Universal Journal of Petroleum Sciences 2 (2014), 16-30
www.papersciences.com

Three-dimensional Non-linear Real -Time Expert Seismology for Oil and Gas Exploration

E.G. Ladopoulos
Interpaper Research Organization
8, Dimaki Str.
Athens, GR - 106 72, Greece
eladopoulos@interpaper.org

Abstract
The innovative method *"Non-linear Real-Time Expert Seismology"* is investigated for the designation of the exact location of the big on-shore and off-shore oil and gas reserves all over the world. The above new technology is applied by using a non-linear 3-D elastic waves real - time expert system and so the land and marine petroleum reserves can be successfully determined. Then exact 3-D images are produced of the underground topography of the area. In addition, the exact location of the oil and gas reserves may be designated in the special areas where anticlines occur. So, the above high innovative and groundbreaking petroleum method is working under Real Time Logic for searching the on-shore and off-shore oil and gas reserves developed on the continental crust and on deeper water ranging from 300 to 3000 m, or even deeper. Also, the new method of oil and gas reserves exploration can be used at any depth of seas and oceans worldwide and for any depth in the subsurface of existing oil and gas reserves. So, 3-D seismic information allows petroleum engineers to see a more reliable view of the underground area. Also, 4-D imaging can be taken on a given area multiple times over an extended period of time. The proposed new method can be used for the exploration of petroleum reserves in very deep depths, like 20,000 to30,000 m. Hence, the international oil companies must be ready to face the new challenges of drilling even deeper, to the basement rock, where huge petroleum fields may await to be discovered, according to the theory of abiotic petroleum generation. As every deep drilling costs more than 100 mill EURO, then oil companies should have many financial losses for dry drillings. So, by the new sophisticated method the exact location of every big petroleum reservoir can be designated. It is therefore clear that peak oil and gas will be reached when science will reach peak technology and the new proposed technology seems to be well suitable for such a success.

Key Word and Phrases
Non-linear Real-time Expert Seismology, Real - Time Logic, 3-D Imaging, 4-D Imaging, Non-linear Real - Time Expert System, Very Deep Drillings, Off-shore Oil and Gas Reserves, On-shore Oil and Gas Reserves.

1. Three-Dimensional & Four-Dimensional Seismology Imaging

It is well known that the energy demand for oil and gas will increase up to 2030 by 50-60%, as it is increasing worldwide yearly at a pace of 1.5 to 2.0%. Furthermore, 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. So, there is an absolute need by international petroleum companies worldwide to increase their stock by finding new oil and gas reserves. For this reason petroleum companies should be looking into other alternatives, like to drill to ever deeper horizons and in the relatively unexplored ocean depths. Also, oceans cover about 70% of the earth's surface and most of the waters are at more than 2000 m deep. Consequently, big oil companies and scientific petroleum organizations are prepared for tapping into the relatively unknown areas with potential for large discoveries.

Moreover, in order to answer to the question how deep big petroleum companies should drill to find petroleum and gas, then the current depth records should be stated. Up to today, the deepest hole ever created by humans lies beneath the tower enclosing Kola's drill, in Russia. A number of boreholes split from the central branch, but the deepest is designated "SG-3," a hole about nine inches wide which snakes over 12.262 kilometers (7.5 miles) into the Earth's crust. The drill spent twenty-four years chewing its way to that depth, until its progress was finally halted in 1994, about 2.7 kilometers (1.7 miles) short of its 15,000-meter goal. The KOLA peninsula borehole, drilled in 1984, reached the crystalline basement, and gases like, He. H2, N2, CO2, methane and other hydrocarbons flowed at a depth of 9101 m [1], [2]. Consequently, it was a very big surprise to the petroleum engineers, that they didn't find the expected transition from granite to basalt at 3-6 kilometers beneath the surface. Data had long shown that seismic waves travel significantly faster below that depth, and geologists and petroleum engineers had believed that this was due to a "basement" of basalt. Instead, the difference was discovered to be a change in the rock brought on by intense heat and pressure, or metamorphic rock.

Beyond the above, deepest gas wells have been in Anadarko basin, Oklahoma, USA. There were two wells, drilled in the 1970s. Well GHK/Lone Star Bertha Rogers #1-27, for which drilling started in 1974 and stopped at 9,583 m when it struck molten sulfur. The second deepest U.S. well was the Lone Star/GHK #1-28 E.R. Baden well (total depth 9,162 m), for which drilling started in 1970 and ended in 1972. Moreover, deepest petroleum producing subsea well is in the Perdido field, located 200 miles south of Freeport Texas operated by Shell. This is the deepest drilling and production facility in the world, placed in 2382 m of water, operated by Shell in the Gulf of Mexico. Full development plan calls for a total of 35 wells. Another very deep producing offshore well is in the Tahiti field in the Gulf of Mexico, in a depth of more than 8138 m, a record for the Gulf, according to Chevron.

The existence of very big oil and gas reserves in very deep depths of the earth's subsurface can be proved by the abiotic theory of hydrocarbon generation. In addition, the finding of very deep gas reservoirs, down to almost 10,000 m, with extremely high success rates of more than 55%, has also been reported as evidence of abiotic generation of hydrocarbons. So, big petroleum companies should be rethinking about oil and gas exploration strategies in view of the substantial evidence about abiotic hydrocarbon origin. On the other hand, it was analyzed theoretically, via thermodynamic computations, the possibilities for hydrocarbon generation at high pressures and temperatures and showed that it is possible. By using therefore the abiogenic theory of hydrocarbon generation it can be concluded that Earth's hydrocarbon budget is much larger than it is currently thought.

