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Full Length Research Paper

Continuous Expert seismology by non-direct oil reserves Expert framework

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A non-linear 3-D elastic waves real - time expert system is proposed for the exploration of land and marine oil reserves, according to the new theory of "*Real-Time Expert Seismology*". This Generic Technology will work under Real Time Logic for searching the land and marine petroleum developed on the continental crust and on deeper water ranging from 300 to 2000 m, or 3000 m, or even more. Hence, the proposed real - time expert system will be the best device for the exploration of the continental margin areas (shelf, slope and rise) and the very deep waters, too. Furthermore, the above expert system will be suitable for the exploration of land oil reserves, as well. The objectives for exploration of marine and land oil resources are to locate, characterize and evaluate the size of such reserves. Hence, there is a research and development responsibility for the acquisition and analysis of geophysical, geological and reservoir engineering data for the land and the seas all over the world, in order to be explored their petroleum and gas reserves. Thus, through the new technology of *"Real-time Expert Seismology"*, will be effected the exploration of a significant part of marine and land oil reserves very fast and by a low cost.

Key words: Real-time expert seismology, land oil reserves, marine oil reserves, non-linear real - time expert system, real- time logic, generic technology.

INTRODUCTION

As the energy demand for oil and gas is increasing worldwide yearly at a pace of 1.5 to 2.0%, then it will increase up to 2030 by 50 to 60%. The total estimated petroleum all over the world in place stands today approximately at 1.5 trillion barrels, and with current petroleum consumption at 90 million barrels per day, the hydrocarbons in place are predicted to last for the next 40 years. Consequently, there is an absolute need by oil companies all over the world to increase their stock by finding new petroleum and gas reserves. For this reason the big oil companies should be looking into other alternatives, like to drill to ever deeper horizons and in the relatively unexplored ocean depths.

The research and development aspects of marine and land oil reserves can be divided into three main areas:

(a) The acquisition and analysis of geophysical, geological and reservoir engineering data to enable an appreciation to be made of the reserves.
(b) The determination of all-necessary standards and data for the safety to offshore and land operations.
(c) To assist the development of the offshore supplies industry, and to enable it to play a full part in the development of the marine hydrocarbon resources in worldwide markets in the future.

There is a considerable feeling by oil companies and scientific institutes that the unexplored marine and land petroleum and gas resources should be too many, many times more than the terrestrial reservoir of Middle - East. On the other hand, many recent test drillings in the Continental Shelf of Europe and rest world have shown the existence of petroleum resources.

Furthermore, the usual probability considerations indicate that marine oil reserves will be found in areas of thick sedimentary sequences developed on the continental crust. Hence, by such understanding the continental margin areas (shelf, slope and rise) offer good prospects of containing hydrocarbon reservoir. However, up to present the potential of sediments both on and off the shelf remains unquantified. Furthermore,

there are deep waters prospects around the seas all over the world, but because of the paucity of the available information it is not possible at present to quantify the amounts that may be recoverable from them.

Since 1920, the basic and prevalent theory on oil reserves exploration has been *"Reflection Seismology".* The basic idea of this method is to collect reflections of elastic (seismic) waves and through various mathematical operations, by using Snell's law and Zoeppritz equations, convert them to maps of the earth's structure Aki and Richards (1980), Alkhalifah and Tsvankin (1995), Dellinger et al. (1993), Gaiser (1997), Hale (1984), Harrison and Stewart (1993), Thomsen (1988), Thomsen (1999), and Tsvankin and Thomsen (1994) Infer location of oil and gas from structural maps, sometimes of character of reflections, too. Thus, the method of *"Reflection Seismology"* was used almost for a century, with several improvements in the industry of oil reserves exploration.

On the other hand, our proposal on marine and land oil reserves exploration is based on the new theory of *"Real-time Expert Seismology"*, which was very recently proposed by Ladopoulos (2011a, 2011b, 2012). Furthermore, is an extension of the non-linear methods for fluid mechanics. As proposed by Ladopoulos and Zisis (1997, 2000). This is a very "innovative" and "groundbreaking" method on oil reserves exploration. According to the new theory a non-linear 3-D elastic waves real - time expert system is proposed for the exploration of several oil reserves including marine oil reserves, of the seas all over the world. Such Generic Technology will work under Real Time Logic (Emnis et al., 1986; Fritz et al., 1988; Haase, 1990; Jahanian and Mok, 1985, 1986) for searching marine reserves developed on the continental crust and on deeper water ranging from 300 to 2000 m, or even more. The proposed real - time expert system will be therefore the best device for the exploration of the continental margin areas (shelf, slope and rise) and the very deep waters, too. Also, this expert system will be suitable for the exploration of land oil reserves, as well.

