# KAPUNI 3D SEISMIC: APPLICATION OF A MODERN EXPLORATION AND PRODUCTION TECHNIQUE IN NEW ZEALAND

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In the introductory part of this paper, the 3D seismic technique in general is briefly reviewed. The major differences between 2D and 3D reflection seismic are summarised, and the substantial advantages of the 3D technique highlighted. The development of the technique within a few years from the experimental stage to a widely accepted method, applied on a large scale, and even in very difficult operational environments, is outlined. A few examples from outside Australasia exemplify the break-through in geologic knowledge of an area or of a field that can be obtained with 3D seismic.

The Kapuni 3D survey, acquired in 1989 in the southern onshore part of New Zealand's Taranaki Basin, is then discussed in some detail as the main topic of this paper. The discovery and development history of the Kapuni Field are outlined. The rationale behind the decision to carry out a 3D survey prior to the detailed planning of further field development is outlined.

The choice of acquisition technique and field lay-out, and the detailed planning and preparation of the survey, are described. A review of experience gained during actual operations and first processing results concludes the paper.

## DEVELOPMENT OF THE 3D SEISMIC TECHNIQUE

### Introduction

For many years the seismic reflection technique has been the most important oil and gas exploration and field appraisal technique by far and the basic method is familiar to most people involved in the industry.

In the course of the last decade, *a big leap forward* in the seismic technique has taken place, as the 3D seismic method has progressed from an experimental tool to an almost routine operation.

Why has the 3D seismic method gained acceptance so quickly in spite of the fact that it appears to be substantially more expensive than conventional 2D seismic? This question is discussed in the first part of this paper. In the second part, the first application of the 3D technique to an onshore field in New Zealand is described.

### Advantaqes of the 3D seismic technique

In 2D reflection seismic, artificial shock waves are created at or near the earth's surface (at *shotpoint locations*), and their reflections at interfaces between rock layers within the crust are recorded by regularly spaced receiver stations spread out along a surface line. The data obtained in this way are processed and displayed such that, at typically 25m intervals, information on the subsurface is displayed as *wiggly traces*, whereby the distance of each loop from the time zero axis corresponds to the time necessary for compressional waves to travel from the surface point to a particular reflecting interface in the crust plus the time required for the echo to return to the same surface point. In this way, a two dimensional cross section of the crust is obtained. In a typical 2D survey, these cross sections are normally spaced several hundred metres or even kilometres apart. In a 3D seismic survey, on the other hand, reflection data are collected such that a *wiggly trace* is obtained for each point of a regular surface grid (typically 25 x 25 m), the *bin* grid, resulting in a three dimensional cube* of seismic data.

The generation of such a 3D cube of data is one of the two main advantages of 3D seismic. A geo-scientist interpreting 2D seismic data always has to interpolate between individual seismic profiles. Unfortunately, geology tends to be complex and large structures can escape the *net* of a coarse seismic grid. Producing fields, mapped on tight grids of 2D seismic data, have been modelled incorrectly due to fault aliasing and other limitations imposed by the 2D approach. Figs 1 and 2 show a typical example. Fig. 1 shows a structural map of a North Sea field as mapped on a 1974/75 2D seismic grid. Fig. 2 shows a re-interpretation of the same field based on a 1983/84 3D seismic survey. The increase in structural definition is striking, as is the degree of complexity revealed

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*The horizontal dimensions (x and y) of this data cube are distance, while the third, vertical, dimension is two way travel time (in the 2D as well as in the 3D case, seismic reflection time information has to be converted to depth models of the subsurface using information on compressional wave velocities).

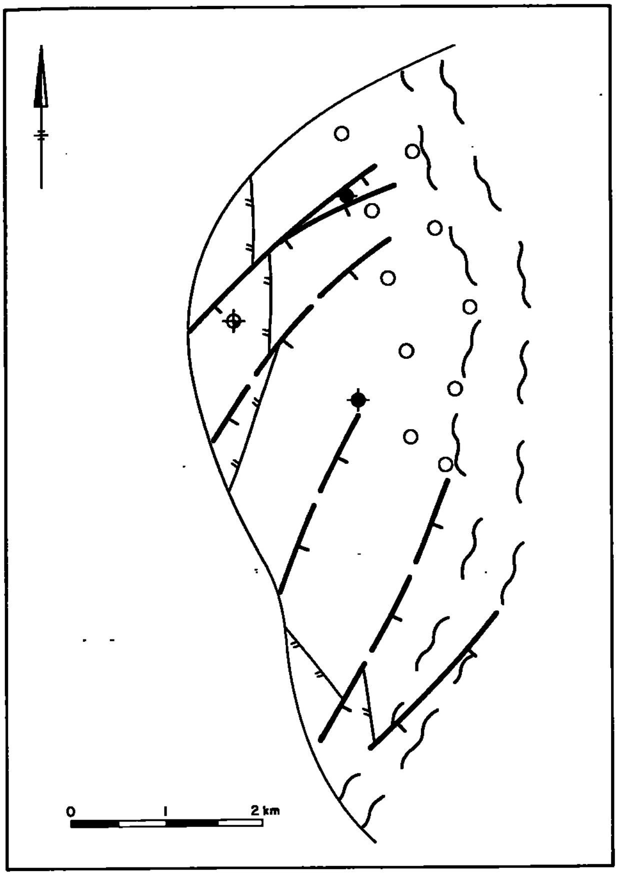


Fig. 1: North Sea Oil Field - fault pattern as mapped on 1974/ 75 2D seismic grid.

by the 3D survey. This is due to the fact that the data obtained in a 3D survey can be displayed on cross-sections at 25m intervals at any desired orientation or even as zig-zag cross-sections (e.g. linking a number of wells).

Data from the 3D cube can be viewed furthermore as *time slices* (maps at certain reflection times). An additional powerful tool is the display of maps of seismic attributes (e.g. amplitude or local dip) of interpreted and *flattened* seismic horizons (Dalley *et al.*, 1989 ). The industry is still learning to reap the full benefits of the 3D seismic method and interesting further developments may be expected.

