AGSO

PROPOSAL FOR AN OCEAN DRILLING PROGRAM SITE SURVEY CRUISE BY THE R/V *RIG SEISMIC* IN THE WESTERN GREAT AUSTRALIAN BIGHT

BY D.A.FEARY

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PROPOSAL FOR AN OCEAN DRILLING PROGRAM SITE SURVEY CRUISE BY THE R/V *RIG SEISMIC* IN THE WESTERN GREAT AUSTRALIAN BIGHT

In support of ODP Proposal 367-Rev2: "CENOZOIC COOL-WATER CARBONATES OF THE GREAT AUSTRALIAN BIGHT: reading the record of Southern Ocean evolution, sealevel, paleoclimate, and biogenic production", by D.A. Feary, N.P. James & B. McGowran

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EXECUTIVE SUMMARY

A 28-day cruise of the *Rig Seismic* to the western Great Australian Bight in early 1996 is proposed to carry out Ocean Drilling Program site surveys. Such a cruise, to collect high-resolution, multichannel seismic data, gravity and magnetic data, bottom photographs, and gravity cores and vibra-cores, is now the essential requirement prior to the scheduling of an ODP drilling leg. A drilling leg across the western Great Australian Bight shelf and upper slope will provide a suite of invaluable scientific data at a cost of some $A10-13m, which will directly contribute to an improved understanding of the factors controlling the distribution and sedimentation patterns of siliciclastic and carbonate deposition across Australia's southern margin since the late Mesozoic.

It is now likely that the ODP drilling vessel *Joides Resolution* will be in the eastern Indian Ocean/southwest Pacific in 1997/98. The necessity to carry out relatively sophisticated processing and interpretation of the high-resolution seismic data over shallow sites on the Eucla Shelf, prior to evaluation of the data by ODP's Operations Group and site safety panels, constrains the site survey cruise to an absolute minimum of 18 months prior to drilling. The requirement for relatively calm weather for seismic operations, combined with the recognition that the Great Australian Bight is a whale breeding area from mid-May until mid-October, means the optimum scheduling window for a site survey cruise is mid-February to mid-April, 1996.

The ODP drilling proposal supported by this site survey proposal advocates the drilling of a transect of holes across the southern continental margin of Australia; the largest cool-water carbonate shelf on Earth today. This latitude-parallel shelf along the northern margin of the Southern Ocean contains fundamental geological and paleoceanographic information of global geodynamic, sedimentological, paleobiological, and paleoclimatological importance. The major objectives of the drilling proposal are: 1) to ascertain the way in which a large, high- to mid-latitude shelf carbonate platform evolved throughout the past 65 m.y. in response to oceanographic and biotic change; and 2) to extract information contained in the carbonate sediments detailing global sealevel fluctuations, physical and chemical paleo-ocean dynamics, biotic evolution, hydrology, and diagenesis. Furthermore, because of architectural and compositional similarities with many older Phanerozoic carbonate platforms, the results from the proposed drilling will be of tremendous importance for the actualistic modelling of ancient open platforms and ramps.

1. INTRODUCTION

1.1 SCIENTIFIC OBJECTIVES

The ODP drilling leg proposed for the western Great Australian Bight (Fig. 1) has the potential to make major scientific advances with significant global scientific impact. The drilling proposal (Feary et al., 1994; listed by ODP as Proposal 367-Rev2) has been assessed by ODP's thematic panels, and achieved rankings of 7th from the Sedimentary and Geochemical Processes Panel and 8th from the Ocean History Panel. Such strong support from two panels, particularly without existing site surveys, makes it highly likely that a drilling leg will be scheduled when the ODP drill ship is next in the eastern Indian Ocean/southwest Pacific (presently expected to be in late 1997/early 1998). However, before the proposal can progress further, there is a requirement that detailed site surveys be completed, processed, evaluated, and submitted to ODP with sufficient time for internal ODP evaluation.

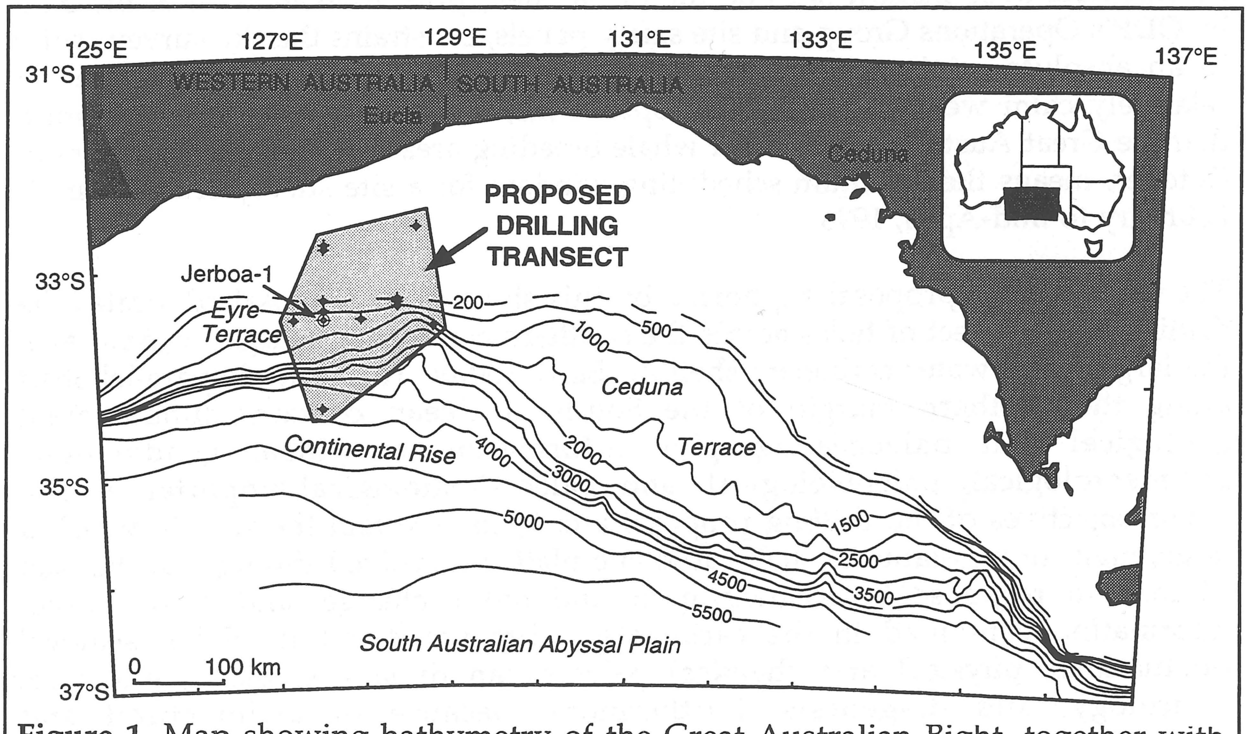

Figure 1. Map showing bathymetry of the Great Australian Bight, together with the location of the proposed ODP drilling transect.

The objectives of the drilling program are set out fully in the drilling proposal (Feary et al., 1994), and are only summarised here:

1) The western Great Australian Bight sites provide an extraordinary opportunity to clarify the history of southern hemisphere climates and global deep water circulation patterns throughout the critically important Cenozoic evolution of the Southern Ocean. This area contains ideal sections, both spatially and temporally, with the potential to sample several critical intervals of oceanic transformation (the Eocene climatic optimum; the Eocene/Oligocene cooling event; the Miocene climatic fluctuations and climatic optimum; and the Pliocene warming event).

2) The southern Australian continental margin is the best cool-water

carbonate factory on the planet, as a result of a combination of a long continental margin facing the fertile Southern Ocean, with its fluctuating subtropical convergence, and broad marginal seas generally not swamped by terrigenous detrital sediment. The western Great Australian Bight is an ideal location to test the sedimentary facies response to climatic (temperate-subtropical-tropical) fluctuations within two of the world's largest and longest lived (Eocene to Middle Miocene; Late Miocene to present) carbonate platforms.

3) Drilling the Great Australian Bight transect will permit the first detailed analysis ever of the nature of stratigraphic packaging, as a response to sealevel fluctuations, within a cool-water carbonate platform environment. In addition, this transect provides an ideal opportunity to determine the sealevel record of the Southern Ocean basin at a proximal site, and to complement the Bahamas and New Jersey sealevel transects at a distal site.

4) The Great Australian Bight drilling transect presents an opportunity to characterise shallow subsurface fluid circulation patterns in cool-water carbonates, in an area of low hydraulic gradient and minimal recharge. It will also provide an excellent opportunity to characterise early seafloor and shallow burial diagenesis and dolomitization within calcite-dominated sediments.

5) The Great Australian Bight drilling transect offers the opportunity for pioneering analysis of the pace and style of Cenozoic evolution of mid-latitude, cool-water, oceanic and neritic calcareous biota, with direct applicability to studies of ancient carbonate platforms presently lacking modern analogues.

In addition to fulfilling the requirement to demonstrate that ODP drilling at these sites would be safe, data collected during the site survey cruise will also provide invaluable scientific results:

- The high-resolution seismic data collected at sites GAB-5B/6B, GAB-8A/9A, GAB-11A, and GAB-12B will form the basis for resolving the size, shape, and internal geometry of the cool-water carbonate mounds and the warmer-water carbonate reefs recently discovered on this margin (Feary & James, 1995).
- The seismic grid collected at sites GAB-5B/6B will provide a high-resolution image of the complex progradational character visible within the distinctive wedge that represents the final siliciclastic depositional event prior to this part of the southern margin becoming carbonate-dominated.
- Bottom photographs and cores from all sites will enable a first-order correlation between the geometry and characteristics of seismic facies and modern faunal assemblages and sedimentology.

1.2 LOCATION OF ODP SITES

The twelve drilling sites proposed in Feary et al. (1994) extend from the inner Eucla Shelf, over the outer shelf and upper slope and across the Eyre Terrace, to the upper continental rise in the Recherche Sub-basin (Figs 1, 2; Appendix 4). Drill sites may be shifted slightly on the basis of the site survey results, and alternate sites will be located so that ODP's Pollution Prevention and Safety Panel has site options available when assessing site safety.

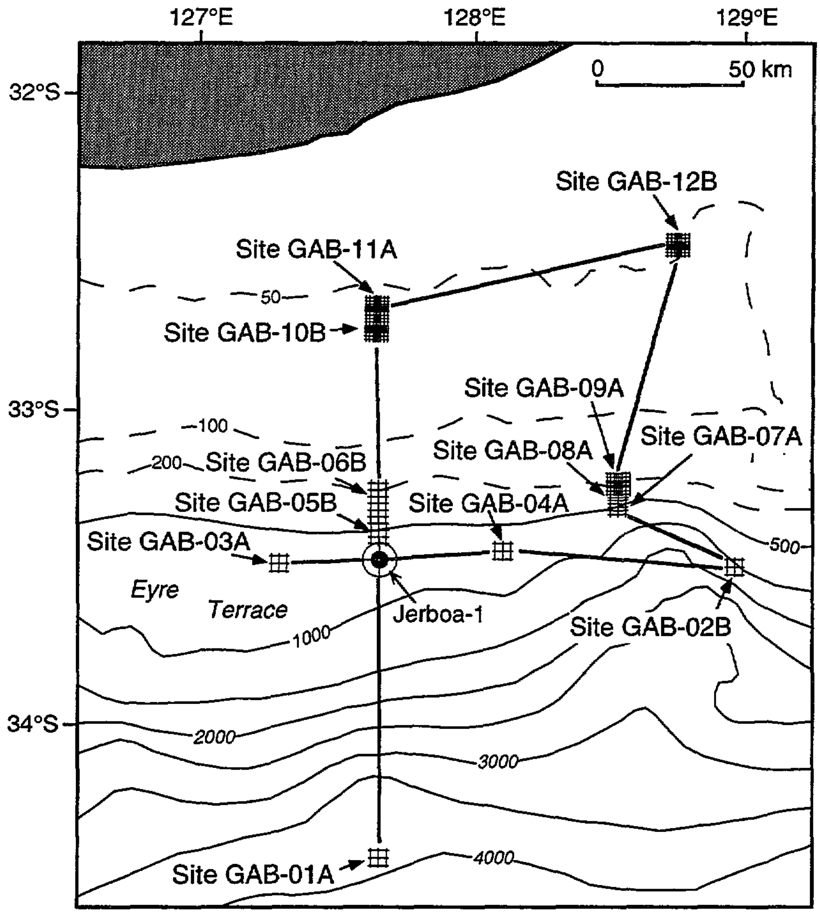

Figure 2. Location of the proposed ODP drill sites in the western Great Australian Bight, together with site survey seismic tracks. Note the higher density of site survey tracklines at the four shallow (<200 m) sites.

1.3 ODP SITE SAFETY REQUIREMENTS

In order to safeguard the on-board personnel, the drilling ship, and the local environment, the Ocean Drilling Program has a stringent set of guidelines to determine whether drilling at any particular site can be carried out with a very high degree of confidence that drilling operations can be safely completed. The stringency of these guidelines is dependant on water depth, with site survey data collection and interpretation for sites in less than 200 m water depth having to conform to very strict Shallow Water Gas Hazards Survey (SWGHS) conditions (these guidelines are presented in Appendix 5). Site surveys in deeper water are not required to be as detailed, but these sites are also carefully examined by the ODP Pollution Prevention and Safety Panel to ensure that there are no pollution or safety risks. Seismic grids collected for site surveys (Appendix 2) will be tied through Jerboa-1 to assist with data calibration.

The ODP shallow water safety guidelines are specifically designed to ensure that relatively thick sedimentary sequences can be safely drilled. In the case of the shallow water sites on the Eucla Shelf, any safety risks are minimised by the thin sedimentary cover (<700 m) over a broad expanse of essentially flat basement, and by the shallow penetration of these drill holes (<550 m).

2. PROPOSED SITE SURVEY PROGRAM

2.1 CRUISE TIMING

A combination of a clearly preferred weather window and environmental constraints dictate that the site survey cruise should be planned for the summer months, between late November and early April, with the optimum period being February-March.

2.1.1 Weather Conditions in the western Great Australian Bight

Weather patterns in the Great Australian Bight are controlled by the position of the band of mid-latitude high pressure systems that pass over Australia from west to east. During the summer months (November to February), these high pressure cells pass directly over southern Australia and the Great Australian Bight, and often a high pressure cell lingers directly over the Bight area. As a result, there are lengthy periods of calm weather in the Great Australian Bight, with wind flow dominantly from the southeast in the mornings and from the continent during the afternoon and evening. Farther south, weak cold fronts between the high pressure cells bring moderate southwesterly winds. During the winter months (May to August), the band of high pressure systems is displaced to the north, and the Great Australian Bight is more influenced by the strong mid-high latitude westerly wind flow, containing embedded strong cold fronts. Wind strength (Fig. 3) and direction (Fig. 4) patterns at Eucla, at the head of the Great Australian Bight, reflect this shift; winds in the summer months have fewer strong winds and gales, and show greater directional variability, compared with the winter months when the area is strongly dominated by southeasterly winds. A wind 'surge' effect ahead of approaching high pressure systems frequently produces higher winds during the early summer, so that the late summer (January to April) is the period with highest probability of calm conditions.

Temperature patterns (Fig. 5) show that Eucla experiences coolest temperatures in July-August, and warmest temperatures in January-February. Rainfall is generally higher in April-September (although only 20-30 mm), and very low between October-March.

2.1.2 Water Conditions in the western Great Australian Bight

Water conditions in the Great Australian Bight are dependant on both local and distant effects. Local winds in the Great Australian Bight and southern Australia area, as described above, produce wave activity that shows a marked fluctuation between the calmer late summer months and the rough winter months. In addition, wave activity generated from far to the south, by storms in the mid-high latitude westerly wind belt (the 'roaring 40's' and 'furious 50's'), impact on the Great Australian Bight. This is particularly the case in winter, when the westerly wind belt is displaced to the north, but is less important in summer. Data from the TOPEX/POSEIDON satellite provides global images of wave height and wind speed every 3.3 days; typical images from February/March 1993 and July/August 1993 illustrate the marked differences in wave activity to be expected in late summer and mid-winter, respectively (Fig. 6).

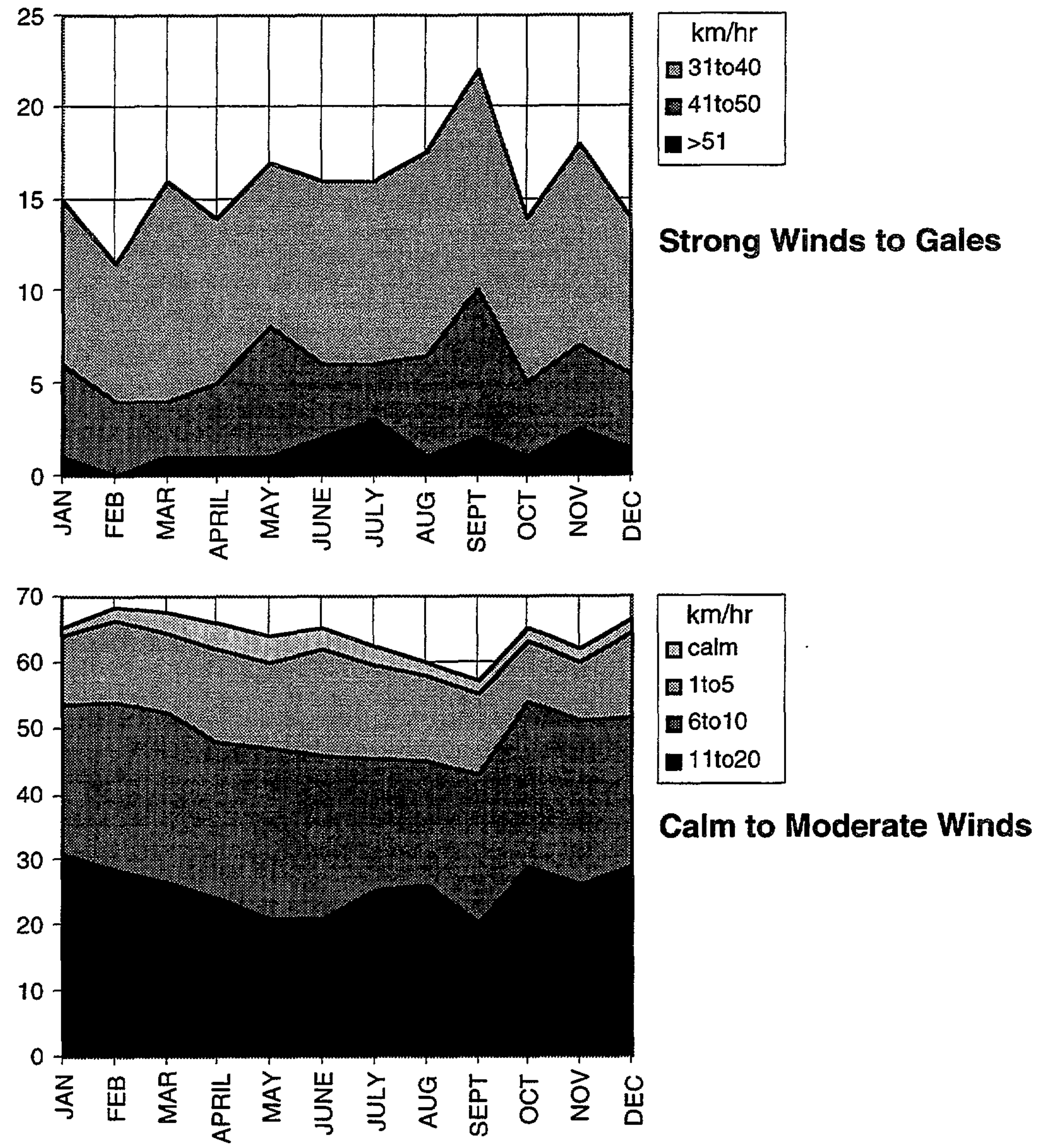

Figure 3. Wind strength data for Eucla, at the head of the Great Australian Bight (see Fig. 1), clearly showing calmer conditions during late summer (January-March). Data displayed are the 35 year average morning (0900 hrs) wind speeds; afternoon data are distorted by off-shore winds that have little effect farther out to sea, at the proposed drill sites.

Current flow in the Great Australian Bight is limited to activity of the Leeuwin Current, a year-round flow of warm, low salinity water southwards along the coast of Western Australia. This flow is strongest in winter, when it is able to flow around Cape Leeuwin and extend eastwards into the Great Australian Bight. However, although the Leeuwin Current flow can be quite strong off the western margin of Australia (up to 1.5 m/sec at Cape Leeuwin), by the time it reaches the central Great Australian Bight it has weakened considerably. It has negligible effect in the central Great Australian Bight during summer.

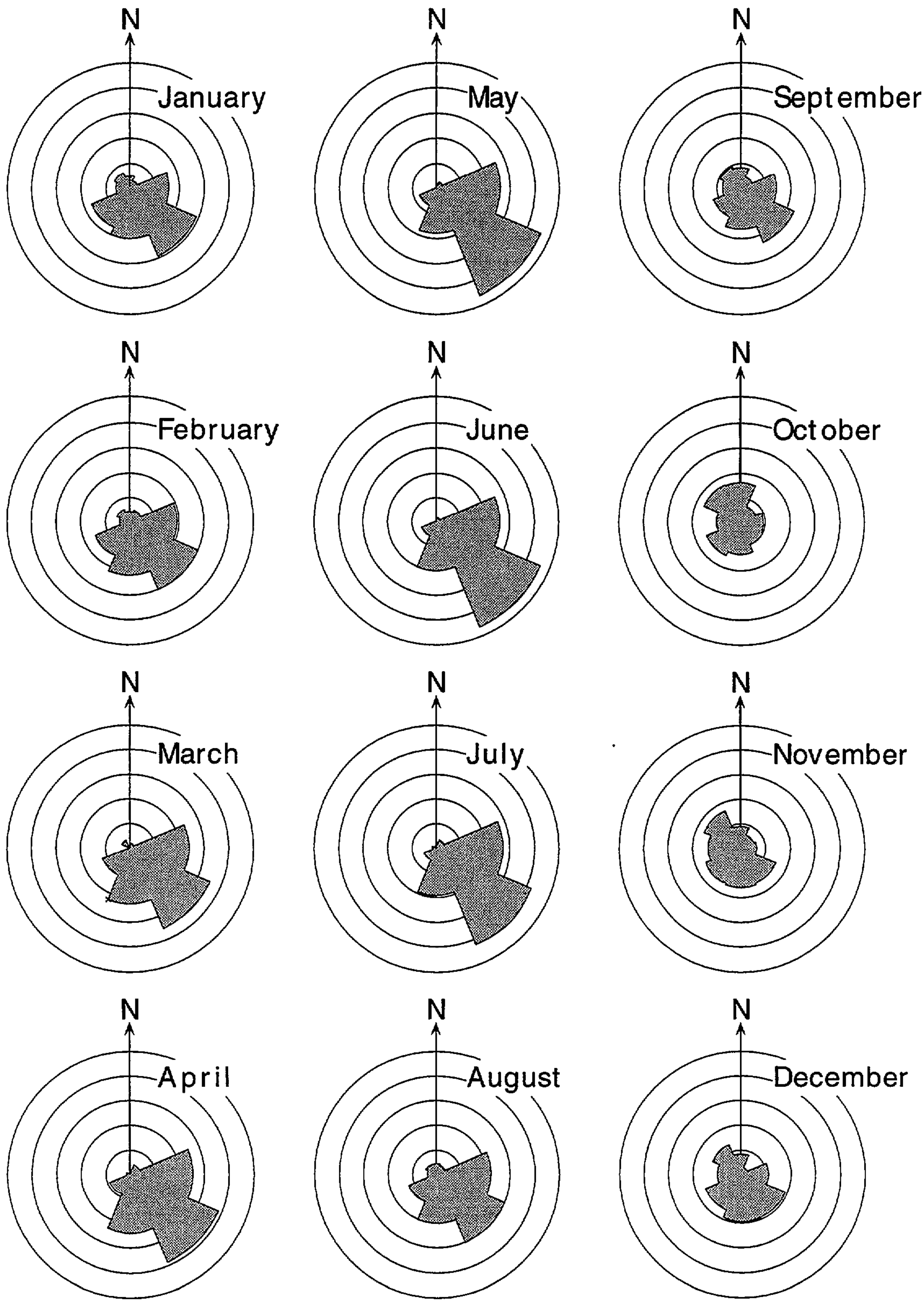

Figure 4. Wind direction rose diagrams for Eucla, at the head of the Great Australian Bight (see Fig. 1). Data displayed are the 35 year average morning (0900 hrs) wind directions for each month; afternoon data are distorted by off-shore winds that have little effect farther out to sea, at the proposed drill sites. Each concentric circle represents 10% of readings.