The benefits of the new theory of *"Real-time Expert Seismology"* in comparison to the existing theory of *"Reflection Seismology"* are the following:

1. The new theory is based on the special form of the geological anticlines of the bottom of the sea, in order to decide which areas of the bottom have the most possibilities to include petroleum.

On the other hand, the existing theory is only based to the best chance and do not include any theoretical and sophisticated model. So oil companies all over the world by using the existing method of *"Reflection Seismology"* must do many expensive test drillings in big areas of seas, if they want to have a chance to find oil and gas reserves. As every deep drilling cost at least 100 mill.

EURO, then every dry drilling would cost a lot of money to the oil companies.

2. The new theory of elastic (sound) waves is based on the difference of the speed of the sound waves which are traveling through solid, liquid, or gas. In a solid the elastic waves are moving faster than in a liquid and the air, and in a liquid faster than in the air.

Existing theory is based on the application of Snell's law and Zoeppritz equations, which are not giving good results, as these which we are expecting with the new method.

3. The new theory is based on a Real-time Expert System working under Real Time Logic, that gives results in real time, which means every second. Existing theory do not include real time logic.

From the above three points it can be well understood, the evidence of the applicability of the new method of *"Real-time Expert Seismology".* Also its novelty, as it is based mostly on a theoretical and very sophisticated Real-time Expert model and not to practical tools like the existing method. So, the new method will be the best technology for searching the very deep waters (2000 to 3000 m, or even more) and the very deep depths of the basement rock of earth (20,000 to 30,000 m).

REAL-TIME EXPERT SEISMOLOGY

Generally, marine operations consist of 90% of all data collected worldwide for oil and gas reserves exploration. The depth of the drillings are usually up to 6000 m, but in order to find big petroleum and gas reserves they must be extended to 10,000 m or even from 20,000 to 30,000 m. Beyond the above, by studying geological surveys all over the world indicate that petroleum reserves do not necessarily end at the edge of the continental shelf. So, there is a serious expectation that main resources will be found in areas of thick sedimentary sequences developed on the continental crust. According to the new sophisticated model the oil reserves should occur in areas of geological anticlines. Moreover, there are good possibilities for finding off-shore petroleum and gas reserves in deeper waters, too, ranging up to 2500 to 3000 m, or even more and in very deep drillings ranging from 20,000 to 30,000 m.

The behavior of a reservoir depends not only on the properties of the liquid and gas, but also on a series of factors that may be termed as the "properties of the environment". Amongst these are such items as capillary - pressure effects, the reaction of rock when subjected to high stress, pressure and temperature gradients at the shallower levels in the Earth's crust and influences of the compressibility as pressure are reduced by fluid withdrawals.

There are four conditions that must be satisfied so that a geological formation, or a part thereof, should form a suitable reservoir, for example for the accumulation of oil.

These are porosity, permeability, seal and closure. The first defines the pore space in the rock - space in which the oil may collect. Permeability is the attribute of the rock that permits the passage of fluid through it. Generally, it is a measure of the degree interconnectedness of the pore space, but some reservoir (for example, in the massive limestone deposits, or in igneous intrusions) depends for fluid flow on a network of fractures within the rock.

Furthermore, the seal is the "cap" of the reservoir and prevents the oil from leaking away, while closure is a measure of the vertical extent of the sealed trap or, in the case of resources accumulation bounded below by a moving body of water, of the "height" of the sealed trap where that height is measured along a line perpendicular to the oil - water contact.

Almost all resources occur in sedimentary basins, in porous standstones or limestones and that seal or cap rock is often a clay or shale, or massive unfractured limestone having little or no permeability. On the other hand, three general categories of resources can be mentioned for marine reserves: structural traps, stratigraphic traps and combination traps.