The second principal advantage of the 3D seismic technique is the major improvement in *imaging* and *positioning* of seismic events that it allows. All seismic data nowadays are recorded digitally in the field and processed in an intricate sequence in large computing centres to enhance the S/N ratio of the data and increase their interpretability. One of the most important processing steps is *migration.*

Each reflecting surface can be considered to be composed of individual points scattering spherical wavefronts back to the surface. For laterally continuous reflecting horizons, the *diffraction hyperbolas* generated by these individual scatterers are largely suppressed by interference but the resulting image is mispositioned in case of dipping events. At terminations of reflectors and other irregularities, diffraction hyperbolas themselves become prominent and *blur* the seismic image. Migration is able to focus and position seismic images (analagous to optical focusing by lenses).

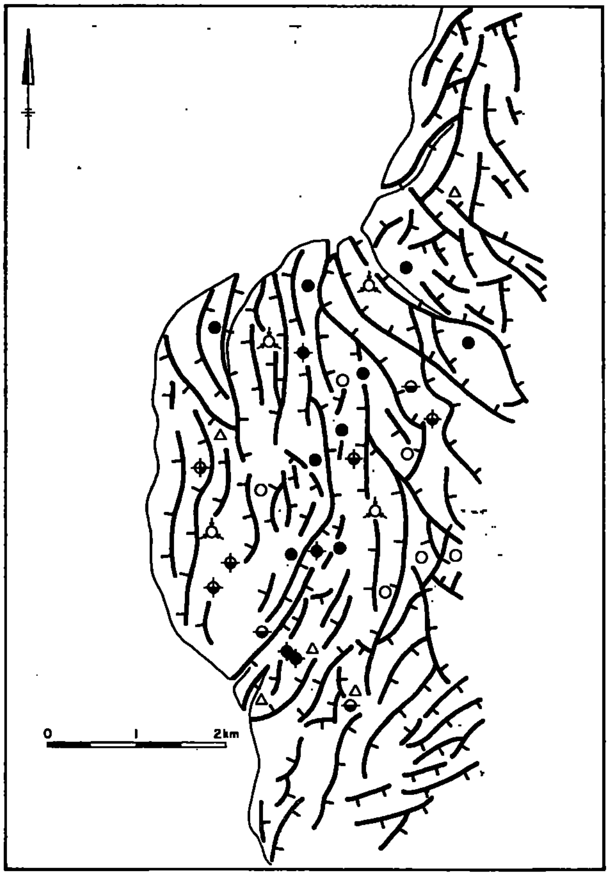


Fig. 2: North Sea Oil Field - fault pattern as mapped on 1983/ 84 3D seismic data set.

2D seismic migration, however, has severe shortcomings as it is unable to process reflections coming from outside the 2D cross sectional plane correctly. *Out of plane reflections* will always be present in case of the azimuth of any dipping reflector not being parallel to the orientation of the 2D seismic profile. Fig. 3 shows a remarkable comparison between a 2D and 3D migrated section located along the same surface line.

The superior positioning and focusing made possible by 3D seismic is of critical importance not only for field appraisal, but also for the positioning of exploration wells. Fig. 4 shows an onshore 2D seismic section and the position of an exploration well planned to test an interpreted horst block prospect. When the well was drilled, the objective sequence was encountered several hundred metres deeper than prognosed and found to be fully water bearing.

A 3D survey, acquired subsequently in the same area, revealed that the well had been drilled on the down-thrown side of the bounding fault (see Fig. 5 showing a 3D cross section located at the same surface position as the 2D section shown in Fig. 4), demonstrating the improvement in structural resolution obtained by the 3D technique.

## Development of the 3D technique

The first 3D seismic surveys for the oil industry were acquired in the mid seventies, when progress in electronics allowed the use of systems with more than a hundred active channels in the field and advances in computing hardware

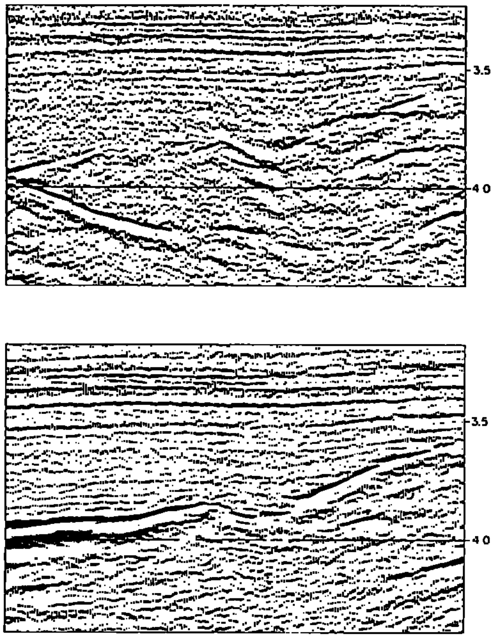


Fig. 3: (a) 2D migrated seismic line forming part of a North Sea 3D survey. (b) 3D migrated seismic cross-section from same 3D survey and in identical surface location as profile shown in (a).

and software made the processing of the large amount of data obtained in a 3D survey feasible.

In spite of the inherent high costs of the method, it gained rapid acceptance and its use has increased dramatically over the years. This is illustrated by Fig. 6, which shows the Shell operated acquisition of land and marine 3D seismic in the period 1975-1987 (after Jennings, 1989). The fact that the oil industry became relatively quickly persuaded to spend substantial amounts of money on a sophisticated geophysical tool has one main reason.

The advantages of 3D seismic, as outlined in the previous paragraph, were demonstrated in practice very clearly with each and every properly acquired, processed, and interpreted survey. The increase in geological knowledge, the improved accuracy of field development plans and exploration proposals, and the increased success of ensuing wells resulting from 3D seismic was very persuasive.

Furthermore, technological advances and increased experience meant that the 3D technique could be applied at decreasing unit costs. Improved technology enabled the use of more and more active receiver channels in the field and many other cost saving measures. Thirdly, the 3D technique became feasible even in operationally very difficult circumstances.