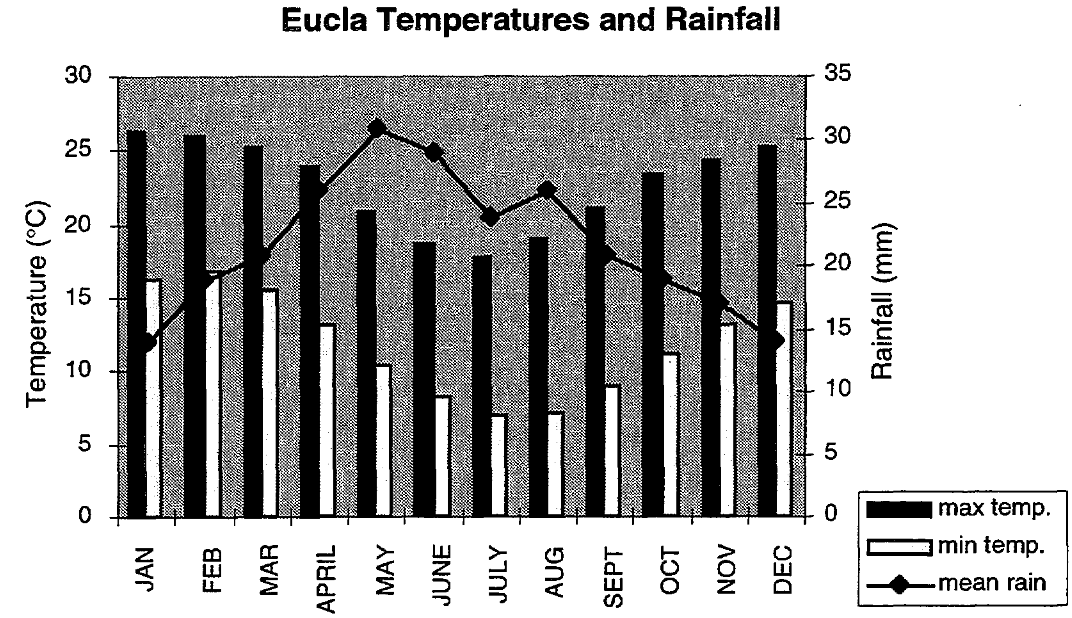

Figure 5. Temperature and rainfall data for Eucla, at the head of the Great Australian Bight (see Fig. 1). Data are 25 year (temperature) and 104 year (rainfall) averages.

2.1.3 Environmental Factors

The Great Australian Bight is a breeding area for Southern Right Whales. The Australian Nature Conservation Agency (ANCA) has advised that the Southern Right Whale breeding season extends from mid-May to mid-October, and that we would be unlikely to gain approval for any work in this area from mid-late April to early-November. ANCA have also indicated that they would appreciate the opportunity to put one or two whale watchers on board *R/V Rig Seismic* during any site survey cruise; once ship scheduling and staffing is completed, we should invite participation by ANCA personnel if space is available.

2.2 SUGGESTED CRUISE PLAN

The tentative cruise plan, based on Fremantle as both departure and arrival port, is shown in detail in Appendix 1. A summary of this cruise plan is as follows:

• transit from Fremantle	3.5 days
• site survey seismic	12.5 days
• coring and photography	4.5 days
• transit to Fremantle	4.0 days
• allowance for poor weather	3.5 days
TOTAL:	28.0 days

The time allowed for poor weather appears low, particularly as the specifications for seismic operations require low noise levels for a streamer towed at 3 m depth. However, it is likely that part of the time allocated for seismic system maintenance will be undertaken during poor weather periods. In addition, if extended poor weather periods are forecast during seismic operations, it may be more efficient to recover the seismic equipment and carry out at least part of the gravity coring component earlier in the cruise than planned.

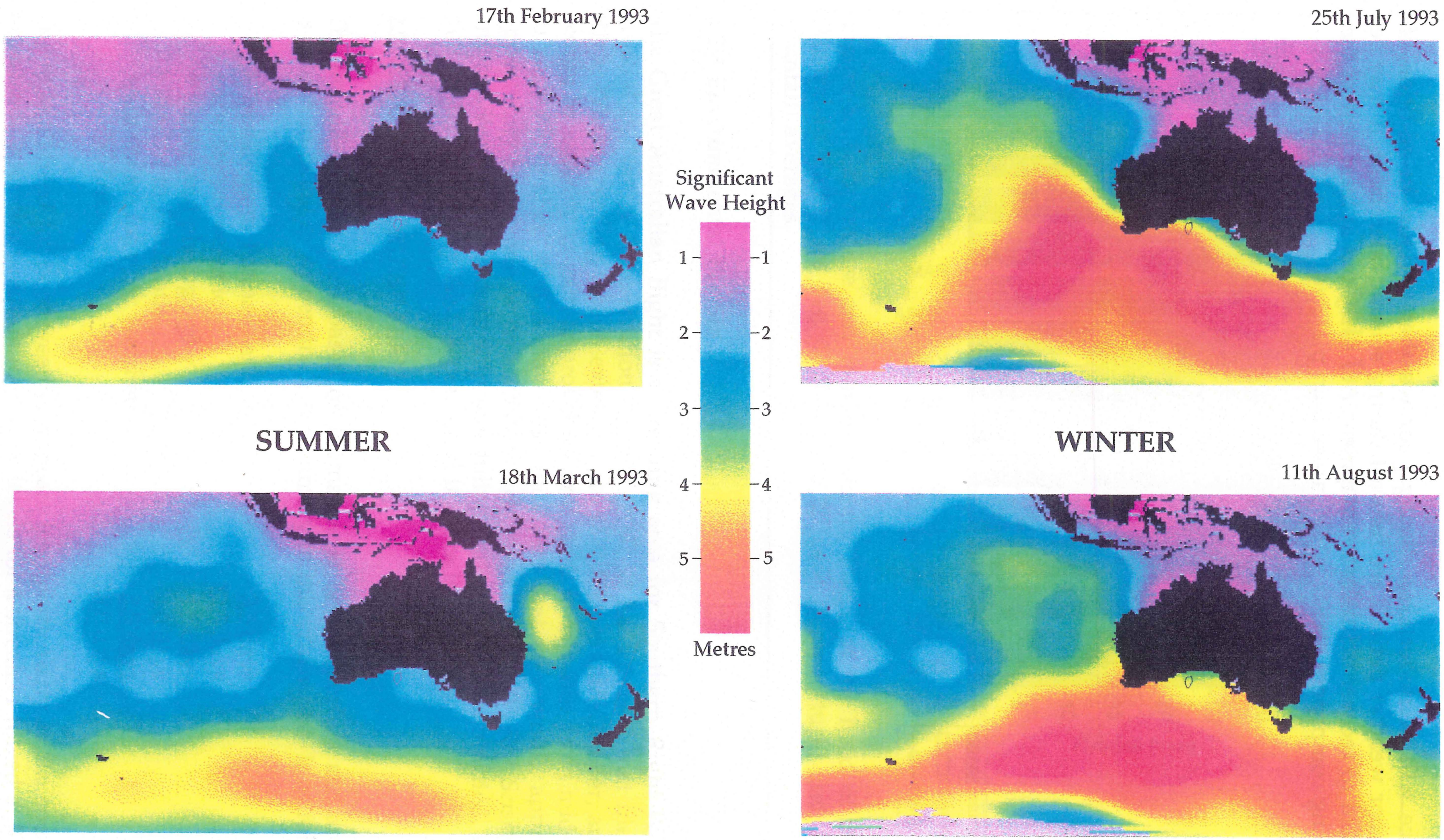

Figure 6. Typical wave height images generated from TOPEX/POSEIDON satellite data. Note the increased wave heights along Australia's southern margin during the winter months (July-September), compared with the lower wave heights during the mid-late summer (January-March).

3. EQUIPMENT REQUIRED

The western Great Australian Bight site survey program will use the AGSO Continental Margins Program vessel *R/V Rig Seismic*, which has the following specifications and equipment:

- 72.5 m overall length, 13.8 m breadth, 6.8 m draft, 1545 gross registered tonnage;
- Norma KVMB-12 main engine, producing 2640 hp at 825 rpm;
- Three Caterpillar 564 hp/482 KVA and one Mercedes 78 hp/56 KVA auxiliary generator engines;
- AVK shaft generator producing 1000 KVA at 440 V / 60 Hz;
- Two forward and one aft 600 hp side thrusters;
- Six A-300 Price compressors, each providing a nominal 300 scfm at 1800 psi.

3.1 SEISMIC PROGRAM

ODP guidelines require grids of short seismic lines over each site, so that a three-dimensional image of reflector geometry can be obtained. In the case of deeper sites (>200 m water depth), these grids are relatively coarse (0.5 nm line spacing). For the shallow sites on the Eucla Shelf (<200 m water depth), ODP site safety requirements dictate that seismic grids are much more dense, with line spacings of 50-100 m. Although the SWGHS guidelines note that lower frequency MCS imaging may be used in conjunction with higher frequency SCS systems (e.g. boomer, sparker), the high-resolution MCS system proposed here, using GI sources, will provide sufficient high frequency data in the upper part of the sediment pile to remove any necessity for an additional SCS system. The 3.5 kHz sub-bottom profiler will be used along all seismic lines, although the likelihood of hard bottom conditions at all shallow sites means that significant sub-bottom penetration is unlikely.

Source configuration required:

- array of 1-3 Seismic Systems Inc GI guns operating in bubble-suppression mode (45/105 in^3 generator/injector chambers);
- minimum phase;
- 1900-2000 psi air pressure, with an out-of-specification limit of 1700 psi;
- nominal peak-to-peak amplitude of 4 bar metres per gun (>3.5 required);
- nominal primary-to-bubble ratio of ≈17:1 (>15:1 required);
- towing depth of 2.5-3 m depth;
- guns synchronised using the AGSO 32-channel gun controller;
- repetition rate of 2.5-3 secs.

Streamer configuration required:

- 160 channel Fjord Instruments (GECO) charge-coupled streamer, with hydrophones in 6.25 m groups (1000 m active);
- sensitivity of 45 mV per microbar;
- DigiCourse 5010-digiBird depth controllers at 100 m spacing, with three 5011-digiCompass combined depth controllers/directional indicators at the front, middle, and back of the streamer;
- offset of 50-70 m;

• streamer depth of 2.5±1.0 m (although poor weather may dictate towing at 3 m);

• dual Magnavox MX-100 GPS navigators to provide seismic cable tailbuoy position.

Acquisition system parameters are:

• AGSO seismic acquisition system running on a DEC MicroVAX 4200;

• recorded on industry-standard IBM-compatible 3480 cartridge tapes in demultiplexed SEG-Y modified 16-bit floating point format;

• 1.0 millisecond sampling;

• 1.5 second records;

• computer-controlled elliptic filters, set at 24 Hz low cut and 360 Hz high cut;

• shot interval of 6.25 m;

• broadside noise levels of up to 8 microbars RMS with bursts of up to 20 microbars RMS (may be relaxed on near traces and near depth controllers); in-line interference may be slightly in excess of 25 microbars RMS (AGSO field tests of noise levels with the streamer at 5 m depth indicate that these requirements can probably be met; further field tests with the streamer at 3 m depth are planned for September, 1995);

• quality control monitoring as specified in the SWGHS guidelines (noise tests, oscillator tests), at the start and end of each site survey and start and end of each site tie-line.

Sonobuoy system parameters are:

• Reftek and Yaesu sonobuoy receivers;

• sonobuoys (at present, AGSO sonobuoy stocks are exhausted; this component of the program will be dependant on obtaining 4 sonobuoys).

3.2 NAVIGATION AND NON-SEISMIC GEOPHYSICS SYSTEMS

• Skyfix differential GPS primary navigation system;

• Skyfix differential GPS secondary navigation system;

• Magnavox MX-610D and Raytheon DSN-450 dual axis sonar dopplers combined with 2 Sperry Mark-37 survey gyro-compasses as tertiary navigation system;

• navigation accuracy greater than 10 m;

• continuous operation of 3.5 kHz (2 KW), 16 transducer sub-bottom profiler and 12 kHz (2 KW) echosounder with correlator;

• operation of Geometrics G801 magnetometer during transit and along seismic lines;

• continuous operation of Bodenseewerk Geosystem KSS-31 marine gravity meter, with gravity ties at beginning and end of program.

3.3 SEAFLOOR SAMPLING PROGRAM

It will be necessary to collect core samples at each site in order to describe the top few metres of the sediment pile, so that requirements for drill casing or a re-entry cone may be evaluated by ODP Operations.

3.3.1 Gravity Coring

The muddy substrates expected in water depths greater than 200 m will be best sampled by gravity coring. It is likely that coring operations will take place when weather conditions are too poor for seismic acquisition, so it is unrealistic to plan for piston coring. The gravity coring configuration will be a 1-tonne weight and core barrels of 6, 8, 10, and 12 metres.

3.3.2 Vibra-coring

On the shallow Eucla Shelf sites (in water depths less than 200 m), previous work (Feary, et al., 1993; James et al., 1994) shows that substrates will probably be either hard carbonate pavement, or a thin cover of carbonate sand overlying a hard carbonate pavement. In order to recover cores at these sites, it will be necessary to use a vibra-corer with 3 m and 5 m towers, deployed from a JADEM winch with a 3-phase power cable.

3.4 SEAFLOOR IMAGING PROGRAM

3.4.1 Sidescan Sonar

Although sidescan sonar surveys are listed as a necessary component of shallow water (<200 m water depth) site surveys in the SWGHS guidelines, it is highly unlikely that sidescan sonar images would achieve the aims set out in the SWGHS document (see section 3.5 below). Nevertheless, the equipment characteristics of the AGSO sidescan sonar, which could easily be deployed if the ODP Science Operator insists that such surveys be carried out, are as follows:

- EG&G-990 digital dual-channel sidescan sonar with on-board digital modem and 650 m of coaxial towing wire;
- 70 kHz operating frequency;
- beamwidth - 1.2° horizontal, 40° vertical;
- beam depression - 30° below horizontal;
- data stored in SEG-Y format on 9-track/DAT tapes.

3.4.2 Seafloor Photography

The AGSO seafloor photography rig will be used to obtain multiple black and white still photographs at each site. More extensive photographic surveys will be carried out at the shallow water sites (<200 m water depth), in order to partially achieve the results otherwise sought with sidescan sonar surveys. The photographic rig configuration will be:

- Benthos-372 underwater camera, with exposure set to f5.6, using Kodak TMax 100 film configured to 400 ASA;
- Benthos-382 flash unit, producing 100 wattseconds flash;
- Benthos bottom contact trigger switch;
- Benthos-2216 12 kHz pinger.

3.5 ADHERENCE TO SWGHS GUIDELINES

In most areas, the AGSO facilities meet or exceed ODP's SWGHS specifications.

However, there are some areas where we request a slight relaxation or modification of these guidelines:

• we suggest a 1.0 millisecond seismic sampling period instead of 0.5 millisecond; using a 1.0 ms period we would be able to obtain higher fold data (80 channel rather than 40 channel), and since the 2.5-3 m cable and streamer depths imply a ghost notch at 300 Hz, an AGSO elliptic anti-alias filter setting of 360 Hz for 1 ms sampling seems appropriate (instead of the recommended 512 Hz);

• quality control plots on-board *R/V Rig Seismic* are provided by high-speed printers, rather than an oscillograph camera;

• we have found that a 50-70 m offset between the centre of the source array and the centre of the near group is the optimum for shallow water recording;

• the weather conditions may require some relaxation of the stipulated streamer noise limits, particularly as the streamer will be at only 2.5-3 m depth; however, we are confident that the results obtained will be the best that can possibly be obtained in such an open ocean setting;

• the AGSO seismic acquisition system has an AC gain step accuracy of better than 0.05% (typically 0.025%, as required);

• compressors are normally run at 1800±200 psi, with the out-of-specification limit at 1600 psi; for this cruise we would require a range of 1900-2000 psi, with an out-of-specification limit of 1700 psi;

• the moderate to poor weather conditions that are normally encountered in the Great Australian Bight (see section 2.1.1 above) make it unrealistic to plan for lines with very shallow (1 m) source and streamer depths;

The only area of major departure from the SWGHS guidelines is the omission of a sidescan sonar component from the site surveys. There is significant and consistent evidence that the seafloor on the western Eucla continental shelf is either a hard limestone pavement, or a thin veneer of relatively coarse sand and rhodolites overlying hard limestone (Feary et al., 1993; James et al., 1994; Y. Bone, pers. comm., 1995). It is almost impossible that this type of surface would display the small-scale seafloor features associated with gas escape from finer grained, muddy sediments (Judd and Hovland, 1992), and which the sidescan sonar surveys required by the SWGHS guidelines are designed to detect. Accordingly, this component has been omitted, with extensive black and white still photography transects over the shallow water sites planned instead.

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5. ACKNOWLEDGEMENT

Permission of JOIDES to reproduce the "Guidelines for Shallow Water Hazards Surveys", prepared by the JOIDES Shallow Water Drilling Working Group (Chair: Mahlon Ball), is gratefully acknowledged.

APPENDIX 1: DETAILED CRUISE PLAN AND TIMING

The following cruise plan and time estimates are based on the vessel departing from and returning to Fremantle. It is likely that poor weather conditions will cause some changes to this plan, e.g., if a period of prolonged poor weather is forecast early in the cruise, it may be more efficient to recover the seismic equipment and sample at the gravity coring sites. The position indicators A to P are shown on the site survey seismic grids presented in Appendix 2.

* transit Fremantle to position A (795.0 nm @ 9.5 kt)	84 hrs
• deploy seismic streamer and source	12 hrs
• seismic site survey GAB-03A (54.4 nm @ 5 kt) (includes 6 hrs system maintenance)	17 hrs
• tie-line from position B to Jerboa-1 (15.5 nm @ 5 kt) (sonobuoy in the vicinity of Jerboa-1)	3 hrs
• tie-line from Jerboa-1 to position C (20.5 nm @ 5 kt)	4 hrs
• seismic site survey GAB-04A (50.3 nm @ 5 kt) (includes 6 hrs system maintenance)	16 hrs
• tie-line from position D to position E (39 nm @ 5 kt)	8 hrs
• seismic site survey GAB-02B (56.3 nm @ 5 kt) (includes 6 hrs system maintenance)	17 hrs
• tie-line from position F to position G (20.7 nm @ 5 kt) (sonobuoy on tie-line)	4 hrs
• seismic site surveys GAB-07A to GAB-09A (170.5 nm @ 5 kt) (includes 12 hrs system maintenance)	46 hrs
• tie-line from position H to position I (40.5 nm @ 5 kt)	8 hrs
• seismic site survey GAB-12B (103.0 nm @ 5 kt) (includes 10 hrs system maintenance)	31 hrs
• tie-line from position J to position K (52.4 nm @ 5 kt) (sonobuoy on tie-line)	11 hrs
• seismic site surveys GAB-10B to GAB-11A (196.6 nm @ 5 kt) (includes 12 hrs system maintenance)	52 hrs
• tie-line from position L to position M (25.6 nm @ 5 kt)	5 hrs
• seismic site surveys GAB-5B to GAB-6B (124.7 nm @ 5 kt) (includes 8 hrs system maintenance)	33 hrs
• tie-line from position N to Jerboa-1 (2.7 nm @ 5 kt)	1 hrs
• tie-line from Jerboa-1 to position O (50.7 nm @ 5 kt) (sonobuoy on tie-line close to GAB-01A)	10 hrs
• seismic site survey GAB-01A (62.5 nm @ 5 kt) (includes 4 hrs system maintenance)	17 hrs
• recover seismic streamer and prepare for sampling	5 hrs
• gravity core and still photography at GAB-01A	8 hrs
• transit to GAB-03A (55.5 nm @ 9.5 kt)	6 hrs
• gravity core and still photography at GAB-03A	7 hrs
• transit to GAB-05B and GAB-06B (18.6 nm @ 9.5 kt)	2 hrs
• gravity core and still photography at GAB-05B and GAB-06B	10 hrs
• transit to GAB-04A (24.8 nm @ 9.5 kt)	3 hrs
• gravity core and still photography at GAB-04A	7 hrs
• transit to GAB-02B (42.8 nm @ 9.5 kt)	5 hrs
• gravity core and still photography at GAB-02B	7 hrs

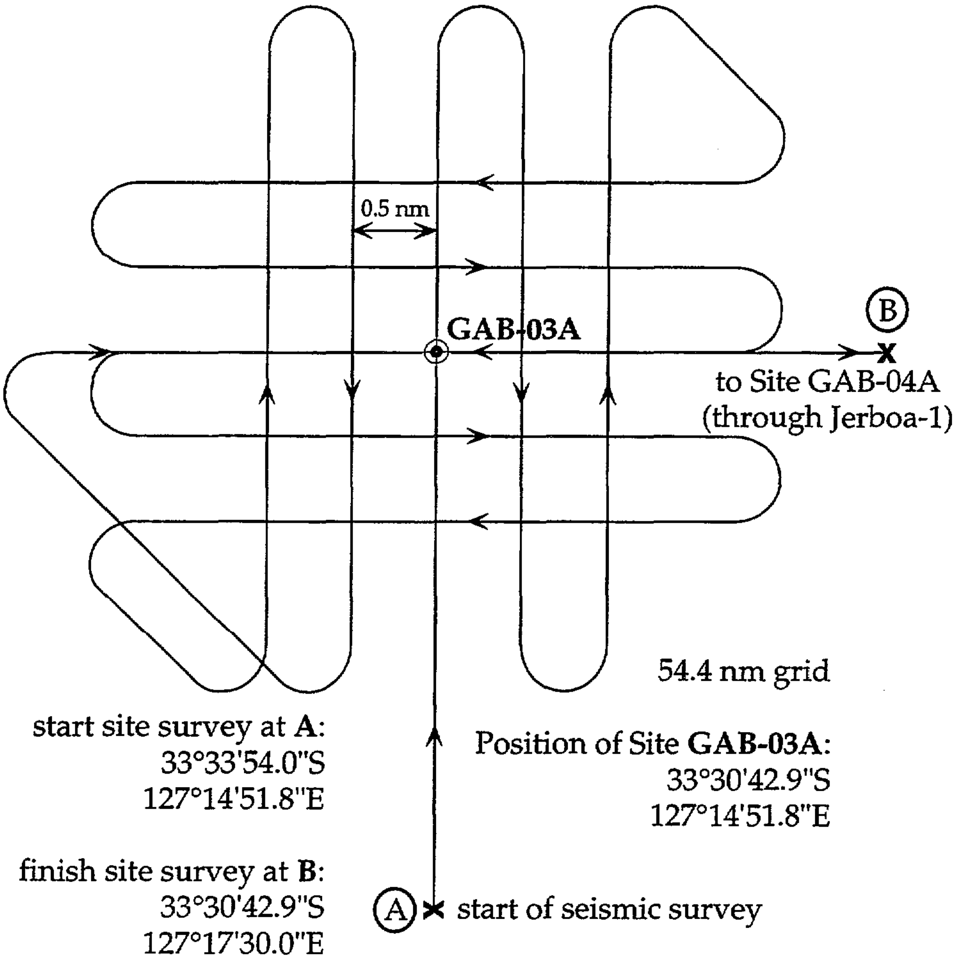
• transit to GAB-07A (24.0 nm @ 9.5 kt)	3 hrs
• gravity core and still photography at GAB-07A to GAB-09A	18 hrs
• transit to GAB-12B (44.8 nm @ 9.5 kt)	5 hrs
• vibra-core and still photography at GAB-12B	10 hrs
• transit to GAB-10B (56.2 nm @ 9.5 kt)	6 hrs
• vibra-core and still photography at GAB-10B and GAB-11A	16 hrs
* transit to Fremantle (830 nm @ 9 kt)	92 hrs

Total of 589 hrs (24.5 days)