Consequently, as the recent theoretical and experimental evidence demonstrates the possibility that petroleum may have formed in the depths of the earth, then international oil companies must be ready to face the new challenges of drilling even deeper, to the basement rock, where very huge oil and gas fields may await to be discovered. So, modern technologies will have a major impact in the future. Through the technological progress to be achieved in the future exploration, then major reductions in costs can be very much expected. It is believed that the expected progress of enhanced oil recovery methods will reduce their future technical cost substantially. Hence, it is absolutely sure that drilling depths will be increasing in the future and the industry should be geared up and ready for meeting the many challenges. According to the current research the drillings in the near future could reach the 20,000 m, or even the 30,000 m in the subsurface of earth.

On the contrary, since 1920 and for over a century the basic and prevalent theory on oil and gas reserves exploration, was *"Reflection Seismology"* and *"Refraction Seismology"*. According to the above methods the basic idea is to collect reflections of elastic (seismic) waves and then through various mathematical operations, by using Snell's law and Zoeppritz equations or the Kirchhoff equations to convert them to maps of the earth's structure. [6] - [14]. So, the methods of *"Reflection Seismology"* and *"Refraction Seismology"* for almost a century, have been used with several improvements for petroleum resources exploration.

By the present research for the on-shore and off-shore oil and gas reserves exploration the modern technology of *"Non-linear Real-Time Expert Seismology"* is investigated, as was recently proposed by E.G.Ladopoulos [15]-[17]. Also, the above theory results as an extension of the non-linear methods for fluid mechanics as proposed by E.G.Ladopoulos. [18]-[29]. So, *"Non-linear Real-Time Expert Seismology"* is a very "*innovative*" and "*groundbreaking*" method on petroleum and gas reserves exploration. According to the above modern technology a non-linear 3-D elastic waves real - time expert system is proposed for the exploration of petroleum and gas resources all over the world, including the off-shore petroleum reserves, of the seas and oceans in the whole world. The above new generic technology will work under Real Time Logic [30]-[34] for searching off-shore fuel reserves developed on the continental crust and on deeper water ranging from 300 to 3000 m, or even much more. Beyond the above, the new exploration method will be the best device for searching the on-shore and off-shore hydrocarbon resources in very deep depths, even approaching 20,000 m or 30,000 m. By using therefore a new and very sophisticated model, then the exact location of the oil and gas reserves may be designated in the special areas where geological anticlines occur.

Also, through the new method exact 3-D images are produced of the underground topography of the area. In addition, 4-D imaging can be taken on a given area multiple times over an extended period of time.

Consequently, there are many basic benefits for the new theory of "*Non-linear Real-Time Expert Seismology*" in comparison to the existing theories of *"Reflection Seismology"* and *"Refraction Seismology"*. Some of them are the following:

a) The new method *"Non-linear Real-Time Expert Seismology"* is based on the special form of the geological anticlines, normal faults, reverse faults or deformations caused by intrusion of the bottom of the sea, in order to decide which areas of the bottom have the most possibilities to include hydrocarbon reserves. This is effected by using the proposed modern technology.

On the other hand, the existing theory is only based to the best chance and do not include any theoretical and sophisticated model. Thus, currently international oil companies by using the existing methods of *"Reflection Seismology"* and *"Refraction Seismology"* must do a lot of 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.

b) The new proposed technology of elastic (sound) waves is based on the difference of the speed of the sound waves which 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.

On the other hand, existing theories are based on the applications of Snell's law and Zoeppritz equations or the Kirchhoff equations, which are not giving good results, as these which we are expecting by the new method.

c) The new method *"Non-linear Real-Time Expert Seismology"* is based on a Real-time Expert System working under Real Time Logic, that gives results in real time, which means every second.

Existing theories do not include real time logic.

From the above described analysis it is clear the evidence of the applicability of the new method of "*Non-linear Real-Time Expert Seismology*". Furthermore 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 methods. 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).

2. Three-dimensional Non-linear Real-time Expert Seismology

In general, off-shore operations consist of 90% of all data collected worldwide for oil and gas reserves exploration. Furthermore, the depth of the drillings are usually up to 6000 m, but as discussed in the previous section in order to find big petroleum and gas reserves they must be extended to 10,000 m or even from 20,000 m to 30,000 m. Also, 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 exploration method the oil reserves should occur in areas of geological anticlines. Beyond the above, there are good possibilities for finding off-shore petroleum and gas reserves in deeper waters, too, ranging up to 2500 m to 3000 m, or even more and in very deep drillings ranging from 20,000 to 30,000 m.

Setting the stage for all studies of reservoir performance is the physical nature of the reservoir itself, its location, structure, lithology, internal geometry and extent. There are four basic conditions that must be satisfied in order a geological part to form a suitable reservoir, for example for the accumulation of oil and gas. These are porosity, permeability, seal and closure. By porosity is defined the pore space in the rock - space in which the oil and gas may collect. Permeability is the attribute of the rock that permits the passage of fluid through it. In general it is a measure of the degree interconnectedness, of the pore space, but some reservoir (e.g. in the massive limestone deposits, or in igneous intrusions) depends for fluid flow on a network of fractures within the rock.

In addition, by seal is denoted the "cap" of the reservoir and prevents the oil and gas from leaking away. Closure is a measure of the vertical extent of the sealed trap or, in the case of hydrocarbon 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.