The experience with 3D seismic in NAM (the Dutch E&P company of Shell and Exxon) illustrates all above points. NAM had already used and identified the potential of the 3D technique in the late seventies and pioneered its development in many ways. Effective use of low coverage techniques has led to a reduction of the unit costs of 3D seismic acquisition to a fraction of earlier rates (see below). Large 3D surveys covering several hundred square kilometres were acquired routinely at sea and in rural onshore areas. Furthermore, already by 1985, large cities and the biggest harbour in the world (the Rotterdam area), and large tide-dominated estuaries plus adjacent transition zones and land areas were covered by integrated 3D seismic surveys. The surveys have used airgun arrays, Vibroseis, and dynamite as seismic source, and geophones and hydrophones as receivers (Kreitz and Bukovics, 1985). These methods were later further improved (Nooteboom and Bukovics, 1989).

For many years, NAM has acquired thousands of kilometres of land and marine 3D seismic per year, e.g. 3099 km$^2$ in 1988 alone (de Wit, 1989). A large percentage of these surveys has been acquired for the exploration function. The resulting increase in success ratio made it all worthwhile; 12 out of 15 NAM exploration wells in 1988 resulted in a discovery - an astonishing success ratio of 80% (de Wit, 1989)! Results on the field development side were equally positive. Upstream oil and gas companies all over the world have repeated these positive experiences.

## Cost effective 3D seismic acquisition

The effort put in to a 3D survey can be summarised in the very simple formula (valid only within the *full fold* coverage area of a survey)

$$NS \times AC = NB \times FC$$

| | |
|---|---|
| NS | Number of seismic source points (shotpoints) |
| AC | Number of active channels of recording instrument used |
| NB | Number of bins (increasing with decreasing bin size or increasing survey area) |
| FC | Fold of coverage |

Geophysical and geological considerations should determine the choice of factors on the righthand side of the equation, which in turn dictates the product on the left, leaving the acquisition operator only a choice between the use of more source points and less active receiver channels or vice versa.

The factor NB is a product of the survey size (selected according to the size of the subsurface target to be imaged and other factors) and the number of *bins* per unit area, which follows from the selected *bin size* (the spacing in x and y of the final subsurface data sets, see above). Many 3D surveys have been rendered worthless by selecting *bin* dimensions which were too large, in an attempt to save costs. Theoretical considerations and extensive practical experience have shown that 25 m x 25 m is a reasonable compromise for most practical applications, corresponding to 1600 bins per square km.

With the number of *bins* largely determined by the subsurface conditions and target, the only fundamental cost determining factor that can be selected by the geophysicist planning a 3D survey is the fold of coverage.

Land seismic, even 2D, is usually very expensive (typically five to ten times more than marine seismic), and since the early stages of land 3D seismic, the *crossed array* (or *block lay out*) technique has been used. This technique means essentially that seismic source points are arranged along shot rows oriented at right angles to one or more receiver lines. Typical realisations result in eight to sixteen fold coverage per *bin*.

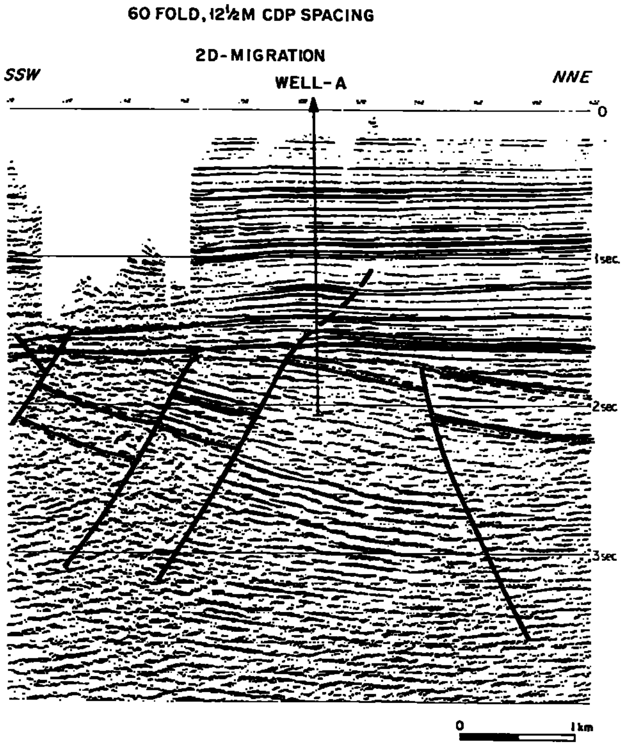


Fig. 4: Onshore 2D seismic line.

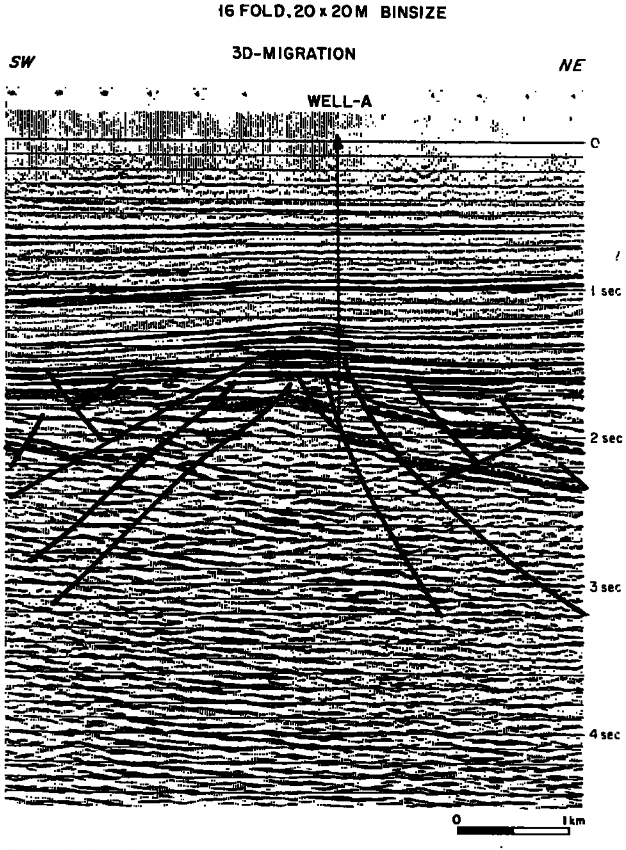


Fig. 5: 3D Seismic line in same surface location as 2D line shown in Fig. 4.

