

LAND SEISMIC POSITIONING

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PAPER EIGHT

BACKGROUND

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by

INTRODUCTION

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It is not the intention of this paper to provide solutions to those problems as there are surveyors attempting to solve them. Instead the intent is to explain some of the methods applied in land seismic positioning so that an understanding of the procedures can be gained. It should be stated that land seismic positioning does not entail any procedures or equipment that are unknown to most survey professionals, although some unusual applications of common procedures are employed. Some different terminology is also employed, as you would expect. Surveyors should be aware that in the exploration industry, the term "Seismic Survey" commonly refers to the geophysical data collection, not to the correct positioning of the source and receiver elements required as part of the "survey".

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Surveying is essential to seismic exploration. Most surveyors have a limited understanding of the seismic process, and as a result many are unaware that the positioning requirements are not extremely difficult, merely different from what may be seen as "normal surveying practice". This paper will attempt to give a simple picture of seismic positioning procedures, so that surveyors can make judgements on whether or not to enter this intriguing and very demanding field.

INTRODUCTION

It is not the objective of this paper to detail all methodologies in land seismic positioning, for the problems are many and there are as many solutions to those problems as there are surveyors attempting to solve them. Instead the intent is to explain some of the methods applied in land seismic positioning so that an understanding of the procedures can be gained. It should be stated that land seismic positioning does not entail any procedures or equipment that are unknown to most survey professionals, although some unusual applications of common procedures are employed. Some different terminology is also employed, as you would expect. Surveyors should be aware that in the exploration industry, the term "Seismic Survey" commonly refers to the geophysical data collection, not to the correct positioning of the source and receiver elements required as part of the "survey".

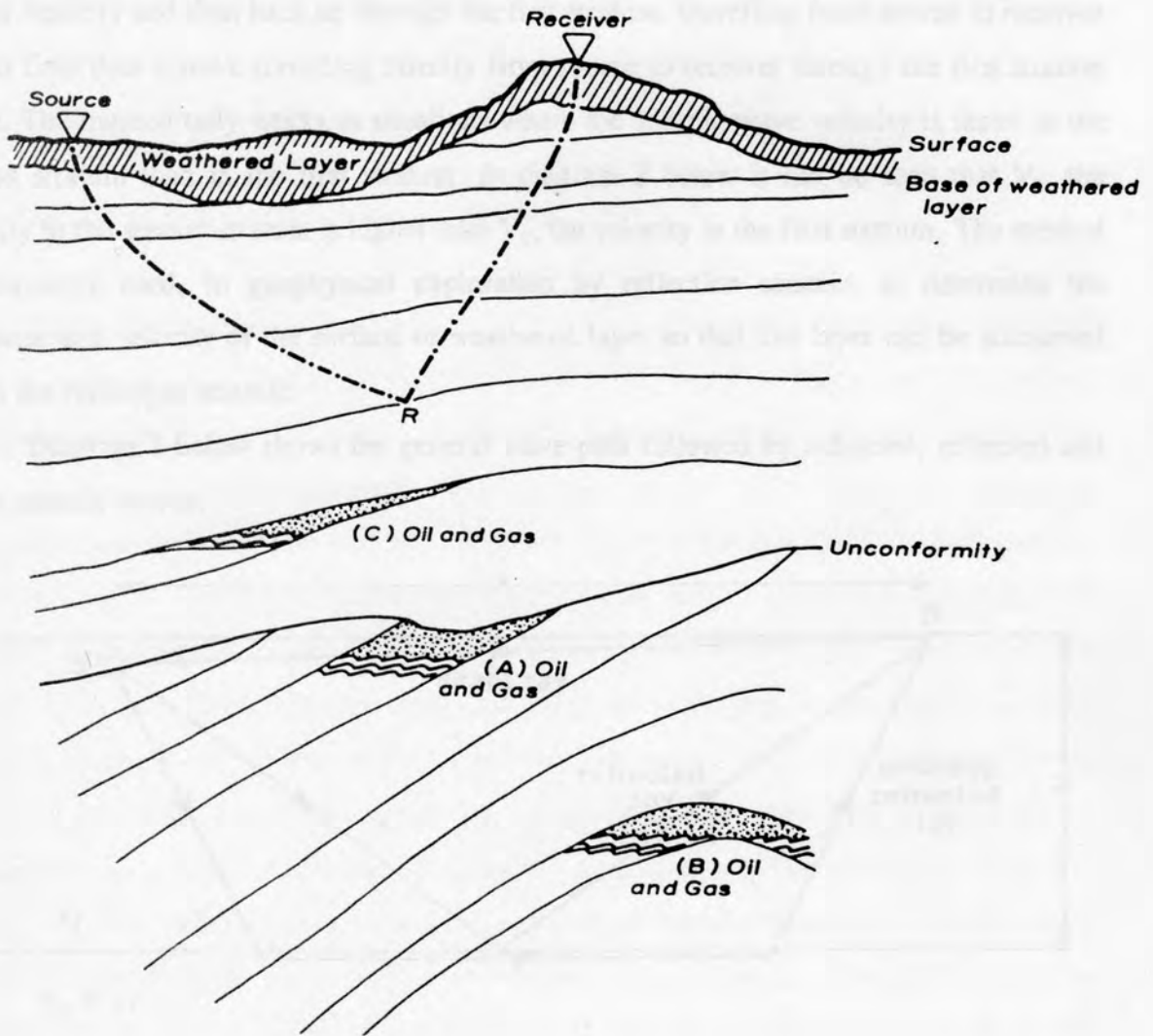
Land seismic positioning commonly employs a much larger range of accuracies within a single project than any other discipline. Some measurements are required to the highest accuracies possible, while for others the limitations of rough pacing and height estimation are acceptable. A combination of precise and estimated measurements is not unique to seismic positioning, for it is also common in engineering projects where earthworks may be approximately placed while structures are to be precisely positioned. But in seismic land positioning the range of accuracies is commonly much larger.