Elastic waves are sound waves, generally three - dimensional and they may be transmitted through matter in any phase - solid, liquid, or gas. Any body vibrating in air gives rise to such waves, as it alternately compresses and rarefies the air adjacent to its surfaces. A body vibrating in a liquid, or in contact with a solid, likewise generates similar longitudinal waves. The frequency of the waves is of course the same as the frequency of the vibrating body that produces them.

The distance between two successive maxima (or between any two successive points in the same phase) is the wavelength of the wave and is denoted by *l*. Since the waveform, travelling with constant velocity *u*, advances a distance of one wavelength in a time interval of one period, it follows that the velocity of sound waves *u* as following:

$$u = l\, v \qquad (1)$$

where *v* denotes the frequency.

As it is obvious the velocity *u* differs when the sound waves are travelling through solid, liquid, or gas. In a solid the elastic waves are moving faster than in a liquid and the air, and in a liquid faster than in the air. Therefore, if somebody is searching for example for oil marine resources over the sea, by transmitting sound waves, then there will be a difference in the velocity of the waves in the air, the sea, the solid bottom and in a potential reservoir.

In order to better explain our method, consider the example of Figure 1. In this case consider that in the bottom of the sea there is a potential oil reservoir. Then, the speed of the elastic waves in the air (u_{air}), will be different from the speed in the water (u_{water}), and different from the speed in the solid bottom (u_{solid}) and different from the speed in the potential reservoir (u_{oil}), while the frequency of the elastic waves remaining the same when transmitted through every different matter.

A real-time non-linear 3-D plane-polarized elastic waves expert system is proposed in order to explore the marine oil resources, for the several closed seas all over the world, according to the new theory of *"Real-time Expert Seismology",* in contrast to the old theory of *"Reflection Seismology".* Such Generic Sound Waves Technology will work under Real Time Logic for searching marine hydrocarbon reservoir developed on the continental crust and on deeper waters ranging from 300 to 3000 m, or even deeper (Figure 2). There are many deeper water prospects around the seas all over the world, but because of the paucity of the available information it is not possible at present to quantify the amounts that may be recoverable from them. For this reason the proposed real - time elastic waves expert system will be the best device for the exploration of the continental margin areas (shelf, slope and rise) and the very deep waters, too. So, through the new technology of *"Real-time Expert Seismology"*, will be effected the exploration of a significant part of marine and land oil reserves very fast and by a low cost.

According to the new theory of *"Real-time Expert Seismology"* the average velocity of the sound waves is calculated by providing important information about the composition of the materials through of which passed the sound waves. For example the velocity of the sound waves through the air is 331 m/s, through liquid 1500 m/s and through sedimentary rock 2000 to 5000 m/s. Also, the law of Reflection states that the angle of reflection equals the angle of incidence (Figure 3). According to the new technique the arrival times of the seismic waves are analyzed. After the sensor measures the precise arrival time of the wave, then the velocity of the wave can be calculated by using the following method.

The travel time *T* of the seismic waves is given by the formula:

$$T = \frac{\left(d^2 + \left(x/4\right)^2\right)^{1/2}}{v} \qquad (2)$$

where *d* denotes the depth, *x* the distance between source of wave and the geophone or hydrophone detector and *v* is the average speed. From (2) follows Equation (3):