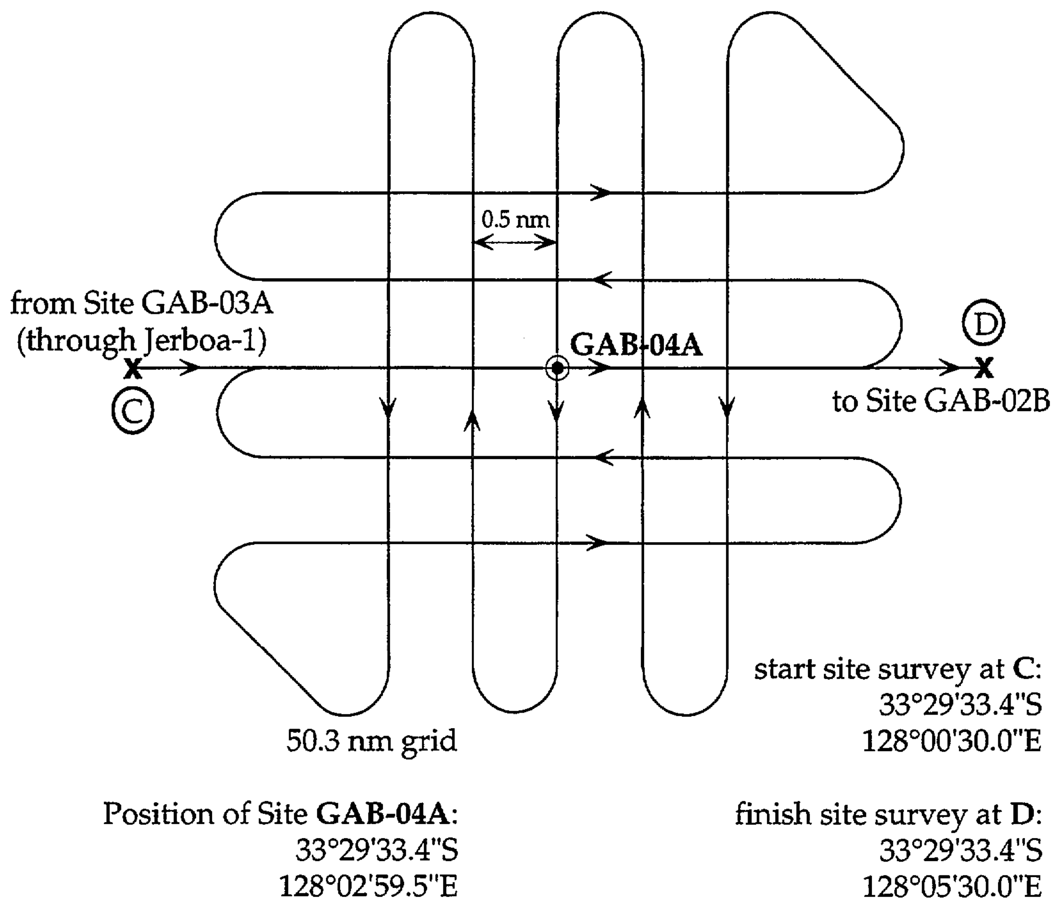
APPENDIX 2: SEISMIC SURVEY GRIDS

The following plans for the site survey seismic grids are presented in the proposed order that they will be recorded:

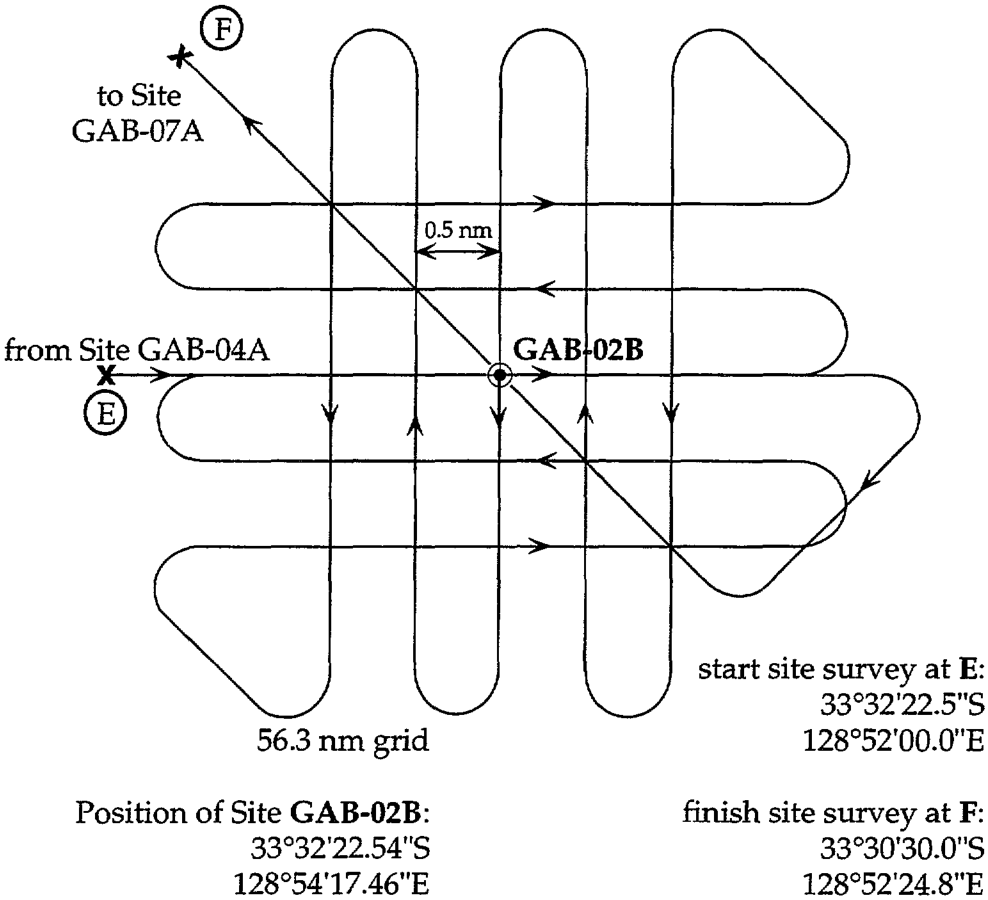
GAB-03A ⇨ GAB-04A ⇨ GAB-02B ⇨ GAB-07A / GAB-08A / GAB-09A ⇨ GAB-12B ⇨ GAB-11A / GAB-10B ⇨ GAB-06B / GAB-05B ⇨ GAB-01A



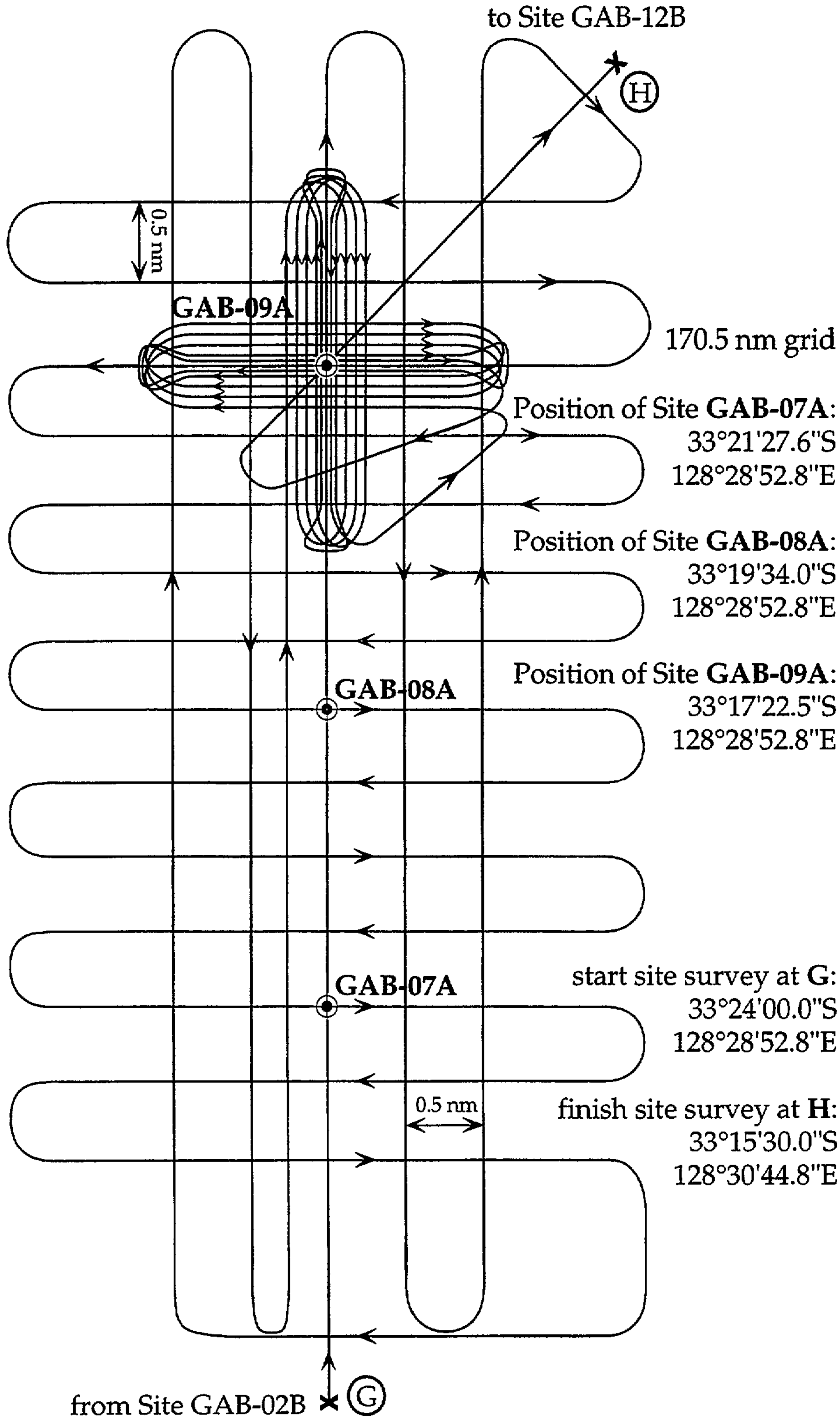
PROPOSED SITE SURVEY TRACK MAP FOR SITE GAB-03A



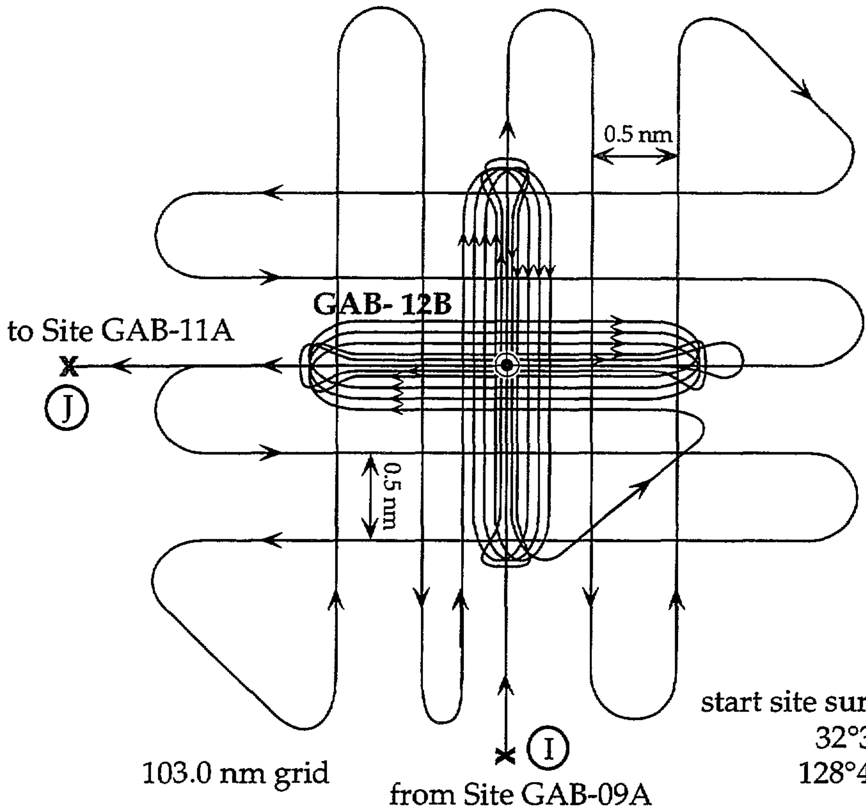
PROPOSED SITE SURVEY TRACK MAP FOR SITE GAB-04A



PROPOSED SITE SURVEY TRACK MAP FOR SITE GAB-02B



PROPOSED SITE SURVEY TRACK MAP FOR SITES GAB-07A TO GAB-09A



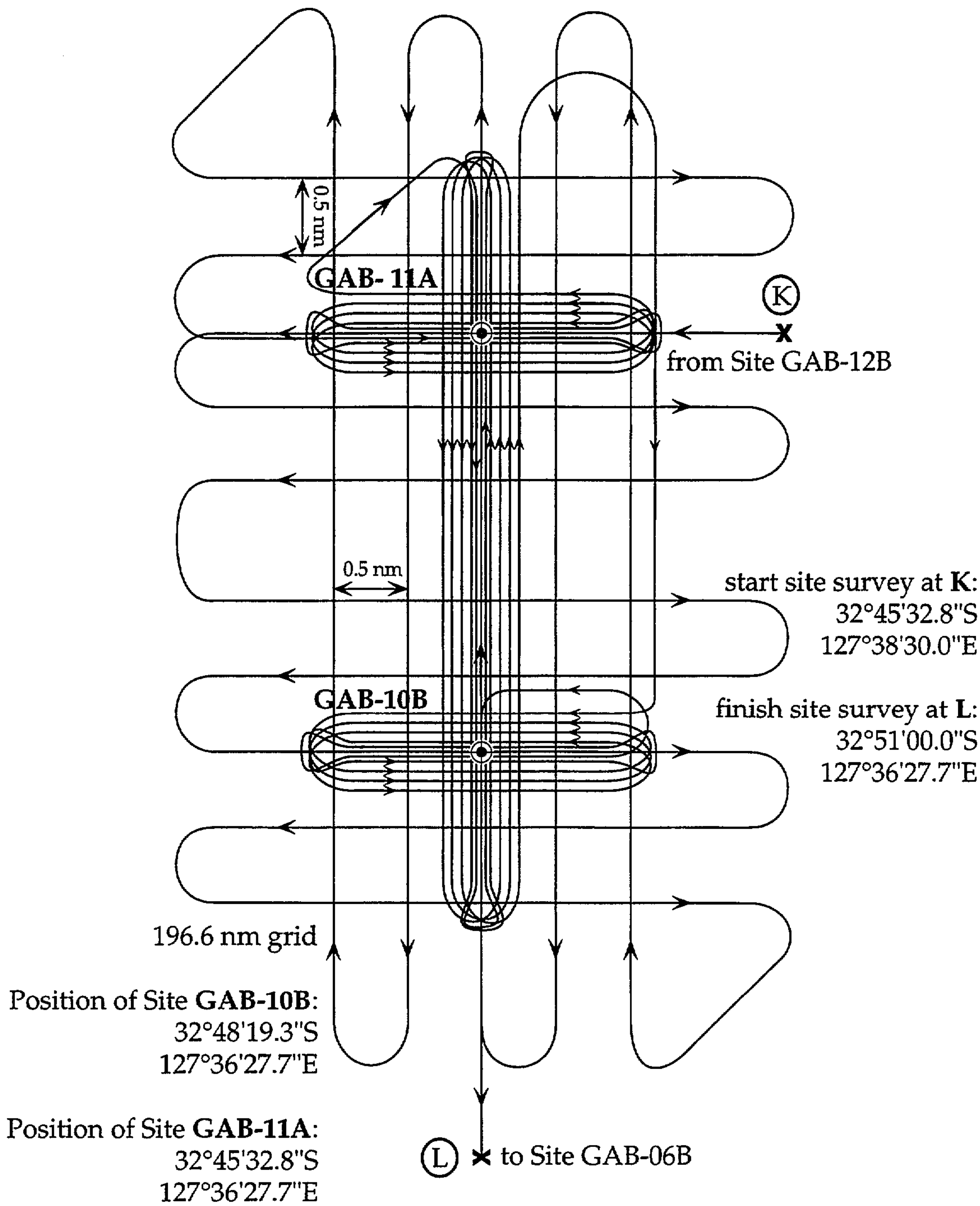
103.0 nm grid

Position of Site **GAB-12B**:
32°33'41.3"S
128°41'33.6"E

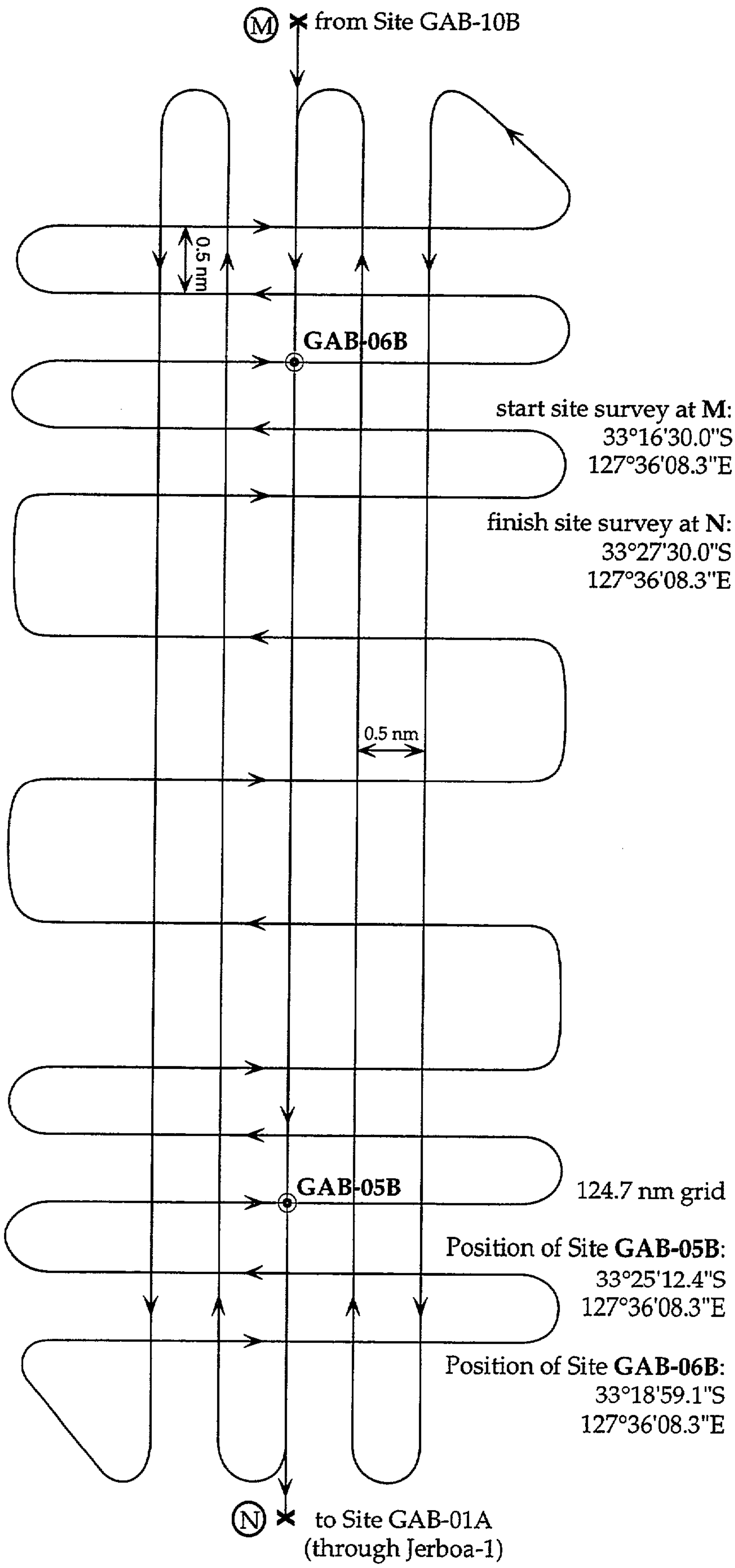
start site survey at **I**:
32°36'00.0"S
128°41'33.6"E

finish site survey at **J**:
32°33'41.3"S
128°39'00.0"E

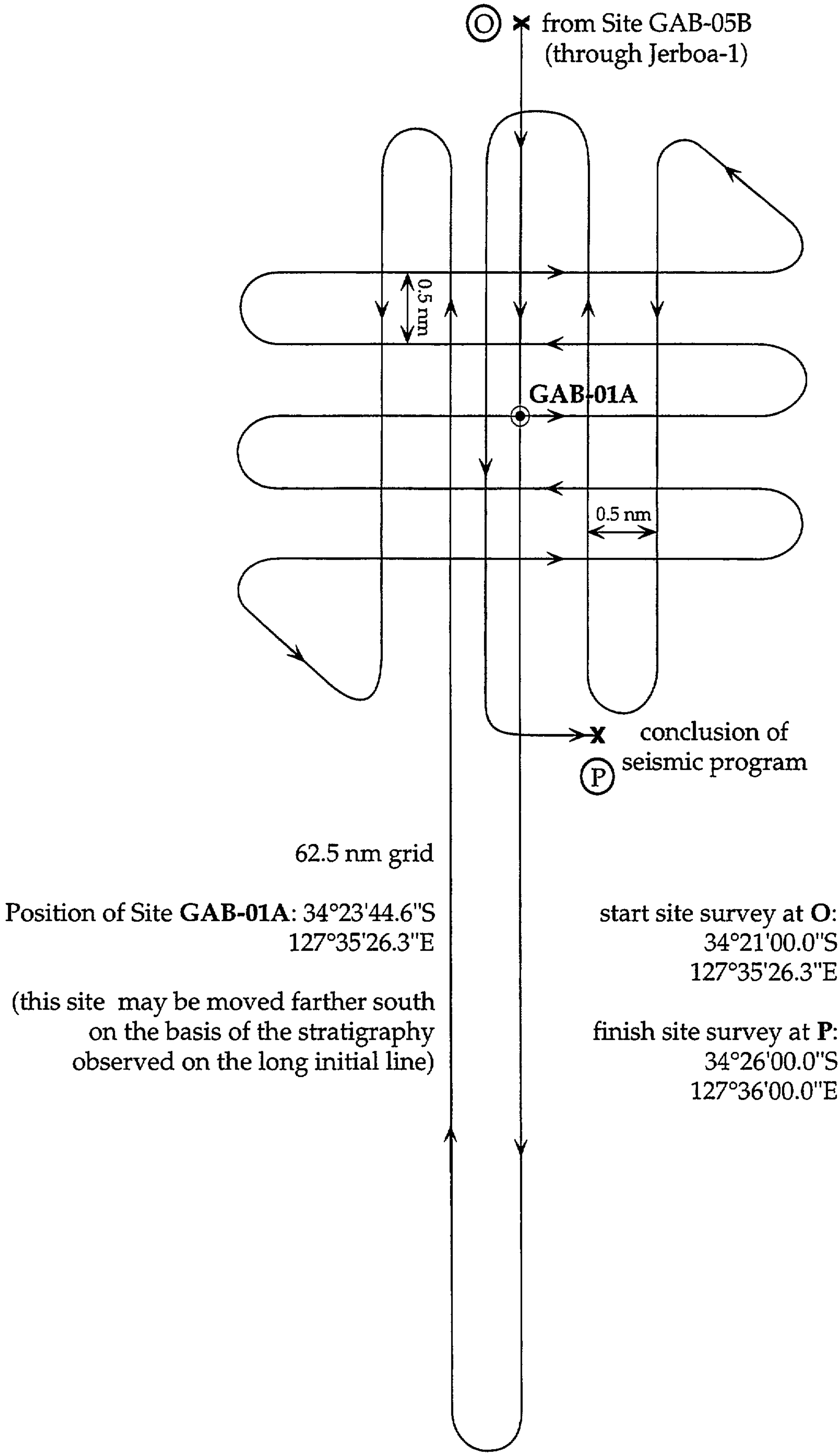
PROPOSED SITE SURVEY TRACK MAP FOR SITE GAB-12B



Proposed site survey track map for sites GAB-10B and GAB-11A



PROPOSED SITE SURVEY TRACK MAP FOR SITES GAB-05B AND GAB-06B



PROPOSED SITE SURVEY TRACK MAP FOR SITE GAB-01A

APPENDIX 3: SEAFLOOR SAMPLING AND PHOTOGRAPHY SITES

Gravity coring sites and short seafloor photography traverses:

Site GAB-01A*	34°23'44.6"S	127°35'26.3"E	3860 m wd
Site GAB-02B	33°32'22.5"S	128°54'17.5"E	1039 m wd
Site GAB-03A	33°30'42.9"S	127°14'51.8"E	680 m wd
Site GAB-04A	33°29'33.4"S	128°02'59.5"E	750 m wd
Site GAB-05B	33°25'12.4"S	127°36'08.3"E	482 m wd
Site GAB-06B**	33°18'59.1"S	127°36'08.3"E	214 m wd
Site GAB-07A	33°21'27.6"S	128°28'52.8"E	469 m wd
Site GAB-08A	33°19'34.0"S	128°28'52.8"E	315 m wd

