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MAIN ASPECTS OF THE IMPLEMENTATION OF SEISMIC PROJECTS

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Abstract: The paper presents the planning and workflow of field seismic explorations. Seismic data acquisition has developed significantly over the last 15–20 years; the paper covers the most important changes and developments of this period and goes step-by-step through the process of implementing a land 3-D seismic project. In order to increase efficiency, the different cost reduction technologies appeared on the vibroseis source side in 3-D seismic, and wireless field technology is becoming more and more accepted among the forms of seismic data acquisition. The advances in seismic acquisition, including simultaneous source acquisition, wireless channel systems, and exponential growth in seismic channel count, are revolutionizing surveys. Improved receiver sampling along with high productivity are the drivers for seismic technology today, which means smaller, lighter and less power-hungry equipment, while also increasing channel counts, minimizing system-related remediation and HSE risk. A new era in land 3-D seismic surveys has arrived in Europe and in Hungary, too. The author used her experience in the implementation of many domestic and foreign 2-D and 3-D land seismic projects as an observer, shift leader, field manager, and then as a project leader in Europe. She combines these practical experiences with specific aspects of field project design and implementation. The aspects covered in this paper contribute to the professionally efficient and financially profitable implementation of field projects.

Keywords: field seismic exploration, implementation of seismic project, seismic survey, seismic data acquisition

1. INTRODUCTION

A seismic survey is a geophysical method that uses the difference in several parameters (elasticity, density, etc.) of the underground medium to infer the nature and shape of the underground strata. The seismic wave sent into the ground is artificially generated and then the return waves are registered by special sensors. Seismic exploration is the most important and effective way to solve the problem of oil and gas exploration. The assessment of oil and gas reserves is an important phase before drilling begins. During a seismic survey, we have the opportunity to form an image of the subsurface structural elements, covering a large measuring area, up to a depth of several kilometers. This method provides the right amount and quality of information cost-effectively compared to other means of gaining measurements.

Field seismic projects have played a leading role in hydrocarbon exploration since the 1950s [1]. In the first period (until 1990), these seismic surveys were made mainly in a 2-D survey system [2], which revealed the geological structures in the vertical section below the measured profile, as a function of depth. Subsequently, 3-D seismic survey technology became widespread, enabling knowledge of complete spatial geological structures [1, 3]. Today, hydrocarbon surveys use almost exclu-sively 3-D and 4-D seismic surveys [4]. Because 2-D surveys provide data in a smaller dimension, only along measurement lines, the 2-D seismic surveys are usually used only to solve local geological problems [5]. While the success rate using 2-D technology has remained constant, the success rate using 3-D seismic data has shown large-scale improvement [6]. The big oil companies have the necessary resources and expertise for the whole progress (from planning to interpreting data) in-house, while smaller oil companies rely on the experience of consultants.

The successful implementation of seismic projects is inconceivable without good advance planning. During the planning, the need for the necessary equipment (instruments, accessories, transport equipment, etc.), and the need for professional staff must be analyzed in detail. Of course, the timing of implementation and the planning of costs are also very important.

2. Seismic surveys

A seismic survey can take place on the surface of the earth (land acquisition) or seafloor (marine acquisition) and can be realized in 2D, 3D or 4D. A source (vibrator unit, dynamite shot, air gun) generates waves into the earth that penetrate through the earth's layers with different seismic responses and reflect from different rock layers. Seismic waves generated by the source are reflected and are recorded at specified locations on the surface by receivers (geophones or hydrophones).

2.1. Marine acquisition

Marine seismic acquisition is mostly carried out using ships with one or multiple air-gun arrays for sources. Air-guns are towed behind the ship and generate a seismic signal at a given interval by forcing highly pressurized air into the water. Seismic receivers are pulled behind the ship, either individually or streamers several kilometers in length. An excellent overview of the theme is given in Dondurur [7].

2.2. Land acquisition

There are four basic components of land seismic acquisition: the location, the sources, the receivers and the recorder. The location of survey determines the sources and receivers. The choices of which sources and receivers to use depend on the target of the survey along with environmental conditions and cost. A survey in a rocky desert, sandy desert, iced area, agriculturally cultivated area, forested area, densely populated area, mountainous area, flat area, or marshy area requires different conditions. This paper discusses 3-D land seismic surveying in the Pannonian Basin only.

3. Planning and implementation of land seismic projects in Europe

3.1. The phase of planning

Pre-planning includes the evaluation of geophysical and non-geophysical parameters (environmental considerations, health and safety requirements, etc.) [8]. When planning reflection land seismic projects, the whole process of practical implement-tation must be taken into account. The implementation process of the seismic projects and the main elements of the process are shown in *Figure 1*. The main blocks of the process are described in detail in the following subsections.

