CHAPTER-1

INTRODUCTION

1.1. EXPLORATION FOR HYDROCARBONS

Exploration for hydrocarbons is a very competitive field and involves high economic risk. Exploration involves prospecting and ascertaining the presence of hydrocarbons in the deeper earth layers. Initiation of this process is done through analysis of regional geological, geophysical and aeromagnetic database. The analysis of remote sensing products and photo-geological database aids in identifying the sedimentary basins, which are the potential area of oil accumulation.

Based on the presence of source rock, reservoir rock, surface expressions, structural deformations and/or analogy with producing fields, the demarcation of potential blocks for detailed surveys is done. The detailed surveys provide reasonable clues for delineation of oil and gas bearing structures.

There are various categories of detailed surveys which can broadly be grouped into geological, geophysical and geochemical categories. In geological survey one studies the nature of exposed rocks in a given area such as exposed sections along river beds, their direction of inclination (dip and strike), collects samples of rocks, fossils etc. All this information helps in recreating the geological history of the area in terms of lithology, structures, faults etc. While geophysical surveys can be gravity, magnetic or seismic, the geochemical mainly rely on sampling and analysis of samples of water, oil, gas, soil, rock etc. Gravity surveys use gravimeter to record gravity anomalies, density and lithology contrasts. Magnetic surveys use magnetometer to measure the magnetic field and record data that provides useful information concerning configuration of basement, thickness, variation of sediments, presence of faults etc. Seismic surveys make use of reflected seismic waves and are a very predominant geophysical tool for subsurface structure delineation.

1.2. SEISMIC EXPLORATION

At the reconnaissance stage, the first problem is to delineate the basins in which a thick sequence of sedimentary rocks has been deposited. Only in these basins petroleum source rocks could have been buried deep enough to reach the temperatures and pressures needed for oil to be formed and expelled into reservoir rocks. At this stage of exploration, only a generalized picture of the subsurface is required, and the gravity and magnetic surveys are particularly useful. Aeromagnetic surveys can be carried out quickly and fairly cheaply even in remote inaccessible areas, and the data can reveal the general form of the igneous or metamorphic basement rocks underlying a sedimentary sequence.

The commercially valuable accumulations of hydrocarbons are usually found at depths of at least a few thousand meters below the ground surface. Although exact knowledge of geology at such depths can come only from drilling a bore hole, but deep drilling is very expensive. The deeper the structures, less is the resolution that gravity or magnetic surveys can give. Under such conditions, seismic reflection methods become useful, and play a prominent role in the search for suitable geological structures.

1.2.1 Seismic Surveys

Seismic exploration is carried out using seismic surveys which are broadly categorized into 3 types. The 2D surveys are done typically for new/virgin areas to delineate and map the structures on regional scale and propose locations for exploratory drilling for initial discovery of hydrocarbons. Based on the orientation of the subsurface, the seismic profiles are laid in both dip and strike directions and seismic data is acquired. The 2D survey provides the image of the geological subsurface cross-section.

3D survey is basically done after the initial discovery of hydrocarbons in the area for further detailing and field/reservoir development. The entire area is covered with a grid of closely spaced shot and receiver lines. Interpolating between lines creates a seismic cube or a volume. The cube when sliced in vertical dimension reveals the cross section of the geologic structure along a line and slicing horizontally provides the horizontal slices representing constant time. 3D survey covering a grid provides more number of data points which can help to map the 3 dimensional computer image of the formation. 3D being more expensive can be avoided and done only for those locations where 2D has revealed some information regarding geological structures suitable for hydrocarbon reserves. This avoids companies from wasting money on unlikely prospects and unsuccessful wells.

Time-lapsed 3D or a 4D survey is done for monitoring the reservoir fluid level movements. It is a 3D survey but done at regular time intervals. The information obtained helps in making decisions concerning production planning and development drilling.

1.3. STEPS IN SEISMIC EXPLORATION

A typical seismic survey involves creating seismic waves by explosion in a hole in the ground. These waves travel in all directions and get reflected from certain subsurface formations and are received by a number of geophones located on the earth's surface in the vicinity of the explosion. The frequency and amplitude of these reflected waves depend on the structural details of the reflecting rock surface and its composition. These waves bring voluminous amounts of useful information with them. This process is called Seismic Data Acquisition, in which amplitude of the reflected wave of a fixed frequency is recorded as a function of time which is essentially a two-way travel time from explosion source to the reflecting horizon and back to the geophone.