Vibra-coring sites and extensive seafloor photography traverses:

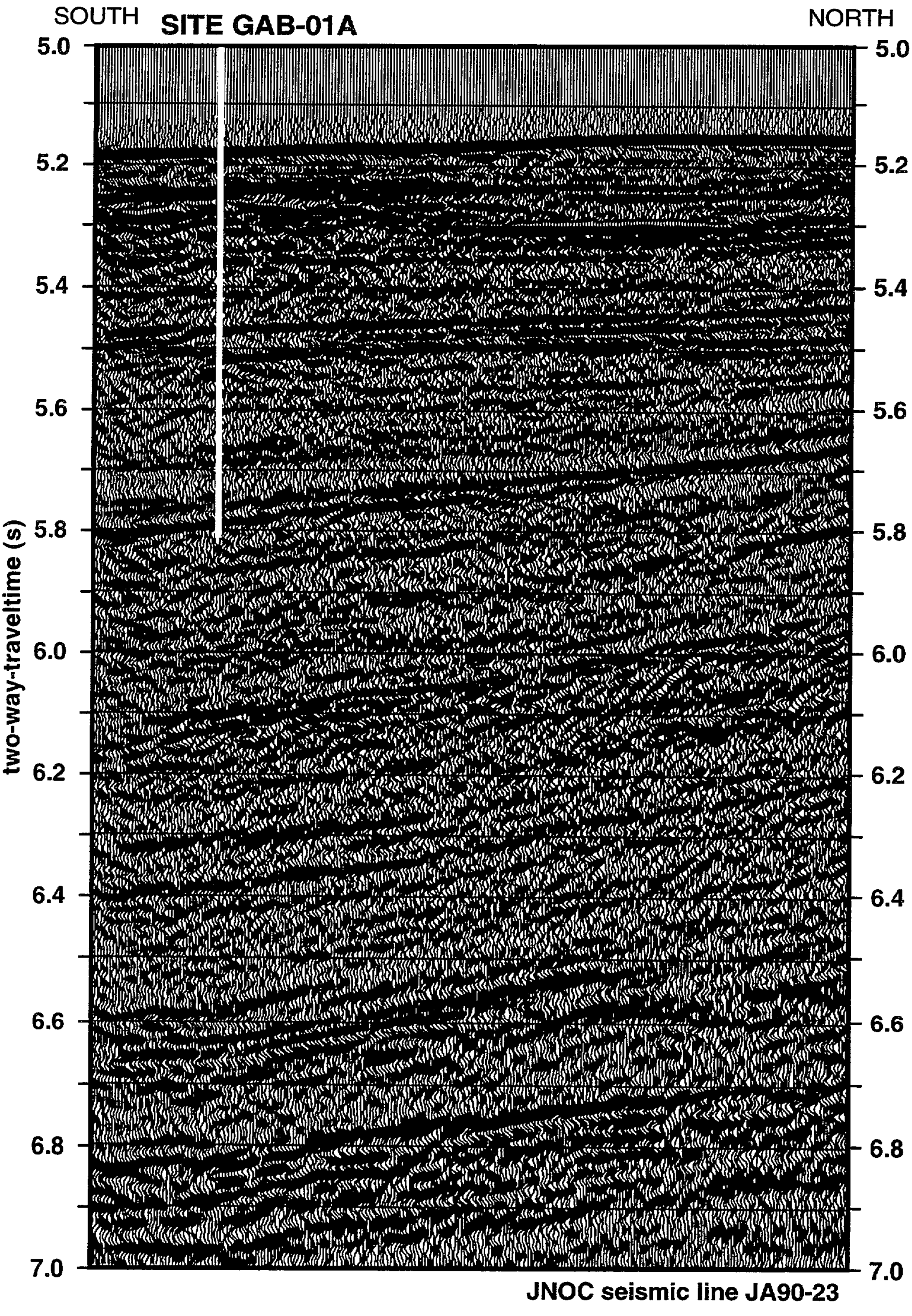
Site GAB-09A	33°17'22.5"S	128°28'52.8"E	196 m wd
Site GAB-10B	32°48'19.3"S	127°36'27.7"E	52 m wd
Site GAB-11A	32°45'32.8"S	127°36'27.7"E	51 m wd
Site GAB-12B	32°33'41.3"S	128°41'33.6"E	50 m wd

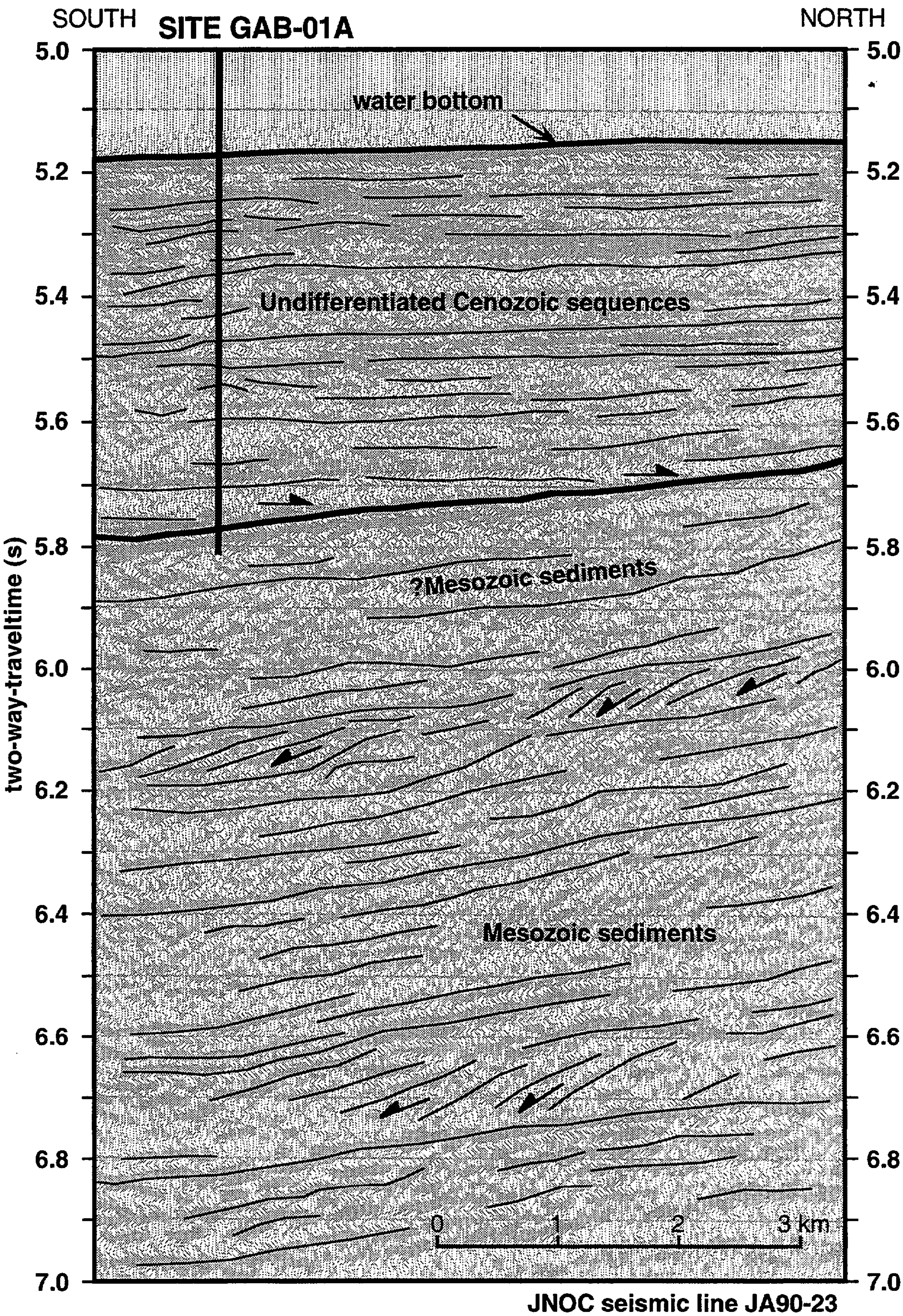
* Site GAB-01A may be relocated on the basis of the extensive site survey planned in this vicinity.

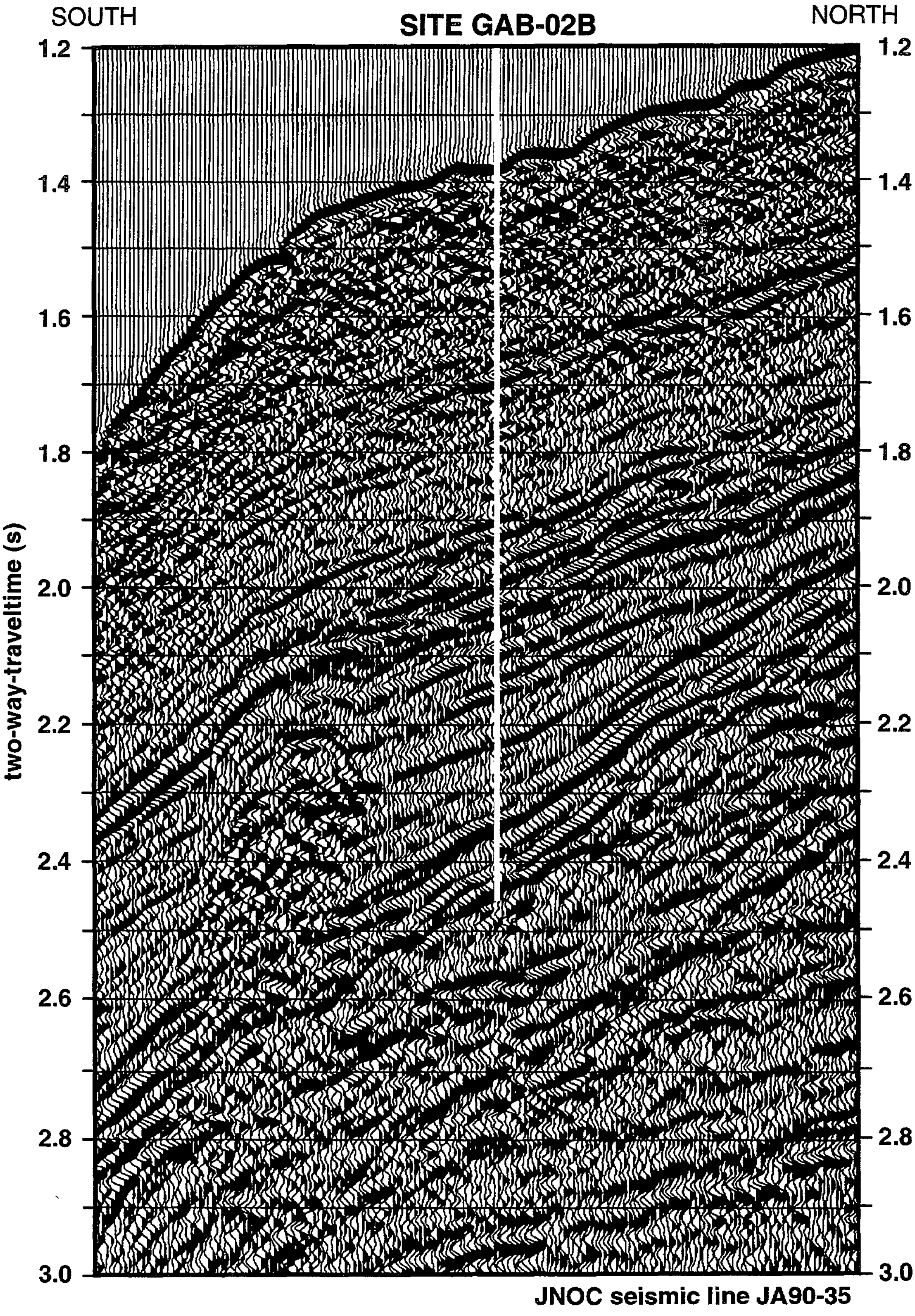
** Poor gravity core recovery at site GAB-06B may necessitate use of the vibra-corer.

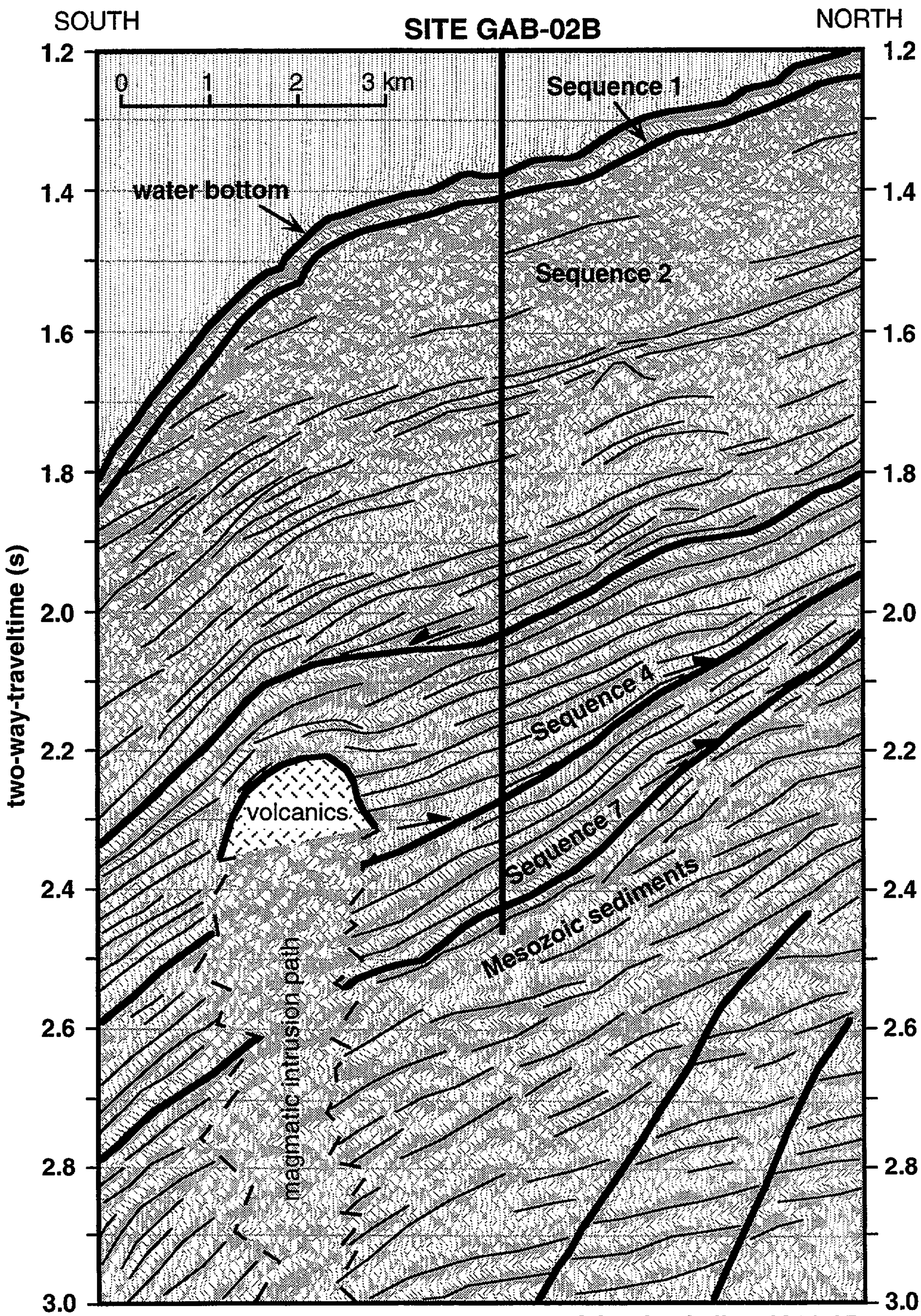
APPENDIX 4: SEISMIC IMAGES OF ODP SITES

The sites proposed for drilling by ODP in the western Great Australian Bight (Feary et al., 1994) were based on detailed seismic stratigraphic analysis of some 5,300 km of high quality airgun seismic data acquired for the Japan National Oil Corporation (JNOC) in 1990. This data was supplemented by older (1979-vintage), moderate-quality airgun seismic collected for Esso Australia Ltd, but reprocessed by JNOC in 1990, and by moderate-quality airgun data collected by AGSO in 1986. The following images showing the projected drill sites, together with seismic stratigraphic interpretations, are from the JNOC (1990) dataset.

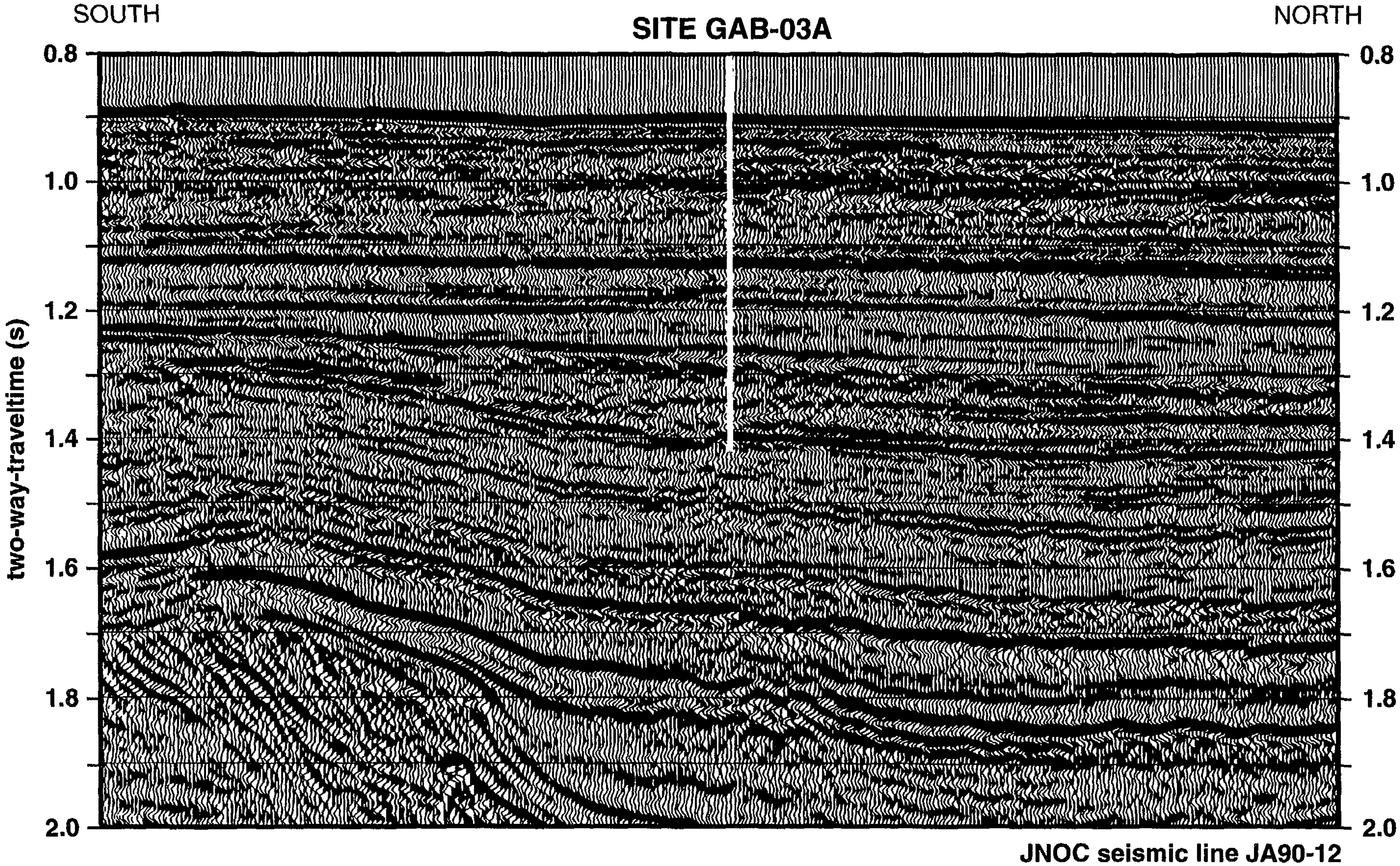

SOUTH
SITE GAB-01A
NORTH
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
two-way-traveltime (s)
JNOC seismic line JA90-23

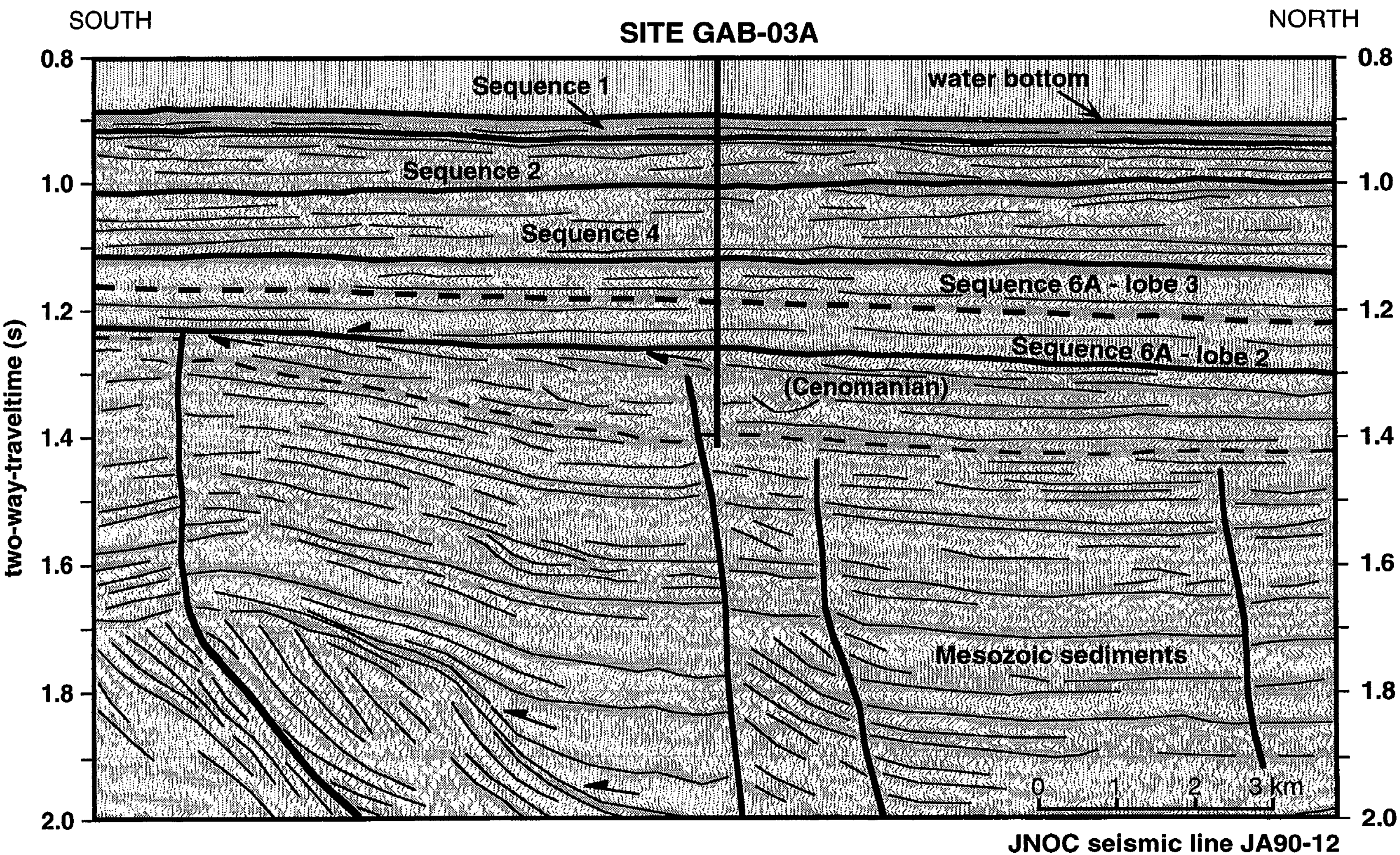

SOUTH
SITE GAB-01A
NORTH
water bottom
Undifferentiated Cenozoic sequences
?Mesozoic sediments
Mesozoic sediments
two-way-traveltime (s)
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
0
1
2
3 km
JNOC seismic line JA90-23