Three general categories of resources can be mentioned for off-shore reserves: structural traps, stratigraphic traps and combination traps. Sometimes there was no trap along the path of the water / hydrocarbon mixture as it moved through the formation on its journey from the source beds. In some cases those traps that were present were insufficient in volume to hold all of the hydrocarbons in the percolating stream and sometimes the seal of the trap was not perfect. In each of these circumstances, some of the oil moved eventually into near-surface locations where most of the light ends evaporated over the years, leaving behind a heavy tarlike residue, so thick that it would no longer flow at ambient temperatures.

Beyond the above, elastic waves are sound waves, usually three-dimensional which may be transmitted through matter in any phase - solid, liquid, or gas. Generally, any body vibrating in air gives rise to such waves, as it alternately compresses and rarefies the air adjacent to its surfaces. Also, a body vibrating in a liquid, or in contact with a solid, likewise generates similar longitudinal waves. It is obvious that the frequency of the waves is the same as the frequency of the vibrating body that produces them. Hence, there are two types of elastic waves produced: a) P-waves, which are primary or “compressional” waves, and b) S-waves, or shear waves.

On the contrary, wavelength of the wave is the distance between two successive maxima (or between any two successive points in the same phase) and is denoted by l. Since the waveform, traveling with constant velocity u, advances a distance of one wavelength in a time interval of one period, then follows that the velocity of sound waves u is given by the following relation:

$$u = l\,v \tag{2.1}$$

where v denotes the frequency.

Consequently, it is clear, that the velocity u differs when the sound waves 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. If searching for example for off-shore oil resources over the sea, by transmitting sound waves, then there will be a difference in the velocity of the waves in the sea, the solid bottom and in a potential reservoir.

In order the new technology to be better explained, consider the example of Figure 1. In the above example consider that in the bottom of the sea there is a potential oil reservoir. In this case, 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.

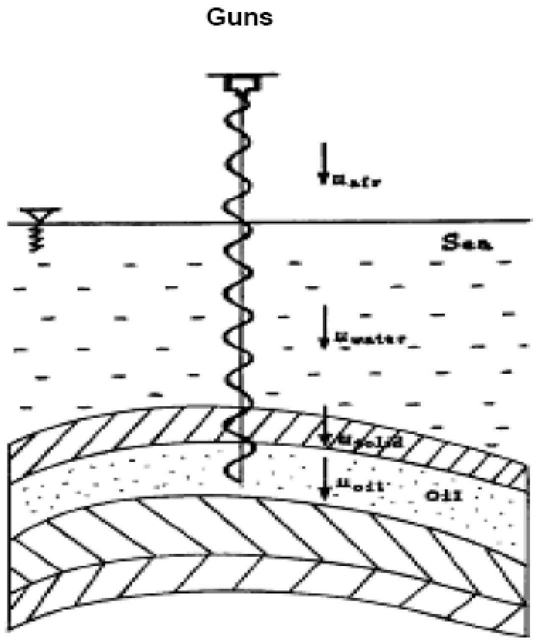

Fig. 1 Elastic Waves Method for the Exploration of Oil Reserves.

Hence, by the present research a real - time non-linear 3-D plane - polarized elastic waves expert system is proposed in order to explore the on-shore and off-shore petroleum and gas resources, according to the new theory of *"Non-linear Real-Time Expert Seismology",* in contrast to the old theory of *"Reflection Seismology".*

This modern and innovative Sound Waves Technology will work under Real Time Logic for searching off-shore petroleum reserves developed on the continental crust and on deeper waters ranging from 300 m to 3000 m, or even deeper and for very deep depths in the subsurface of earth up to 20,000 m or even to 30,000 m (Figure 2). So, according to the theory of abiotic generation of hydrocarbon resources there are many deeper water prospects around the seas and oceans 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.

Furthermore, through the new method exact 3-D images are produced of the underground topography of the area. Consequently, the three-dimensional imaging will be the best device for the exploration of oil and gas reserves in the underground.

In addition, 4-D imaging can be taken on a given area multiple times over an extended period of time. The four-dimensional images will improve the exploration of off-shore petroleum and gas reserves.

So, the proposed real - time elastic waves expert system will be the best device for the exploration of the continental margin areas and the very deep waters ranging of more than 2500 ÷3000 m, too. Beyond the above, through the modern method of "*Non-linear Real-Time Expert Seismology*", will be effected the exploration of a significant part of on-shore and off-shore oil and gas reserves even in drilling depths of 20,000 m to 30,000 m, very fast and by a low cost.

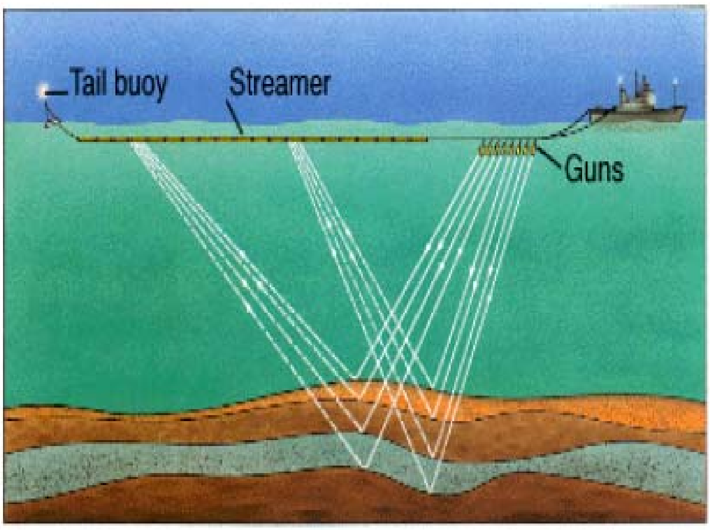

Fig. 2 Non-linear Real-time Expert Seismology.