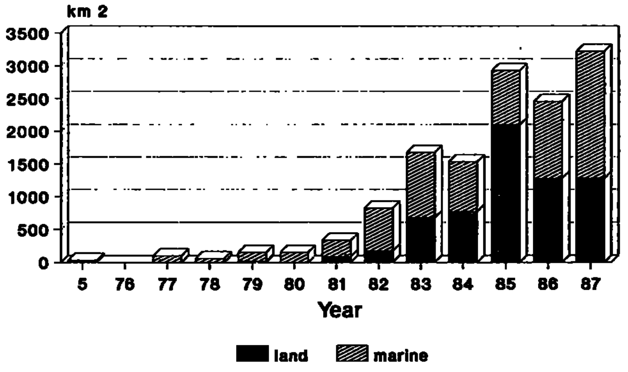


Fig. 6: Shell operated 3D surveys (outside North America) annual production 1975-1987.

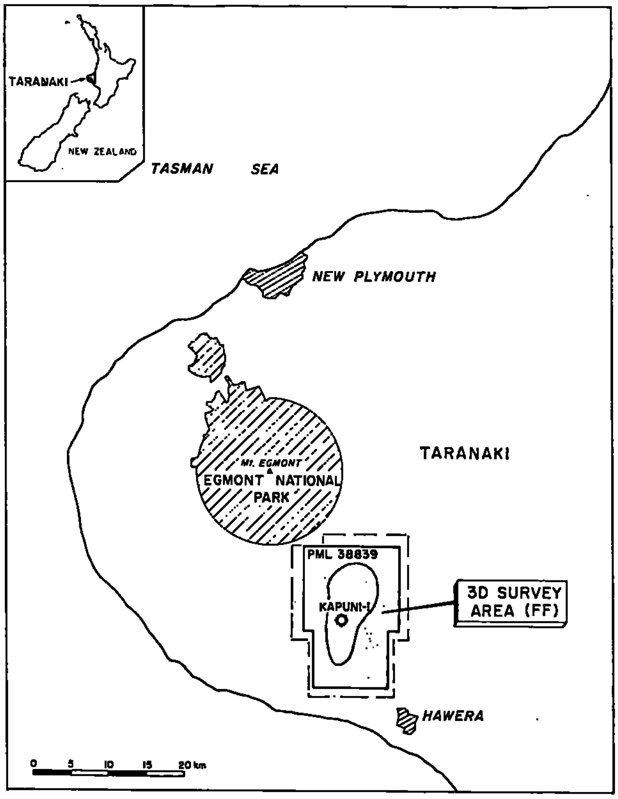


Fig. 7: Location map Kapuni 3D seismic survey.

With this technique, land 3D has become feasible, and the use of an increasing amount of active channels, enabling the use of four to eight receiver lines recording simultaneously, has effected further cost reductions. Costs per square km for typical land 3D are therefore only two to four times the cost of comparable 2D survey costs per line km.

The low coverage obtained with this acquisition technique originally worried many geophysicists. However, theoretical considerations (Marschall, 1984) have shown that 3D migration is a process which improves the signal to noise (S/N) ratio of seismic data very significantly. Many practical examples have confirmed that 3D migrated results of low-fold 3D surveys have S/N ratios comparable or better to 2D surveys acquired with much higher fold of coverage in the same area.

It required considerable technological progress before similar cost savings could be achieved at sea. Originally, 3D marine surveys were acquired by a seismic vessel, equipped with one streamer and one or two airgun arrays, obtaining one (or two at the most) subsurface lines per boat pass, resulting in 3D costs per square km many times higher than the corresponding 2D costs per km. The advent of the two-streamer technique enabled the recording of four subsurface lines simultaneously per boat pass and almost halved 3D unit costs. In 1988, NAM operated a very large 3D survey which was acquired by two boats with two airgun arrays and two streamers each, with both ships sailing in parallel. Each array popped sequentially, resulting in the simultaneous acquisition of 12 subsurface lines, forming a 300 m wide swath, per two-boat pass, with half the fold of coverage when compared to standard marine 3D surveys. The resulting acquisition geometry resembled a land 3D technique in that source points are arranged at lines oriented at an angle to four receiver lines recording simultaneously. This technique (made possible mainly by progress made in computerised navigation and real time positioning of ships, airgun arrays, and streamers) resulted in further dramatic cost savings. Published NAM results (de Wit, 1989) are again used for illustration: Two-subsurface-line acquisition in 1986 resulted in marine 3D unit costs of ca NZ$40 000/km$^2$, use of a ship with two streamers/two airgun arrays resulted in four subsurface line acquisition in 1987 with unit costs of ca Nz$20 000/km$^2$ while the two ship technique described above resulted in unit costs of ca NZ$14 000/km$^2$ in 1988!

### Processing

Progress on the processing side has matched developments on the acquisition side. 3D processing is very demanding both on computer and human resources, and processing costs are a substantial part of a total 3D seismic budget.

However, the continuous development of ever more powerful hardware and software has reduced demands on CPU time and manpower, and therefore costs, to a fraction of earlier values. However, processing of, e.g. the Kapuni 3D will require more then 500 hours CPU time of a CRAY YMP (plus 40 GByte Memory) and several man-years of specialist staff.

The quality of the processing has also improved very significantly. A case in point is the vastly improved routines for handling large static corrections using refraction information. Most importantly, further progress is being made in improving focussing and positioning of reflections in spite of strong lateral velocity contrasts. Pre-stack 3D DMO is offered now by most major 3D processing centres, but full pre-stack depth migration is still in the experimental stage. A breakthrough on this front is eagerly awaited in order to overcome some of the current technical limitations of the 3D method.