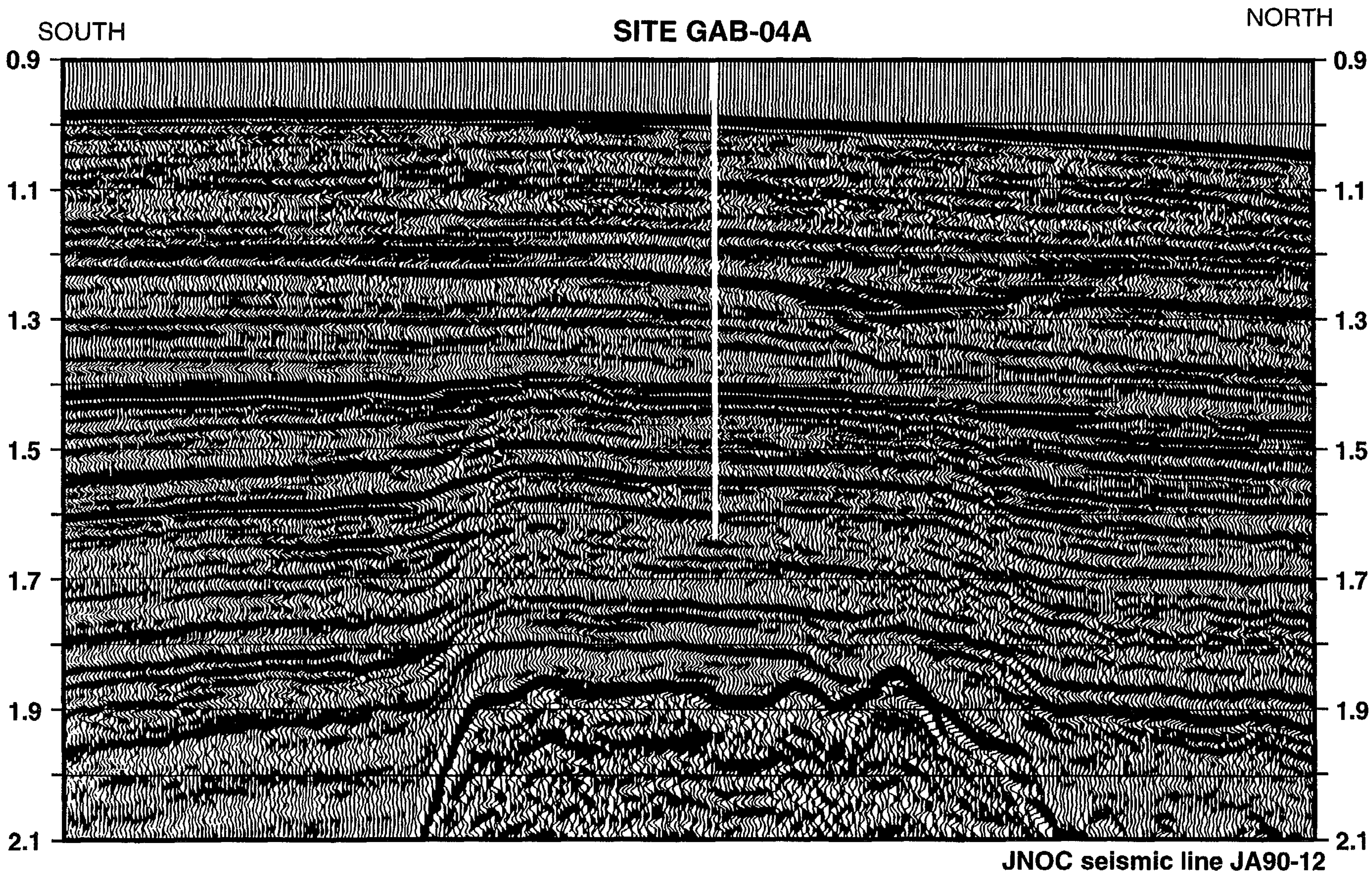

SOUTH
SITE GAB-02B
NORTH
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
two-way-traveltime (s)
JNOC seismic line JA90-35

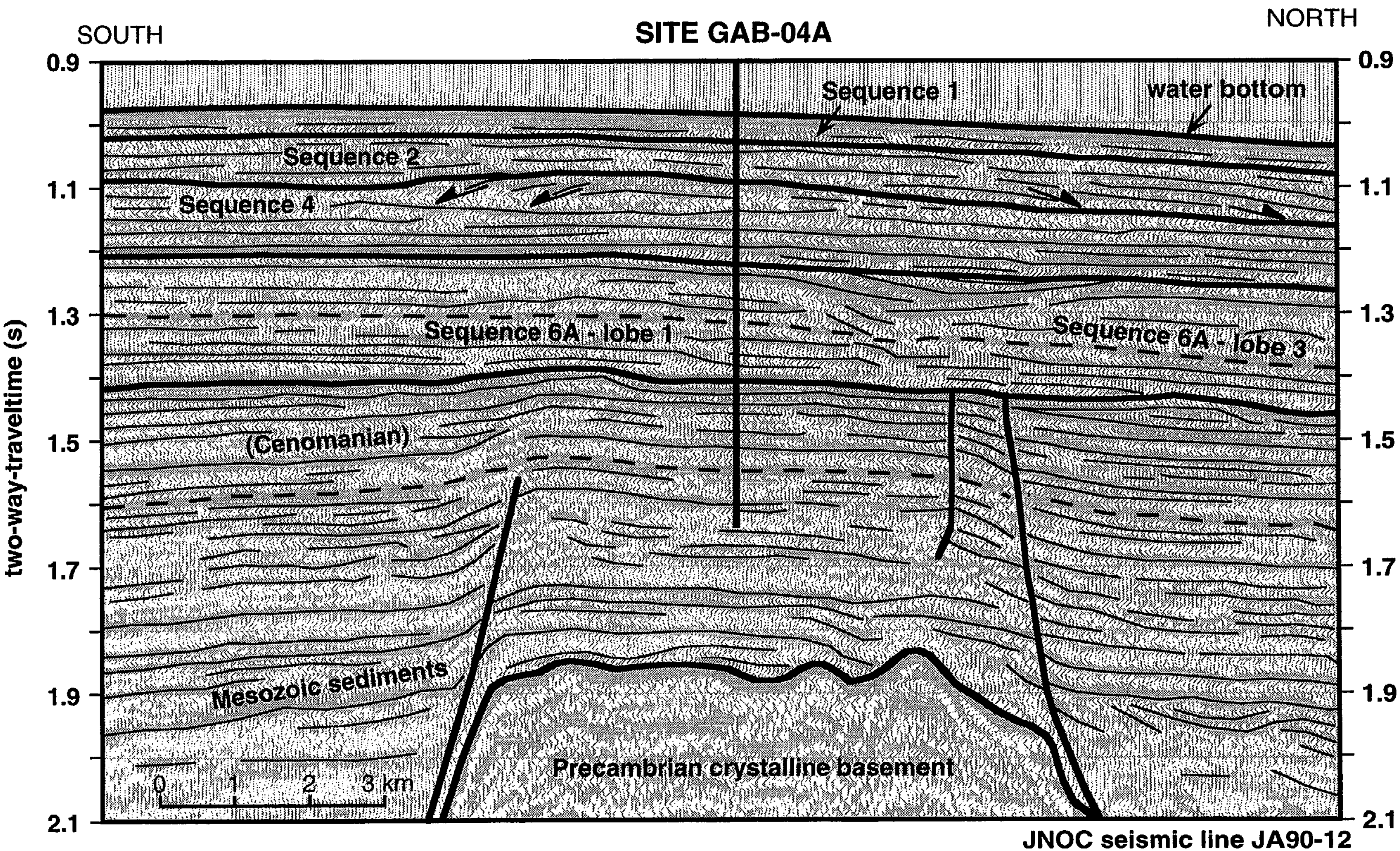


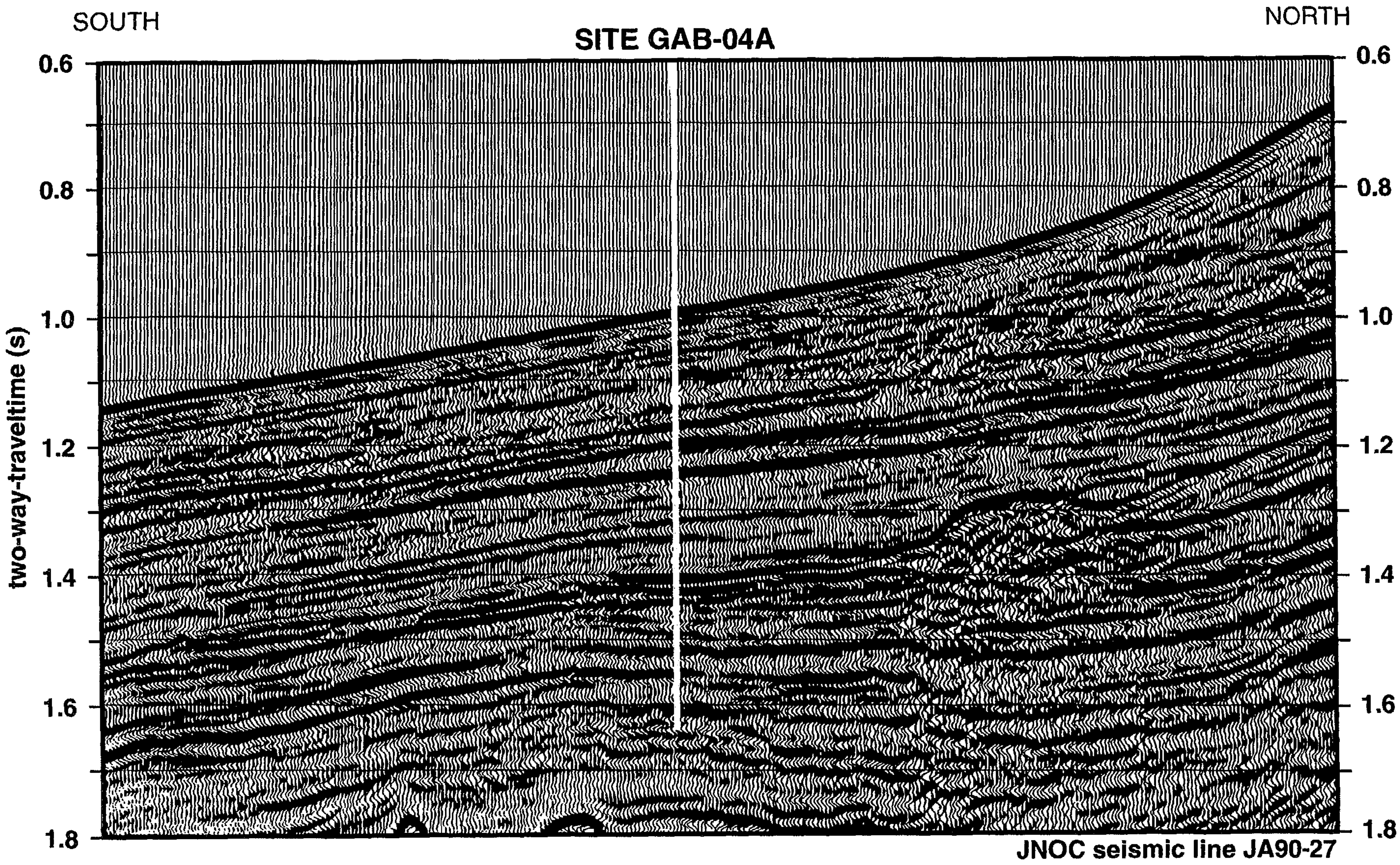
JNOC seismic line JA90-35

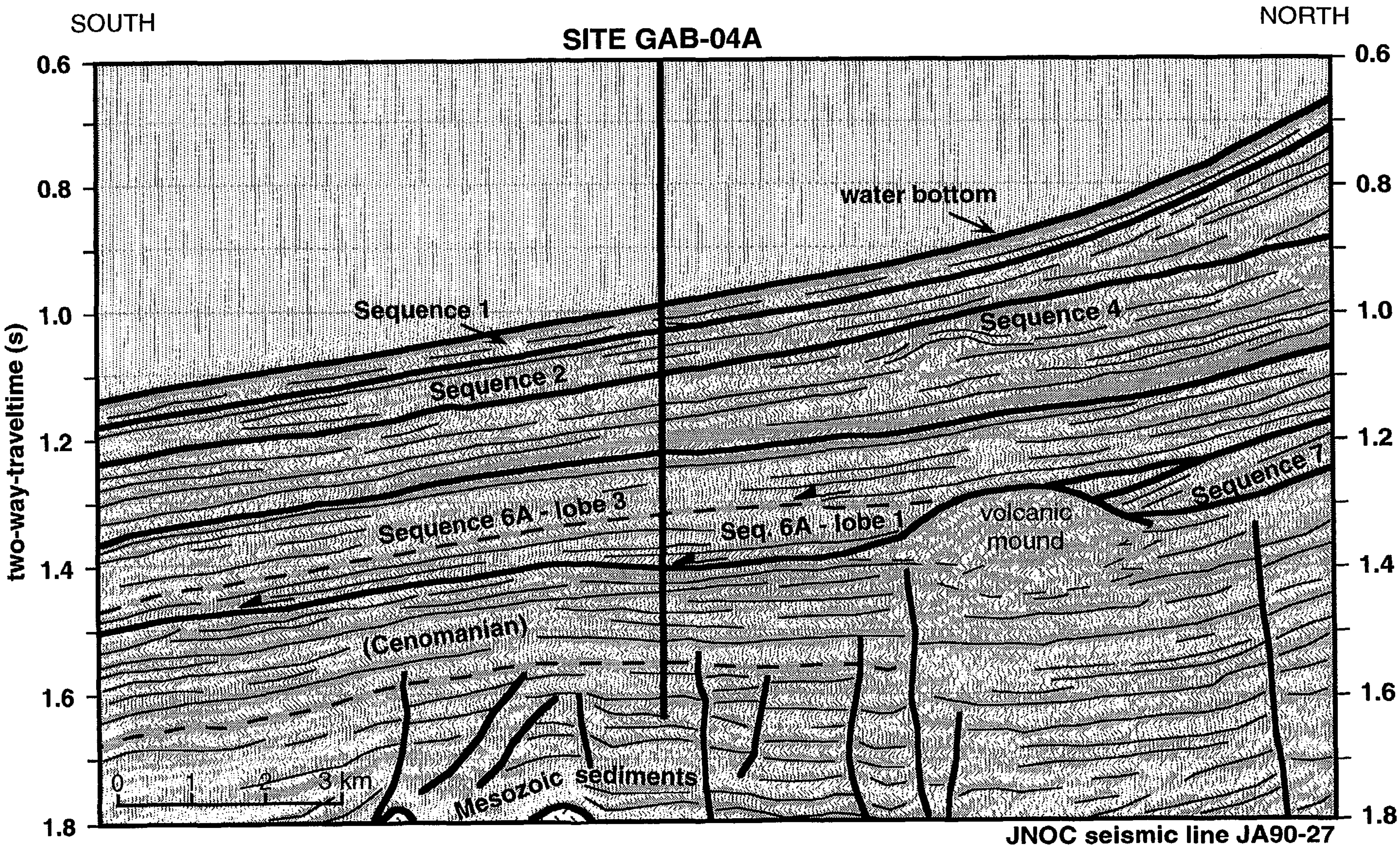

SOUTH
SITE GAB-03A
NORTH
two-way-traveltime (s)
0.8
1.0
1.2
1.4
1.6
1.8
2.0
JNOC seismic line JA90-12

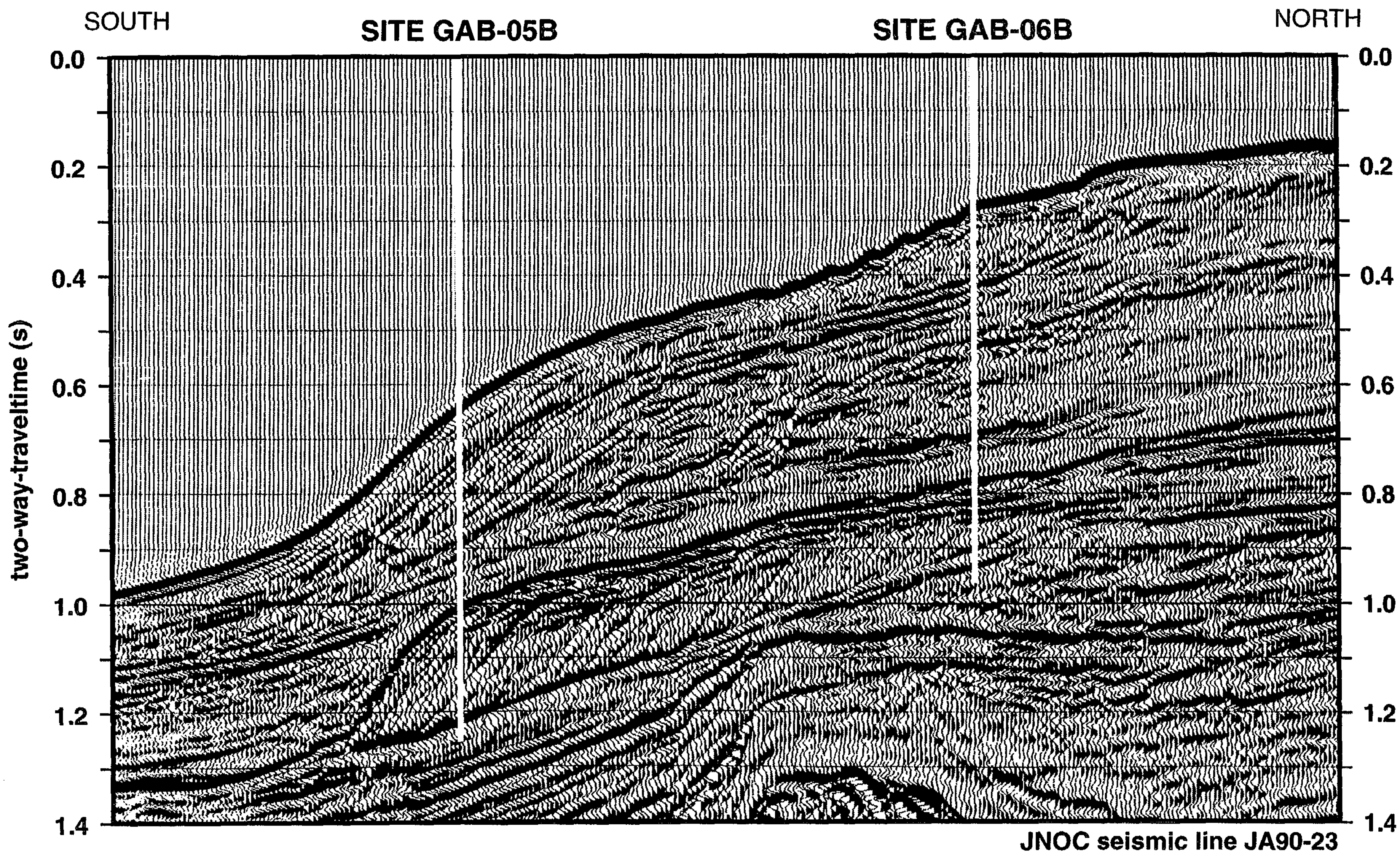

SOUTH
SITE GAB-03A
NORTH
Sequence 1
water bottom
Sequence 2
Sequence 4
Sequence 6A - lobe 3
Sequence 6A - lobe 2
(Cenomanian)
Mesozoic sediments
0 1 2 3 km
two-way-traveltime (s)
0.8
1.0
1.2
1.4
1.6
1.8
2.0
JNOC seismic line JA90-12

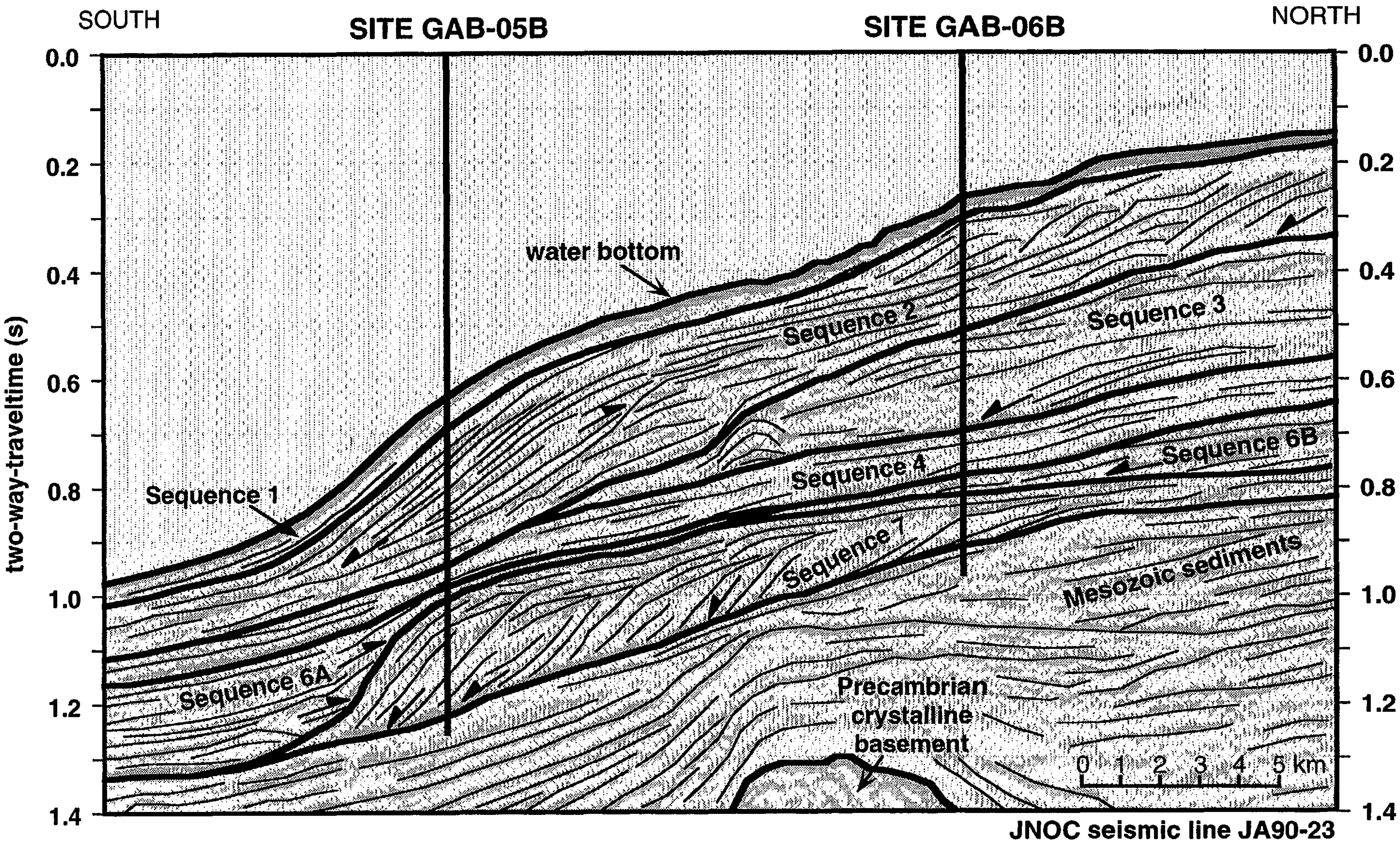

SOUTH
SITE GAB-04A
NORTH
two-way-traveltime (s)
0.9
1.1
1.3
1.5
1.7
1.9
2.1
JNOC seismic line JA90-12