To understand this variance it is necessary to understand seismic method itself.

SEISMIC PROSPECTING

In seismic exploration, seismic (or shock) waves are propagated through the earth's interior and the travel times are measured of waves that return to the surface after refraction or reflection at geological boundaries within the ground. These travel times may be converted into depth values and, hence, the distribution of sub-surface interfaces of geological interest may be systematically mapped (sic Kearey & Brooks, 1984). That is to say, the analysis of the timed return waves can yield a representation of sub-surface structures, especially sub-surface boundaries of reasonably simple geometry. It should be noted that seismic methods do not, in general, give detail of the actual materials in the ground, but instead indicate the boundaries between different materials. For example the application of seismic exploration in the search for hydrocarbons such as oil and gas does not definitively reveal the existence or otherwise of the hydrocarbons: seismic can indicate the existence of an anticlinal structure in a sedimentary basin, and such a structure is common as a repository for a hydrocarbon reservoir (an oil or gas field).

Diagram 1 below indicates the sort of structures that may be of interest to geophysicists in the endless search for hydrocarbons.



Diag 1. Hydrocarbon Reservoirs (Waters K.H. 1987)

Seismic exploration uses two methods to determine the geometry of sub-surface strata: Refraction and Reflection.

Refraction Method

The seismic refraction method utilizes seismic energy that returns to the surface after travelling through the ground along refracted ray paths (Kearey & Brooks 1984). The

refracted seismic waves pass downward through one stratum, along the edge of a stratum of higher velocity and then back up through the first stratum, travelling from source to receiver in less time than a wave travelling directly from source to receiver through the first stratum alone. The method only works in situations where the seismic wave velocity is faster in the second stratum than in the first stratum. In diagram 2 below it can be seen that V_2 , the velocity in the second stratum is higher than V_1 , the velocity in the first stratum. The method is frequently used, in geophysical exploration by reflection seismic, to determine the thickness and velocity of the surface or weathered layer so that this layer can be accounted for in the reflection seismic.

Diagram 2 below shows the general wave path followed by refracted, reflected and direct seismic waves.