## THE KAPUNI 3D SEISMIC SURVEY

### Discovery and development of the Kapuni Field

Shell BP and Todd Oil Services Limited (SBPT) was established in 1955 to operate on behalf of Shell (Petroleum Mining), BP (Oil Exploration) NZ (D'Arcy at the time) and Todd Petroleum Mining (the *Kapuni Mining Companies*) in the western areas of New Zealand. SBPT's first prospecting licence comprised most of onshore Taranaki, and a systematic exploration programme extending over several years was initiated. In addition to field geology, gravity and magnetics, etc., a land 2D survey covering some 650km was acquired in the period 1956-1958. This survey was interpreted and integrated with all other available data. A major prospective structure was identified and tested in 1959 by SBPT's first exploration well, Kapuni-1 (Fig. 7).

This well resulted in a large gas-condensate discovery in Eocene quartzose sandstones, the swamp and flood plain coal measures of the Mangahewa Formation (Kapuni Group) (Pilaar and Wakefield, 1978; Robinson and King, 1987). This field is the oldest field in New Zealand still producing today. Producing zones are in the depth range 3000 - 3600 m.

Subsequently, the Government awarded Petroleum Mining Licence (PML) 38839, covering the area of the field, to SBPT. The field was brought on stream in 1970 and a total of 14 wells have been drilled to date.

In addition to the original regional seismic grid, three more 2D seismic surveys have been carried out over the Kapuni field by SBPT in 1971, 1973, and 1979. As a result, an approximately 2 x 2 km grid over the central part of the PML has been obtained. This sparse grid does not provide adequate data for mapping the reservoir sands, particularly on the flanks of the structure, and therefore does not allow the compilation of an adequately detailed geological model of the field. This was corroborated by the results of the infill well KA-14, drilled in 1987, which encountered much better developed reservoir sands than anticipated.

With the necessity for additional seismic over the Kapuni field clearly identified, a decision between additional 2D lines or a 3D survey had to be made. Reprocessing of existing 2D lines indicated that the Kapuni Field might be affected by a dense pattern of faults. The structural and stratigraphic complexity of the Kapuni Field clearly required acquisition of a dense 2D grid or a 3D programme. Given the current state of 3D seismic technology, the 3D option was considered to be more cost efficient. After careful technical and economical analysis, the Kapuni 3D survey was approved by the Kapuni partners in 1988 and acquisition was planned for 1989, almost twenty years after the start of production.

### Survey planning and preparation - general aspects

The survey area is located south-southeast of Mt Egmont (Taranaki) on its sloping ring plain (maximum elevation difference ca. 500 m). The area is generally gently undulating, but includes a few hilly areas and is dissected by several deeply entrenched rivers. The land is covered by dairy farms of ca 50-100 hectares, with paddocks separated by fences and high box thorn hedges. The survey area includes the Kapuni production facilities and the four settlements of Manaia, Kaponga, Eltham, and Normanby.

Detailed planning started in March 1988. This early planning was a key element in ensuring the smooth execution of the large project. From the beginning, safety and environmental aspects formed an integral part of the overall survey planning. This will be highlighted by a number of facts detailed in this paragraph.

Survey area determination was based on the subsurface target area to be 3D imaged and on an estimated migration operator half width of 2 km at the objective level. The resulting area of required surface work extends beyond the

Egmont National Park. A close investigation revealed that most of the survey objectives could be met even if the survey area would be reduced by a rectangle in the NW corner, avoiding any intrusion into the National Park.

The resulting survey area was 305 km² (full fold coverage) or 380 km2 (surface work). Required bin size was calculated to be 25 x 25m, and a 12 fold of coverage was specified. A standard, well proven field lay-out, based on 480 recording channel system, was selected (Fig. 8). Design of the field layout and the selected roll-along technique is detailed in Appendix 1. The field lay-out chosen is a good compromise between geophysical considerations (the desire to record data over a wide offset range, including many short offsets, and the corresponding tendency to narrow receiver line spacing) and logistic aspects, which make wide spacing of receiver lines more attractive. The roll-along technique selected requires relatively large amounts of material, but ensures rapid progress, which not only reduces costs, but also minimises disturbance to land owners and users.

### Receiver and source parameters

Standard receiver pattern and parameters were selected (Fig 9). For background on pattern design in general the reader is referred to Ongkiehong and Askin (1988). The large survey area and the selected field lay-out meant that ca. 14 200 shotpoints in total had to be planned. In selecting the source parameters, factors other than geophysical aspects had to be taken into consideration as well. Geophysically, best results are achieved when seismic sources are activated below the base of the weathered (low velocity) layer. In the Kapuni area, weathering thickness varies considerably, and shotholes would have to be drilled to 15 m or deeper to reach consistently well consolidated sediments. Given local subsurface conditions, this requires the use of heavy drilling equipment, which has to be moved by helicopter or large trucks. This is not only costly, but also the associated noise, and deep tracks in case of trucks, are a nuisance to the local communities. Furthermore, deep shotholes carry the risk of influencing the local water table. Therefore, a pattern of shallow charges (Fig. 9) was used. This technique, well proven in other areas, can be implemented using very light, low noise drilling equipment and does not influence the water table. However, it has some geophysical disadvantages, the main one being creation of *ground-roll* (surface seismic waves, partly masking the wanted seismic signal) to a much greater extent than the deep shothole technique. However, modern processing techniques, notably k-f filtering, allow suppression of this shotgenerated noise to a very large degree. The successful use of this technique in the Kapuni 3D is a good example that technical progress (in this case advances in seismic processing techniques) may allow us to alleviate the negative aspects of a necessary technical operation (use of seismic source points in a seismic survey).

### Time schedule

The time schedule for the acquisition phase was also governed by external considerations. It had to take place between the haymaking and calving/lambing seasons, essentially in the period January to June (i.e., six months or less).

### Preparations

Upon deciding on the main survey parameters, planning and preparations progressed on several fronts. Tenders for the main acquisition contract were invited from a short list of major specialist geophysical companies, selected not only by technical capabilities, but also by general safety policies and safety track record. In November 1988, the contract was awarded to CGG of France, a company with previous operating experience in New Zealand.