$$T^2 = \frac{4d^2 + x^2}{v^2} \qquad (3)$$

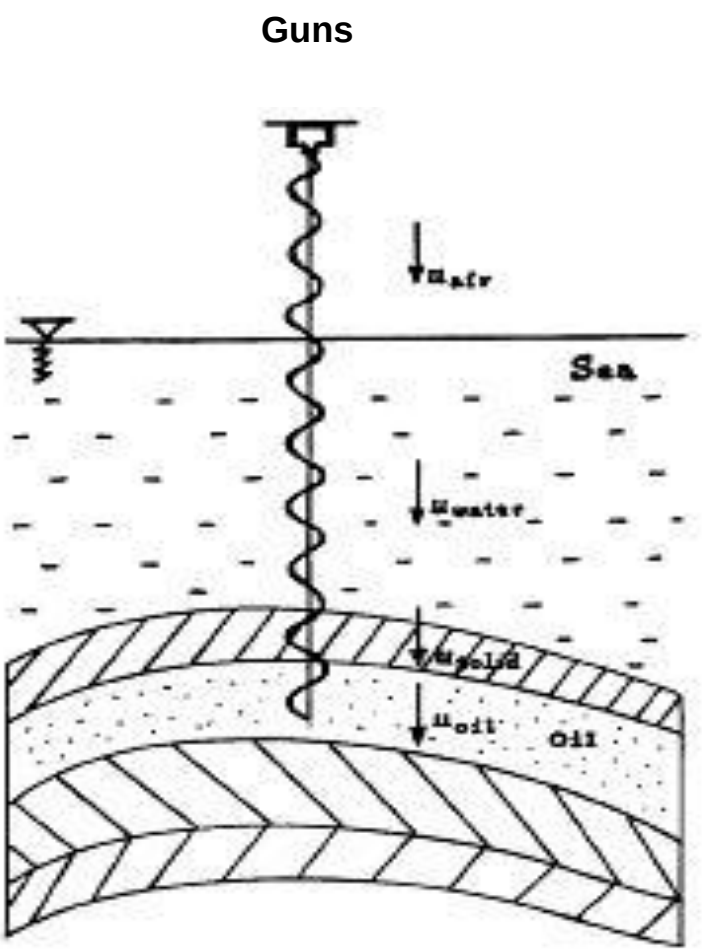

Figure 1. Elastic waves method for the exploration of oil reserves.

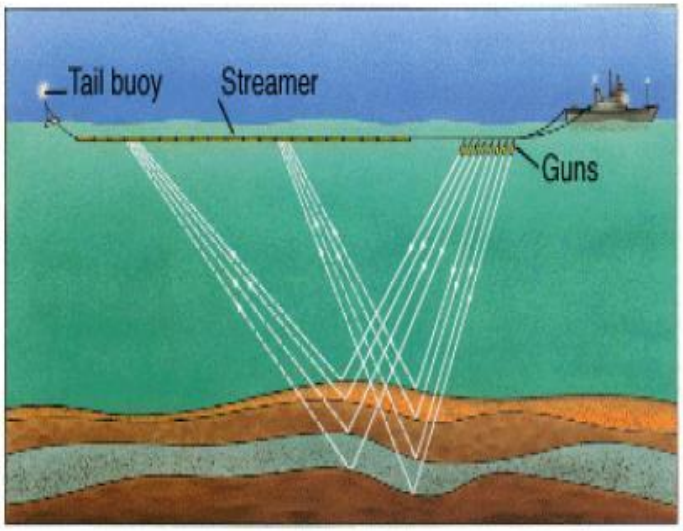

Figure 2. Real-time Expert Seismology.

$$T_o \approx \frac{2d}{v} \quad (4)$$

From Equations (3) and (4) follows:

$$T^2 \approx T_o^2 + \frac{x^2}{v^2} \quad (5)$$

and finally from (5) the mean velocity is equal to:

$$v \approx \left[\frac{x^2}{T^2 - T_o^2} \right]^{1/2} \quad (6)$$

Thus, a real time expert system is used and the apparatus permitted excitation of any combination of elements and reception of any other, visual analysis of the responses, and transfer of the signals to the PC for post processing. The sequencing of transducer excitation, digitiser configuration and subsequent data analysis was performed by a rule based Real-Time Expert System. From the information gathered, the Expert System applies knowledge via a series of software coded rules and provides any one of the following conditions: speed in the air (u_{air}), speed in the water (u_{water}), speed in the solid bottom (u_{solid}) and speed in the potential reservoir (u_{oil}).

REAL-TIME LOGIC FOR OIL RESERVES EXPLORATION

Real-time logic (RTL) is a reasoning system for real-time properties of computer based systems. RTL's computational model consists of events, actions, causality relations, and timing constraint. This model is expressed in a first order logic describing the system properties as well as the systems dependency on external events. The Real-Time Logic system introduces time to the first logic formulas with an event occurrence function, which assign time values to event occurrences. Such real-time logic systems were studied by Jahanian and Mok (1985, 1986).

Beyond the above, real-time computing in common practice is characterized by two major criteria: deterministic and fast response to external stimulation, and both human and sensor and actor based interaction with the external world. Real-time is an external requirement for a peace of software; it is not a programming technology. There are some special software tools for the implementation of real - time systems. Such real-time programming languages were investigated by several scientists like Emnis et al. (1986), Fritz et al. (1988) and Haase (1990).