According to the new theory of *"Non-linear Real-Time Expert Seismology"* the average velocity of the sound waves is calculated by providing important information about the composition of the solids through of which passed the sound waves. For example the velocity of the sound waves through the air is 331 m/sec, through liquid 1500 m/sec and through sedimentary rock 2000 to 5000 m/sec. Furthermore, according to the law of Reflection the angle of reflection equals the angle of incidence (Figure 3). Then according to the new method 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.

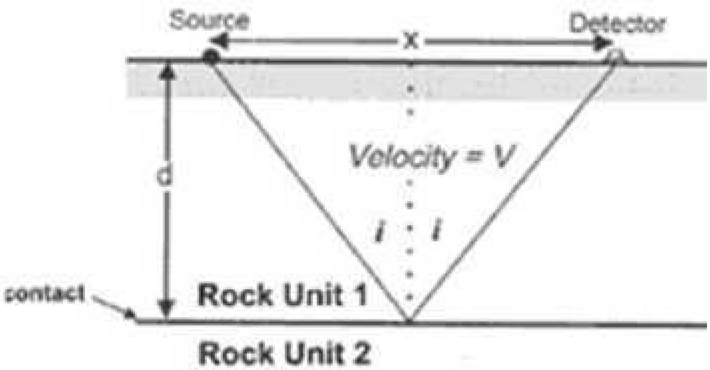

Fig. 3 Law of Reflection.

The travel time T of the seismic waves is calculated as following:

$$T = \frac{2\left(d^2 + x^2/4\right)^{1/2}}{v} \tag{2.2}$$

where d denotes the depth, x the distance between source of wave and the geophone or hydrophone detector and v is the average speed.

Beyond the above, from (2.2) follows equation (2.3):

$$T^2 = \frac{4d^2 + x^2}{v^2} \tag{2.3}$$

Also, the normal incident time T_o is given by the formula:

$$T_o = \frac{2d}{v} \tag{2.4}$$

From eqs (2.3) and (2.4) follows:

$$T^2 - T_o^2 = \frac{x^2}{v^2} \tag{2.5}$$

In addition , from eqn (2.5) follows that the travel time curve for a constant velocity horizontal layer model is a hyperbola whose apex is at the zero-offset travel time T_o:

$$\frac{T^2}{T_o^2} - \frac{x^2}{(T_o v)^2} = 1 \tag{2.6}$$

Finally, from (2.5) the mean velocity is equal to:

$$v = \frac{x}{\sqrt{T^2 - T_o^2}} \tag{2.7}$$

Hence, a real time expert system is proposed 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. Then 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 water (u_{water}), speed in the solid bottom (u_{solid}) and speed in the potential reservoir (u_{oil}),

3. Refraction in Three-dimensional Non-linear Real-time Expert Seismology

In general, the seismic refraction method is similar to the reflection method because the same instruments and shock wave sources are used. On the contrary, as the name implies, the objective of the refraction method is to measure refraction of shock waves as they pass across formation or structural boundaries (Figure 4). Beyond the above, refraction is governed by Snell's Law, which relates velocity to the angle of incidence and to the angle of refraction.

Consider the travel time T_1 of the seismic waves in the first solid is given by the formula:

$$T_1 = \frac{2\left(d_1{}^2 + (\frac{x}{2} - x_{l_1} - x_{l_2})^2\right)^{1/2}}{v_1} \tag{3.1}$$

where d_1 denotes the depth, x the distance between source of wave and the geophone or hydrophone detector, x_{l_1} the distance between the ends of the first two waves (Figure 4), x_{l_2} the distance between the ends of the next two waves (Figure 4), and v_1 is the speed of the wave in the first solid.

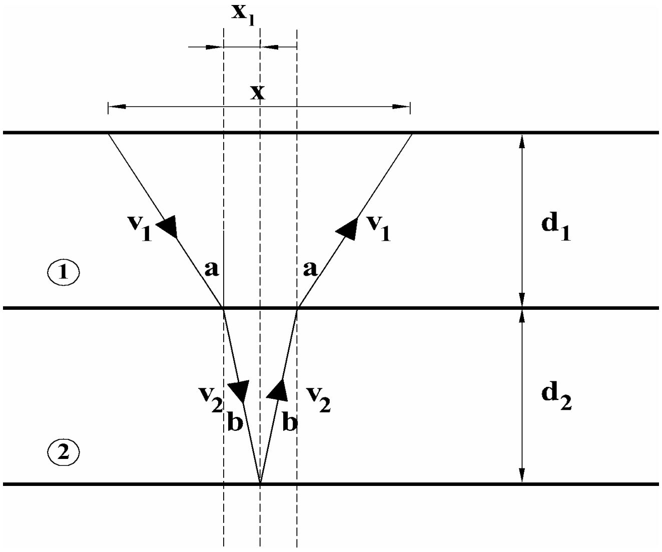

Fig. 4 Law of Refraction.