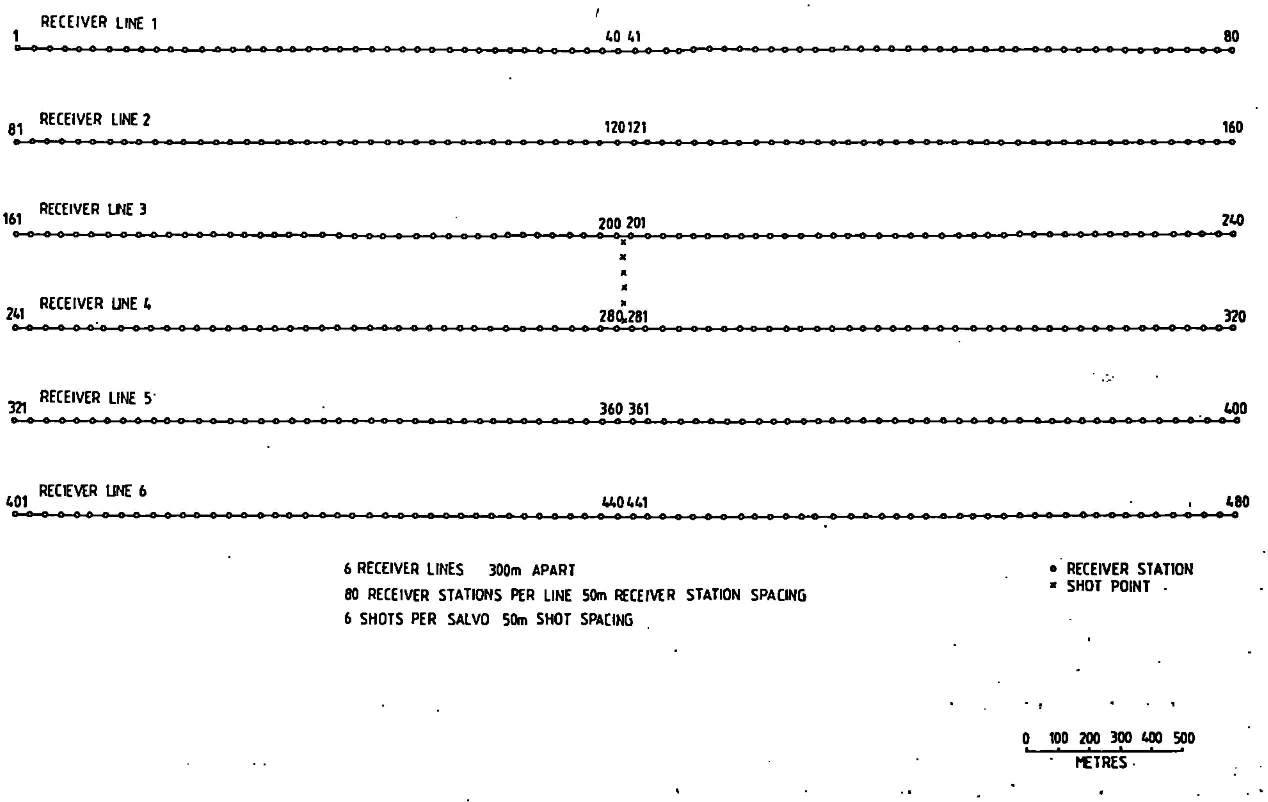


Fig. 8: Field lay-out Kapuni 3D.

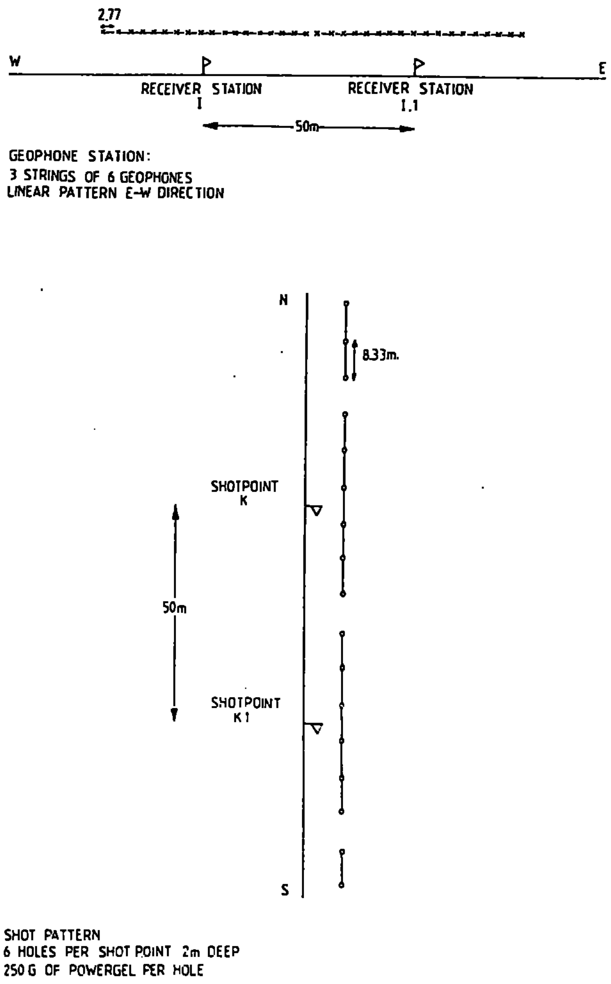


Fig. 9: Source and receiver patterns Kapuni 3D.

During the same period, all general permits required for the survey were applied for. Furthermore, a public relations campaign was implemented, aimed to inform all local residents about the purpose of the survey and the techniques to be used, before they were contacted individually by the permit personnel.

In the same period, SBPT had extensive contacts with the Taranaki Division of Federated Farmers, which resulted in agreements on general ground rules for the execution of the 3D survey and in the appointment of a Federated Farmers' Liaison Officer.

In the period November 1988 to February 1989, a project team was gradually mobilised by SBPT, simultaneous to the mobilisation of CGG's seismic party. CGG subcontracted experienced local companies for permitting, drilling and restoration. Four general public meetings were held in the area and, additionally, the population was informed via local media. Individual permitting started on 20 November 1988, three months ahead of the planned start of recording.