The acquired data is sent for data processing. The basic objective of all Seismic Data Processing is to convert the information recorded in the field into a form that most conveniently facilitates geological interpretation. The data initially recorded on magnetic tapes are transformed into a corrected record section comparable in many ways to a geological structure section, in the data processing center. One objective of the data processing is to eliminate or at least suppress all noise. Another objective is to present the reflections on the record sections with the greatest possible resolution.

There are a number of processing techniques such as trace correction, stacking, compositing, velocity analysis, Normal-move-out correction, true amplitude registration, migration, plotting etc. The processed seismic data is sent as input to interpretation process.

1.4. RESEARCH MOTIVATION

The data at each shot and receiver point is recorded as a seismic trace. Each seismic trace has an amplitude value at each sampling time instant. The time is referred to as TWT meaning two way travel time, as this is the time taken for the seismic wave to travel from shot point to the reflecting subsurface and return back to be received at the receiver. This seismic data is available in a universally accepted 'SEG-Y' format designed by SEG (Society of Exploration Geophysicists). The next most significant step after data processing is the interpretation of seismic data. This involves obtaining accurate and meaningful inference from reflectors which can be tied to the geology of subsurface in terms of structural lithology of possible hydrocarbon bearing elements. This process is termed as Seismic Data Interpretation.

There are recognized human experts who routinely interpret processed seismic data using their knowledge base in the form of certain thumb rules. Currently, seismic data interpretation is done largely by seismology experts manually who read the seismic section using visual and other coloring tools [**Sternbach, 2002**]. Hydrocarbon exploration depends greatly on the process of interpretation of seismic data because this forms the basis of decisions leading to further explore and drill. This requires large financial commitments and because of this exploration industry historically has been one of the very first to put to use new advances in various fields especially computer technologies into practical use.

1.5. CURRENT SCENARIO WITH SEISMIC DATA INTERPRETATION

This interpretation is a complicated process and depends not only on sophisticated technology, but also, to a large extent, on the experience and interpretive powers of field geophysicists. The interpretation of seismic data into geologically valid models of earth structure and then assessing the probability that any such structure might trap an accumulation of hydrocarbons is mostly an art, acquired only by experience.

Seismologists routinely carry out interpretation, but there is fair amount of uncertainty in terms of geological structure. A given set of seismic data is likely to be interpreted in two different ways by two different seismologists with widely varying conclusions. Each ‘expert’ develops his own unwritten rules to interpret the seismic charts and their conclusions often deviate from the actual structures found.

This uncertainty is partly because of extreme geological complexities and partly because there are no formal rules, and each expert uses his individualistic knowledge-base of unwritten thumb rules, that he or she has developed over the years.

1.6. ARTIFICIAL INTELLIGENCE

Information Technology has encroached into almost every sphere of human activity/endeavor. Artificial Intelligence branch of computer science helps in designing systems that can exhibit intelligence and accomplish tasks that are usually associated with intelligent human behavior. AI is being successfully used in various industries and aims to simulate the human decision making process on computers so that they can solve complex problems- that require intelligence if done by humans. There are a large number of successful applications of AI in diverse disciplines **[Palaz, 1986].**

Evolution of AI started with an attempt to emulate intelligent human behavior. Further the technology improved and was designed to better fit the human requirements. For example, the design of passenger jets, helicopters and hang gliders resulted from the study of how birds fly. This gave an insight into things like lift, drag, weight reduction and propulsion. . However, the technology of flight in use today is that which differs considerably from those of birds. The artificial solutions are those that carry more cargo, can fly faster and for longer periods than the natural solution. Although, the technology of today has its birth in attempting to duplicate the nature, it has now been further refined and redesigned over the years to better fit human requirements. Al uses symbolic representation of knowledge which makes it capable of handling relations between objects, events, etc. much more efficiently. AI can handle complex, non-numeric problem-solving tasks where there are uncertainties or when the available information is incomplete. It has now become a generic term for a group of computer technologies including natural language systems, vision systems, robotics, automatic programming, and expert systems.