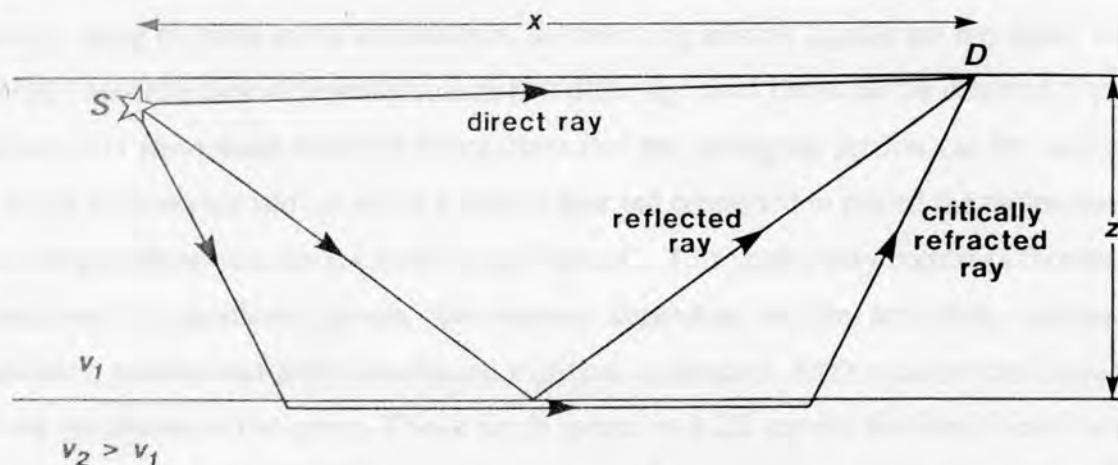


Diagram 2. Paths of direct, refracted and reflected waves (Kearey & Brooks 1984)

Reflection Method

Reflection seismic is an exploration method in which disturbances are generated in the ground, and the waves reflected from the geological interfaces are observed on the surface. This helps to map sub-surface structures, by measuring the arrival times of the reflected events, and to determine stratigraphic features by analysing the characteristics of the reflected signals. Reflection seismic acquisition systems essentially comprise a source pattern, a detection spread, and digital recording systems (sic. Lavergne 1989). There are two basic types of reflection seismic: 2D (or two dimensional) where a single geological section is produced as an end product, and 3D (or three dimensional) where a three

dimensional model of all detected sub-surface structures is created. The geophysical value of a 3D seismic survey is far greater than that of a 2D survey in most cases, but then so is the cost. The general trend, in the oil and gas industry especially, is to reduce exploration budgets, not to increase them.

2D Reflection and Refraction Seismic Surveys

These two seismic survey methods have many common characteristics and so shall be dealt with as one. The end result, as detailed above, is a single two dimensional geological section. In order to obtain seismic data, receivers are laid out along this section, or seismic line, at regular intervals. Each receiver consists of a number of geophones connected together to a single recording channel. When a seismic source is then emitted, generally along or close to the seismic line, the returning seismic signals are recorded, with extremely accurate time differentials, such that differing travel times can be detected at each receiver. It is from these differing travel times that the geological section can be built up. The string of receivers laid out along a seismic line and connected to record the return waves from a single seismic source is known as the "spread". This spread may consist of thousands of receivers or geophone groups, the number depending on the recording equipment capabilities, geophysical requirements and logistical constraints. Each receiver may have 24 or more geophones in the group. Thus a single spread on a 2D seismic line could involve the placing in the ground of 50,000 or more geophones. A more common layout would be 480 channels or receiver groups of 8 geophones (a total of 3,840 geophones). If the receiver groups were separated by 25 metres, this single spread would cover 12 kilometres.

As the survey proceeds along the seismic line, sources are emitted at different points along the seismic line and the return waves are recorded through changing receiver combinations, generally rolling along in one direction with the source placed in the centre of the spread, except at the start and end of the line where the source may be offset from the centre of the spread. Diagram 3 below shows an indicative layout when the source is central to the spread along the line and when it is offset, commonly at the end of the line.