Also, from (3.1) follows equation (3.2):

$$T_1^2 = \frac{4\left(d_1^2 + (\frac{x}{2} - x_{l_1} - x_{l_2})^2\right)}{v_1^2} \tag{3.2}$$

The normal incident time T_{1o} is further given by the relation:

$$T_{1_o} = \frac{2d_1}{v_1} \tag{3.3}$$

From eqs (3.2) and (3.3) one has:

$$T_1^2 = T_{1_o}^2 + \left[\frac{2(\frac{x}{2} - x_{l_1} - x_{l_2})}{v_1}\right]^2 \tag{3.4}$$

Beyond the above, by replacing (3.3) in (3.4) we obtain:

$$d_1 = \frac{(\frac{x}{2} - x_{l_1} - x_{l_2})T_{1o}}{(T_1^2 - T_{1_o}^2)^{1/2}} \tag{3.5}$$

By using the same method, then the travel time T_2 of the seismic waves in the second solid is given by the formula:

$$T_2 = \frac{2\left(d_2^{\;2} + x_{l_1}^{\;2}\right)^{1/2}}{v_2} \tag{3.6}$$

in which d_2 denotes the depth, x_{l_1} the distance between the ends of the two waves (Figure 4) and v_2 is the speed of the wave in the second solid.

Consequently, from (3.6) follows equation (3.7):

$$T_2^{\;2} = \frac{4(d_2^{\;2} + x_{l_1}^{\;2})}{v_2^{\;2}} \tag{3.7}$$

The normal incident time T_{2o} is given by the relation:

$$T_{2o} = T_o - T_{1o} - T_{3o} = \frac{2d_2}{v_2} \tag{3.8}$$

From eqs (3.7) and (3.8) follows:

$$T_2^{\;2} = T_{2o}^{\;2} + \left(\frac{2x_{l_1}}{v_2}\right)^2 \tag{3.9}$$

Also, by replacing (3.8) in (3.9) we have:

$$d_2 = \frac{x_{l_1}(T_0 - T_{1o})}{\left[(T - T_1)^2 - (T_o - T_{1o})^2\right]^{1/2}} \tag{3.10}$$

Because of Snell's law following relation is valid:

$$\frac{v_2}{v_1} = \frac{\sin b}{\sin a} \tag{3.11}$$

where a denotes the angle of incident and b the angle of refraction.

Finally, if T is the total travel time of the waves in the three solids ($T = T_1 + T_2 + T_3$) and by using (3.2), (3.7) and (3.11) one obtains:

$$\frac{T_1}{T_2} = \frac{x_{l_1}\left(d_1^{\;2} + (\frac{x}{2} - x_{l_1} - x_{l_2})^2\right)}{(\frac{x}{2} - x_{l_1} - x_{l_2})(d_2^{\;2} + x_{l_1}^{\;2})} \tag{3.12}$$

By following the same method the travel time T_3 of the seismic waves in the third solid is given by the following relation:

$$T_3 = \frac{2\left(d_3{}^2 + x_{l_2}{}^2\right)^{1/2}}{v_3} \tag{3.13}$$

where d_3 denotes the depth, x_{l_2} the distance between the ends of the next two waves (Figure 4) and v_3 is the speed of the wave in the third solid.

Then from (3.13) follows equation (3.14):

$$T_3{}^2 = \frac{4(d_2{}^2 + x_{l_2}{}^2)}{v_3{}^2} \tag{3.14}$$

Furthermore, the normal incident time T_{3o} is given by the relation:

$$T_{3_o} = T_o - T_{1_o} - T_{2o} = \frac{2d_3}{v_3} \tag{3.15}$$

From eqs (3.14) and (3.15) we obtain:

$$T_3{}^2 = T_{3_o}^2 + \left(\frac{2x_{l_2}}{v_3}\right)^2 \tag{3.16}$$

Also, by replacing (3.15) in (3.16) one has:

$$d_3 = \frac{x_{l_2}(T_0 - T_{1o} - T_{2o})}{\left[(T - T_1 - T_2)^2 - (T_o - T_{1_o} - T_{2o})^2\right]^{1/2}} \tag{3.17}$$

Because of Snell's law we have:

$$\frac{v_3}{v_2} = \frac{\sin c}{\sin b} \tag{3.18}$$

where b denotes the angle of incident and c the angle of refraction.

Finally, if T is the total travel time of the waves in the three solids ($T = T_1 + T_2 + T_3$) and by using (3.9), (3.14) and (3.18) follows:

$$\frac{T_2}{T_3} = \frac{x_{l_2}}{x_{l_1}}\left(\frac{d_2{}^2 + x_{l_1}{}^2}{d_3{}^2 + x_{l_2}{}^2}\right)^{1/2} \tag{3.19}$$

From equations (3.12) and (3.19) can be calculated the unknown x_{l_1} and x_{l_2} .

In addition, by following the same method if the elastic waves travel inside m solids, then d_m is calculated by the relation:

$$d_m = \frac{x_{l_{m-1}}(T_0 - T_{1o} - T_{2o} - .... - T_{(m-1)o})}{\left[(T - T_1 - T_2 - .... - T_{(m-1)})^2 - (T_o - T_{1o} - T_{2o} - .... - T_{(m-1)o})^2\right]^{1/2}} \tag{3.20}$$

which reduces to:

$$d_m = \frac{x_{l_{m-1}}(T_0 - \sum_{i=1}^{m-1} T_{io})}{\left[(T - \sum_{i=1}^{m-1} T_i)^2 - (T_o - \sum_{i=1}^{m-1} T_{io})^2\right]^{1/2}} \tag{3.21}$$

So, between the m and the (m-1) solid the following relation is valid:

$$\frac{T_{m-1}}{T_m} = \frac{x_{l_{m-1}}}{x_{l_{m-2}}}\left(\frac{d_{m-1}{}^2 + x_{l_{m-2}}{}^2}{d_m{}^2 + x_{l_{m-1}}{}^2}\right)^{1/2} \tag{3.22}$$

4. Real-time Logic for Three-dimensional Non-linear Real-Time Expert Seismology

Real-time logic (RTL) is a reasoning system for real-time properties of computer based systems. In general, RTL's computational model consists of events, actions, causality relations, and timing constraints. Hence, the RTL model is expressed in a first order logic describing the system properties as well as the systems dependency on external events. Also, the RTL system introduces time to the first logic formulas with an event occurrence function denoted @. Such a function assigns time values to event occurrences. This kind of real - time logic systems were studied by F. Jahanian and A. Mok [25] ,[26].