It was believed that the role of IT is that of an enabler to enable the geologists, geophysicists and the other technical personnel involved, to take appropriate and timely decisions for better reservoir productivity. But with the advent of Artificial Intelligence, it is now possible that the role of decision maker can be assumed by Expert Systems.

Computer can, perhaps, consider and analyze vast number of alternatives much better than human brain and thus arrive at a more rational decision than any expert human being can do. Its application in petroleum engineering is very recent and is gradually evolving and has the potential to dominate or take over other analytical tools used in the Exploration and Production industry.

The uncertainty in interpretation of seismic data due to seismologists' individualistic expertise and heuristics has motivated to apply artificial intelligence to this significant part of petroleum exploration. Applying artificial intelligence to seismic data interpretation is aimed at minimizing the dependence on human experts and taking more logical decisions than heuristics permit.

Development has been undertaken, as part of this study, of an expert system, which has a database/a knowledge bank, to hold the rare and largely individualistic interpretation knowledge solicited from experts, and also hold heuristics and rules within its rules database. The formulated rules mimic expert's way of thinking, reasoning and decision making to generate an acceptable inference about a particular region.

Other alternative techniques of AI, the virtual intelligence tools like Artificial Neural Network modeling **[McCormach, 1991]**, Support Vector Machines, **[Joshi et al., 2007]** can possibly be used for such an interpretation. These involve designing network models which can be trained in the same fashion as human brain learns from experience. However, the present study is restricted to development of a rule-based expert system for seismic data interpretation.

1.7. RESEARCH OBJECTIVES

At the onset, the following research objectives were laid down outlining the major aspects of the undertaken research work. The development of the expert system involves

1. Understanding the significance of dependency of seismic interpretation process on human experts.

2. Development of expert system's knowledge-base from sources such as literature and discussions with experts to gather heuristics and thereby, convert these into rules.

3. Identification of significant seismic attributes and development of analytical procedures including their coding that aid the interpretation process.

4. Choosing an expert system shell from the available ones that suits the intended purpose.

5. Development of expert system by customization of the chosen shell, 'Flex', through incorporation of knowledge-base, rule-base and inference strategy.

6. Design and development of an interface for user-friendly interaction of user with the expert system and for invoking of pre-programmed analytical procedures to aid interpretation of seismic data.

7. Generation of interpretation by the expert system, along with explanations.

8. Testing and validation of the developed expert system.

9. Development of extensive 'help' to assist the user in using the expert system at all levels.

1.8. METHODOLOGY OF EXPERT SYSTEM DEVELOPMENT

Currently, the seismic data interpretation is manually accomplished by visually inspecting the seismic maps, which have the seismic data and shows subsurface disposition of the line of reflection. The seismologists make use of visual and coloring tools to identify the features of interest and make decisions concerning the presence or absence of structures suitable for oil accumulation.

The expert system has been developed using an expert system shell 'Flex' from Logic Programming Associates, UK. The rules of thumb, heuristics and analytical procedures used for seismic map interpretation, have been collected from various sources such as available literature and interviews with interpretation experts. This information converted into rules and documented into declarative *'if…then'* format has been added into the knowledge base component of the expert system. Analytical procedures have been developed that work on the seismic data present in the form of reflected wave amplitude as a function of two way travel time. Apart from the primary attribute, amplitude, few of the other seismic attributes such as 'instantaneous phase' and 'reflection strength' which are strong indicators of the subsurface structures have also been used in the analytical procedures. These procedures are developed in C++ programming language.

The rules so developed have been chained in a forward chaining manner, in order to fire, put questions, gather responses, and build the conclusion from the collected information. This is a data-driven approach, where step by step, the system gathers information, develops a line of reasoning and generates a conclusion.

The system allows for interpretation of available seismic snaps both manually and analytically. The manual interpretation is primarily based on the visual inspection of the section accompanied by gathering of information by the system through question-answer module. The rules fire in the background based on the responses provided by the user to the system.

The system is capable of doing the analytical interpretation of the seismic map subject to the availability of seismic data. This part of the expert system starts with visual inspection and invites the appropriate analytical procedures to do analysis on seismic data.

One of the analytical techniques built into the system, is cross-correlation, where a reflecting horizon is tracked by cross-correlating the amplitudes of adjacent traces, across a user-specified time window. The technique tracks a reflecting horizon by following the maximum amplitude value within the time window.