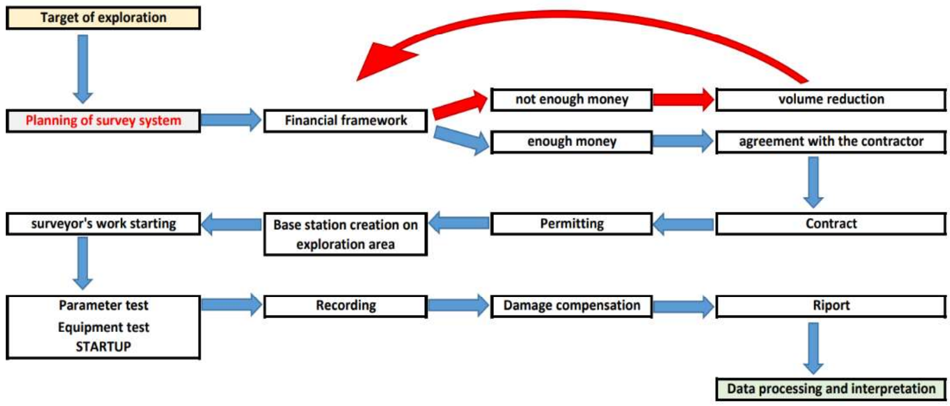

Figure 1
Flowchart of seismic project implementation

3.1.1. The target of the exploration

The pre-planning aims define the geological target of the survey with the associated geophysical parameters [8]. The target of the exploration must be clearly defined. There is usually a primary target, such as delimiting the location and shape of a reservoir rock that is already known from somewhere. There may also be secondary targets for the research, such as examining cover layers or mapping other structures. In many cases, the exploration goals conflict with each other, in which case the optimal solution must be found with careful consideration. The exploration goal should accurately describe its location, extent, depth, possible slope, and geology [6, 9]. If there is a secondary exploration goal, it is best if it is located more shallowly than the main goal, because reflections from deeper will usually be weaker [6].

The price of seismic exploration should be determined according to the benefits of the research. Not only the costs of field seismic survey but also the costs of processing and interpretation and even damage compensation must be taken into account here. The cost of seismic recording is the largest part, 70–80% of the total cost.

The survey is usually performed by a contractor (“service” company). In order to receive bids from contractors, expectations must be accurately described. When negotiating with contractors, it is very important that we set our quality expectations. Here we not only need to describe the quality of the survey or surveying equipment we expect, but we also have to set standards for the whole crew (the accommodation of workers, quality of food, personal protective equipment, HSE [Health-Safety-Environment] guidelines, rest times, etc.). Deadlines of the sub-processes need to be clarified and the contractor must know the progress of the survey.

3.1.2. Planning of survey system

The survey system can be designed by geophysical parameters. Chaouch and Mari [8] describe the definition of the geophysical parametersthat have to be used during planning. The survey system must be defined as 2-D or 3-D. The selected target of the exploration will be determined by the shape of the network, the distances between the lines, and fold numbers [6]. The main acquisition parameters of the required 3-D survey system are presented in *Table 1*, which also shows the evolution of the geometry of 3-D surveys over the last 20 years: the space sampling and the line distances are getting denser today, the number of active channels is significantly higher and thus the CDP coverage is higher. It is worth planning at least two options; these parameters are indicative of whether the contractor has sufficient capacity to perform. A map of the designed line network should be prepared and any obstacles identified. In addition, further obstacles may occur during the survey (unexpected field object or permitting problems). Unpredictable events cause temporal and financial uncertainty that should be addressed during the planning phase.

All parameters must be determined: the source type, the recorder system, the telemetry system [10], types of cables and geophones, the navigation system, and the calculating method for static correction. The local conditions must be taken into account (weather, topography, environment, agriculture, infrastructure, culture, religion, holidays, customs, etc.).

3.1.3. Financial framework

In addition to the costs, the financial framework required for the successful implementation of the project also includes the profits of the service company. Projects should not be planned without profit because these underfunded projects will certainly not be successful and may even result in a number of future stability issues for service companies. Therefore, it is important that if there is not enough money available for the implementation of the project, then the professional goals (tasks) of the project should be narrowed down (volume reduction).

In the last 10–15 years, the prices of seismic records have been steadily declining. This is due to technical progress and its consequences. With the spread of wireless technology, the survey geometry has become much denser, surveying has become faster, and resource requirements have been reduced, eliminating the need to move tons of cables per day. Fewer people with smaller and fewer vehicles work faster, resulting in lower costs. This allows the seismic company to apply for the job at a lower seismic record price. The supply in the market has increased year by year, new seismic companies have appeared on the European seismic market, so there is a lot of competition, which further depressed the prices. In the early 2000s, the price of a field seismic record in Central Europe was 170–240 EUR (~40 sources/km^2), around 2010 it was only 100–200 EUR (~80 sources/km^2), and today it is ~ 40–80 EUR (~100 sources/km^2). In 2011, the cost of a 530-km^2 3-D seismic survey (~46,000 source points and ~77,000 receiver points, in flat terrain, without blasting, using the pure vibroseis method, with 250 people on crew per shift) in Southeast Europe was 7.4 million euros, which did not include the amount of damage compensation, data processing, preparation phase or device mobilization costs, only the cost of field seismic acquisition.

The purchase value of the equipment used for this seismic survey is approximately 20–25 million euros, which is why the seismic survey is usually performed by a specialized service company with its own equipment and own professionals.