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. There are some special software tools for the implementation of real - time systems. Such a type of real - time programming languages were investigated by several scientists like R.Emnis et all [27] , W. Fritz , V. H. Haase and R. Kalcher [28] and V. H. Haase [29].

Also, RTL uses the following three types of constraints:

a. Event constants are divided into three cases. Start/stop events describe the initiation/termination of an action or subaction. Transition events are those which make a change in state attributes. In other words a transition event changes an assertion about the state of the real-time system or its environment. The third class, which are the external events, includes those that can be impact the system behavior, but cannot be caused by the system.
b. Action constants may be primitive or composite. In a composite constant, precedence is imposed by the event-action model using sequential or parallel relations between actions.
c. Integers assigned by the occurrence function provide time values, and also denote the number of an event occurrence in a sequence.

Also, RTL translates assertions about the physical state of the system over time into **algebraic relations**. Such relations describe the occurrences of the appropriate transition events, using equality and inequality predicates. RTL uses state predicates as a notation device for asserting truth-values to attributes during a time interval.

Finally, there is a set of axioms from the event-action model of the system, by translating the system specifications and characterizing the following properties:

1. Relations between actions and their start/stop events.

2. The sporadic and periodic event constraints.
3. The cause relations which may initiate a transition event.
4. Some artificial constraints can be added to the specification, in order to prevent the scheduler from executing particular actions. This is a useful way to prevent execution of actions that are not required.

5. Oil & Gas Reserves Exploration by Three-dimensional Non-linear Seismic Waves

Suppose that a seismic wave of any sort travels from left to right in a medium. Then the equation of the traveling wave is given by the formula:

$$y(\zeta, t) = A\cos(\omega t - k\zeta) \tag{5.1}$$

in which k denotes the wave number given by the formula:

$$k = 2\pi / \lambda \tag{5.2}$$

and λ is the wavelength, t the time, A the amplitude of the motion and $\omega = 2\pi v$, v the frequency. A sinusoidal transverse wave traveling toward the right , at intervals of period 1/8 can be seen in Figure 5.

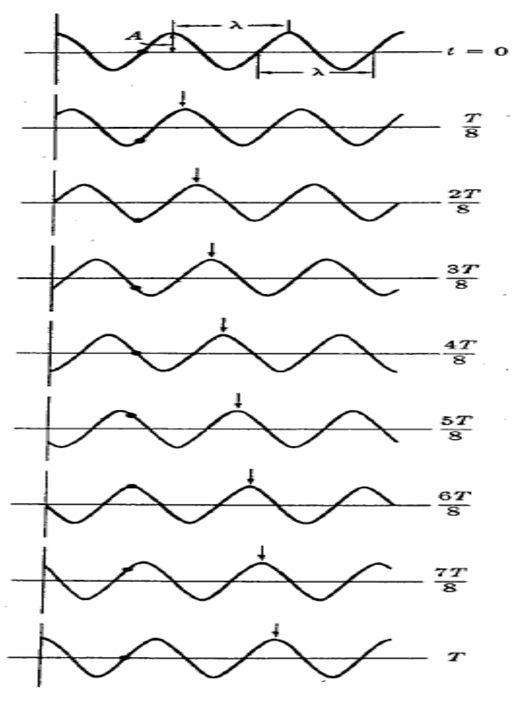

Fig. 5 A sinusoidal transverse wave traveling toward the right, at intervals 1/8 of a period.

Beyond the above, a very important factor is 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 6.

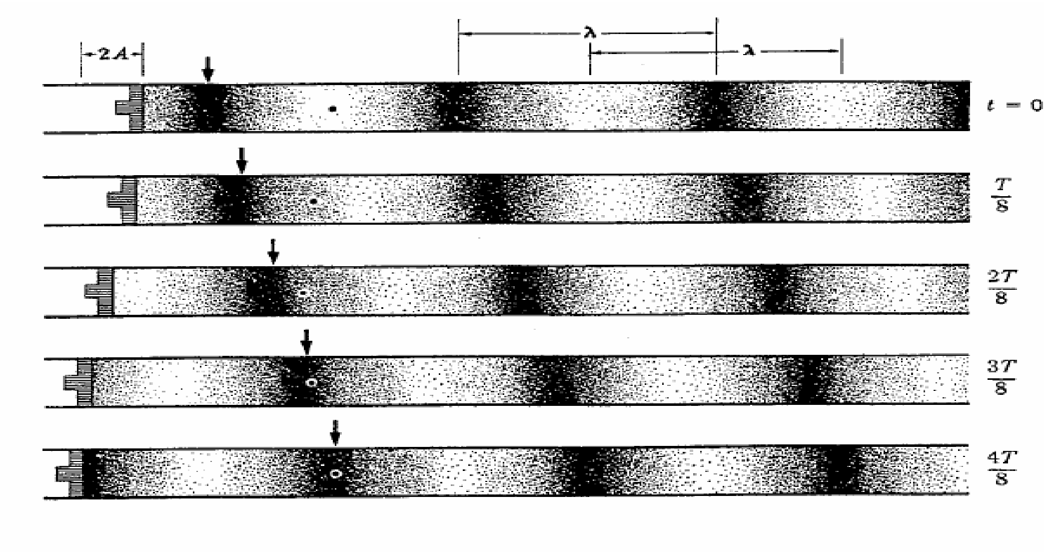

Fig. 6 Sinusoidal longitudinal waves, traveling toward the right, at intervals 1/8 of a period.