The observation made was that this technique fairs quiet well when tracking continuous horizons, but fails when tracking the discontinuous horizons. The seismic attributes ‘instantaneous phase’ and ‘reflection strength’ are characteristic of the reflecting horizon and are more or less constant for a given reflection horizon. These attributes were computed from the available data and used for tracking the horizons with discontinuities.

These analytical procedures invited by expert system, yield information for further firing of analytical rules from the knowledge-base. The gathered data adds on to the information so far generated and serves as a procedure to further confirm the findings. The plots generated by analytical procedures are displayed for comparison with the horizons in the seismic maps. The enriched interpretation is generated and displayed by the system.

The user interaction with the expert system is through a user-friendly interface developed in visual programming language, Visual Basic. The user interface allows the user to choose from, a list of available seismic sections for interpretation. The seismic data corresponding to the seismic map is also loaded based on its availability within the system. The provision to add a new seismic section to the available list is also part of the features provided in the system. Data corresponding to the section can also be uploaded so that analytical procedures can be used over it during interpretation.

'Flex' has been linked with Visual Basic user-interface through a tool called Intelligence Server. This mainly constitutes a set of files which make possible connection and communication between these two parts of the expert system. The expert system is made convenient for end-user usage by providing context-sensitive help.

The expert system has been packaged into an installable setup program, which can be deployed on any stand alone windows machine.

1.9. CHAPTERS SCHEME

Chapter 2 of this thesis contains the '**Review of Literature'** which covers the significant information concerning the research and developments in the area of seismic exploration, seismic surveys and seismic data interpretation techniques. The chapter also discusses various seismic attributes, their characteristics and classifications. The developments in the area of seismic attributes and their role in the analytical techniques have also been covered in this chapter. This information has played a predominant role in development of the analytical part of the expert system. The field of artificial intelligence has been a major contributor to a number of new developments in petroleum geophysics, especially, some of the systems have been developed using tools like artificial neural networks. The chapter also covers details of certain significant systems developed using AI. The AI based expert systems have been widely used in process industry for diagnosing and trouble shooting. The chapter elaborates on the developed expert systems and their significant features.

Chapter 3 elaborates in detail, the '**Theoretical Developments'** in the fields of seismic surveys, seismic data acquisition, processing and interpretation of seismic data through seismic attributes. It also covers the explanation of procedure of various analytical techniques involved in the process of interpretation. The equations and formulae have been elaborated along with their role in delineation of the subsurface geology of the given area. It further outlines the significance of seismic attributes in generation of knowledge-base for the expert system.

Chapter 4 of this thesis covers the '**Theoretical Developments in the area of Expert Systems'**, their components and their functionalities. The major advantages of the expert systems, the chaining strategies and their significance are also discussed in this chapter. The role of the expert system in mimicking the expert's thinking, reasoning, decision making and capability of offering explanation for reached conclusions, is outlined in this chapter, to establish the basic foundation of the developed expert system.

Chapter 5 covers the '**Expert System Development for Seismic Data Interpretation'**. It discusses the four major components of the developed expert system, mainly concentrating on the visual inspection based manual interpretation, and seismic data based analytical interpretation of the system. It also covers the process of generation and inclusion of knowledge-base into the expert system. Lastly, it elaborates the user-friendly features of the system and discusses the development of the context-sensitive help. Samples of the developed rules, code-snippets of the analytical procedures, screen-shots depicting the process of working with the expert system have been added in this chapter.

Chapter 6 is on **'Results and Discussion'** and describes the work done in terms of the seismic sections examined, visually as well as analytically. The details of the horizons tracked using the discussed analytical techniques such as cross-correlation technique, have been included. The limitation of the cross-correlation technique, in tracking discontinuities has been overcome by using seismic attributes like, 'instantaneous phase' and 'reflection strength'. The computation of these attributes as a function of time, from base amplitude data, for every sampling instant, has been shown with data samples used for analysis during the research work. The plots obtained with these analytical procedures and their comparison done with the corresponding horizons in seismic snaps has been added to this chapter. Further fine tuning in case of tracking discontinuities such as faults, has been shown by traversing, a faulted horizon in both directions.

Chapter 7 includes '**Conclusion and Recommendations'.** In this chapter, the conclusions of the research work have been given. The chapter describes the systems' capabilities, limitations and the recommendations have also been made for the future enhancement of the work.