Table 1

A possible list of the main acquisition parameters in the 2000s and 2020s

In the early 2000s		
3D survey parameters (the data are examples only)	*Option 1*	*Option 2*
Receiver line interval (m)	500 m	300 m
Source line interval (m)	500 m	400 m
Receiver point interval (m)	50 m	50 m
Source point interval (m)	50 m	50 m
Source point in salvo	10	6
Number of channels per line	120	128
Number of active lines	14	18
Number of channels of active patch	1680	2304
Number of geophones per channel	12	12
Geophone groups length	25 m	25 m
Geophone array	linear, in-line	linear, in-line
Folds	42	72
Number of Vibrators	3 + 1 spare	4 + 1 spare
Number of Sweeps/VP	1–6 (to be tested)	1–6 (to be tested)
Sweep length	10–16 sec	10–16 sec
Sweep frequency	6–120 Hz (to be tested)	6–120 Hz (to be tested)
Max offset	4594 m	4168 m
Aspect ratio	0.92	0.80
Record length	8 sec	8 sec
Sample rate	2 ms	2 ms
Filters	Anti-alias only	Anti-alias only

In the 2020s	
3D layout (the data are examples only)	
Receiver line interval (m)	250 m
Source line interval (m)	250 m
Receiver point interval (m)	25 m
Source point interval (m)	25 m
Source point in salvo	10
Number of channels per line	280
Number of active lines	24
Number of channels of active patch	6720
Folds	168
Geometry type	orthogonal

3.2. The phase of implementing

3.2.1. Contract

The contract is an agreement with the contractor. All conditions and parameters must be fixed in the contract. It is important that all conditions and requirements are clearly set out in the contract. A field supervisor must be provided who is independent of the contractor and is able to supervise the whole process. During the survey, this person represents the client company. If it is expedient to change any of the parameters specified in the contract during the seismic survey, this can be initiated with the consent of the supervisor to the ordering company.

3.2.2. Permitting

Permitting means obtaining the necessary permits from the competent authorities and the landowners in the exploration area to carry out the project. It is important to contact the national and local authorities, obtain all necessary permits (explosion permit, environmental permit, road usage, entry into protected places, etc.). It is necessary to walk around the area in advance in order to assess the difficulties, to identify the problematic parts, to prepare for all of them or to avoid them, and to find an alternative. If the exploration is not in the desert but in a densely populated or intensively farmed area, consultation with the landowners is very important: it is essential to inform them of the exploration area and the planned time schedule in advance and get any necessary permissions from them . The lack of a single ownership consent can also cause serious problems – recording may stop for days, resulting in a significant loss of revenue. The implementation of the project can only be started with all the necessary permits because the absence of a single permit can prevent full surveying.

3.2.3. Base camp creation

The project field base station needs to be designated and constructed within or near the exploration area. It must be possible to place instruments, accessories, and means of transport on the base and ensure their proper guarding (protection of property). The site must comply with current HSE requirements. The accommodation and catering of the measuring team must be organized (this is also a very significant cost, depending on the number of employees).

3.2.4. Starting the fieldwork

3.2.4.1. Tests

We can start implementing the project fieldwork only if the planning has been done carefully, the client and the service company have concluded the contract, and all permits have been received. The parameter test and the equipment test can be done before effective work. The types of major tests are listed in *Table 2.*

Table 2
Types of main tests

PARAMETER TEST	STATUP TEST
The most suitable SWEEP parameters for the measurement must be determined:	**All equipments of the measurement must be tested:**
• Sweep frequency	• Geophone test
• Sweep length and amount	• Vibrator test
• Vibrator number and force	• Recording Instrument test • Surveyor Instrument test

The tests are performed in the presence of the field supervisor. During vibroseis measurements, can be variable vibrator and sweep parameters – included in *Table 2* –must always be selected according to the local seismic-geological conditions at the specific research site; this test process is called the parameter test. During the parameter test, we optimize the quality requirements of the signal-to-noise ratio with the costs. The appropriate sweep parameters are selected by the field supervisor according to local conditions. According to Gombár and Deák [11], the signal-to-noise ratio of seismic recordings made with a vibrator is proportional to the relation (1).

$$S/N \approx Pf \cdot Dr \cdot Nv \cdot \sqrt{Ns \cdot SL} \quad (1)$$

where
P_f – peak force of one vibrator,
D_r – drive level (20–80%),
N_v – number of vibrators,
N_s – number of sweeps at the same source point,
SL – sweep length.

The specific field recording is always preceded by a technical audit, called startup testing, where the state of the equipment is checked to see if the equipment is in accordance with the manufacturers' specifications. The entire recording cable instrument is tested simultaneously as shown in *Figure 2*, but geophones are tested separately. Using a purely wireless system has simplified this process, as fewer devices need to be tested.

Figure 2
Recording instruments test in the field before seismic acquisition

3.2.4.2. Land surveying – Surveyor staff

The location of the receiver and source lines is determined in the field by the geodetic group. Land surveying has been changing over the years because of developing technologies that have made this profession much easier and more efficient. A few years ago the only tools available to surveyors were optical levels and theodolites, but today, several kinds of surveyor work rely on GPS systems. A civilian GPS system would also provide sufficient accuracy for general orientation. DGPS systems are used to measure accurate survey coordinates. They refine the coordinates using precisely measured ground transmitters.