On the contrary, by differentiating the wave equation (5.1) one has:

$$\partial y / \partial \zeta = kA \sin(\omega t - k\zeta) \quad (5.3)$$

$$\partial y / \partial t = -\omega A \sin(\omega t - k\zeta) \quad (5.4)$$

By combining eqs {5.3) and {5.4) and as the velocity is equal to:

$$u = \omega / k \quad (5.5)$$

then finally one obtains:

$$\frac{\partial y}{\partial \zeta} = -\frac{1}{u}\frac{\partial y}{\partial t} \quad (5.6)$$

which by a second differentiation reduces to:

$$\frac{\partial^2 y}{\partial t^2} = u^2 \frac{\partial^2 y}{\partial \zeta^2} \quad (5.7)$$

Generally, 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, there are infinitely many. Hence, in Figure 7 can be seen three transverse waves, all traveling 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 of the above cases 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. For this reason the proposed new method is called ***"Non-linear Real Time Expert Seismology"***. But more complex seismic waves could be generated 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.

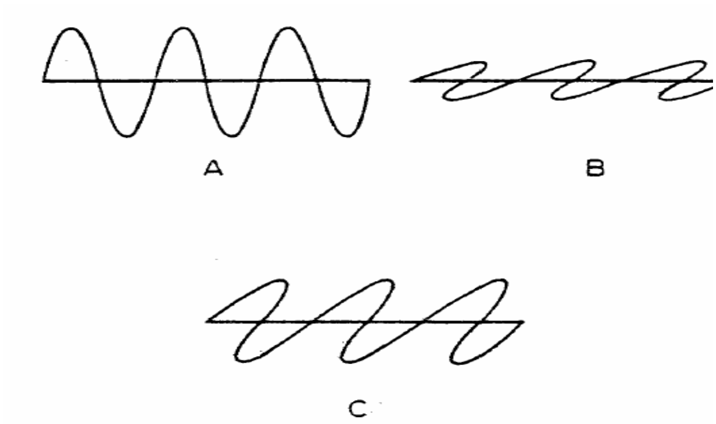

Fig. 7 Transverse waves, traveling in the same direction, but lying in different planes from one another.

6. Conclusions

By the current research the new theory of *"Non-linear Real-Time Expert Seismology"* has been investigated for the exploration of on-shore and off-shore oil and gas reserves at very deep drilling depths even to 20,000 m or 30,000 m.. As the test off-shore drillings are very expensive with costs of at least 100 mill. EURO for every drilling and many times unsuccessfully as very often such drillings are dry, which means a big loss of funds for the international oil companies, then the highly innovative and groundbreaking exploration method *"Non-linear Real-Time Expert Seismology"* has been proposed and investigated in order to solve any problem of very deep drillings. Consequently, by the proposed sophisticated method for energy applications it will be established a strong scientific and technical base for the Science & Technology worldwide in the emerging areas of oil reserves exploration in the energy field. So, through the new technology of *"Non-linear Real-Time Expert Seismology"*, the exploration of a significant part of on-shore and off-shore oil and gas reserves all over the world become possible in water depths ranging to 2000 m to 3000 m, or even deeper and to very deep drillings in the subsurface of the earth even approaching 20,000 m or 30,000 m, as according to the theory of abiotic generation of hydrocarbon resources the oil and gas reserves should be placed in such depths.Through the new method exact 3-D images are produced of the underground topography of the area. Also, 4-D imaging can be taken on a given area multiple times over an extended period of time.

The oil and gas markets are multi-billion markets all over the world. Hence, such a contribution requires an international approach, rather than a local approach, as it is referred to a market all over the world with value of many billions. It is therefore expected in order the international oil companies to keep and to improve their leading role in the worldwide Science & Technology in the petroleum field, to get involved in the new and groundbreaking technology in the area of Energy, which is proposed by the present investigation.

Finally, as the proposed new exploration method *"Non-linear Real-Time Expert Seismology"*, is based on a very sophisticated modern technology, then it is expected to get the best results. So, 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. It is therefore not necessary to make test drillings in the half ocean in order to find petroleum, like the existing methods.

References

1. *Kozlovsky Ye.A.*, 'The world's deepest well', *Scien. Amer.*, ***251*** *(1984), 98 - 104.*
2. *Erzinger J., Wiersberg T. and Zimmer M.,* 'Realtime mud gas logging and sampling during drilling', *Geofluids,* ***6*** *(2006), 225 - 233.*
3. *Gold T. and Soter S.,* 'The Deep-Earth-Gas Hypothesis', *Scien. Amer.*, ***242*** *(1980), 130 - 137.*
4. *Kropotkin P.N.,* 'Earth's Outgassing and Genesis of Hydrocarbons', *J. All-Union Mendeleyev's Chem.Soc.*, ***31*** *(1986), 60 - 67.*