A detailed safety training programme was agreed upon between SBPT and CGG, amounting to a total of more than 240 man-days of various kinds of special safety training. Most of this training was scheduled prior to or at the start of the survey. Topographical surveying started in late December. The drilling subcontractor constructed six special lightweight hydraulic auger drills, mounted on Kubota 4 x 4 minitractors (Figs. 10a and b). An explosive storage facility, built to more stringent specifications than postulated by New Zealand safety regulations, was prepared. Tests on optimal shot hole restoration methods were conducted. For security reasons it was decided to load the pre-drilled shot holes only on the day when they were shot/recorded.

By late February, all parts of the survey party had been mobilised. It comprised ca. 120 personnel, 60 vehicles, 1 helicopter (for moving the spread material), a Sercel SN 368 recording-instrument with 1540 SU-E station units, ca. 90 km telemetric cable, 27 720 geophones, a Mc Seis 1500 Oyo LVL recorder, 8 Geodimeter 400 total stations (topographical surveying), various computing hardware (including a Micro Vax 2000), and many other items.

## Execution phase

Operational progress was very satisfactory (Fig. 11) and a slight delay at survey start was more than compensated for later. Shothole drilling started on 13 February, actual shooting and recording operations were completed in less than four months (in the period 26 February to 18 June) resulting in an average production of ca 125 shots/day or 83 km$^2$/month. Restoration of the last shothole was completed within three days of end of recording. The main operational problem was the rapid deterioration of the cable material in use caused by livestock and rodents. More than 120 km of electrical fencing were moved together with the geophone spread in order to deter cattle and sheep, but obviously could not stop rodents. Therefore an extensive cable checking and repair scheme had to be implemented to maintain the electrical integrity of the spread material.

Each member of the SBPT project team had a special area of responsibility: Administration, Seismic QC, Positioning QC, Farming/Environmental Aspects and Safety. In this way, adherence to all specifications was closely monitored and unnecessary damage to third party property was virtually eliminated. The close co-operation between the SBPT and the CGG safety officers resulted in a very high safety awareness in the party.

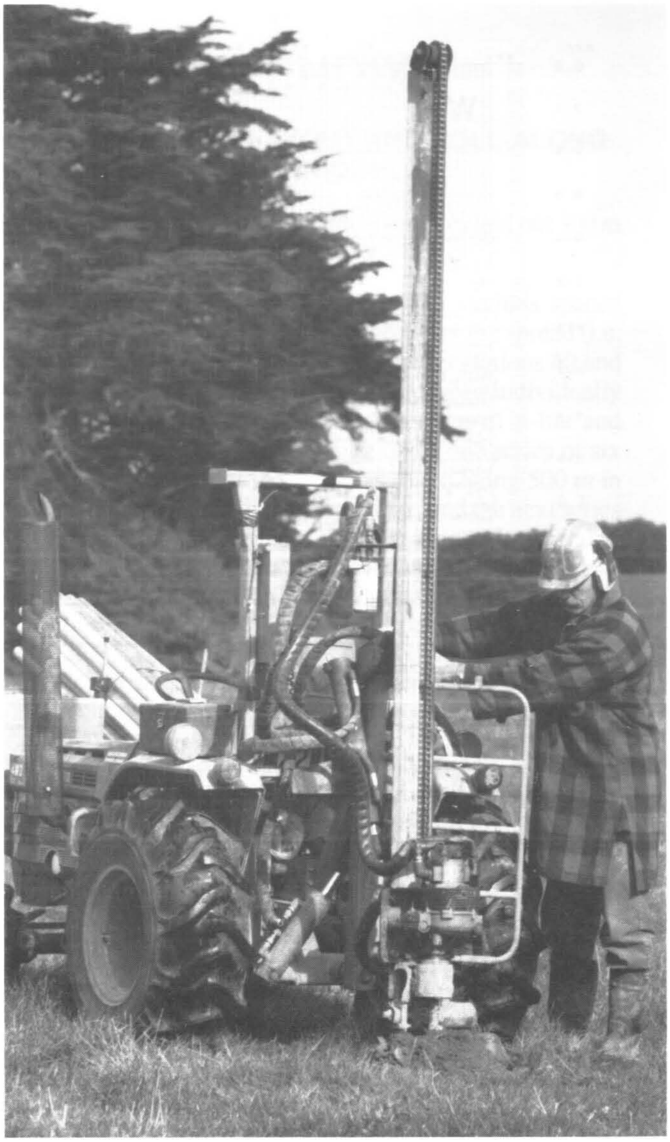
Other measures taken to ensure a high standard of the survey included organisation of several detailed technical and safety audits, conducting weekly meetings on safety and operational aspects, etc.

## Acquisition results

The dedicated efforts by the contractor and the SBPT project team were rewarded by excellent results: the survey was acquired on time and within budget, seismic quality was consistently good, the efficiency of the operation high (as witnessed by the high production rate), and the positioning accuracy, a key factor determining data quality, very high. Most importantly, excellent relations with third parties were maintained and negative effects on the local environment and community minimised. Regrettably, one accident resulting in time off work did occur, however, the safety standard of the party in general was commendable.

## Outlook

Processing is underway in Shell's main processing centre in The Hague (The Netherlands). First results (a test stack of a line segment) indicate that a final product of high quality can be expected (Fig. 12). Final processed results are expected to be available in March/April 1990, and will be interpreted on



Figs. 10a and b: Hydraulic auger drill mounted on Kubota 4x4 tractor.

an interactive trace interpretation system. This is scheduled to take place in the second and third quarter of 1990.

## CONCLUSIONS

The progress made in the development of the 3D seismic technique makes it an economic proposition for the evaluation of oil and gas fields even if they have already produced a substantial part of their ultimatly recoverable reserves. In line with the commitment of the Kapuni Mining Companies to manage and produce the Kapuni field in the most responsible and efficient way, it was decided to carry out a 3D seismic survey over the whole area of PML 38839.

The successful completion of the acquisition phase has demonstrated that the application of this modern and logistically complicated technique is well feasible in New Zealand and that careful advance planning and supervision of a large 3D seismic project are key elements in obtaining optimal results. SBPT's efforts are now concentrated on ensuring that the processing and interpretation phases are equally successful and contribute optimally towards further field development planning.