Important tasks of the surveyor staff are to prepare lines (clearing vegetation or forest), to provide tracks, protected areas, to set the line network, to supply input for the SPS file (this is the standard format for exchanging geophysical positioning data), and to physically mark on the field the geophone points and the source points (in recent years, the marking of source points has become less and less common, because by coordinating the digital map with GPS placed in the vibrator, the operator can see exactly where he needs to generate the vibration). This can be done with stakes, stones in brightly coloured bags (in the desert), reflective caps, etc. Identification numbers must also be included on each marker. The job of surveyor staff is also to produce maps of geophone and source points with identification numbers for seismic acquisition workflow. Up to date, these maps inform the whole crew.

3.2.5. Recording

Seismic measurement data acquisition and recording requires appropriate source and sensor systems as well as control and digital data acquisition instruments.

3.2.5.1. Wave generation

There are two types of wave generation: pulse wave source and vibration wave source. The pulse wave source can be weight drop, exploding at the surface, exploding in a blasthole, and Air Gun. An Air Gun is mainly used for marine acquisitions [12].

The requirements for wave generation:

– good quality, high amplitude, wide frequency signal;
– easy and fast to operate;
– cost-effective;
– safe;
– minimal environmental damage.

Vibrators [13] are high-performance shaking machines that were introduced in the USA in the late 1960s; this technique has been used since 1975 in Hungary. They can create any non-pulse waveform to penetrate the ground. An important parameter of vibrators is their weight, which usually determines how much energy they are able to pump into the ground. A vibrator can also be used in urban environments. The vibrator has largely supplanted explosive technology due to its speed, safety, environmentally friendly properties, and better seismic properties:

– a better S/N ratio can be provides due to the correlation;
– adjustable parameters (force, sweep length and amount, sweep frequency);
– repeatability (important for 4D surveys).

Explosives are now used only where vibration is not possible (steep mountains, marshy areas). The peculiarity of the vibrator technique is that very strong surface noise waves are generated. To damp them, several vibrator units are used at the same time, a few meters apart (see *Figure 3*). Thus, the waves propagating on the surface are generated in phase-shift to each other. Selecting the distances properly can reduce each other. The other method is when a team of several vibrators repeats the vibration by moving a smaller distance forward. Channels registered in this way are simply added. This movement is called “move up”.

Figure 3
A vibrator group belonging to GES Ltd.

The special waveform of the vibrator is called a sweep. The commonly used sweep length is 6–20 seconds. The sweep emitted by the vibrators may have an increasing frequency or a decreasing frequency over time. The rate of frequency change can be linear, logarithmic, or exponential. Typical exploration vibroseis sweeps are in the frequency range of ~10 to 100 Hz [13]. Applying a wider frequency range results in a higher resolution, but depending on the depth, signals with a lower frequency are less absorbed [14].

Between 2000 and 2010, seismic surveys in the Pannonian Basin typically used 3–4 vibrators for source generation (see *Table 1*) at the same point, usually with sweep numbers of 2–4. Nowadays, only 1 or 2 vibrators with 1-2 sweep numbers (pushing toward low frequencies) are typical in accelerated surveys. The fuel consumption of vibrators is a significant item in the cost, so cost reduction has also appeared here. To produce low frequencies, the vibrator mass increases with the high hydraulic peak force of heavy vibrators (which can be more than 70,000 lbs).

The technologies on the vibroseis source side have improved in the last 10 years, new methods have been developed, such as "slip sweep" or "blended sweep", which both increase efficiency and productivity. A slip sweep means that a vibrator group starts sweeping without waiting for the other vibrator group's sweep to be completed, this method was Rozemond's idea [15]. The slip sweep recording supplies the potential to drastically increase vibroseis production rates and to reduce the costs [16, 17]. During the slip sweep recording one vibrator begins sweeping before the previous sweep has terminated, so slip sweep data is contaminated by harmonic noise; for this problem Yongsheng et al. [16] presented a new method for eliminating harmonic distortion in slip sweep data. The slip sweep has been used effectively in the desert and other large open areas, leading to significant productivity gains, but there have also been attempts to use the slip sweep in the Pannonian Basin [17]. With slip sweep, the number of records per unit time depends primarily on the slip time, so the sweep length can be increased without loss, thus improving the signal-to-noise ratio [17]. Blended sweep acquisition allows a finer spatial source sampling and a wider range of source azimuths in a cost-effective way; for this method a good overview can be found in Berkhout et al. [18].