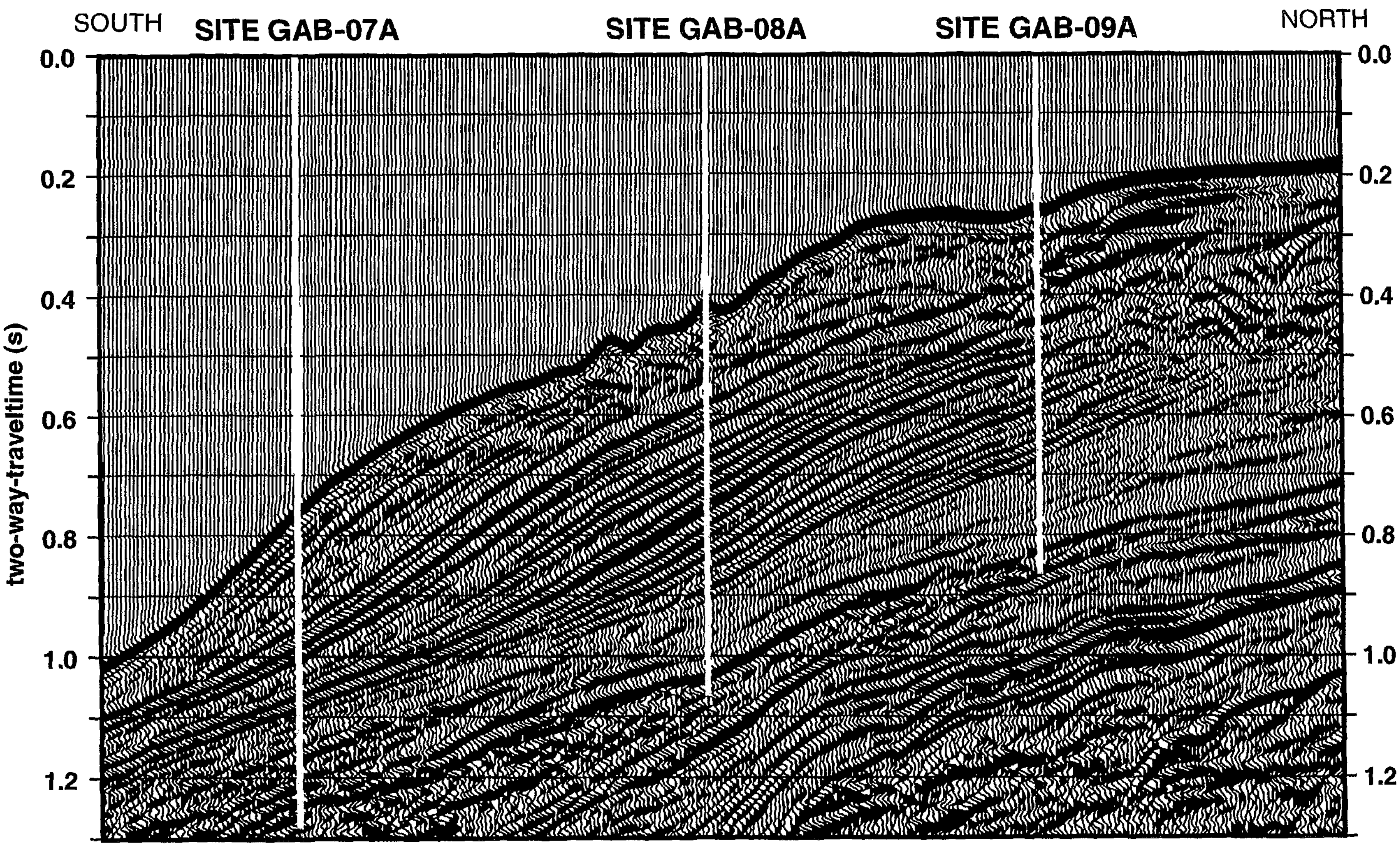

SOUTH
SITE GAB-04A
NORTH
0.9
1.1
1.3
1.5
1.7
1.9
2.1
two-way-traveltime (s)
Sequence 1
water bottom
Sequence 2
Sequence 4
Sequence 6A - lobe 1
Sequence 6A - lobe 3
(Cenomanian)
Mesozoic sediments
Precambrian crystalline basement
0 1 2 3 km
JNOC seismic line JA90-12


SOUTH
NORTH
SITE GAB-04A
two-way-traveltime (s)
0.6
0.8
1.0
1.2
1.4
1.6
1.8
JNOC seismic line JA90-27

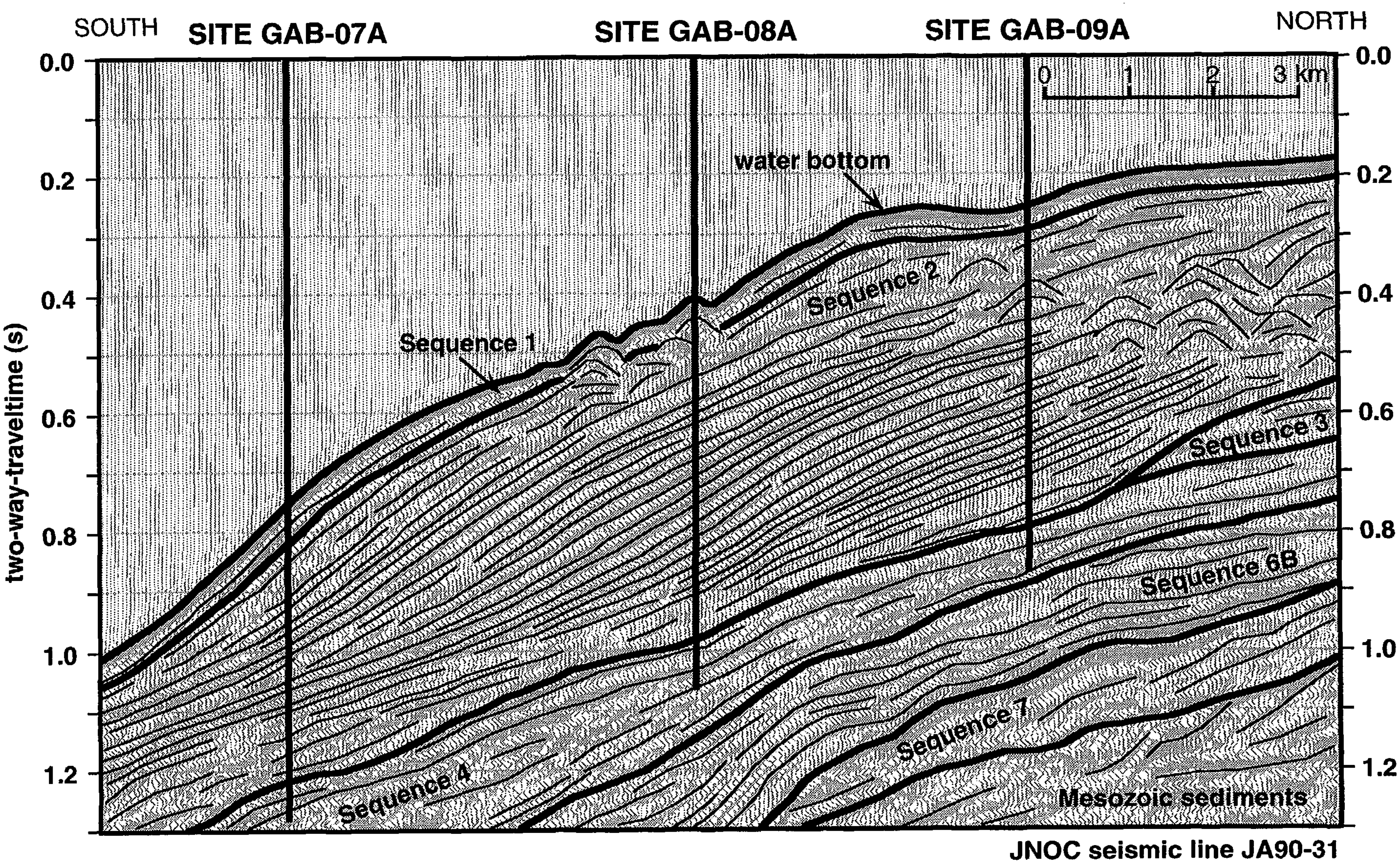

SOUTH
NORTH
SITE GAB-04A
0.6
0.8
1.0
1.2
1.4
1.6
1.8
two-way-traveltime (s)
water bottom
Sequence 1
Sequence 2
Sequence 4
Sequence 6A - lobe 3
Seq. 6A - lobe 1
volcanic mound
Sequence 7
(Cenomanian)
Mesozoic sediments
0 1 2 3 km
JNOC seismic line JA90-27

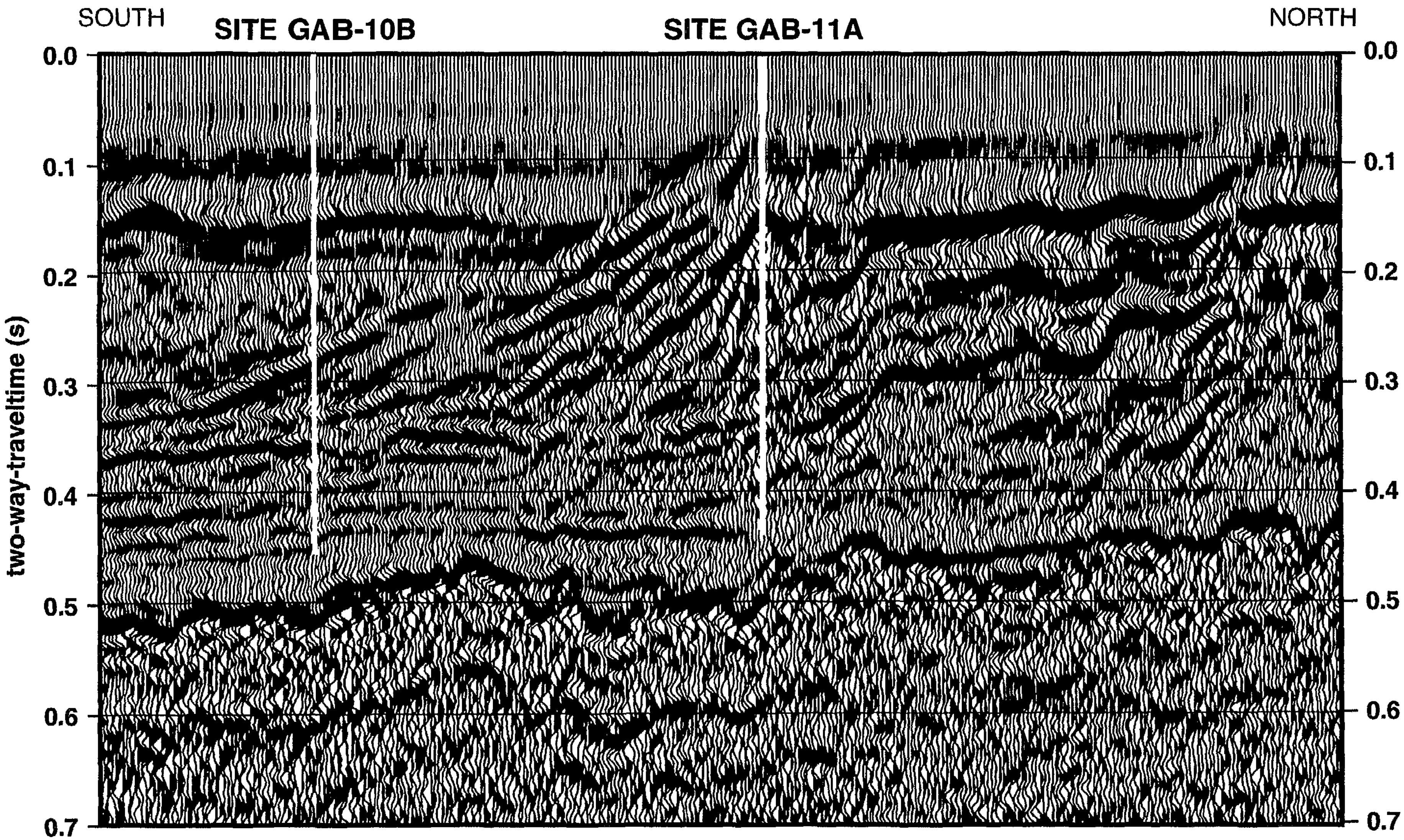

SOUTH
SITE GAB-05B
SITE GAB-06B
NORTH
two-way-traveltime (s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
JNOC seismic line JA90-23


SOUTH
SITE GAB-05B
SITE GAB-06B
NORTH
two-way-traveltime (s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
water bottom
Sequence 1
Sequence 2
Sequence 3
Sequence 4
Sequence 6A
Sequence 6B
Sequence 7
Mesozoic sediments
Precambrian crystalline basement
0 1 2 3 4 5 km
JNOC seismic line JA90-23

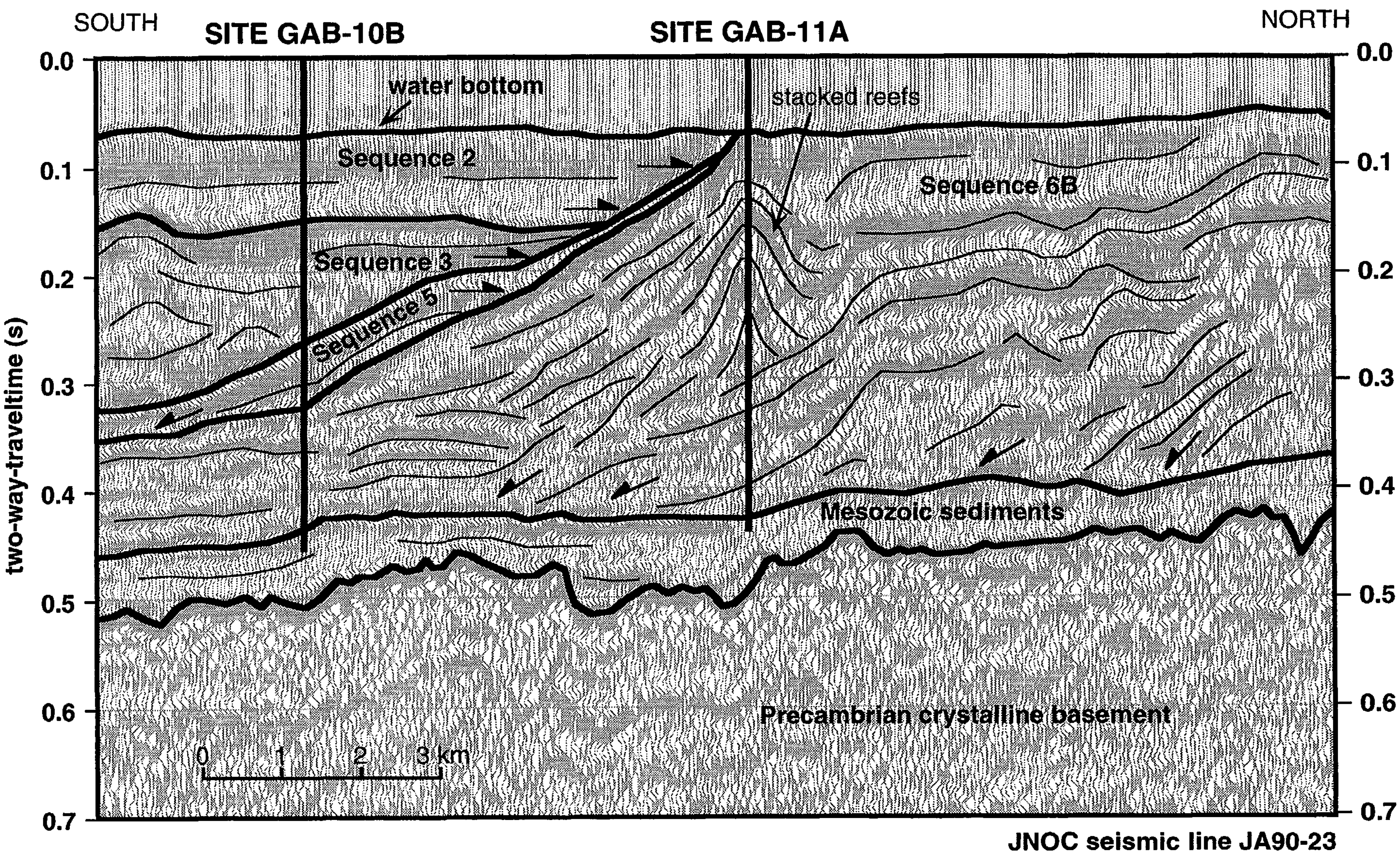


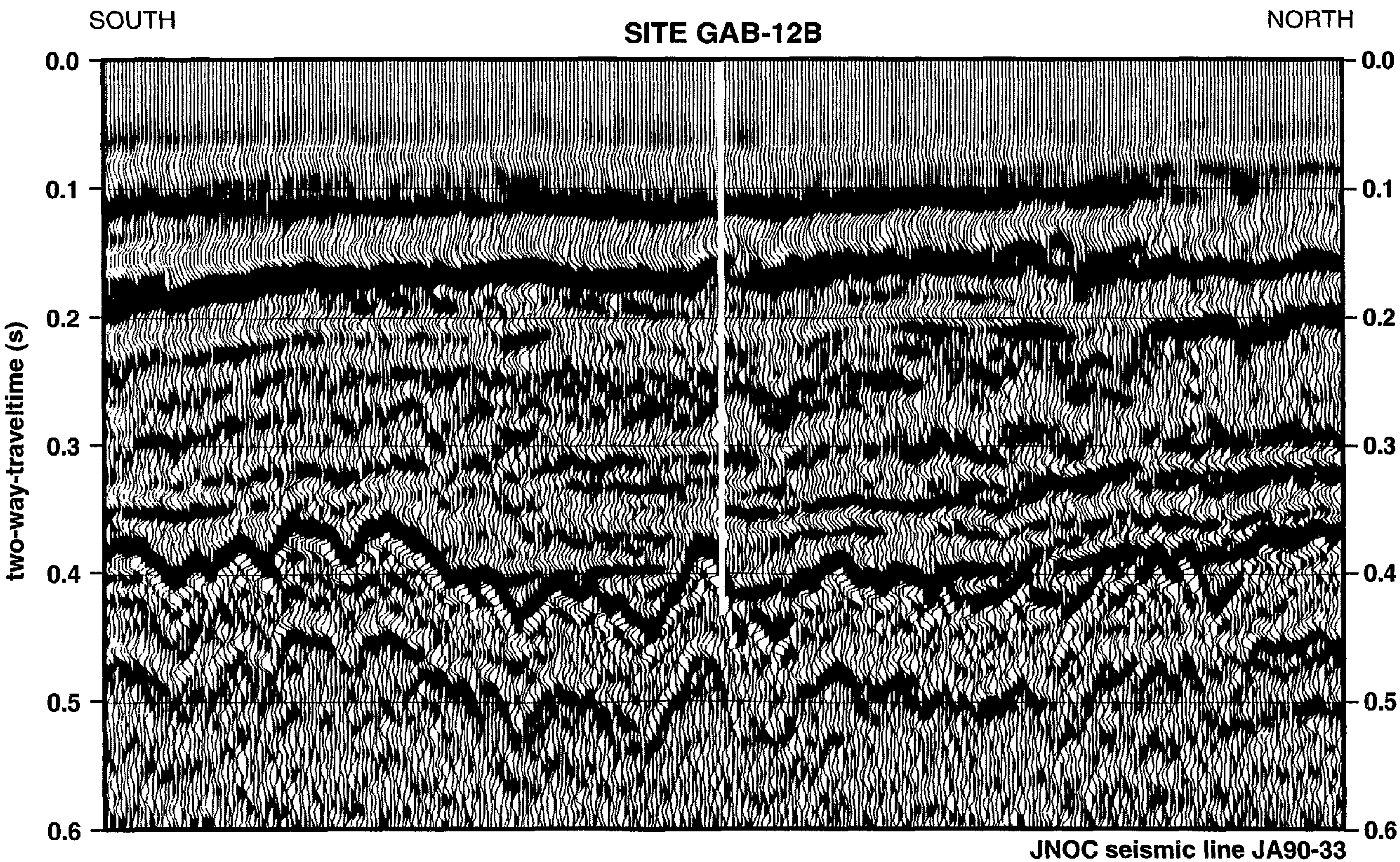
JNOC seismic line JA90-31

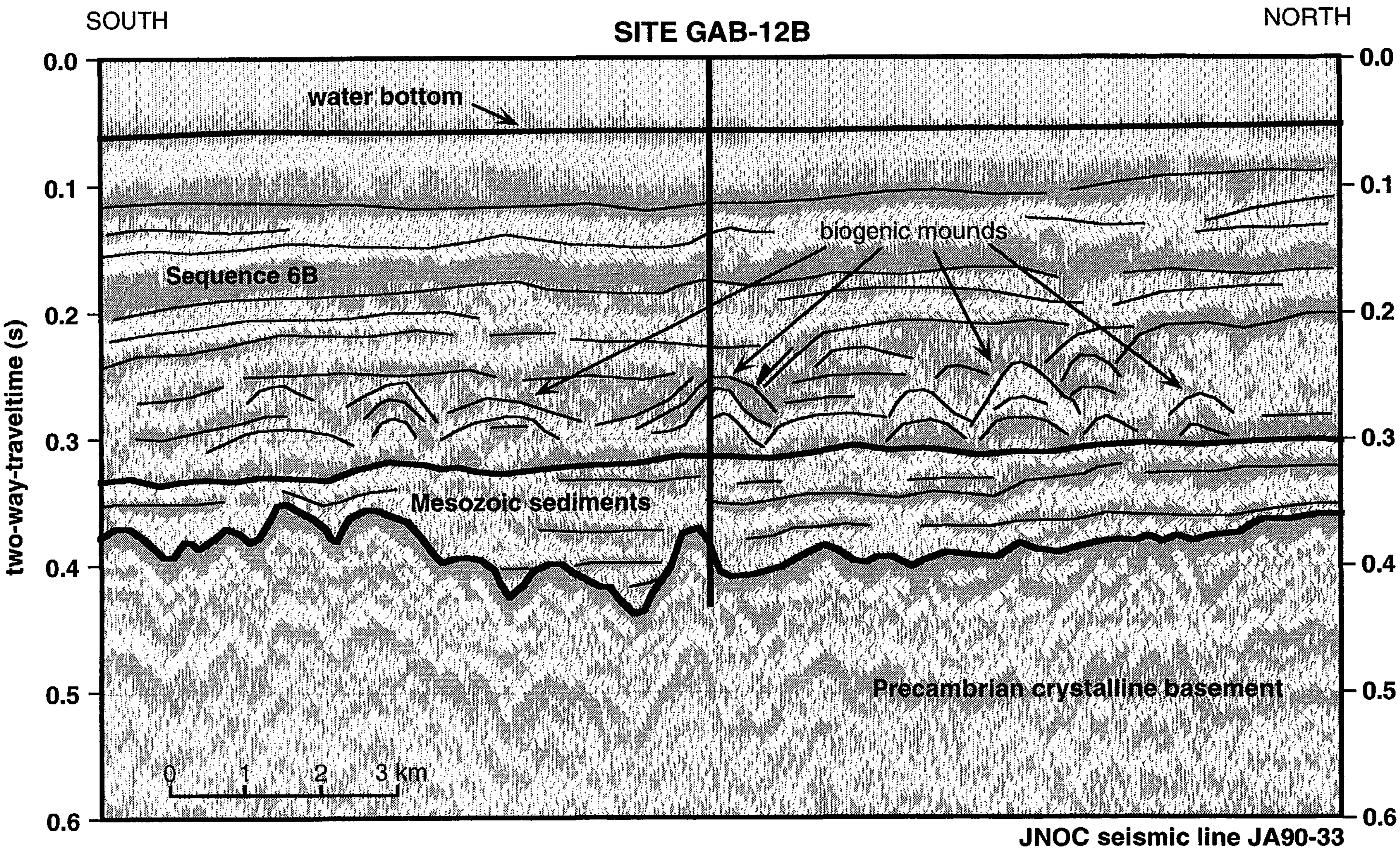

SOUTH
SITE GAB-07A
SITE GAB-08A
SITE GAB-09A
NORTH
0 1 2 3 km
water bottom
Sequence 1
Sequence 2
Sequence 3
Sequence 4
Sequence 6B
Sequence 7
Mesozoic sediments
two-way-traveltime (s)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
JNOC seismic line JA90-31



JNOC seismic line JA90-23


SOUTH
SITE GAB-10B
SITE GAB-11A
NORTH
water bottom
stacked reefs
Sequence 2
Sequence 6B
Sequence 3
Sequence 5
Mesozoic sediments
Precambrian crystalline basement
0 1 2 3 km
two-way-traveltime (s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
JNOC seismic line JA90-23


SOUTH
SITE GAB-12B
NORTH
two-way-traveltime (s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
JNOC seismic line JA90-33


SOUTH
NORTH
SITE GAB-12B
water bottom
biogenic mounds
Sequence 6B
Mesozoic sediments
Precambrian crystalline basement
two-way-traveltime (s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0 1 2 3 km
JNOC seismic line JA90-33

APPENDIX 5: ODP GUIDELINES FOR SHALLOW WATER HAZARDS SURVEYS
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Guidelines for Shallow Water Hazards Surveys

A Report of the JOIDES Shallow Water Drilling Working Group

JULY 1994

Mahlon Ball, Chair

TABLE OF CONTENTS

SUMMARY

During their October 1992 meeting, concern regarding potential for gas blowouts in shallow water settings caused the JOIDES and ODP safety panels to disapprove a number of proposed drill sites on the New Jersey shelf. The special blowout danger in shallow water drilling is that gas, with its attendant threats of fire and explosion, will reach the sea surface at or in close proximity to the drilling vessel. In ODP drilling, this danger is compounded by the drill ship's lack of a blow out preventer (BOP) and limited capability to use weighted drilling mud to contain gas release on a scale comparable to a standard oil and gas exploration rig.