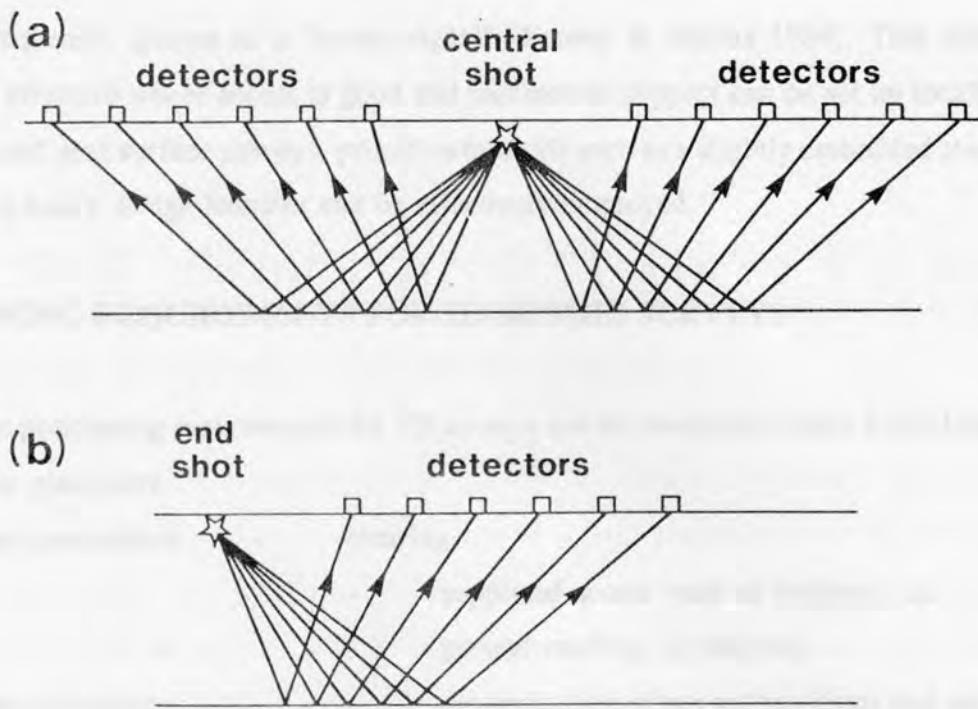


Diagram 3. Source/Receiver Layouts (Kearey & Brooks 1984)

The description given above can apply equally to Refraction surveys, but in general Refraction is applied for shallower depth studies over shorter spreads. Thus the spread may consist of 6 channels of 8 geophones. At 25 metre receiver intervals the spread would then be 150 metres.

Seismic Sources

The original seismic source was natural earthquake waves, with the difference in arrival times at differing sites providing information on the gross internal layering of the earth. Explosives provide a cheap and highly efficient seismic source. Charges may be set on or above the ground surface, in shallow shot holes or in holes deep drilled into the bedrock. The advantages of explosives are their portability and flexibility, especially in difficult terrain. Their disadvantages are in the special safety and handling requirements, in the irregularity of the transmitted source and in the drilling required to place the charges.

The other main land seismic source is the implementation of percussive force on the ground surface. This is most commonly employed in vibroseis, in which tractor-mounted vibrators pass into the ground an extended vibration of low amplitude and continuously

varying frequency, known as a "sweep signal" (Kearey & Brooks 1984). This method is extremely effective where access is good and mechanical support can be set up locally. For refraction and near surface surveys, primitive methods such as a slightly embedded steel plate struck by a heavy sledge hammer can be effectively employed.

POSITIONING REQUIREMENTS FOR 2D SEISMIC SURVEYS

The positioning requirements for 2D surveys can be considered under 3 sub-headings:

1. Line placement.
2. Line preparation - clearing.
 - supply of access such as bridging, etc.
 - ground marking or pegging.
3. Line surveying - determination of pegged positions and supply of coordinates.