Figure 4
High-sensitivity 5 Hz GSG-5 (by SERCEL)

3.2.5.2. Seismic sensors

Seismic sensors (geophones and hydrophones) can be used to detect seismic waves. Geophones *(Figure 4)* are used on land and boreholes, and hydrophones are used in marshy areas, in transition zones, and for marine measurements. Groups of geophones are formed to attenuate surface disturbance waves. Thus, the geophones are connected in series or in parallel. It is important to know the transmission characteristics of the geophone group [19]. In practice, the length of the geophone group is often chosen to be the same as the distance of receiver points. This results in a continuous, non-overlapping layout, and could laid out by workers without error. Today the single sensor systems are widely spread which makes laying out workflow easier and faster. The geophone strings are heavy and take up a lot of space on cars when they are transported, and care must be taken to arrange them geometrically during layout, while the single geophone is smaller, lighter, and therefore faster to deploy, and smaller vehicles are suitable for its transport.

3.2.5.3. Recording instrument

The task of the recording instrument (in the recorder truck, also known as the "dog house", shown in *Figure 5*) with cables is to record the results of the survey with the same quality requirements. All accompanying conditions are recorded so that all data is available later during processing (it was raining, the weather was windy, a train was moving, agricultural machines were working near the layout, etc.).

Figure 5
A recorder truck in the field (left) and the inside of the recorder unit (right)

Figure 6 shows a simplified line structure of a 3-D survey with a Sercel 428XL cable syste, which is the most commonly used cable system from the 2000s. The geophone lines are connected by a line management device called LAUX. Because of the faster data transfer, optical jumper cables are used in addition to traditional cables. Through these, the 3-D data is transferred to the recorder truck, where the seismic record can be visualized for the first time. 12 V batteries are used to keep the lines alive. A battery must be connected to each LAUX and LAUL panel. It is usually necessary to insert one LAUL into the line after 40 FDUs.

One of the main problems with recording is the unreliability of the cables. All connection points are errorprone. Therefore, digitization takes place near the geophones, in the FDU ("Box"). The geophone groups are connected to the FDU. There are amplifiers and filters at the input of the FDU. These signals are fed into the recorder via cables (shown in *Figure 6*). Transmitting digital data is more secure than transmitting analog signals (these are sensitive to cable lengths, impedance changes, connections, etc.).

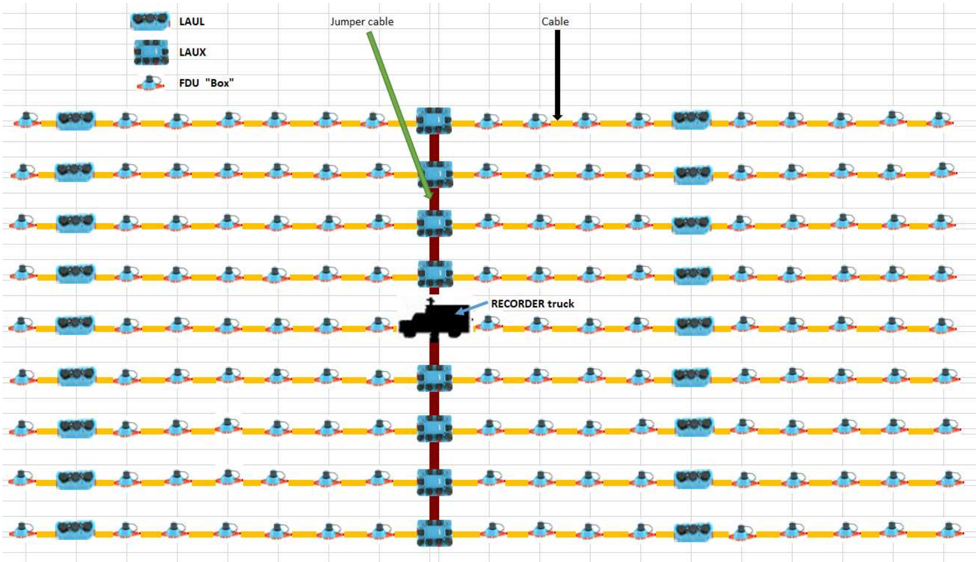

Figure 6
Elements of layout with cables in a 3-D seismic project

Reliability can be further enhanced by transmitting digital data not by cable but by radio frequency transmission [20] or by using wireless seismic technology. Today, the most advanced technology is the wireless (cable-free) field technology, which is becoming more and more accepted also in Europe. Wireless systems are recorded mostly at the sensor. Advancements in modern electronics have given an opportunity for using the completely cable-free single seismic recording unit as a "node" [21]. A node is a stand-alone acquisition unit, which contains all of the elements and technologies needed to sense, acquire, digitize, filter, and store seismic data. Every node is comprised of internal Li-ion batteries, a processing unit, analog-to-digital converter, filters, memory, clock for timing precision, transceivers, and internal geophone sensor [21]. Wireless autonomous data recording is possible in challenging areas and this system delivers the ultimate in high fidelity data, its tools easy deployment and retrieval.

