5.2 Seismic Systems

5.2.1 Acquisition system

The marine seismic acquisition system is designed to: 1) acquire single and multi-channel seismic data, sonobuoy data and source signal information, 2) data quality control via easy display of source and receiver information (e.g. depth of guns within the array, streamer depth, parameter and data errors, single- and multi-trace display, etc) and rapid modification of control parameters, and 3) user-friendly programs and parameter files to allow easy and rapid restart of data acquisition following system crashes. This system is an AGSO in-house series of FORTRAN/VAX Macro ASSEMBLER programs written specifically for execution on a Digital MicroVAX VI computer using a VMS (Virtual Memory System) operating system. The seismic data is stored in demultiplexed form using a modified SEG-Y format (as defined by the Society of Exploration Geophysicists) and internally called the BMR 16 BIT Floating Point SEG-Y format within AGSO, on Fujitsu 3480 cartridge tapes (capacity of 200 Mbyte).

Two types of seismic source-receiver systems are applicable for the Macquarie Ridge survey: 8-channel and 96-channel. For the 8-channel system, nominally a four-GI (Generator-Injector) airgun array was used as a sound source but at times, only three or two guns comprised the array because of air supply or electrical connection problems to individual guns. In contrast, the 96-channel system used an array of ten sleeve guns with 1,2,3,4-gun grouping. Line numbers were assigned consecutively, with a line consisting of the main traverse AND its transit to the next line. The primary line was named AGSO *Survey number.Line number.01*. If the streamer and/or guns required maintenance, the ship performed multiple loops until the problems were fixed. Recommencement of seismic acquisition on the same line was then named *Survey number.Line number.02* etc.

As stated earlier, all AGSO marine siesmic data is recorded in demultiplexed form and in modified SEG-Y format (Table S1). The records are written in a format conforming to the report "Recommended Standards for Digital Tape Formats", Geophysics, 1975, 40, 344-352, with the following modifications:

The first 3200-byte record on the cartridge tape is the Reel Identification Header (part 1). This record consists of 40 card images of 80 bytes each and output in ASCII format.

The next 400-byte record is the binary equivalent of the Reel Identification Header (Part 2). It is written in SEG-Y standard 16/32-bit fixed point-format.

The Trace Data Blocks have a 240-byte trace header that is also written in standard fixed-point format. The header contains information on cable depths and gun array firing times and depths. Trace data are recorded as binary floating-point words of 16 bits length, consisting of a 12-bit mantissa and a 4-bit exponent, as follows:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
s	exponent				mantissa										

Quality Control for Data Acquisition:

In the AGSO seismic data acquisition system, the operator has: 1) a VDU (Visual Display Unit) that shows most of the important data parameters controlling the seismic acquisition in addition to errors incurred during the acquisition process, and 2) several other devices for data quality control (Figure S1). These devices include:

Operator's console - a VT420 terminal which has a main display (for various important parameters) updated every shot, and also shows major errors

Operator's printer - mimics everything the operator types on the VDU console as well as software errors

Music display - Televideo or VT420 VDU, lists errors on shot point data, etc

Gun display - VT420 showing the state of each air or water gun

Depth display - KAGA colour monitor showing the depth of the seismic cable

RMS/Average display - VT420 VDU showing the RMS (Root Mean quare) and D.C. (Direct Current) offset of channels in the seismic cable, alo serves for calibrating the amplifiers

Storage display - VT340 VDU displaying single or multiple traces

Shot Logger - Epson printer showing the cable depth and Syntron bird wing angles every shot, and listing the RMS, D.C. offsets at some user-defined print interval

Gun logger - Epson printer that logs gun firing errors and depths every shot

Cycling monitor - Epson printer that lists, in bit-image mode, the cable signal for every channel on the cable

Slow monitor - Epson printer that lists, in bit-image mode, the cable signal for one channel. It lists 1 bit every shot for signals that are positive

Fast monitor - Epson printer that lists, in bit-image mode, the cable signal for one channel. It lists 4 bit every shot at some user-defined signal level

Special monitor - Epson printer that lists, in bit-image mode, the cable signal for one channel. It lists 4 bit every shot at some user-defined signal level. This listing is make to be torn off by scientists for use on board the ship. it need not be catalogued or saved

DFX8000 - Epson printer that prints and plots RMS, D.C. offsets or replays seismic traces on an on-off basis

Data Recording System Test:

A TESTS option of the system can be called to perform normal cable and amplifier tests, including those tests that are done by the operator during normal data acquisition, such as at the start and end of lines. Test options include:

1. Noise test - checks the amount of cable signal without the guns firing

2. Oscillator test - is used to calibrate the amplifiers

3. Amplifiers test - disconnects the seismic cable and shorts the inputs to the amplifiers and tests the noise levels of the amplifiers and Phoenix A/D converter

4. Impulse test - applies an oscillator signal of 4 Hz into the front of the amplifiers to do an impulse test

5. Test low cut filters - checks the 3 dB points of the current filter setting of the low cut seismic filter

6. Test high cut filters - checks the 3 dB points of the current filter setting of the high cut seismic filter

7. Automatic test sequence - runs a sequence of tests on the cable and amplifiers for a number of shots. The test sequence is

1) cable noise
2) amplifier oscillator gain
3) impulse
4) amplifier noise
5) low cut filter response
6) high cut filter response.

Seismic Recording Geometry:

Formula for Offset Calculation:

Source Near Offset: NRS = TLL + SL + GL/2 - (GC + SCE/2)
= TLL + 17.75 m

Source Far Offset: FRS = NRS + (N - 1)GL = NRS + 175 m
= TLL + 192.75 m

8-channel Seismic Acquisition Parameters:

Seismic Cable Configuration:

Group length: GL = 25 m
No. of active channels: N = 8
Active length: AL = 200 m
Stretch length: SL = 50 m
Tow leader length: TTL: varies in a range of 60 to 130 m
Gun Length: SCE = 7.5 m
Gun chain length: GC = 41 m
Antenna to stern: NS = 46 m
Depth transducer birds located after channels: 0, 4, 8
Water breaks located after channels: 0, 8
Compass birds: None

Seismic Source:

Source type: GI (Generator-Injector) operated in harmonic mode with G=105 cu. in. (cubic inches) and I=105 cu. in.
Source Volumn: 210 cu. in. (3.44 liters) for 2-gun array
315 cu. in. (5.16 liters) for 3-gun array
420 cu. in. (6.88 liters) for 4-gun array
Shot interval: varied with lines (50, 75, 80 m)

Acquisition Parameters:

Sample rate: 2 msec
Record length: 12 sec
Tape format: BMR 16 bit floating point SEG-Y
Amplifiers:
Gain: varied with lines (32, 64, 128, ect)
Low-cut shoulder frequency: 8
High-cut shoulder frequency: 180
CDP fold: ranges from 1 to 2

96-channel Seismic Acquisition Parameters:

Seismic Cable Configuration:

Group length: GL = 25 m
No. of active channels: N = 96
Active length: AL = 2400 m
Stretch length: SL = 150 m
Tow leader length: TTL: varies in a range of 95 to 110 m
Gun Length: SCE = 13.5 m
Gun chain length: GC = 40 m
Antenna to stern: NS = 46 m
Depth transducer birds located after channels:
0, 8, 16, 24, 32, 40, 48, 56, 64, 72, 80, 88, 96
Water breaks located after channels: 0, 24, 48, 72, 96
Compass birds located after channels: 20, 52, 84

Seismic Source:

Source type: 10 x 150 cu. in. Sleeve gun array
Source Volumn: 1500 cu. in. (24.6 liters)
Shot interval: 50 m

Acquisition Parameters:

Sample rate: 2 msec
Record length: 16 sec
Tape format: BMR 16 bit floating point SEG-Y
Amplifiers:
Gain: 64
Low-cut shoulder frequency: 8
High-cut shoulder frequency: 180
Shot interval: 50 m
CDP fold: 24

Streamer Configuration:

Hydrophones:

The marine hydrophones used in the 8- and 96-channel streamers are manufactured by Teledyne Exploration (Model T1). Piezoelectric transduers used as hydrophones, such as the T1 hydrophone, are designed to operate over a relatively large frequency range that extends several octaves below the resonant frequency of the device. As a result, these hydrophones are called non-resonant transducers. Piezoelectric ceramic compounds respond to acoustic pressure by bending and the production of an electric charge. In order to avoid noise due to acceleration of the cable through the water, two piezoelectric elements are put back-to-back in each hydrophone so that each element responds positively to acoustic pressure but the acceleration noise voltages cancel (Figure S2) (so called "acceleration cancelling"). The T1 hydrophone is intended to operate at depths no greater than 38 meters of water otherwise permanent damage could occur with a dramatic decrease in sensitivity.