In general, Real-Time Logic uses three types of constraints:

1. Action constants may be primitive or composite. In a composite constant, precedence is imposed by the event-action model using sequential or parallel relations

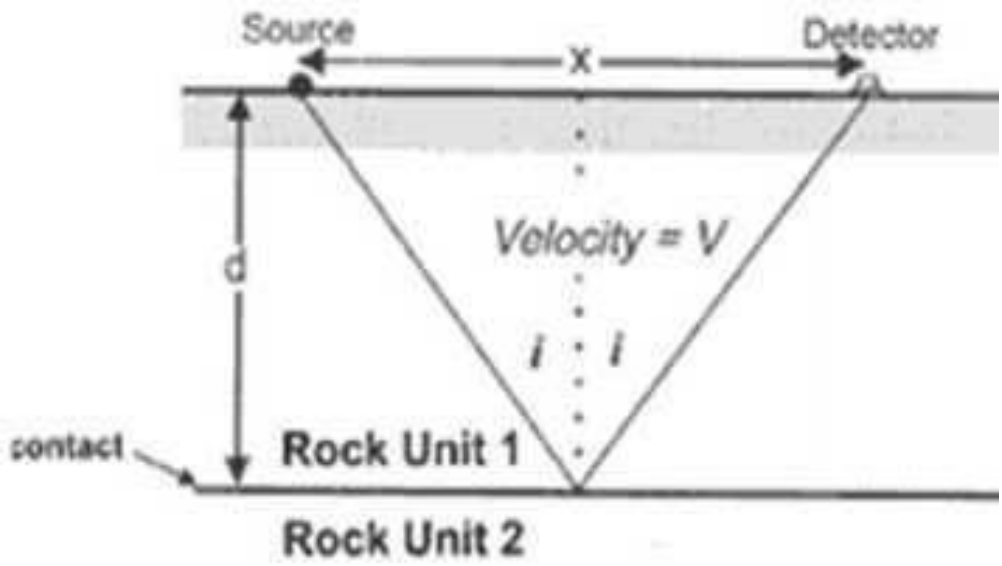

Figure 3. Law of reflection.

between actions.

2. Event constants are divided into three cases. Start/stop events describe the initiation/termination of an action or sub-action. Transition events are those which make a change in state attributes. This means, that a transition event changes an assertion about the state of the real-time system or its environment. The third class, which is the external events, includes those that can be impact system behavior, but cannot be caused by the system.

3. Integers assigned by the accurance function provide time values, and also denote the number of an event occurance in a sequence.

Moreover, the Real-Time Logic System introduces time to the first order logic formulas with an event occurance function denoted by e. The mechanism to achieve a timing property of a system is the deduction resolution.

Let us further consider the following example: Upon pressing button □ 30, action TEST is extended within 300 time units. Dusting each execution of this action, the information is sampled and subsequently transmitted to the display panel. Also, the computation time of action TEST is 90 time units.

This example can be further translated into the following two formulas:

□ x: e (Ω button 30, x) □ e (□ TEST, x) □
e (□ TEST, x) □ e (Ω button 30, x) + 300
□ y: e (□ TEST, y) + 90 □ e (□ TEST, y)

SEISMIC WAVES

Suppose that a seismic wave of any sort travels from left to right in a medium, then the equation of the travelling wave may be written as following:

$$y(\square, t) \square A\cos(\square t \square k \square) \quad (7)$$

with k the wave number equal to :

$$k = 2\pi / \lambda \quad (8)$$

and λ the wavelength, t the time, A the amplitude of the motion and $\omega=2\pi v$, v the frequency. A sinusoidal transverse wave travelling toward the right, at intervals of period 1/8 can be seen in Figure 4.

It is further important to distinguish between the motion of the waveform, which moves with constant velocity u along the string, and the motion of a particle of the string, which is simple harmonic and transverse to the string. In order to be understandable the mechanics of seismic waves, consider Figure 5.