5. *Glasby G.,* 'Abiogenic Origin of Hydrocarbons: An Historical Overview', *Resource Geology,* ***56*** *(2006), 85 - 98.*
6. *Aki K. and Richards P., 'Quantitative Seismology, Theory and Methods',* Freeman Press, San Francisco, *1980.*
7. *Hale D.,* 'Dip-move out by Fourier transform', *Geophysics,* ***49*** *(1984), 741 – 757.*
8. *Thomsen, L.,.*'Reflection seismology over azimuthally anisotropic media', *Geophysics,* ***51*** *(1988), 304 – 313.*
9. *Thomsen L.,* 'Converted-wave reflection seismology over inhomogeneous, anisotropic media', *Geophysics,* ***64*** *(1999), 678 - 690.*
10. *Dellinger J. A., Muir F. and Karrenbach M.,* 'Anelliptic approximations for TI media', *J. Seismic Exploration,* ***2*** *(1993),.23 – 40.*
11. *Harrison M. and Stewart R.,* 'Poststack migration of P-SV seismic data', *Geophysics,* ***8*** *(1993), 1127 – 1135.*
12. *Tsvankin I. and Thomsen L.,* 'Nonhyperbolic reflection moveout in anisotropic media', *Geophysics,* ***59*** *(1994), 1290 – 1304.*
13. *Alkhalifah T. and Tsvankin I.,* 'Velocity analysis for transversely isotropic media', *Geophysics,* ***60*** *(1995), 1550 – 1566.*
14. *Gaiser J. E., '3-D converted shear wave rotation with layer stripping',* U.S. Patent. 5 610 875, *1997.*
15. *Ladopoulos E.G.*, 'Non-linear singular integral representation for petroleum reservoir engineering', *Acta Mech*., ***220*** *(2011), 247-253.*
16. *Ladopoulos E.G.,* 'Petroleum reservoir engineering by non-linear singular integral equations', *Mech. Engng Res*., ***1*** *(2011), 1-10.*
17. *Ladopoulos E.G.,* 'Oil reserves exploration by non-linear real-time expert seismology', *Oil Asia J.,* ***32*** *(2012), 30 - 35.*
18. *Ladopoulos E.G.,* 'Non-linear singular integral representation for unsteady inviscid flowfields of 2-D airfoils', *Mech. Res. Commun.,* ***22*** *(1995), 25 – 34.*
19. *Ladopoulos E.G.,* 'Non-linear singular integral computational analysis for unsteady flow problems', *Renew. Energy,* ***6*** *(1995), 901 – 906.*
20. *Ladopoulos E.G. and Zisis V.A.,* 'Non-linear singular integral approximations in Banach spaces', *Nonlin. Anal., Theor. Math. Appl*., ***26*** *(1996), 1293 – 1299.*
21. *Ladopoulos E.G. and Zisis V.A.,* 'Existence and uniqueness for non-linear singular integral equations used in fluid mechanics', *Appl. Math*., ***42*** *(1997), 345 – 367.*
22. *Ladopoulos E.G.,* 'Non-linear singular integral representation analysis for inviscid flowfields of unsteady airfoils', *Int. J. Non-Lin. Mech.,* ***32*** *(1997), 377 – 384.*
23. *Ladopoulos E.G.,* 'Collocation approximation methods for non-linear singular integro-differential equations in Banach Spaces', *J. Comp. Appl. Math*., ***79*** *(1997), 289 – 297.*
24. *Ladopoulos E.G.,* 'Non-linear multidimensional singular integral equations in 2-dimensional fluid mechanics analysis', *Int. J. Non-Lin. Mech*., ***35*** *(2000) , 701-708.*
25. *Ladopoulos E.G. and Zisis V.A.,* 'Non-linear finite-part singular integral equations arising in two-dimensional fluid mechanics', *Nonlin. Anal., Th. Meth. Appl*., ***42*** *(2000), 277-290.*
26. *Ladopoulos E.G., 'Singular Integral Equations, Linear and Non-Linear Theory and its Applications in Science and Engineering',* Springer Verlag, New York, Berlin, *2000.*
27. *Ladopoulos E.G.,* 'Non-linear unsteady flow problems by multidimensional singular integral representation analysis', *Int. J. Math. Math. Scien*., ***2003*** *(2003), 3203-3216.*
28. *Ladopoulos E.G.,* 'Non-linear two-dimensional aerodynamics by multidimensional singular integral computational analysis', *Forsh. Ingen*., ***68*** *(2003), 105-110.*
29. *Ladopoulos E.G.,* 'Unsteady inviscid flowfields of 2-D airfoils by non-linear singular integral computational analysis', *Int. J.Nonlin. Mech*, ***46*** *(2011), 1022-1026.*
30. *Jahanian F. and Mok A., 'Safety Analysis of Timing Properties in Real Time Systems',* Dep. Comput. Scien., University of Texas at Austin, *1985.*
31. *Jahanian F. and Mok A.,* 'A Graph-Theoretic Approach for Timing Analysis in Real-Time Logic', *Proc. Real-Time Systems Symp. (IEEE), p.p. 98-108, New Orleans, LA, 1986.*
32. *Emnis R. et al, 'A Continuous Real-Time Expert System for Computer Operations',* IBM J. Research Devel., *1986.*
33. *Fritz W., Haase V.H. and Kalcher R, 'The use of standard software in real time programming - an example demonstrating the integration of ADA, Oracle and GKS', in Puente J. (ed)* Proc. 15th IFAC/IFAP Workshop on Real Time Program, Pergamon, *1988.*
34. *Haase V.H., ''The use of AI-Methods in the implementation of real-time software products',* IFAC 11 th Triennial World Con., Tallium, Estonia, *1990.*