Streamer:

The basic unit of streamer is 6.25 meter group composed of 10 hydrophones. Two 6.25 m groups in series form a 12.5 m group and two 12.5 m groups coupled in parallel form a 25 m programmable group. This 25 m group, as used in this survey, is termed a "channel".

A streamer is composed of many segments or sections which are coupled together to form the whole streamer. These segments include: active sections, stretch sections, tension cells, lead-in cables, deck cables/jumper cables, communication coils, streamer oil, couplers and processor modules (Figure S3). The active section is the main and longest section of the streamer. An active section is 100 meters long and consists of four programmable 25 m groups(Figure S4). A Water Break detector is mounted in front of each section and can be set active whenever is required at the time of survey. In contrast to some configurations, the Depth Sensor (Depth transducer) is not built in to the active section but is part of the Cable Leveller. The stretch sections are 50 meters long each and are used on the front and on the tail end of a streamer to isolate the active sections from the vibration and oscillatory forces imposed by the vessel and tail buoy.

The streamer used for 200 m cable seismic system in this survey was "banded" to reduce cable noise passing between the channels. "Banded" refers to stainless steel bands that are used to clamp the skin of the streamer to oil block spacers at intervals of 12.5 meters. The oil block spacers block the flow of oil through the section of the streamer which serves to: 1) reduce noise induced by the flowing oil and 2) attenuate the acoustic wave transmitted within the streamer in such a way that this wave is reflected at the banded block, resulting in destructive interference.

Besides the built-in Water Break detector, Compass Birds and Depth Transducer Birds attached to the active section in varous positions (for actual locations of birds see 'Data recording parameters' and 'Streamer configuration diagram') for measurement of the direct wave arrival times, cable depths and cable orientation.

General annotation for schematic diagram:

TL: tow leader
Ad/TC: adaptor section (1.3 m) with tension cell built in
S: stretch section (50 m)
A: 100 m active section composed of 4 programmable groups of 25 m each

Active section configuration:
| Wb | G1 | G2 | G3 | G4 |

Wb: water break built in active section
G : 25 m programmable group composed of 4 x 10-hydrophone groups

B: cable leveller with depth transducer built in
WB: active water break
CB: compass bird
TB: tail buoy

2400 meter streamer:

```
TL | Ad/TC | S1 | S2 | S3 | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 |
                       |          |          |     |      |          |
                     B1,WB       B2         B3   CB   B4,WB       B5
```

```
 A10 | A11 | A12 | A13 | A14 | A15 | A16 | A17 | A18 | A19 | A20 |
    |            |      |      |             |            |            |
   B6         B7,WB   CB   B8           B9         B10,WB       B11
```

```
 A21 | A22 | A23 | A24 | S4 | TB
     |      |            |
    CB    B12       B13,WB
```

200 meter streamer:

```
TL | Ad/TC | S1 |   A1   |   A2   | S2 | TB
              |       |         |
           B1,WB    B2     B3,WB
```

List of equipment:

- 2400 m and 200 m Fjord Instruments transformerless seismic streamers of 25 m group length and with Teledyne T1 hydrophone of 25 m group length
- Selectable water break channels
- Syntron RCL-3 cable depth controllers
- 16 x 150 cubic inches Halliburton Geophysical Services sleeve gun array, 10 guns fired in each array as 1, 2, 3, 4-gun groups
- GI (Generator-Injector) gun array of 4-gun group (G = 105 cubic inches, I = 105 cubic inches)

- 6 x Price Model A300 air compressors of 300 scfm, each rated at 2000 psi
- Digital seismic acquisition system designed around DEC (Digital Equipment Corportion) MicroVAX computer
- AGSO charge-coupled amplifiers Model DME-026
- Phoenix analog multiplexer with AGSO developed IFP (Instantaneous floating point) amplifier and converter
- Data recorded on Fujitsu 3480 cartridge drives
- Information stored in BMR demultiplexed SEG-Y format

5.2.2 8-channel system

In conjunction with HAWAII MR1 operations (Fig. 15), we acquired 8-channel seismic (8CS) reflection data. Linking surface (imaged by HAWAII MR1) to sub-surface (imaged by 8CS) faults within the sediment and igneous basement is essential if we are to understand the relationship between strike-slip and thrust faults. Data were acquired digitally using an AGSO 200 m (8-channel), 25-m group interval streamer. The source was an AGSO array consisting of 4 (840 in^3), 3 (630 in^3), or 2 (420 in^3) GI (generator-injector) airguns. The 8CS data will be processed through migration, especially important where dips are steep along most of the Macquarie Ridge Complex, on both Sun workstations using Sioseis software and on a Cray supercomputer using Geovecteur software at the University of Texas at Austin.