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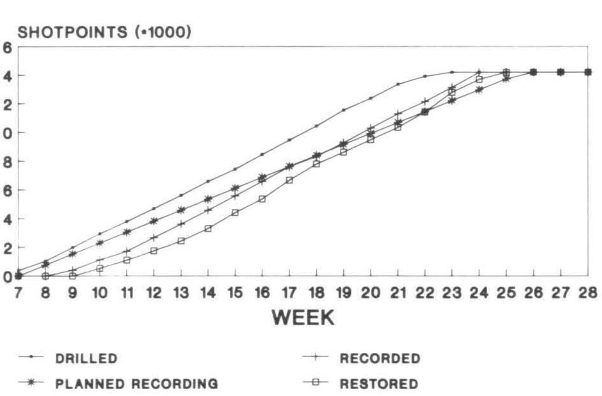

Fig. 11: Cumulative production Kapuni 3D seismic acquisition.

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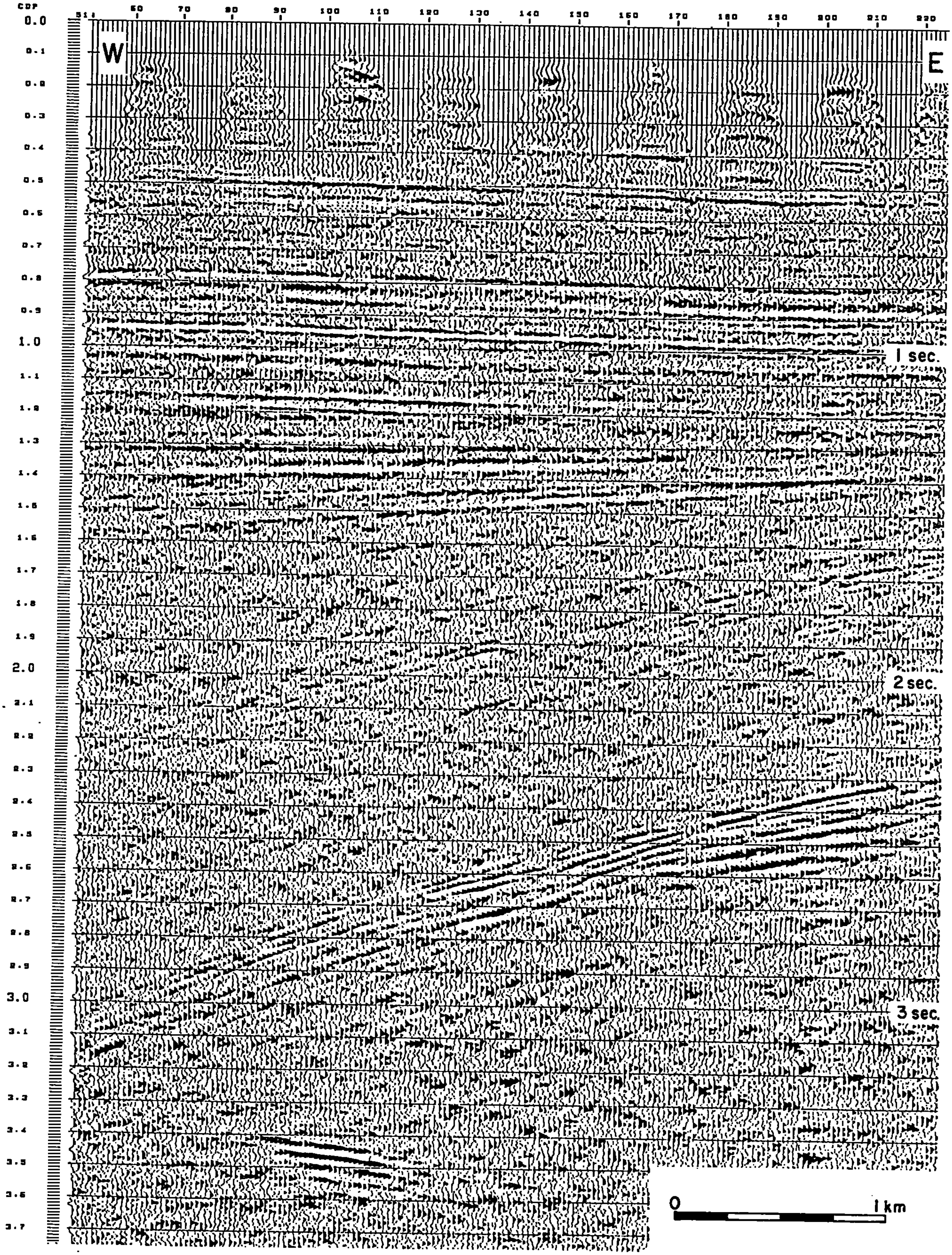

Fig. 12: 2D Stack (preliminary processing) Kapuni 3D test line.

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# APPENDIX 1

## KAPUNI 3D FIELD LAYOUT AND ROLL-ALONG TECHNIQUE

The basic spread consists of six receiver lines laid out 300 m apart (Fig. 8).

Each receiver line has 80 active receiver stations spaced 50 m apart. Six shots located in the centre of the spread (i.e. between receiver lines 3 and 4 and receiver stations 40 and 41), 50 m apart along a shot line, are recorded individually on a fixed spread (centre spread configuration in in-line and cross-line direction). After completion of one series of six shots, the active part of the spread is rolled along 500 m in the direction parallel to the receiver lines and the next series of six shots is recorded onto it. The roll along in the direction parallel to the receiver lines is repeated until the boundary of the lay-out is reached, at which the point the field lay-out is moved up 300 m in the direction perpendicular to the receiver lines. The receiver line at the bottom of the layout is then picked up and moved up to the top of the set-up. Shooting progress in the next stretch proceeds backwards as compared to previous stretch.

The above field technique is most effective if all receiver stations belonging to the six receiver lines currently in use, plus one line ahead, are all in the field simultaneously over the whole length of the layout.

Receiver lines were planned to be laid out in an E-W direction (parallel to direction of steepest geological dips). Since the E-W extent of the survey area is more than 17 km, it was split into two overlapping zippers in the E-W direction each ca 10 km wide, a manageable distance for the logistics of the above layout and roll-along technique.