of drift to the whole lithosphere. Part of the spectacular success of the method lies in the fact that the raw data are processed to produce a seismic section, which is an image of the subsurface structure.

Reflectors of two formations, Basal Sand and the Top of Lower Goru, are marked on the seismic section with the help of a synthetic seismogram of the Bilal-01 well. Time and depth contour maps show the presence of horst and graben structures in the study area. These Uplifted horst structures may act as structural traps in the area and are favorable places for hydrocarbon accumulation.

For the confirmation of reservoir lithology, a Facies analysis is done of the Naimat Basal-01 well, which reveals the result as the reservoir lithology as sand.

After the Gassamann Fluid Substitution, there is a decrease in both density and velocity in the marked (reservoir) area. There is comparatively less decrease in density and velocity in the presence of oil as compared to gas; it is because of the density contrast of oil and gas.

References

- Batzle, M. L., and Wang, Z., 1992, Seismic properties of pore fluids: Geophysics, 64, 1396-1408.
- Berryman, J. G., 1999, Origin of Gassmann's equation: Geophysics, 64, 1627-1629.
- Chopra, Satinder, and Kurt J. Marfurt. "Seismic attributes, A historical perspective." Geophysics 70.5 (2005): 3SO-28SO.
- Coffeen, J.A., 1986, Seismic Exploration Fundamentals, PennWell Publishing Co.
- Dobrin and Savit., 1988, Geophysical Exploration, Hafner Publishing Co.
- Gassmann, F., 1951, Über die elastizität poröser medien: Vierteljahrss-chrift der Naturforschenden Gesellschaft in Zurich, 96, 1-23. The English translation of this paper is available at http://sepwww.stanford.edu/sep/berryman/PS/gassmann.pdf.
- Han, De-hua, and Batzle, M. L., 2004, Gassmann's equation and fluid-saturation effects on seismic velocities: Geophysics, 69, 398-405.
- Handwerger, D. A., et al. "Synthetic seismograms linking ODP sites to seismic profiles, continental rise and shelf of Prydz Bay, Antarctica. Ocean Drill. Prog., Sci. Res. Vol. 188. 2004.
- Kadri I.B., (1995), "Petroleum Geology of Pakistan'', PPL, Karachi, Pakistan.p143-154.
- Kazmi, A.H., & Jan, M.Q., (1997). "Geology & Tectonics of Pakistan," Graphic Publishers, Karachi, Pakistan.
- Kearey, Philip, Michael Brooks, and Ian Hill."An introduction to geophysical exploration." John Wiley & Sons, 2002.
- A. (1991). Geology and new trends for petroleum exploration in Pakistan

- Kingston, D. R., Dishroon, C. P., & Williams, P. A. (1983). Global basin classification system. AAPG bulletin
- Kumar, Dhananjay. 2006, A Tutorial on Gassmann Fluid Substitution: Formulation, Algorithm and Matlab Code, Chevron Energy Technology Company, California.
- Lucia, F. J., 1995, Carbonate reservoir characterization: New York, Springer-Verlag, 226 p.
- McQuillin, R., Bacon, M., and Barclay, W., 1984 An introduction to seismic interpretation, Graham & Trotman Limited Sterling House, 66 Wilton Road London SW1V 1DE
- Powell, C. (1979). A speculative Tectonic history of Pakistan and surroundings: some constraints from the Indian Ocean: In A Farah and K.A Dejong (Editors), Geodynamics of Pakistan, Geol. Survey of Pakistan, Quetta. p 5-24.
- Russell, B. R., Hedlin, K., Hilterman, F. J., and Lines, L. R., 2003, Fluid-property discrimination with AVO: A Biot Gassmann perspective: Geophysics, 68, 29-39.
- Smith, T. M., Sondergeld, C. H., and Rai, C. S., 2003, Gassmann fluid substitutions: A tutorial: Geophysics, 68, 430-440.
- Telford, William Murray, and Robert E. Sheriff."Applied geophysics." Vol. 1. Cambridge University Press, 1990.
- Wang, Z., 2001, Fundamentals of seismic rock physics: Geophysics, 66, 398-412
- Zaigham, N.A., and K.A. Mallick, 2000, Bela ophiolite zone of southern Pakistan: Tectonic setting and associated mineral deposits: GSA Bulletin, v.112, no. 3, p.478-489.