1. Line Placement

The position at which the geological section or 2D seismic line is to be obtained is determined by geophysicists and geologists, based on geological and geophysical information from any number of sources, and sometimes on a little "educated estimation". The desired location may be rigid, placement of the line to sub-metre accuracy being required, but the normal approach to 2D line placement is to define an "accuracy corridor" within which the line must be placed. This corridor may be as wide as plus or minus 500 metres in initial reconnaissance seismic, but is more commonly plus or minus 50 to 100 metres.

The method used for line placement will then vary dependent upon the accuracies required, for instance:

Plus or minus 100 to 500 metres

The line can be set out by the use of hand held G.P.S. or feature identification from orthophotos or topographic maps for end control, then hand held compass can be used for controlling the line layout, with periodic checks against ground features or G.P.S. to ascertain local magnetic variation.

Plus or minus 25 to 100 metres

The above methods may be used if good feature data in the form of accurate

topographic maps or orthophotos is available, but if not then lines will have to be set out by conventional traverse from coordinated trigonometric stations, or in remote areas from control established by G.P.S. or other suitable methods.

Plus or minus 0 to 25 metres

Full conventional survey traverse will be required except in those parts of the world, notably Holland, France and Germany, where very accurate large scale topographic maps exist, allowing reliable scaling to the metre level.

Where 2D lines are designed too close to features such as buildings, roads, utility lines and wells etc that could be damaged by the use of explosives or vibrators, it is often necessary to offset the "shot" or source points off the line or along the line to provide "safety distances" from these features. It may be preferable to bend the line around such features, with the approval of the client, incorporating bends which are commonly less than 5°.

2. Line Preparation

In country with easy access, such as farmland with moderate relief, this may involve only the pegging of the lines at the prescribed receiver intervals (and these are usually sequentially numbered for easy reference), the marking out of the required source locations (or "shot points") and to ensure access to the line by vehicles and personnel by checking access roads etc and providing line diagrams or "mud maps".

In tropical rainforest, preparation is usually combined with line placement and may also include the cutting and preparation of helipads, construction of bridging and walkways for personnel and provision of bush campsites for staff working along the line.

3. Line Surveying

Field Work

Finally we get to the actual determination of the as-pegged position of the line. A variety of methods are employed in the seismic industry, dependant on the accuracy required by the client after consideration of various geophysical factors and cost elements. At the bottom end of the accuracy scale are tacheometric surveys using Wild T0 style compass theodolites, while at the top end of the accuracy scale are total station surveys based on 1st

order trig networks or control provided by geodetic standard differential G.P.S. surveys. Higher accuracy is becoming the industry standard. More esoteric methods are now being commonly employed, such as precise digital barometric heighting, real-time G.P.S. and combinations of these two.

A typical 2D survey in Papua New Guinea could see the implementation of a high standard differential G.P.S. control network connected to the national Geodetic grid, with G.P.S. control placed at each end of lines and every 10 kilometres along the lines (usually on a helipad for clear sky). Total station surveys could then be run along the lines between the G.P.S. control points, locating all receiver stations and "shot points". Checks are commonly undertaken as the fieldwork proceeds to ensure the receiver and shot intervals have been set out or pegged within specified accuracies.

Common accuracy standards worldwide are now becoming stricter: 1:5,000 or 1:10,000 for horizontal closure between control, and 10cm Km . Accuracy standards for the interval between receiver points has recently taken a step up, with a 1992 project near Balimo requiring every receiver interval be accurate to plus or minus 2%. The project consisted of 400 kilometres of 2D lines, pegged at 12.5 metre intervals. This was a total of 32,000 intervals. The accuracy required for these intervals relates to the ability of the seismic recording system to resolve the sub-surface structures from the received return waves. With the increase in seismic data resolution accuracy, due to improved field equipment and procedures, but especially as a result of advances in processing and dedicated software, it must be expected that demands on positioning accuracy will be increased in the future.