Figure 7
Quantum single-point sensor node by INOVA

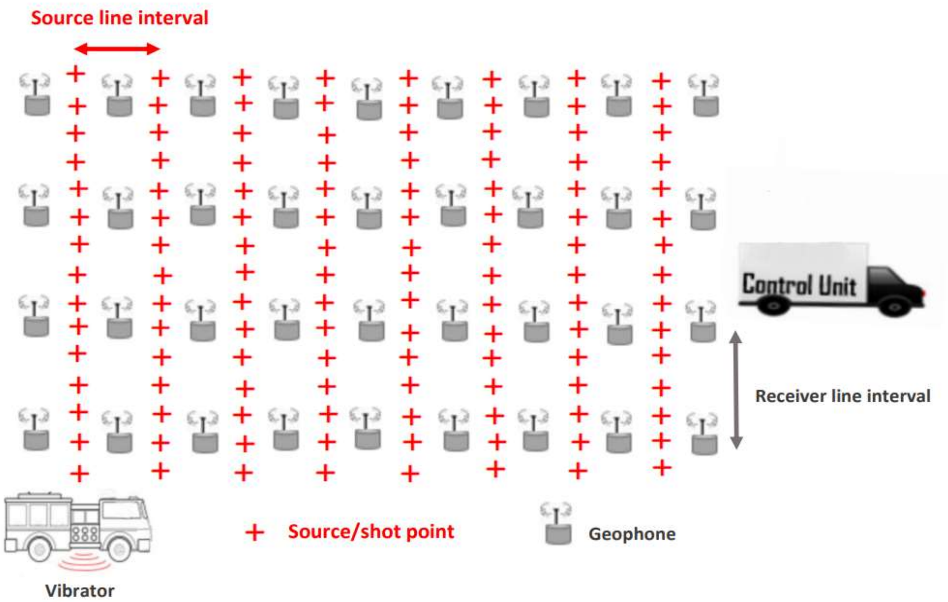

Figure 8
A wireless geophone network orthogonal 3D geometry

It is also possible to use a wired and wireless system together, but the dominance of wireless technology is becoming more common. With this newer technology, real-time quality control is not performed in the field. Shooting blind with autonomous recording systems frees the cables, which are the most vulnerable parts of the system, but it is important to mention that less logistics is needed along with this. This means fewer tools, fewer people, fewer cars, and less maintenance, that is, overall lower operational costs and less error. Wireless technology is revolutionizing seismic data acquisition together with point receivers and MEMS-based digital sensors [22, 23]. The new recording system is based on a wireless platform, providing the ability to reduce footprint and improve operational efficiencies; its single-point sensor node (see *Figure 7*) offers a large surface area and a strong geophone spike and can be buried to improve coupling and reduce environmental noise. The use of wireless geophone networks (WGN) for seismic land data acquisition *(Figure 8)* is summarized by Makama et al. [21] and cable-free land seismic acquisition is discussed in several research articles [23–26]. Need to use in the future an ultra-high channel count point receiver recording system, productivity enhancement techniques and incorporating advanced processing tools.

The big advantage of a wireless system over a wired system is that in urban seismic situation, these tools overcome hazards of traffic or yard-based operations. It is more suited for environmentally or geopolitically sensitive areas, for dense vegetation and extreme topography, and the survey flexibility provides fewer coverage gaps. It gives an easier and faster survey layout, with no need for special equipment training for field personnel or time-consuming deployment programming, and the data download is simple and fast.

3.2.5.4. Resources

The seismic channel number (the recently recorded 3-D seismic surveys now have 5,000-10,000 active recording channel) gives the number of resources as the channels are moved by people and vehicles. Hundreds of seismic channels need to be moved daily, which requires sufficient human and field vehicle capacity. The composition of the crew's human resources and vehicle resources are in *Table 3.* The number of resources required needs to be optimized, because it is not good for the number of members of the team or car-fleet to be either higher than necessary (additional cost)or lower (slower progress). The completion of the project is documented in time (day by day) by the progress map (shown in *Figure 9*).

During the surveying, the number of seismic records per day is one of the most important factors, because often payment is based on this, which means revenue, unless there is a time-based contract. By implication, the less time the crew spends in the entire research area, the less cost will be incurred and the greater the profit.

Table 3
Crew resources

THE COMPOSITION OF THE CREW'S **HUMAN & VEHICLE** RESOURCES	
Human resources	**Vehicle resources**
project manager	recorder truck
field manager	5–15 vibrators
2-3 field leaders *(who coordinate the units and assist the field manager)*	trucks and jeeps for seismic instrument *(cables, geophones, batteries, etc.)* transporting
QC (quality control of seismic records)	Field buses and jeeps for human transporting
observers *(in recording unit)*	drilling trucks
vibrator unit staff	tanker truck and water-tanker truck
drilling and explosive handling staff	
cable units staff	
surveyor staff	
support staff *(maintenance of seismic equipment and vehicles, permittmen, administration, etc.)*	

3.2.5.5. Quality control

The seismic records can first be viewed by the observers in the recording truck when a wired system is used, but the seismic data in the "dog house" are not ideal for interpretation, so these raw field recordings are pre-processed by the field QC. When using wireless technology, the observer is shooting blind with an autonomous recording system, and the common source point records are generated weeks later by the transcriber from the stand-alone receiver station. QC field processing is extraordinarily important for this technology. Continuous data quality control was already an important task 15–20 years ago but the use of new technologies has increased the importance of QC. The goal of the seismic data pre-processing is to enable the use of appropriate header information, data that are free of noise-dominated traces and flawed vertical stacking in subsequent processing steps; to create an accurate picture of the subsurface, it must remove or at least minimize artifacts in these records and noise in the data obscuring the subsurface image.