It is PCOM's conviction that passive margin drilling must play a central role in the study of the history of relative sea level variations and that these studies are of scientific merit. This conviction led to PCOM's establishment of a Shallow Water Drilling Working Group. The responsibility assigned this group was to determine the specifications of shallow water hazards surveys necessary to minimize potential for gas blow outs in sedimented shelf drilling.

The main conclusions from this meeting were:

1. Open-hole drilling in shallow water is reasonably safe if proper hazards surveys are conducted and combined with proper data processing and interpretation.
2. Hazards Surveys must be a requirement for ODP drilling on sedimented shelves in water depths of 200m or less.
3. Sub-bottom penetrations at those depths, without BOP and mud-weight capabilities, must be limited to 1000m.
4. Operational procedures for shallow water drilling such as: dropping the drill string, monitoring the seabed for gas escape, and safety contingency plans must be developed.
5. Interpretation of the survey data in terms of shallow gas hazards should be made by experts in the field who are also not associated with the scientific proposals justifying the program.
6. ODP's slim, open-hole drilling from a dynamically positioned vessel is a relatively safe method for shallow water operations but blowouts must be avoided.

1. INTRODUCTION

1.1 Background

During their October 1992 meeting, concern regarding potential for gas blowouts in shallow water settings caused the JOI and ODP Safety Panels to disapprove a number of proposed drill sites on the New Jersey shelf. The special blowout danger in shallow water drilling is that gas, with its attendant threats of fire and explosion, will reach the sea surface at or in close proximity to the drilling vessel. In ODP drilling, this danger is compounded by the drill ship's lack of a blow out preventer (BOP) and capability to use weighted drilling mud to contain gas release on a scale comparable to a standard oil and gas exploration rig.

1.2 Shallow Water Drilling Working Group

It is PCOM's conviction that passive margin drilling must play a central role in the study of the history of relative sea level variations and that these studies are of scientific merit. This conviction led to PCOM's establishment of a Shallow Water Drilling Working Group. The responsibility assigned this group was to determine the equipment, dimensions and costs of shallow water hazards surveys necessary to minimize potential for gas blow outs in sedimented shelf drilling.

The Shallow Water Drilling Working Group (SWDWG) met in February 1993. Attendees included representatives of PCOM, PPSP, ODP-TAMU, SSP, TEDCOM, and industry, with members of SEDCO-FOREX, site survey companies, well control specialists and major oil companies. Important written contributions to this meeting were made by Deminex; Vernon Greif, SEDCO-FOREX; Colin Leach; U.S. Minerals Management Service; Joar Saettem, IKU, Norway; Well Control and System's Design; Alister Skinner, British Geological Survey and Peter Trabant, Marine Geohazards consultant.

1.3 Flexibility

The following guidelines are open to change. Regulatory and scientific differences make change a necessity. For example, the requirements for presence of BOP versus water depths, for nations bordering the North Sea, vary from 25 to 400m. Evolution of geophysical equipment used in high resolution hazards surveys is in a constant state of flux. In general, state of the art equipment will be required for ODP shallow water surveys. This means that our guidelines will have to be updated continually.

1.4 Acknowledgments

The following made important contributions to the development of this report:

Harold Barber	Seascan
Jake Booth	Mobil Oil
Earl Doyle	Shell Oil U.S.
Craig Fulthorpe	U.T.I.G.
Vernon Greif	Sedco-Forex
James Hooper	McClelland Engineering
Larry Kuhlman	Neal Adams Firefighters
Clyde Lee	Sytech
Gary Marsh	Shell Oil U.S.
Chris Nehring	Sedco-Forex

Particularly valuable assistance was given by Alister Skinner of the British Geological Survey who provided guidelines for multichannel seismic data acquisition written by P.M. Walker of Shell U.K. that are adopted for our use. In a similar manner, Earl Doyle's specifications for quality control of multichannel hazards surveys are followed in this report. Contributions by Dietrich Horn (PPSP) of Deminex and Jack Keinzle of the U.S. Minerals Management Services are also incorporated in the procedures adapted by the SWDWG.

2. SHALLOW WATER SITE SURVEY GUIDELINES

2.1 Site Survey Objectives

The objective of a shallow water gas hazards survey (SWGHS) is to identify occurrence of gas, from the sea-floor down to at least 1,000 m, at a site proposed for ODP drilling. SWGHS is required at proposed sites to allow the Science Operator (ODP-TAMU), together with the JOIDES PPSP and the ODP-TAMU Safety Panel, to properly evaluate the safety aspects of a site and to determine whether drilling should be undertaken or not. These guidelines are applicable at sites where the water depth is less than 200 metres and where the Science Operator has not specifically waived the requirement for a shallow water gas hazard survey.

ODP-TAMU shall be involved with the proponents in the planning of Shallow Water Gas Hazards Surveys and shall be responsible (both technically and fiscally) for quality control during data acquisition, processing, and interpretation of Shallow Water Gas Hazards Surveys of highly-ranked proposals that PCOM may wish to schedule for drilling. Funds to conduct Shallow Water Gas Hazards Surveys (including ship time, data acquisition, and data processing) are the responsibility of the proponent(s). In order for the Science Operator (ODP/TAMU) to be involved in the planning of the SWGHS , proponents should contact the Science Operator (Director's office) at the earliest possible stage in their planning.

Shallow water is defined as water depths less than 200 m. The reason for selecting this depth is that experience in the oil industry has shown that gas blowouts at greater depths are not catastrophic to the drill rig, whereas blowouts from depths of less than 200 m can be.

Evidence of shallow gas can be found in sea-floor morphology (pock marks), in natural gas leaks at the sea-floor, or in seismic reflection data. Judd and Hovland (1992) show excellent examples of how these data can indicate shallow gas.

It is assumed that prior to the SWGHS proponents will have acquired seismic data sufficient to justify the scientific objectives and to specify actual drill sites to address the science objectives. The SWGHS specifications are designed so that safety aspects of specific sites can be evaluated. In general the SWGHS will provide the proponent with images of the scientific targets that are better than those acquired previously. The proponent should bear in mind that sites may have to moved for safety reasons and that alternate sites could be picked from the SWGHS, providing the area covered by the survey is large enough to do this.

The surveys will have seven general requirements, which are outlined below and described in detail in subsequent sections.

- 2.2 Accurate navigation
- 2.3 A dense survey grid
- 2.4 Side scan surveys to identify sea-floor features
- 2.5 High resolution MCS imaging of the sub-surface down to at least 1,000 m.
- 2.6 Independent quality control of MCS data acquisition
- 2.7 High resolution imaging of the sub-surface down to about 100 m.
- 2.8 Independent interpretation of the data by an expert in the field of shallow gas

2.2 Navigation

Positioning data should be acquired by a method which allows absolute accuracy of about 10m. Differential GPS or mobile electronic systems are acceptable.

Positioning data requires processing on-line to allow the survey vessel to run along the required line pattern and for control of seismic shot interval and position. Raw positioning data should also be recorded to allow post-processing. Post-processing should remove spurious data, correct errors (if any) and take advantage of smoothing techniques. It also provides a quality control check on the real-time acquisition and information on potential systematic positioning biases.

Care should be taken to ensure that the correct offsets are applied in the computation of all points such as antenna and sensor positions.

2.3 Survey Grid

It is required that at the minimum an area of 1 km by 1 km, centered on the proposed site, be surveyed with a line spacing shown in Figure 1.

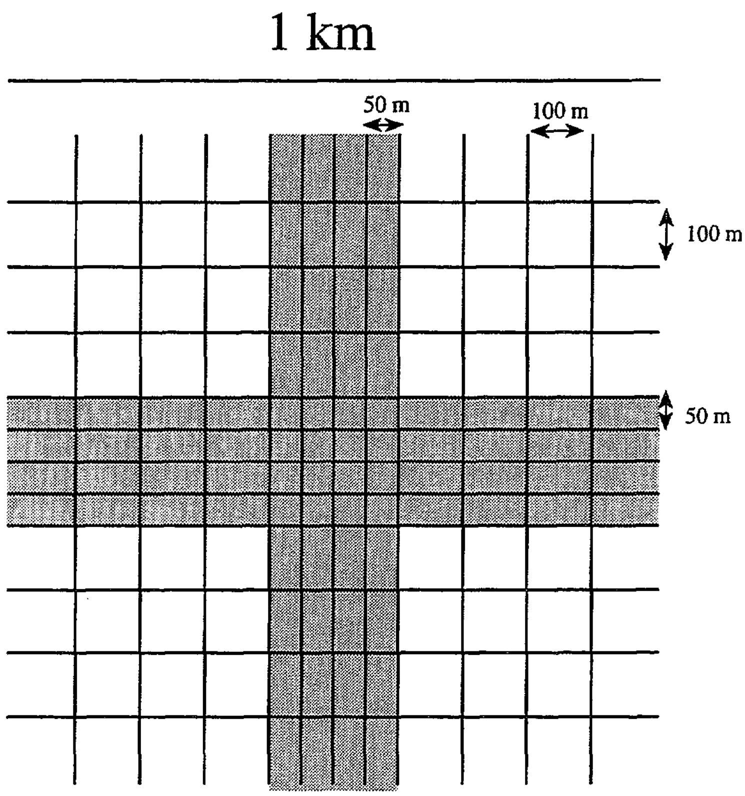

Figure 1. Minimum grid spacing for MCS gas hazards site survey.
The proposed site is at the center of the grid.

Several factors must be considered when defining the survey area:-

a) If the final well location is not precisely known, the area surveyed should cover all possible locations.

b) Should possible gas accumulations be detected, the survey area should be large enough for the identification of alternative locations.

c) If several closely spaced wells are likely, it may be more economical to perform one large survey, rather than several small ones.

Even if there is little flexibility to move the final well location, surveys of very small areas are not cost effective or useful. Very short seismic lines (of a few hundred meters) are difficult to interpret and take almost as long to acquire as lines of reasonable length (in excess of 1 kilometer).

If top hole well logs are available from nearby wells, lines should be acquired to tie these wells to the location for correlation purposes. Even if no top hole well data is available, tie lines may still be useful to relate drilling conditions at the proposed location to those at an already drilled location.

The recommended minimum survey area for shallow gas detection is 1 kilometer by 1 kilometer of full fold coverage, centered on the proposed location. This surveyed area should permit a recommendation for a move of location if necessary. However, features may be larger than 1 kilometer, so to assist in interpretation of the data, a few longer (several kilometers) lines should be considered. These could be tie lines to adjacent wells and lines through the proposed location.

Line spacing will dictate the ability to detect features of limited lateral extent. To ensure detection of small gas pockets at shallow depths, a line spacing of 50 meters around location is recommended. This could be relaxed to 100 meters line spacing away from location. Should the location need to be moved away from shallow gas to an area of 100 meters spaced lines, additional infill lines to 50 meters may be required, depending on local geology. Should no suitable drilling location be found within the 1 kilometer survey area, an additional survey will be required, but the longer lines may act as a basis for selection of the new location.

The survey grid should be oriented such that one seismic line heading is perpendicular to the geological strike. This will generally be the primary 2D exploration seismic line heading. Should the location need to be moved away from shallow gas, and the orientation of the lines has been selected to coincide with the heading of 2D exploration seismic data, it may be possible to move the well location within the survey area to an alternative position suitable for the scientific objective. If 3D seismic data is available, coincident line heading will not be required.

2.4 Sidescan Sonar

Evidence of shallow gas can be found in sea-floor morphology (pock marks), in natural gas leaks at the sea-floor, or in seismic reflection data. Judd and Hovland (1992) show excellent examples of these data can indicate shallow gas. Side scan sonar data play an important role in quantifying the morphology of the sea-floor and are necessary data in these surveys.

A dual channel side scan sonar linked to a graphic twin channel recorder shall be used to provide information on the sea-floor morphology and to identify and locate seabed obstructions and other local features. Suggested specifications and operating variables are listed below:

Operating Parameters:

Beamwidth:	Horizontal: 1.2° ;Vertical: 50°
Beam Depression:	20° below horizontal
Operating Frequency:	105 ±10 kHz
Cover:	200%
Positioning:	to 10m accuracy

Data should be of good quality, achieving energy return to 200 meters. Assessing the threshold for detection of seabed contacts is particularly difficult with sonar on account of the wide range of variables. Apart from consideration of record quality generally (such as propeller noise and operator ability), these variables include the shape, composition (hardness) and attitude of the contact, the contact range, the towing height of the sensor, the nature of the surrounding seabed and vessel speed. Linear targets such as a thin cable a few centimeters thick can often be detected, whereas sediment patches might be a few meters across. As a very general guide, at the commonly used 200 meter per channel range and in reasonably favorable operating conditions, seabed projection becomes detectable at about 20 cm elevation. A plotting accuracy of 10 meters is considered realistic.

Accuracy can be improved in a number of ways. These include fish tracking systems, running lines in opposite directions and advanced plotting techniques. On the other hand, manufacturer's tables relating, for instance, beamwidth and tow speed to detection probability for a given range need to be treated with caution, since many arbitrary assumptions have to be made. We desire minimum detectable projection at about 50 cm.

2.5 High Resolution Imaging of the Subsurface from the Seafloor Down to at Least 1,000 m

2.5.1 Objective

The objective is to identify all gas accumulations within the upper 1000 meters of the sub-seabed floor. In practice, there are limits to vertical and lateral resolution, and resolution will degrade with increasing sub-seabed depth. A realistic objective in the upper 1000 meters of sub-seafloor is the resolution of potential gas accumulations of at least 5 meters thickness, and 200 meters diameter aerial extent. Gas accumulations of less than 5 meters thickness will be detected (1 meter thickness in ideal conditions) but the top and bottom of the unit may not be resolvable. With this objective at 1000 meters sub-seabed, smaller gas accumulations will be detected in the shallower levels. Acquisition and data processing parameters should therefore be specified to provide optimum vertical and lateral resolution throughout the objective interval.

In principal (and in practice) it is possible to use seismic sources and receivers with a bandwidth from about 10 Hz to 2+ kHz. Frequencies at the upper end of the spectrum do not penetrate much below a few tens of meters, but they can be used to study the upper tens of meters of the section. Frequencies at the lower end of the spectrum penetrate more deeply and are used in the MCS mode to study the deeper section. In a SWGHS both data are required. They can be acquired by either using a single system (broadband MCS system with appropriate processing) or two separate systems (say an MCS system and a deep tow boomer or an MCS system with a ship mounted 3.5 kHz system). Specifications for both are supplied in this document, but the data aquirerer should be aware of these options.

Even with data acquired to the limits of available technology, these surveys do not guarantee that all shallow gas accumulations will be detected. Due to limitations in resolution and data interpretation, the surveys should be viewed as a preventive measure, reducing the risk of encountering a gas accumulation.

2.5.2 Equipment

To achieve the objective, multi-channel, digitally recorded, high resolution seismic data are required. The parameters listed below provide minimum acquisition standards for shallow gas detection. Although local geological conditions may allow relaxation of these standards, they should provide acceptable seismic data in most areas.

2.5.3 Seismic Source

The outgoing seismic signal should be stable and, for a source tow depth of less than 3 meters, have the following far field characteristics within the bandwidth of the operational filters:

a) Peak-to-peak amplitude in excess of 3.5 bar meters.

b) Bandwidth of at least 20 to 170 Hz at -6 dB.

c) Primary to bubble ratio in excess of 15:1.

d) Repetition rate of no more than 3 seconds.

e) Preferably minimum phase.

Examples of sources meeting these specifications are Seascan's "Tricluster 80" or Geoquip's "Q-10".

The seismic controller must synchronize guns to fire within 100 microseconds of each other. Examples of source controllers are Reftek Model 43 or Sino Technology Model ECS-2.

2.5.4 Hydrophone Streamer

a) 48 groups minimum.

b) Group length of 12.5 meters.

c) 600 meters minimum active length.

d) Sensitivity in the order of 5 volts per bar (transformer coupled).

e) Depth controllers and indicators at least every 100 meters.

f) Equal spacing of hydrophone elements throughout the streamer.

Example is Teledyne Model 29500 Programmable Hydrostreamer cable. Filter settings are 27 Hz (low cut) and 512 Hz (anti-alias).

2.5.5 Acquisition Parameters

Data will be digitally recorded with a system having appropriate resolution and bandwidth. An example is Texas Instruments DFS V (or approved equivalent) configured for a shot interval every 6.25 meters and using a Raytheon LSR 1807M graphic recorder (or approved equivalent) to do a read after write display of the near trace. Record length 1.5 sec (sub seafloor), filter (approximate) low cut 10 Hz and 500 Hz anti alias, display constant horizontal scale at approximately 1" = 150 m.).

The recommended minimum seismic acquisition standards for shallow gas surveys are as follows:-

a) Sample rate: 0.5 millisecond
b) Record length: 1.5 seconds
c) Shot interval: 6.25 meters
d) Number of channels: 48 minimum
e) Streamer group length: 12.5 meters
f) Source and streamer tow depth: 2.5 meters
g) High cut filter: 512 Hz
h) Low cut filter: 27 Hz
i) Source-near trace offset: minimum
(maximum offset should be half water depth)
j) Maximum feathering angle: 6 degrees
k) Streamer noise levels (RMS): 8 microbars with bursts of up to 20 microbars.
(8 microbar level may be relaxed on near traces and near depth controllers

Specifications for streamer noise levels are of particular importance to ensure adequate signal-to-noise ratio within the seismic data. They should be reviewed on a site specific basis while the seismic data is being acquired, by assessment of signal-to-noise, throughout the objective interval.

In general, interference in excess of 25 microbars RMS can be tolerated as long as it is in-line to the streamer, i.e. from ahead or astern. Very little noise can be tolerated from broadside, i.e. the beam, and the 8 microbars RMS specification should be applied. For noise arriving between the in-line and broadside cases, the range of geological dips expected and seismic velocities will dictate the arrival angles of acceptable noise levels. Interference should also be reviewed, therefore, on a site specific basis by assessment of signal-to-noise. If possible, lines should be shot such that the interference arrival direction is in-line.

To further improve resolution, a few lines with source and streamer towed at very shallow depths (1 meter), and shorter streamer group lengths (6.25 meters) should be considered. These lines require a seismic source which will provide suitable high frequencies when towed at a shallow depth. Acquisition may be difficult due to the low weather tolerance of the shallow source and streamer tow depths. However, at least two lines over the drilling location should be considered, in addition to the full grid of 2.5 meter tow depth lines.

2.5.6 Data Processing

The objectives of processing seismic data include improvement of signal-to-noise ratio, improvement of vertical and lateral resolution, suppression of multiple events, and enhanced display of data.

Processing of data should be undertaken with extreme care since it is possible to create and destroy events on the seismic record. As a rule of thumb, the minimum processing of data should be undertaken and processing which destroys relative amplitude information must be avoided. Careful analysis of processing tests permits selection of those processing steps which enhance the data. When undertaking processing tests the area selected should be representative of the site. Care should be taken to alter only one variable at a time so the effect can be assessed. Processes should not be applied unless there is obvious benefit. On occasion, even though a process may be of obvious benefit in one way (e.g. multiple suppression) it may be disadvantageous in another (e.g. data suppression and noise creation).

Careful velocity analysis is of particular importance to ensure correct CMP stacking of the data. Velocity analyses should be undertaken at locations chosen with reference to the local geology. The minimum interval should be every 500 meters along the seismic lines. In some areas, where the geology is rapidly changing, (e.g. channels, salt domes) velocity analyses maybe required more frequently with detailed velocity plots such as those offered by Sytech Corporation.

Velocity analyses will be severely degraded by significant lateral velocity variations, e.g. gas charged sand. This can be particularly important for stacked anomalies, and a more careful approach to velocity estimation is necessary if data are to be stacked correctly and reflector amplitudes preserved.

The recommended minimum processing sequence is:-

a) Demultiplex
b) Designature
c) Gain recovery
d) Deconvolution before stack (DBS)
e) Normal Moveout (NMO)
f) Mute
g) Stack
h) Deconvolution after Stack (DAS)
i) Time Variant Filter (TVF)
j) Relative amplitude display
k) Equalized display

Seismic processing systems are available, which allow seismic data processing on-board the vessel, sometimes on-line. These systems are very useful for quality control purposes. However, the on-board processed data should be used with extreme care for interpretation as the processing may have been undertaken by personnel inexperienced in seismic processing, and without adequate quality control. Processing and plotting packages may also be less sophisticated than those onshore.

2.5.7 Interpretation

Interpretation of data for shallow gas detection is subjective and should only be undertaken by experienced personnel. All sources of available data should be incorporated. Wherever possible this should include top hole well data, borehole data, exploration seismic data, adjacent site survey data, regional geological data, and other knowledge of the area. The interpretation of all the data sets acquired during the survey should be carefully integrated for the overall interpretation of the survey area.

Interpretation of the site survey data within the regional framework is important for a full understanding of the geology and potential hazards. Input from the proponent may be useful at this stage, but responsibility for the final interpretation remains with the Science Operator.

2.5.8 Conventional Seismic Analysis

One characteristic seismic response of a gas charged sediment is a high amplitude reflection, although under certain conditions, low amplitude reflections are also possible. Theoretically, the reflection should also be phase reversed where gas is present, but this may not be apparent. Other indicators of gas in sediments are masking of underlying reflection and 'pull down' of underlying reflection, caused by the seismic wave passing through the lower velocity gas pocket. In practice these last two indicators are rarely seen, as they are very sensitive to the geometry of the acquisition spread with respect to the size and depth of the gas pocket. Consequently, identification of possible gas pockets primarily depends on identifying anomalously high amplitude reflections.

High amplitude reflections are caused by a strong impedance contrast. Impedance depends upon the seismic velocity and density of the strata. Therefore, strong impedance contrasts may be purely of lithological origin rather than due to gas accumulation. Constructive interference of reflected seismic waves may also cause high amplitude reflections (tuning effects). The more resolute the seismic data, the easier it is to discriminate genuine high amplitude events from tuning effects.

A small proportion (about 5 percent) of gas in a sediment will cause a high amplitude reflection of similar magnitude to that caused by a large proportion of gas (say 75 percent), so it is difficult to directly quantify gas content from the seismic response. If a closure can be mapped, and the top and bottom of the reservoir unit detected, gas overpressure (in excess of hydrostatic pressure) caused by the height of the gas column can be calculated. However, this is a simplistic approach, based on hydrostatic pressure variations only. It also assumes accurate detection of the top and bottom of the reservoir. Predictions of gas pressures based upon seismic data should be used with extreme care.

2.5.9 Seismic Attribute Analysis

Seismic attribute analysis, which includes variation of amplitude versus offset (AVO) effects, may assist in the discrimination between seismic events caused by shallow gas accumulations and those caused by lithology, e.g. lignite.

Seismic attributes such as increased reflection amplitudes, phase reversal, high frequency loss, and low velocities can be indicative of shallow gas accumulations. The ability to detect variations in these attributes can be enhanced by attribute analysis and display. However, variations in these attributes can also be caused by lithological changes and seismic processing, so interpretation based upon attributes should be undertaken with caution.

AVO effects are generated by changes in plane-wave reflection coefficients as a function of angle of incidence AVO variations can be caused by many factors (e.g. reflection coefficient, array attenuation, tuning, noise, spherical spreading, absorption, emergence angle, reflector curvature, hydrophone sensitivity, and instrumentation and processing). With care, AVO analysis may assist in distinguishing gas related amplitude anomalies from other types of anomalies. In general, over the range of angles of incidence typical of rig site survey data, the top of a gas charged sand layer will show a marked increase of amplitude with offset, whereas a water charged sand will show a very small decrease of seismic amplitude with offset.

2.5.10 Calibration

Direct calibration of the data in the form of nearby top hole well data or borehole data is the most useful tool for assessing the significance of the seismic response and should always be carefully integrated with the data.

Where the geological structure and interpreted lithologies provide a potential trap and no direct calibration is available, anomalous amplitude reflections should always be assumed to be related to gas accumulations.

2.5.11 Depth Conversion

The conversion from seismic travel time to depth below seabed, based on stacking velocities or interval velocities, is accurate to better than 5 percent of the depth when determined with care. Depth predictions can be further improved if top hole well data is available.