5.2.2.1 200 m streamer

5.2.2.2 GI airgun array

5.2.3 96-channel system

Deep seismic reflection data have been extremely successful in imaging throughgoing crustal faults, igneous basement and Moho configurations, and igneous basement reflection character. Knowledge of these parameters in the Macquarie Ridge region will form key input in testing transform and subduction initiation models along the feature. The 96-channel seismic reflection data were acquired using an AGSO 2400 m digital streamer, with 25-m group interval. The source will be a tuned AGSO array consisting of 10 x 150 in^3 airguns each, for a total of 1500 in^3 capacity. Record length is

16 s. These data will be processed through migration, especially important in areas of rough topography which characterize the Macquarie Ridge Complex. Processing will be performed on the University of Texas Center for High-Performance Computing's Cray Y-MP/8-864 supercomputer using CGG's GeoVecteur software.

5.2.3.1 2400 m streamer

5.2.3.2 Sleeve gun array

An effective way to eliminate bubble oscillations, aside from using the GI Guns mentioned previously, is to use an array of guns that have a variety of air-chamber capacities and characteristics, which are then fired simultaneously. The interval between the initial pulse and the first bubble pulse will be different for each gun of a different capacity. The pressure signal actually recorded from the array will consist of an impulse representing the sum of the initial pulses from all the guns followed by a train of much weaker bubble pulses spread over a period of time and partially canceling one another. As long as the guns emit their initial pulses simultaneously and are far enough apart that they do not interact substantially with one another, the initial-pulse sound pressure produced at a great distance below the array is equal to the sum of the sound pressures of the individual guns. Large guns generate a signal dominated by low frequencies, whereas the small guns have signals dominated by relatively high frequencies. Through a combination of gun volumes, one can achieve an approximately balanced frequency spectrum.

It is with this theory in mind that the Sleeve Gun II array was designed for use in shooting the 96-channel deep seismic survey. Sleeve Guns are a product of Halliburton Geophysical Services of Houston, Texas. The array consisted of 16 guns, 10 that were always in use and 6 spares in case of breakdowns. Each gun has a 2460 cm^3, or approximately 2.5 liters capacity. Because it is not feasible or efficient to design a tuned array made up of a single sir guns each of different volumes, guns of the same volume were grouped together. The group volume was then the sum of the individual guns that make it up, in effect, representing a single gun equal to the sum capacity and producing a frequency signature expected from such a gun capacity. The guns were arranged into four groups consisting of 6, 5, 3 and 2 guns. The combination of working guns was such that there was always a group with 4 guns firing, one with 3 guns firing, one with 2 and a last group with only 1 gun firing for a total of 10 firing guns.

It is important that all guns in the array fire simultaneously to maximize the overall array pulse. Unlike the GI Guns, which use a hydrophone to record the firing of the guns, the sleeve guns use the magnetic pickup concept patented by Texas Instruments, which has proved to be one of the most reliable methods in the timing of air guns. An electrical pulse is generated by magnets in the top of the shuttle when it approaches the timing coil on the gun cap. Sleeve guns are different from conventional air guns because the moving shuttle is external rather than internal. Deployment, retrieval and towing can cause damage to this shuttle if the guns get banged together. Three chambers control the movement of the shuttle. They are the air-spring return chamber, the firing chamber and the main chamber. Figure 1 shows the gun in charged condition.

The air-spring return chamber is constantly fed by the air supply, in this case a combination of two to three 138 bar compressors (the number of compressors was dependent on ship speed and any air leaks within the system), through the fill passage. The air-spring return chamber serves two purposes. One, it holds the shuttle closed when the gun is not firing. Two, it provides a spring that returns the shuttle from its open (or firing) position.

The firing chamber controls the firing of the gun. It is fed by the solenoid valve, which is normally closed. When an electrical pulse is sent to the solenoid valve, Figure 2a, the valve opens and lets air enter the firing chamber, creating a force imbalance that opens the shuttle. Once the shuttle is completely open, Figure 2b, small exhaust ports in the firing chamber dump the air pressure. Once this chamber and the main chamber have exhausted, Figure 2c, the shuttle returns to its closed position.