3.2.6. Damage compensation

Damage compensation means the repair and monetary compensation of damage caused during the survey (agricultural, road, and building damage). This must be done in full, as failure to do so could result in lengthy lawsuits. It is advisable to agree with the owners concerned at the permitting stage on the amounts on which the compensation is based. Due to advances in acquisition technology, the footprint of seismic projects is getting smaller, as fewer large trucks travel, fewer people work in the fields, there is less line clearing, and the size of the sensors used is smaller, thus the reduction in costs is also reflected in the amount of damage compensation.

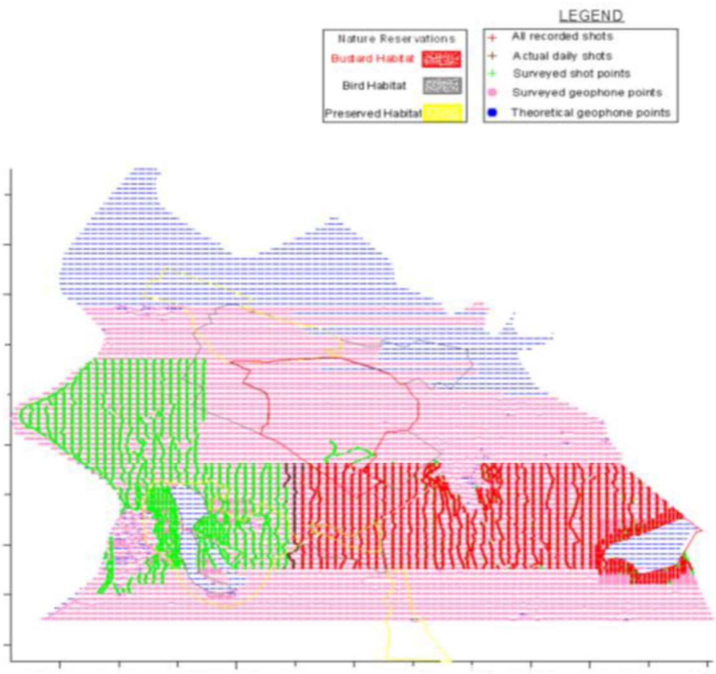

Figure 9
Progress map of a 3-D seismic project

3.2.7. Data processing and interpretation

A stack *(Figure 10)* is created from the field seismic records during different sub-processes (shown in *Figure 11*), and then the processed seismic profile is made by applying seismic migration.

Hydrocarbon exploration strives for the most detailed image of the subsurface. Global competition for hydrocarbons drives the need to expand exploration and raise recovery rates, while at the same time the full cost of the operation is very important. But no matter how much the costs dominate, seismic professionals will always play a key role in the quality of seismic data acquisition required and the proper processing/interpretation of data. The technologies and field seismic devices have been evolving and refining year after year for several decades [27]. Companies use high-technology tools to obtain data improvements. The amount of tools that can be used is now limited only by money. In the age of digitization, managing the huge amount of data generated is not impossible due to continually expanding computer capability. The continuous development of data processing should not be overlooked either [4, 28]. The sole goal of hydrocarbon exploration is to find valuable and exploitable raw material. This requires the most accurate processing and interpretation possible. Optimization is also needed during processing to get the best possible geological image from our measurement results. The role of companies involved in the processing of seismic data has also strengthened over the past decade.