Furthermore, by differentiating the wave equation (7) one obtains:

$$\square y / \square z \square kA\sin(\square t \square kz) \quad (9)$$
$$\square y / \square t \square \square \square A\sin(\square t \square kz) \quad (10)$$

By combining eqs (11) and (12) and as the velocity is equal to:

$$u = \omega / k \quad (11)$$

Then we obtain:

$$\frac{\square y}{\square \square} \square \frac{1}{u} \frac{\square y}{\square t} \quad (12)$$

which by a second differentiation takes the form:

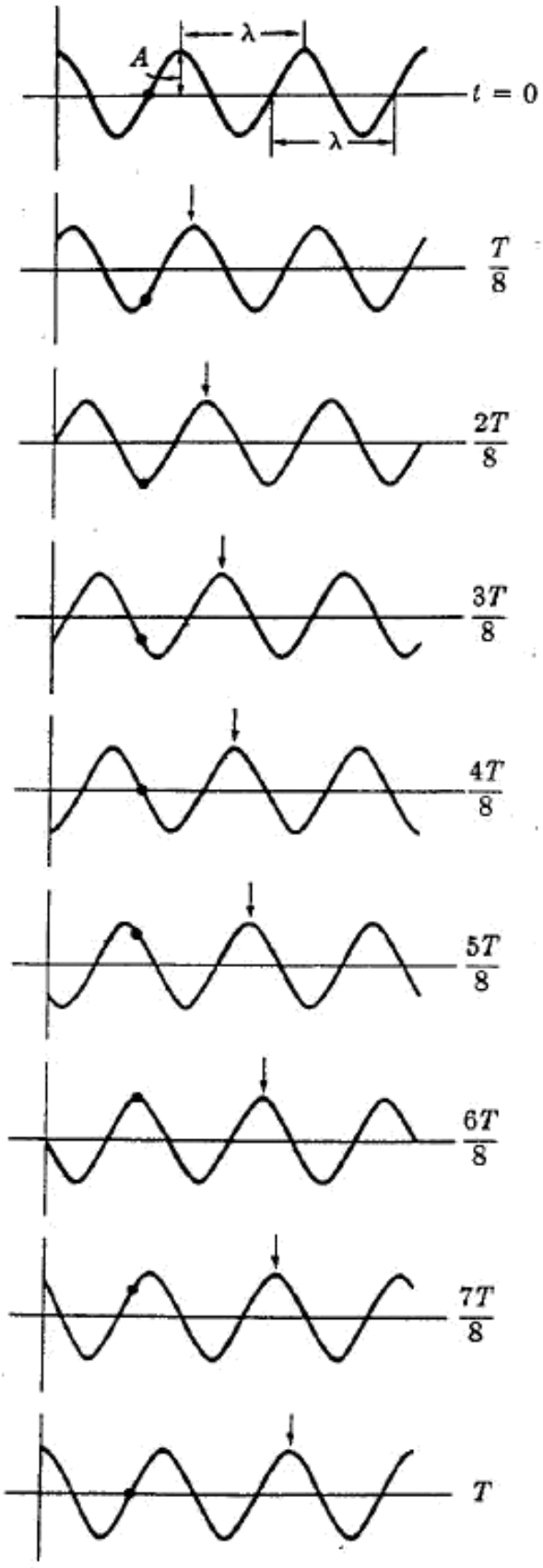

Figure 4. A sinusoidal transverse wave travelling toward the right, at intervals 1/8 of a period.

$$\frac{\partial^2 y}{\partial t^2} = u^2 \frac{\partial^2 y}{\partial x^2} \qquad (13)$$

In a transverse wave motion the individual particles vibrate in a direction perpendicular to the direction of propagation of the wave. But there are many such directions - indeed, they are infinitely many. In Figure 6 three transverse waves are illustrated, all travelling in the same direction, but lying in different planes from one another: A in a vertical plane, B in a horizontal plane, C in a plane inclined at an angle of 45° to each of these. In each case the motion of each individual particle is restricted to a single straight line, and the entire wave to a single plane. Each of these waves is said to be plane - polarized. Also, because of their non - linear behavior, are called non - linear plane - polarized. But we could also generate more complex seismic waves by moving one end in any periodic manner, not restricted to a single straight line. In such cases, each particle has two - dimensional motion (it moves in a plane) and the entire wave is three - dimensional. Even then the wave is not necessarily un-polarized, while if the vibrations are ordered in any case, the wave is to some degree polarized.