2.5.12 Workstations

The use of workstations can assist in the interpretation of seismic data for shallow gas detection. Workstations allow expansion of data displays in areas of concern for easier identification of shallow gas indicators. Seismic attributes can be examined using color displays such as color coded amplitude, instantaneous amplitude, instantaneous phase, and instantaneous and averaged frequency.

Using workstations, tuning effects can be more easily discriminated from high amplitudes caused by shallow gas, on the basis of changes in relative amplitude along the reflector.

2.5.13 Shallow Gas Indicators

The following list is based upon a list provided in the AAPG Memoir 42.

The interpreter should look for the following indicators of shallow gas. Of these, item (a) is the prime indicator.

a) Is the reflection from the suspected reservoir of anomalously high amplitude?
b) Is the amplitude anomaly structurally consistent?

c) If of anomalously high amplitude, it there one reflection from the top of the reservoir and one from the base?
d) Do the reflector amplitudes of the top and base reflections vary in unison, decreasing at the same point at the limit of the reservoir?
e) Is a flat spot visible?
f) Is the flat spot horizontal or is it dipping consistently with gas velocity sag?
g) Is the flat spot unconformable with the structure but consistent with it?
h) Is the flat spot located at the downdip limit of anomalously high amplitudes?
i) Is a phase change visible?
j) Is the phase change structurally consistent and at the same level as the flat spot?
k) Is there a low frequency shadow below the suspected reservoir?
l) Is there an anomaly in moveout derived interval velocity?
m) Is there evidence of pull down or gas velocity sag on underlying reflectors?
n) Is a study of amplitude versus offset on the unstacked data likely to assist?
o) Are there indications of gas migration on the shallow gas (or other) survey data?

In practice, any one indication can be spurious. Shallow gas interpretation on seismic data necessarily involves accumulation of evidence. The more positive answers to the above points, the greater the confidence in the identification of shallow gas.

2.5.14 Reporting

Reporting should be concise and relevant to the survey objective. Consideration should be given to all potential users of the report and any information they require must be readily accessible. Speculative interpretations, unless substantiated by published data should be avoided.

The objective of a shallow gas survey is to identify and map possible gas accumulations. The report should therefore clearly indicate the depth and lateral extent of any such accumulations. Any information used in the interpretation of the data and assessment of the shallow gas potential should be included. Whenever possible, top hole well data should be used to calibrate the data and improve the interpretation.

Interpretation of the seismic data may also be useful for other aspects of drilling such as casing setting studies and detection of potential zones of difficult drilling. The report should therefore clearly indicate the depth and lateral extent of any relevant features e.g. sub-seabed channels, and a prognosis of lithology throughout the objective depth interval.

The reporting should provide a brief but clear statement of expected drilling conditions at the proposed location. This statement should not be confused by discussion of features in the survey area which have no relevance to drilling at the location. It is recommended that a one-page summary of this information is provided in the report.

Topics to be addressed by the report should include:-

a) Summary of results (including interpretation)
b) Results (including interpretation)
c) Operations
d) Calibrations
e) Data reduction and processing
f) Survey equipment
g) Data quality

2.5.15 Charting

Recommended chart scale is 1:10,000.

Charting should include the following:

a) Seismic shot point.

b) The lateral extent of anomalous amplitude reflections presented in time (TWTT) and depth below sealevel or seabed. For clarity of presentation, several charts may be required.

c) Depth below mean sealevel to reflections of interest if there is a potential structure.

d) Shallow faulting if this is relevant to potential shallow gas distribution.

e) Lateral extent and depth of any features which may affect drilling operations (e.g. channels).

f) Interpreted profiles through the proposed location, highlighting potential hazards and significant soil units.

2.6 Quality Control Specifications

Quality of data acquisition for SWGHS shall be controlled by the Science Operator. The parameters that are important in terms of quality control are described in the sections 2.6.1 to 2.6.14

2.6.1 Cable Noise

Cable towing noise at normal shooting parameters will be recorded using production filters at fixed gain on the field tape during minimum straight line run-in of one and one-half cable lengths at start and finish of each line. Recording period will be of a normal record length during which time the source will not be activated.

Cable noise will be measured on any hydrophone group at the discretion of the quality control supervisor using multi-channel paper monitors and the recording filter in use. One channel will carry a 20 Hz reference oscillator signal, which when passed through the recording system, will be calibrated to produce a measured and quantified voltage level in microvolts for the purpose of determining streamer noise.

Cable noise in microbars RMS is defined as peak to peak noise of the cable, when operating under conditions described above, at the recording amplified input in microvolts RMS divided by sensitivity of the detector group in microvolts per microbar when loaded with cable and amplifiers.

Average cable noise will not exceed 5.0 microbars RMS equivalent, for a 12.5 m group length except for groups that are adjacent to depth controllers, or tail buoy, or less than 200 meters offset from the stern of the ship, where average noise of 8 microbars RMS will be tolerated.

Coherent noise from the survey vessel itself, or from other sources (rigs, pipelines, or other vessels) shall be treated with the same limitations as stated above assuming a constant amplitude, in the case of amplitude decreasing with time, a maximum of 8 microbars as averaged over a 250 ms period beginning with maximum amplitude will be accepted.

Seismic interference will be accepted only within the following limitations on: near before far traces equal to 8 microbars; far before near traces equal to 18 microbars; all traces within a 250 ms period equal to 4 microbars; where these value shall be the maximum amplitude experienced with the period of interference.

Residual shot energy at normal firing cycle will be recorded in the same manner as outlined above for cable noise for 10 seconds after record start at least once per day. RPM of propeller shaft, ship speed in knots, sea state, time, date, SOL, EOL, and line number will be annotated on noise strips.

2.6.2 Defective Traces

A seismic trace will be considered as defectively recorded if:

a) system noise, including all wiring from hydrophones to tape recording heads exceeds the previously mentioned quality control specification when all normal shipboard equipment is operating

b) it is dead, wild, intermittent, or more than 6 dB down relative to contiguous traces,

c) polarity does not conform to SEG standards as defined in 7.0 below,

d) its amplitude is distorted or its pulse envelope leads or lags more than 1 ms when input is paralleled,

e) electrical leakage is exhibited or cable insulation between pairs and from ground is less than 0.5 megohm,

f) it fails to met and pass manufacturer's instrument or able quality control tests.

2.6.3 Cable Depth

Cable depth transducers will be spaced along the streamer at a maximum interval of 100 m.

Specified mean cable towing depth is 3 m or as agreed in writing.

When a change in cable depth is authorized due to weather or other circumstances, the depth may only be changed upon completion of a given line. No line shall be recorded with more than one cable depth. Maximum deviation from specified streamer towing depth at any transducer is plus or minus 1.0 m.

Depth transducers will be zeroed and calibrated whenever the streamer is deployed.

2.6.4 Offset

Offset is to be defined as the distance between the center of the energy source array and the center of the nearest active group, and will be approximately 150 meters to facilitate noise isolation for digital streamer recording. Direct water arrivals will be digitally recorded on magnetic tape on auxiliary channels at every shot from hydrophones at a minimum of four positions along the streamer. These may be recorded on a single channel.

2.6.5 Misfires

The following will be considered misfires:

a) loss of magnetic recording on digital system,

b) loss of time zero or signature pulse,

c) more than 7 parity errors on one recording,

d) defective traces as described in 2.6.2 above,

e) loss of more than 10% of total air gun array volume, unless there is access to a signature model to indicate wavelet being utilized, and approval to continue has been gained from the on board quality control supervisor,

f) a minimum of 1900 psi must be maintained,

g) a spread of more than plus or minus 1.0 ms among individual acoustic pulses of units of the source array,

h) autofiring or misfiring of units of the source array,

i) variation in depth along streamer between adjoining transducers exceeding 1.0 m except during or immediately following adjustment of controllers.

j) two or more waterbreaks in a state of malfunction, if waterbrake equipment is provided,

k) interruption of primary navigational positioning system, unless a redundant system is provided,

l) failure of gun timing controller,

m) over-driving or clipping of any trace,

n) loss of raw navigation data being permanently recorded.

2.6.6 Monitor Records for Digital System

Multi-channel paper monitors will be made at every 40th shot, or as required to display all traces and systematically annotated as produced.

Oscillograph camera will be optically aligned and photography will produce permanent records with appropriate contrast.

Timebreak, recording system time base and 100 Hz cross-reference signal from the cameral timing line generator, 10 ms timing lines, record number, and all seismic detector groups will be displayed.

Timing reference and timing line signals will coincide within limits of 0.002 seconds on a 2 second monitor record.

Monitor records will be annotated such that traces are not ambiguous.

2.6.7 Polarity

Polarity convention will be in accordance with the SEG Committee on Technical Standards recommendations, such that compressional waves produce negative voltages which are recorded as negative numbers on magnetic tape, and deflect galvanometers downward to produce wavelet minimal (white) troughs on monitors.

All seismic channels will be recorded and processed with identical polarity.

Polarity will be checked by tap test prior to commencing survey and will be documented on hard copy at start of survey, and again whenever sections of streamer are replaced, or whenever there are permanent electrical disconnections, or whenever any change in signal routing is made.

Polarity corrections will be made when necessary at the point of reversal, such that identical polarity exists at all test points coupled between hydrophones and magnetic recording heads.

2.6.8 Tape Transports (if used)

Tape transport skew, both static and dynamic, will be within manufacturer's specifications for sample rate, bit packing density, and recording speed.

Tape speed will be maintained within 1% of manufacturer's specifications. Tape heads will be cleaned between each production tape prior to loading.

2.6.9 Recording Media

All seismic data will be recorded on new and certified media.

Each medium will contain the following information on permanent labels:

a) project designation,
b) line number and shot point sequence
c) format, bit packing density, and sample rate,
d) a boat name and number
e) direction of traverse
f) date.

2.6.10 Seismic Sensor Acquisition Not To Commence

Recording of data from an individual sensor will not commence on any line when the following conditions occur:

a) existence of any conditions described in section 2.6.7,
b) one or more units of the source array or its sensor are malfunctioning,
c) more than 2 of 24 traces, or 2 adjacent traces, or any one of the near 4 are defective as defined in section 2.6.2,
d) if more than one cable depth transducer is inoperative,
e) polarity is not within specification,
f) multi-channel monitor camera is inoperable,
g) single channel section plotter not functioning,
h) primary navigational positioning system malfunctioning,
i) streamer noise exceeds limits defined in section 2.6.1,
j) gun string depths vary by more than plus or minus 1.0 m,
k) streamer depth exceeds 1.0 m from specified operating depth,
l) air pressure falls below 1850 psi from a normal 2000 psi operating pressure.

2.6.11 Seismic Sensor Data Acquisition Not To Continue

Acceptable data recording will not continue for a specified sensor if the following conditions occur:

a) cable noise exceeds specification,
b) 1 or more traces in a 24 trace system, or 2 adjacent traces, or any 2 traces among the near 6 traces are defective as defined in section 2.6.2,
c) more than one streamer depth detector is inoperative,
d) streamer depth varies ore than plus or minus 1.0 m from specified operating depth, or more than 1.0 m between adjacent depth transducers,
e) or more successive misfires, or more than 25 misfires during any 120 seismic shots,
f) misfire rate exceeding 5% on any line,
g) malfunction of any non-redundant unit of the source array or its sensors for more than 10% of any line, or variation in depth of source by more than plus or minus 1.0 m,
h) air pressure falls below 1900 psi from normal 2000 psi,
i) primary navigation system malfunctioning, or calibration not verified,
j) single trace, monitor camera, data logger, or extended header printout fail for more than one hour,
k) off-line variation is greater than 100 m except when avoiding obstruction.

2.6.12 Reshooting

Reshooting will be carried out in such a manner that a full fold stack of data acquired within the specifications of this document will be gathered on a continuous basis.

2.6.13 Documentation and Reports

Recorded production and test data will be identified such that no ambiguity can exist. Each monitor record will be stamped, or any appropriate alternative method containing the following information:

a) date, line and shot number, and channels displayed,
b) reel and file numbers,
c) misfires, cable or group malfunctions, instrument troubles, missed time breaks,
d) possible sources of unwanted energy, position of other boats in the area with respect to the cable, or other phenomena which could affect the data quality,
e) trace numbering convention used, including description of auxiliary traces, if necessary.
f) Observers will keep neat and legible logs showing:
g) position of energy source with respect to the boat and hydrophone group nearest the vessel on each line, and highlighted when changes are made,
h) date, time of each shot, area identification, and line numbers,
i) source and detector depths,
j) reel, file and shot point numbers,
k) recording system fixed parameters,
l) position of all variable control settings,
m) adequate description of all unusual circumstances surrounding any change affecting data quality.

2.6.14 Recording Instrument Specifications

The system will conform to manufacturer's published specifications, except that system noise at maximum gain will be no more than 1.5 microvolts RMS, crossfeed separation shall be greater than 80 dB at fixed gain, AC gain step accuracy will be 0.025% step-to-step gain, and harmonic distortion shall not exceed 0.0%.

Appropriate technical manuals along with schematics shall be maintained on board for all equipment used. Instrument test schedules and procedures shall adhere to manufacturer's recommendations and industry standards. The quality control supervisor may change test schedules as needed.

Digital/multiplexed streamer systems shall be capable of efficiently producing daily, weekly, and monthly tests to determine dynamic range, pulse test, harmonic distortion, gain accuracy, crossfeed, system equivalent input noise, gain linearity, header recording quality, and tape skew.

2.7 Data Concerning The Top 100 Meters Below The Seafloor

If the bandwidth of the MCS system does not allow recording of frequencies up to several kHz then an independent system should be used to evaluate the shallow geology (see section 2.5.1).

Shallow geology at the site can be assessed using, for example, a sub tow boomer acoustic source, single channel receiver and graphic recorder (or approved equivalents). Example instrument specifications and settings are set out below:

Source	
Type:	EG&G Sub Tow Boomer
Power Supply:	EG&G 231/232
Transducer/Source Depth:	3 m
Hydrophone:	Integral
Recording Unit	**Make/Model**
Graphic Display:	EPC 3200s
Fire Control:	Gardline FCU
Time Variable Gain:	TSS 307
Band Pass Filter:	Krohn-hite 3500
Swell Filter:	TSS 305
Operating Parameters	
Energy/pulse:	300 J
Firing Cycle:	375 ms
Recorder Sweep:	125 ms
Timing Lines:	12.5 ms
Print Delay:	150 ms
Band Pass Filter:	1-6 kHz

Table 1 presents characteristics of a number of other potentially acceptable single channel analog system sources.

	Fundamental frequency	Bandwidth	Resolution (m)	Penetration (m)
Huntec Deep Tow Boomer	1.5-3.5 kHz	0.2-5.5 kHz	0.2	15-80
Pingers	3.5 kHz	1.4-4.5 kHz	0.6	5-40
1 kJ sparker (multi-tip)	0.8 kHz	0.2-2.0 kHz	2.0	100-150
Mini sleeve exploder	250 Hz	60-1000 Hz	1.5	800-1000
13 kJ sparker (9 tip)	100 Hz	40-300 kHz	2.5	1000-1200
Airgun array (4 x 40 cu. in)	80 Hz	10-200 Hz	4.0	1500-2500

Table 1. Characteristics of commonly used seismic sources

A seismic velocity of 1600 meters per second is assumed in converting travel times to depths, in view of the generally soft nature of the superficial sediments. In most circumstances, this figure is likely to be within 5 % of the true value. Laterally, plotting accuracy is affected by errors of towing offset, of the positioning system and of the limitations of a omnidirectional source. Moreover, geological complexity, reflector depth and survey line spacing all affect accuracy and in ways which are not easily predictable. As a broad guide, practical limits on this survey are estimated at 0.2 meter to 10 meters depth and 0.5 meter for reading accuracy, 0.5 to 1 meter for contour interval and 10 meters for plotting accuracy.

Analog subbottom seismic reflection profilers: Subbottom reflection profiles shall be acquired in a manner that will allow optimum detection and resolution of subsurface anomalies and structural information within two target depth intervals of 0.05 (shallow) and 1.0 (medium) seconds, two-way travel time. The subbottom profiling systems should be complementary; no gaps should be present over the entire 1.0 second interval of data required. The subbottom profiler should employ a rapid-firing, single or multiple frequency source/receiver system centered within a range of 0.8-20 kHz (e.g. tuned transducer, boomer, sparker). A 19-inch, dry paper, flatbed recorder shall be used to record a continuous analog display of subbottom information to 0.05 seconds (minimum), two-way travel time. Alternative data acquisition systems and strategies will be considered, with approval by the Science Operator.

2.8 Interpretation

It is important that all the data relating to gas hazards at a proposed site be evaluated by an independent authority in gas hazards. This authority could be an individual, a small group of experts, or a company. Selection of this authority will be made by the Science Operator.

2.9 Magnetometer

Magnetic data are not required for detecting shallow gas hazards, but may be helpful in locating man made iron objects if they exist. If there is reason to think that man made hazards exist a magnetometer survey may be specified by the science operator. If it is then the instrument should be sufficiently sensitive to resolve unambiguously at least a two gamma anomaly with respect to background intensities. To optimize target resolution, the sensor should be towed at a constant height above and as close to the seafloor as possible in a manner consistent with overall survey strategy. If used, an operator's log listing survey parameters (i.e., tow height, vessel speed, cable length out) will be maintained.

3. DRILLING PROCEDURES IN SHALLOW WATER

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Problem Definition and Assumptions

The problem is defined as one of assuring ship and personnel safety if ODP drilling operations are to be conducted in shallow water areas where the existence of hazardous amounts of shallow gas are deemed to be geologically possible, i.e. sedimented continental margins, but not coral atolls or shallow mid-ocean ridges, etc.

The situations of interest break down into three general cases:

Case 1: Water depths greater than 200m

Only existing ODP safety preparations and precautions would apply to any site to be drilled in water depths greater than 200m which passed PPSP review. It is assumed in this case that inadvertent release of shallow gas would not present an abnormal safety hazard to the ship or crew since the possibility of a dangerous surface gas "boil" or flammable gas at the sea surface would be effectively mitigated by the 200m-plus water column.

Case 2: Water depths less than 200m, and seafloor penetration less than 1000m bsf

Special technological requirements to allow drilling such sites include:

a) sonar monitoring of the borehole at the seafloor for earliest possible detection of released gas bubbles, and,

b) an emergency pipe release capability to allow rapid drive off even if the pipe is stuck in the hole or there is thought to be insufficient time to safely retrieve the drill string.

The assumptions made in this case are that the site could only be accepted for drilling if a tightly specified seismic survey processed specifically to identify shallow gas pockets had been done and no gas hazards were identified. Such surveys are expected to be unreliable to identify gas hazards at depths greater than 1000m subsurface.

However, because of the unpredictable nature of shallow gas, prudence dictates that the two precautions above be available as a final safety measure for protection of the ship as drilling proceeds.

Case 3: Water depths less than 200m, and seafloor penetration greater than 1000m bsf

Special requirements to allow drilling at such sites include items 1) & 2) above, plus:

3) adequate BOP/well control measures to contain and kill any type of hydrocarbon kick if previously undetected pressures are encountered at penetration depths greater than 1000m bsf.

The inclusion of full well control capability implies that conventional oilfield casing and seal systems will be used and that adequate casing, cementing, sealing, and pressure testing steps will be taken in the installation of the casing, BOP and riser to guarantee pressure containment in the event of a kick.

Technology Assessment

Sonar monitoring of the borehole at the seafloor

The Mesotech sonar used for reentry work is deemed suitable by the manufacturers as a gas bubble detector tool. The frequency (675 kHz) is within the range of the recommended frequencies for gas bubble detection. Gas bubbles make very good sonar targets and are expected to be detectable even in murky water where TV monitoring would fail. Resolution of the system would be limited to individual bubbles about 1.5-2 inches diameter or smaller bubbles making a cluster at least that size. This resolution limit is controlled by video presentation (pixel density), rise time of the transducer, and angular resolution of the transducer assuming a target distance of about 10m.

Delivery of the sonar to the seafloor and aiming it at the "wellhead" could be accomplished by mounting the sonar on a pan and tilt mechanism and attaching to the clump weight of the taut wire. This would require either a second conductive line in the water with the taut wire or restringing the taut wire system with a suitable E-M cable. A simpler approach might be to hang the clump weight with the sonar over the side from a crane boom and string the wire to the sonar in a slack form suspended by a buoy in a manner similar to the deployment of water guns for VSP experiments. Either method could probably be worked out with minimal cost and difficulty.

Additionally sonar monitoring stations would have to be set up and monitored 24 hours a day if this early detection system was to have any real value.

It would also be advisable to do regular local current profiles at shallow water sites. Updated information on current directions would dictate the best choice of direction for driving off the ship if rapid abandonment was necessary.

Emergency Pipe Release Capability

Although a number of techniques to achieve emergency pipe release can be conceived the most attractive would be to acquire an off-the-shelf double shear ram BOP unit complete with a hydraulic accumulator unit from a rental company. The accumulator system would be sized to allow only two or three shear operations expected to be necessary in an emergency release situation. It would be necessary to modify the upper guidehorn to allow for mounting the BOP module in the guidehorn with the hydraulic accumulator system located on the main deck in the moonpool area. Modifications for mounting in line with the upper guidehorn are estimated at $25,000.

A typical BOP module and accumulator unit is available off-the-shelf from Petco/Weatherford for $2530/day rental. Thus the costs for one leg for this equipment would be about $215,000. It is reasonable to suggest that, given adequate advance preparation time, an alternative approach could be pursued by locating a salvage BOP/shear ram assembly plus accumulator system and modifying them specifically for ODP requirements at a one time cost of, perhaps, $50-60,000.

Well Control - BOP - Riser

The question of achieving well control capability for the ship when drilling in water depths less than 200m has occasionally been posed as if the shallow water (shallow by ODP standards) might present a low-cost approach not achievable for riser drilling as envisioned for more normal ODP sites. Unfortunately, this concept cannot be substantiated.

Shallow water riser drilling (less than 200m) would require only a handful of riser joints without buoyancy systems. The storage area required for the joints would not be significant.

However, this is virtually the only benefit to be expected in shallow water. In every other detail, well control capabilities would require the same equipment and shipboard modifications described in past riser drilling analyses: risers tensioners, BOP, rig floor BOP storage and deployment features, Koomey (or other) BOP control system, mud return and solids separator systems, mud logger system, etc. There is no "short-cut" system that can be expected to provide adequate well control capabilities to contain and allow remedial action necessary to kill a gas kick. Furthermore, if some novel, "poor boy" well control system could be invented for ODP's special requirements in these cases, it is highly unlikely that offshore oil and gas regulatory bodies would grant approval for use of such a system within their jurisdictions. Any such request might, in fact, backfire and cause such an agency to take a closer look at ODP drilling operations within their waters, resulting in undesirable new regulations for ALL ODP drilling planned in those areas.

Full well control capability would also require control over preferential release of downhole pressures up the drill string while conducting wireline coring operations. An additional backflow preventer would have to be integrated into the drill string to contain pressure during those instances when a core barrel is in place holding open the standard (or LFV) float valve and the pipe is open ended at the top, e.g. when stabbing the sinker bars to go after a core barrel. This requirement is not difficult. If off-the-shelf equipment is not available that mates with ODP wireline core barrels, a variation of the LFV could be developed at minimal cost which could be expected to serve the purpose.

Estimating the cost and shipboard space impact for any switch to riser/BOP drilling capabilities has already been done during the Riser Workshop in April 1987. Similar analysis work would be done in pursuit of the Deep Drilling RFP currently in the hands of several prospective vendors. Application to shallow water/shallow gas objectives would follow similar requirements except for the length of the riser and the load rating of the riser tensioners. Each of these studies, even in their most preliminary stages, suggests that major and expensive changes to the current shipboard configuration would be required. Space for the science laboratories would certainly be impacted.

4. CONCLUSIONS

The main conclusions from this meeting were:

1. Open-hole drilling in shallow water is reasonably safe if proper hazards surveys are conducted and combined with proper data processing and interpretation.
2. Hazards Surveys must be a requirement for ODP drilling on sedimented shelves in water depths of 200m or less.
3. Sub-bottom penetrations at those depths, without BOP and mud-weight capabilities, must be limited to 1000m.
4. Operational procedures for shallow water drilling such as: dropping the drill string, monitoring the seabed for gas escape, and safety contingency plans must be developed.
5. Interpretation of the survey data in terms of shallow gas hazards should be made by experts in the field who are also not associated with the scientific proposals justifying the program.
6. ODP's slim, open-hole drilling from a dynamically positioned vessel is a relatively safe method for shallow water operations but blowouts must be avoided.

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