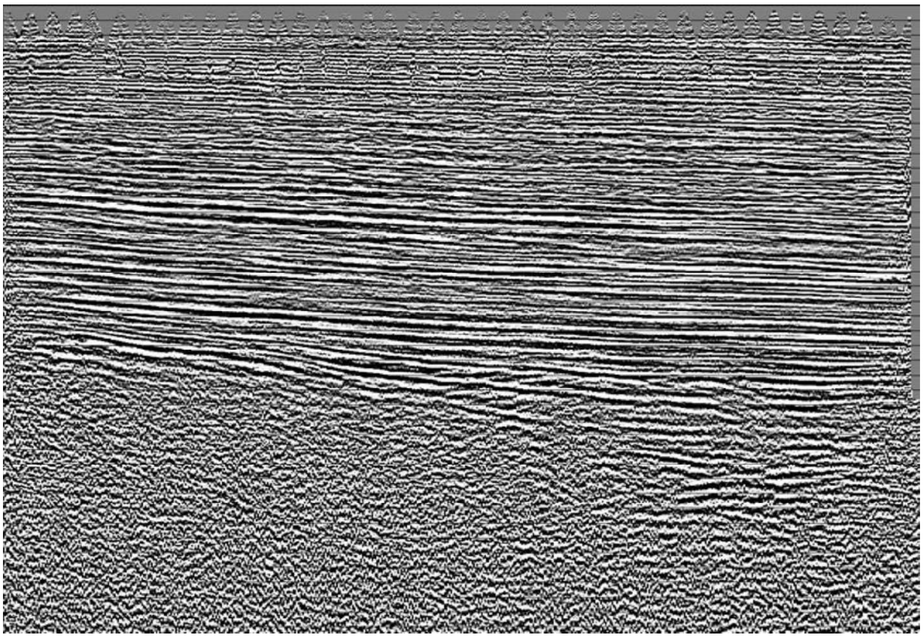

Figure 10
Stack inline

Complex processing – the combined application of several geophysical data processing methods – can greatly increase the reliability of the final result. Geophysical inversion as a tool allows the simultaneous application of several geophysical methods [29]. The accuracy of the evaluation is greatly aided by laboratory determinations of the velocities of the P and S waves performed on the core samples because this is the only way to determine the exact acoustic velocity of each rock. The advantage of ultrasonic measurements in the laboratory is that the effects of individual physical conditions (such as pressure, temperature, pore-filling) can be modeled under controlled conditions, and the disadvantage is that the core samples represent only a very small representation of subsurface formations [30]. The information obtained from laboratory tests is essential for understanding the properties of subsurface formations. All this requires the development and use of new petrophysical models that help to process and interpret field data and describe the processes that occur in nature more accurately.

After data analysis, during the interpretation, the wells are selected based on the processed seismic data.

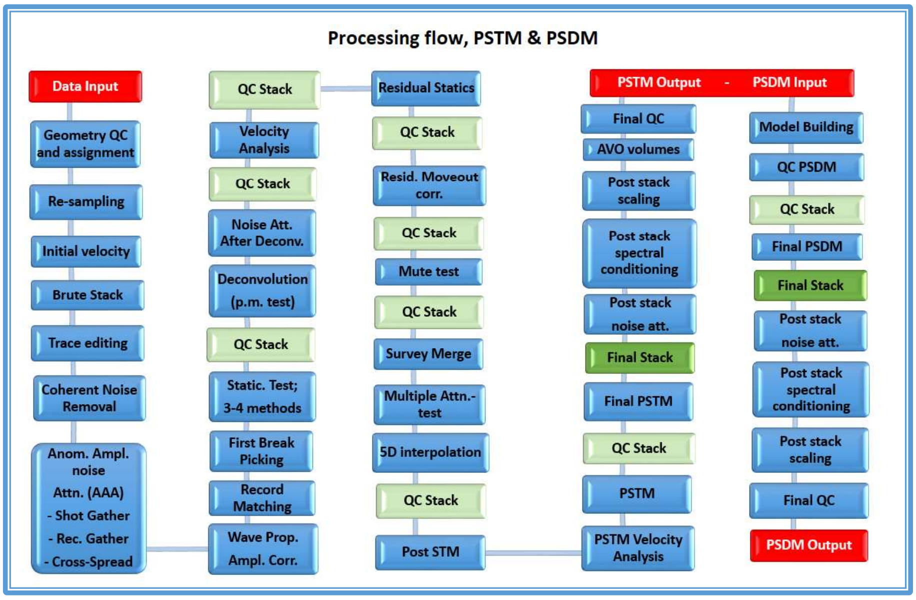

Figure 11

Main steps for seismic data processing

3.2.8. Final report of the project

The most important elements of the final report are presented in *Figure 12*. The final report of the project includes the final report of the fieldwork, the final report of the data processing and interpretation ordered in the contract, and the financial final report of the costs incurred. The final report must be presented and handed over to the customer. Financial payment for the project will be made against an invoice submitted after the final report has been accepted.

Final report and presentation
planned/realized surveyed points (receiver/source) and area size (km/km2) .
all test (startup, parameter, final) .
seismic arrey geometry .
field crew .
workhours / resources .
standby / speciality / difficulty .
weather and field conditions .
time analysis / production .
GANTT CHART of the exploration .
damage assessment .
HSE events .
processed data .
COSTS .

Figure 12

Main elements of the final report

4. Conclusion

Oil companies and their exploration crews are continually striving for a better understanding of the subsurface. Land seismic projects have changed greatly in the last two decades and have become more challenging year by year: the clients need reliable 3-D data, denser surveys at a lower cost with a reduced environmental footprint and lower HSE risk. A new era in land 3-D seismic survey has arrived in Europe and advancements in modern seismic tools have given an opportunity for completely cable-free seismic recording. Wireless technology has been used for seismic acquisition in Europe since the 2010s, in Hungary since 2014, significantly increasing productivity. Based on the author's experiences, this paper presents the main aspects and processes of 3-D land seismic projects in the Pannonian Basin, and each sub-process is detailed.

It is important to mention that each survey is unique depending on local and field conditions. To implement professionally successful and financially profitable projects, the elements outlined above must be fully taken into account. Implementing seismic projects is a task with several factors that go well beyond geophysics. All this requires complex engineering, economic and current legal knowledge as well as effective teamwork. In focus should be on collecting data as accurately as possible, interpreting seismic information in as much detail as possible, and increasing its reliability, yet in practice, cost-effectiveness is the center of all projects, so each sub-process requires careful preparation. The key to success is essentially good planning, continuous optimization, speed, and ultimately an accurate subsurface image.

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