CONCLUSIONS

In the present investigation the new theory of *"Real-time Expert Seismology"* has been introduced and investigated for the exploration of land and marine oil reserves. As the test marine drillings are very expensive with costs of many millions (or billions) of EURO or USD and many times without any success, which means a big loss of funds, then the highly innovative and groundbreaking technology *"Real-time Expert Seismology"* has been proposed. By this new basic technology for energy applications a strong scientific and technical base will be established for the science and technology all over the world in the emerging areas of oil reserves exploration in the energy field. So, through the new technology of *"Real-time Expert Seismology"* will be effected, the exploration of a significant part of marine and land oil reserves very fast and by a low cost.

The oil market is a market of many billions every year all over the world. So this contribution requires a worldwide approach, rather than a local approach, as it is referred to a market all over the world with value of many billions of EURO or USD. We expect therefore in order for the big oil companies to keep and to improve its leading role in the science and technology in the whole world, to get involved in the new and groundbreaking technology in the area of energy, which we are proposing.

Thus, the potential areas and markets of application of the proposed technology will be the oil market all over the world. The method's results will be applicable to all oil

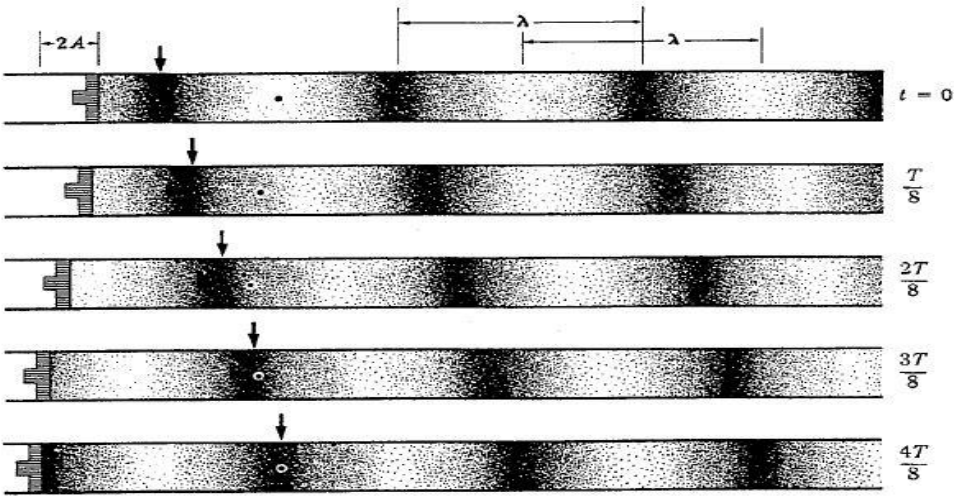

Figure 5. Sinusoidal longitudinal waves, travelling toward the right, at intervals 1/8 of a period.

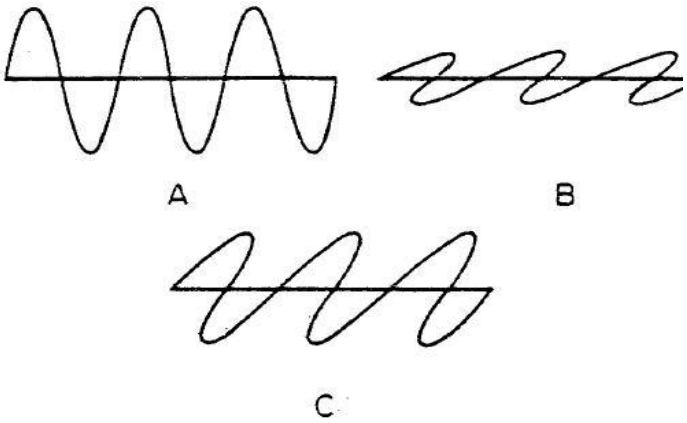

Figure 6. Transverse waves, travelling in the same direction, but lying in different planes from one another.

companies and scientific organizations working on oil exploration in the whole world. We are expecting through our proposed new technology the cost for oil exploration to be reduced too much, as there will be no need for so many test drillings, as today. The test drillings cost many million (or billion) of EURO or USD, and our method will reduce them in the possible minimum.

As our proposed new technology *"Real-time Expert Seismology"*, is based on a non-linear 3-D elastic waves real - time expert system, working under real logic, then is expected to give the best results. Furthermore, our proposed high technology method is based on a very sophisticated model by checking the geological anticlines of the bottom of the sea, in order to decide which areas of the bottom have the most possibilities to include petroleum. So it is not necessary to make test drillings in the half ocean in order to find petroleum, like the existing methods.

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