After the shuttle has been opened all the way, there is no longer any pressure in the main chamber or in the firing chamber. The pressure in the air-spring return chamber is therefore sufficient to close the shuttle.

The Sleeve Guns are towed vertically on the Rig Seismic, unlike other Sleeve Guns, which are designed to be towed horizontally within the array (see Figure 3). Due to the potential for water to become trapped inside the gun chambers, they must be retrieved and deployed from the ship charged to at least 14-20 bars, introducing a cause for caution in their handling.

The 2.36 liter Sleeve Guns weigh approximately 59 kg each and are 0.74 meters in length. The total energy of the source array is on the order of 3.4 x 10^5 J. The first gun in the array is towed 40 m behind the ship. There is 0.5 m between each gun and 2.5 m between the guns of adjacent groups, for a total array length of 13.5 m. There are 5 buoys attached to the array at a distance of 9 m from the array. The 5 buoys are attached to the array adjacent to guns 6, 7, 11, 13 and 16. See Figure 3 for a simple schematic of the Sleeve Gun array. Figures 4 and 5 provide a more detailed explanation of the Sleeve Gun and its parts. (Note that the ones in this survey are cataloged as a 'Sleeve Gun II'. There does exist a model named 'Sleeve Gun I'. These are of the same design, however are of a much smaller capacity.)

The figures referred to in this section were taken directly from:

Operation and Maintenance Manual, Sleeve Gun 2721723-1, HGS Products, Houston, Texas, Revision B, 02/24/88.

5.2.4 GI airgun array

The purpose of any underwater source of seismic energy is to introduce a sudden positive pressure impulse into the water. The impulse involves a compression of the water particles creating a shock wave that spreads out spherically into the water and then into the earth. A delayed effect of the shock wave is an oscillatory flow of water in the area around the explosion, which gives rise to the subsequent pressure pulses designated as bubble oscillations.

The GI Guns used in this survey are the result of research done by Seismic Systems, Inc., of Houston , Texas, and Sodera of France, in an attempt to eliminate the bubble oscillation. Unlike traditional attempts to eliminate this secondary pressure pulses by using the individual bubble pulses against each other in destructive interference, the GI Gun eliminates the possibility of secondary oscillations at the origin through the use of a properly timed air injection within the primary bubble.

The GI Gun is made up of two independent air guns within one body. (Refer to Figure 1 for a general overview of the GI Gun and its parts and Figure 2 for a more explicit, mechanical description.) The first is the Generator, so named because it generates the primary pulse as a normal air gun would; the second air gun is the Injector, used to inject the second pulse to control the oscillation of the primary bubble pulse. (Thus the name "GI" Gun, G for Generator and I for Injector.)

Both the Generator and Injector have their own reservoir, shuttle, set of exhaust ports and its own solenoid valve. There is one common hydrophone that provides both the time break and the shape of the near field signal for permanent signature monitoring. This hydrophone is positioned such that it remains inside the air bubble upon its generation, eliminating the possibility of crosstalk from other guns.

As is described in Figure 3, there are three basic steps involved in each shot of the GI Guns. In Phase 1 the Generator is fired and the blast of compressed air produces the primary pulse and the bubble starts to expand. In Phase 2, the bubble of air has nearly reached full expansion. The pressure inside the bubble is below hydrostatic pressure, and the bubble will soon start to collapse under hydrostatic pressure. At this point the velocity of the bubble is null and there is a fair amount of time available to trigger the injection. At this point, in a simple air gun, the bubble would begin to continually collapse and expand, creating a bubble oscillation. Each oscillation generates a new seismic impulse in addition to the signature of the primary pulse. Thus, a reduction in oscillation would result in a less obscured seismic record. When a bubble is generated it continually expands due to momentum, until about 200 ms after the shot, at which time its radius is approximately 3.05 m. The pressure inside the bubble would be approximately 13,789.5 N/m^2, which is 241,316 N/m^2 below the ambient hydrostatic pressure. Here, the expansion stops and contraction begins. The rapid shrinking of the bubble causes an increasing inward velocity of the water and a rapidly increasing pressure in the contracting bubble. At 400 ms the bubble has collapsed to its smallest diameter and highest pressure, and expansion starts again. The result of this continual collapse and expansion is the bubble oscillation. The Injector, therefore, must fire before the bubble is allowed to collapse. In Phase 3 of the GI Gun sequence, the volume of air released by the Injector prevents the natural oscillation of the bubble from occurring. The timing of the injection is dependent upon the hydrostatic pressure surrounding the bubble, which is in turn a function of its depth below the surface of the water. Throughout most of this survey, because the guns were towed at a depth of approximately 6-10 m on average, the delay in firing the Injector was on the order of 52 to 58 milliseconds, as is determined from the graph in Figure 4. Note the schematic of Figure 5 for an explanation of what the term 'delay' implies.