Office Work

Seismic positioning commonly includes the following elements:

1. Control of line positioning and line preparation crews. This includes physical location of the line ends and control of the setting out procedures. This facet may include a substantial amount of people and project management.
2. Observation and computation of G.P.S. and other control networks as required.
3. Preparation of line access maps or "mud maps".
4. Reduction and processing of field observations locating the receiver and source points. Check computations of closures and receiver intervals.
5. Computation of final receiver and source point coordinates on the mapping grid specified for the project.

6. Reformatting of positional data into formats suitable for co-processing with the seismic data. The required formats have generally been designed by geophysical standards groups and the application of software which will automatically produce these formats is fairly essential for efficient operation.
7. Preparation of computer or manually generated plots and vertical sections for each line.
8. Preparation of "Line Files" containing hard copies of all data, permanent mark diagrams, line access maps as well as original field notes and survey reports.

3D SEISMIC REFLECTION SURVEYS (to the author's knowledge refraction surveys are only undertaken as 2D).

In a 3D survey, returns are recorded at a grid of receivers from a single source. The source is then moved and additional recordings made. It is then possible to generate a three dimensional sub-surface model. The standard implementation of three dimensional seismic surveying consists in spreading the source lines perpendicular to the receiver lines. Several parallel lines of receivers can be used simultaneously to obtain multiple coverage over rectangular areas. A more elaborate method consists in laying out sources and receivers uniformly around a square. With an equal number of sources and receivers a complete seismic coverage of the square can be obtained (Lavergne 1989). A number of other layouts are also occasionally used.

POSITIONING REQUIREMENTS FOR 3D SEISMIC SURVEYS

For the sub-surface strata to be correctly and comprehensively modelled, the surface elements (receivers and source points) need to be placed accurately according to a pre-designed layout which is based on geophysical constraints and guidelines. It is possible to complete a 3D survey using somewhat randomly placed receiver and source points which are then accurately located, but the final seismic data is much more reliable and useable if a regular set out grid is adopted, rather than a more random design based on easy access and limited disturbance.

Accordingly it is normal to attempt a regular grid for a 3D seismic survey. Receiver and source elements then need to be set out accurately on the ground. The accuracies of

placement of the source and receiver lines, which are quite commonly perpendicular to each other, is much higher than in 2D surveys. On a 3D survey in southern Australia in 1993, the specified accuracy for each receiver and source point **placement** was plus or minus 2.5 metres from the design coordinates. Thus, in general, all points for a 3D seismic survey must be set out by theodolite and e.d.m. as a minimum standard. The use of real-time G.P.S. on "open sky" 3D seismic projects is now becoming common, with the set out and observation of points being undertaken at the same time.

Processing and production of final positioning data and documentation is much the same as with 2D seismic surveys.

POINTERS FOR SURVEYORS CONSIDERING A CAREER IN SEISMIC SURVEY

1. A graduate surveyor with common sense and skills in geodetic computing and computer operations is capable of forming a successful career in seismic positioning.
2. An interest and preferably some education in geophysics would be of great use.
3. Seismic projects are very production orientated. Thus if a surveyor is capable of surveying a certain number of line kilometres in one day, he is expected to achieve the same every day. Should he fall behind his "quota" an effect is felt through the entire seismic project. For the surveyors are followed by the drillers, and the drillers are followed by the recording crew, etc. All personnel in seismic have to be able to operate under pressure.
4. Seismic projects are commonly undertaken in inhospitable and remote locations. Working hours are extremely long and there are usually no days off during the project. Being able to get on with people 24 hours a day is essential to success and happiness in the industry.

A COMMENT ON SEISMIC SURVEYS UNDERTAKEN IN PAPUA NEW GUINEA

Many seismic surveys have been undertaken in Papua New Guinea and presumably many more will be undertaken in the future. To date very few, probably no, graduate Papua New Guinea surveyors have been employed on these projects. Surveying staff have generally been brought in from overseas. Exploration companies should be encouraged to employ Papua New Guineans on these projects, either as direct employees or as sub-contractors.

Papua New Guinean consultants should be encouraged to bid for the positioning aspects of such surveys.

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