There are three parameters which the operator of the guns may alter to produce a desired pulse. For a given Generator volume, and under given conditions of pressure and depth, the operator may change the following:

1. The volume of air to be injected (by simply adding or removing plastic volume reducers into the chambers of the gun),
2. The moment of the injection, recall Figures 4 and 5 (input into the acquisition system in the computer room), and
3. The duration of the injection (by adding or removing an inner static sleeve set in front of the exhaust ports).

Figure 6 compares the Near Field signature given by a GI Gun with the three parameters tuned to an optimum and the signal emitted by the Generator when fired alone (analogous to a simple air gun). This mode using optimum parameters is referred to as the "True GI Mode". Two additional modes are the "Harmonic Mode" and the "Air Gun Mode", the difference between modes being the relative volumes of the Generator and Injector and the delay time between their respective pulses.

The Harmonic mode reduces the bubble oscillation. The oscillation following the initial signal is quasi-sine wave shaped and therefore provides a far-field signature with an excellent primary-to-bubble ratio, even with one single GI Gun. See Figure 7 for a comparison of the oscillation signature of the harmonic mode and the air gun mode. In the Harmonic mode, the injection is willingly detuned to reshape and selectively adjust the oscillations of the bubble. For instance, a reduced volume of injection can be used to produce a signature having a smooth and reduced oscillation with a greatly improved primary-to-bubble ratio. The purpose in choosing to use a mode other than the "True GI Mode", which would seem the ideal choice, would be to choose to fire a more powerful signal using a greater volume, than to minimize the effects of the bubble oscillation. The oscillation signature is still much less than would be observed with a traditional air gun.

The four GI Guns used in the survey were towed at the end of a 42 m cable from the back of the ship. The guns were suspended in a horizontal position from the bundle. The gun array is 7.5 m long from the center of the first gun to the center of the last gun. Figure 8 shows the basic array design. Note that the guns are 2.5 m apart from center to center. A tail buoy is used to keep the array from sinking and is attached by a 9 m rope. Changes in gun depth throughout the survey may be attributed to a change in the position of the buoy which is itself a function of the speed of the ship--the faster the ship the further back is the buoy and the shallower the array. Figure 9 shows this arrangement for towing a single gun array.

This survey was completed using what has been termed by Seismic Systems, Inc., the "GI 210 Mode", one variation of the Harmonic Mode. Again, refer to Figure 7 for an idea of what the near-field trace signature looked like throughout the survey. The "210" refers to the total volume of the gun, in this case, the Generator and the Injector were each 105 in^3, or 1.722 liters. Being that the maximum size of the chambers is in fact 1.722 liters, there was no need for adding a volume reducer to the either the Generator or the Injector. Two compressors supplied 2000 psi to the guns throughout the survey.

For the most part problems with the guns were due to wearing of the solenoids. In rare instances was surveying continued with less than three guns. Many auto fires were reported in the system, however the majority were assumed to be electrical problems and therefore false. For example, it was proven when after turning off a gun it was still reported to have auto fired, thus a more likely explanation of many of the recorded auto fires would be a glitch in the acquisition system as opposed to a true gun firing problem. See the chart entitled 'GI Gun Log Summary' for a detailed list of the number of guns that were firing throughout the survey.

All figures, except Figure 8, were taken from one of the two following manuals:

Operation and Maintenance Manual, GI Gun™, Seismic Systems, Inc., Houston, Texas, and Sodera, La Valett, France.

GI Gun™: The air gun that controls its own bubble, Seismic Systems, Inc., Houston, Texas, and Sodera, La Valett, France,.

Also referred to:

Introduction to Geophysical Prospecting, Fourth Edition, Dobrin, Milton and Savit, Carl, McGraw-Hill, Inc. 1988.