DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD 1975/122

WESTERNPORT SEISMIC PROFILING SURVEY,

VICTORIA

1973

by

B.H. DOLAN

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SUMMARY

The Bureau of Mineral Resources, Geology & Geophysics (BMR) carried out a shallow-water, high-resolution seismic profiling survey in Westernport, Victoria. Seismic reflection and refraction techniques were employed. Records were obtained in water as shallow as 1 m, and achieved a resolution of 1 m. Boundaries between sedimentary formations, some of which are aquifers, were recorded to a depth of up to 120 m. The refraction technique provided velocity data on these formations and the underlying rock.

1. INTRODUCTION

The aims of the survey were to provide seismic cross-sections of Westernport Bay to help delineate aquifers and other geological features under the bay, and to evaluate the effectiveness of the shallow seismic profiling system by correlation with borehole data. The geological information is to be used by the Victorian Mines Department as part of their geological model of the aquifers in the Westernport area. The Western Study Group of the Environment Protection Authority is also interested in this information for their study.

The investigation was carried out by a party from BMR consisting of B.H. Dolan (geophysicist and party leader), A.B. Devenish (part-time), P.V. Mooney (technical officer), and S.J. Hall (field hand). P.J. Gunn and J.J. Carillo-Rivera of the Victorian Geological Survey provided assistance with geological information and position fixing for the vessels. The vessels for the survey were the Melbourne and Metropolitan Board of Works boat Investigator, which had been used on a previous BMR Survey (Dolan, 1973) and the R.V. William Buckland belonging to the University of Melbourne.

2. GEOLOGY

The geology of the Westernport area is described by Jenkin (1962). A simplified stratigraphic sequence taken from Jenkin is shown below.

TABLE 1

Stratigraphic sequence in the Westernport area

CAINOZOIC Quaternary		Mangrove swamps, salt marsh and tidal mud flats. Contemporary beach deposits. Swamp deposits and alluvium. Cranbourne sand and similar sands near Lang Lang. Fluviatile deposits including Cardinia sand. Warneet beds and Granville gravels.
Tertiary	Pliocene to Miocene	Marine sands at Warneet. Baxter sandstone and equivalents on French Island and at Lang Lang. Sherwood marl and Flinders limestone.
	Oligocene to Eocene	Carbonaceous clay, sand, and gravel with seams of brown coal. Basic volcanics (Thorpdale volcanics) and associated sediments. Carbonaceous clay, sand, and gravel with minor brown coal.
MESOZOIC	Cretaceous and/or Jurassic	Feldspathic sandstone and mudstone of the Strzelecki Group including the Wonthaggi coal measures and the Rhyll arkose.
PALAEOZOIC	Devonian	Granite and granodiorite
	Silurian to Ordovician	Mudstone, sandstone, shale, and quartzite

The main aquifers in the area are the Sherwood marl and the Thorpdale basalts.

3. PRINCIPLES OF THE TECHNIQUES

The reflection method

In the reflection method a pressure wave is introduced into the water by a transducer. The frequencies of this energy (100-2000 Hz) are such that the wave will pass through sedimentary layers. Energy will be reflected at boundaries between media of contrasting acoustic impedance, which depends mainly on the density of the sediment.

The amplitude of the reflected signal increases with the contrast in acoustic impedance. For example a boundary between sand and silt would result in about 10-20% reflection of the pressure wave, whereas a boundary between sea water and average sand would result in about 30-40 percent reflection (Taylor Smith & Li, 1966).

The reflections are received by a pressure-sensitive transducer array (hydrophone) towed by the vessel, and are recorded graphically in a time scale. The pulses are transmitted regularly at short intervals (less than one second) as the vessel moves at a constant speed of about 5 knots across the area of investigation. Reflections from a boundary are therefore recorded continuously. The record produced looks somewhat like a geological section but with the 'depth' scale actually a time scale (Plate 3). The true depth is the product of half the time and the average velocity. For water this velocity is approximately 1.5 km/s and varies with salinity and temperature. For sea water in a temperature range of 0-30°C this value is correct to 4 percent (Matthews, 1939). The velocity in unconsolidated sediments usually ranges from 1.5 to 1.8 km/s, increasing with the degree of consolidation (Shumway, 1960). Consolidated sediments, igneous rocks, and metamorphic rocks have velocities from about 1.8 to 7 km/s.

The resolution is affected by the wavelength of the transmitted energy, the existence of additional interfering transmissions, and interference to the transmitted and received signals by signals arriving by other than direct reflection. The signals received from sub-bottom horizons are often affected by interference from 'multiples', signals from some horizon which reflect off the air/water interface and are again returned from the water bottom. In deep water, i.e. where the water depth is greater than twice the deepest sub-bottom reflections, multiples do not pose a problem, but as the water depth decreases the problem becomes greater (Sargent, 1969).

Once a horizon is clearly identified the accuracy of depth determination depends on measuring the time to the leading edge of the pressure wave reflected from that horizon and knowing the average velocity.

The refraction method

In the refraction method the transmission and reception transducers are moved apart while the pressure pulse is being transmitted at regular intervals. By recording the arrival of the energy on a time scale a measure of the velocity in the water and underlying formations can be determined. The depth to a formation with a higher acoustic velocity can be interpreted from this information.

A plot is made of the arrival time against distance. From this plot a measure of the velocity in a formation is made by a line of best fit. The accuracy of the determination is affected by irregularities in the refractor. Generally marine sediments are sufficiently horizontal to permit a fairly accurate ($\pm 3\%$) determination of velocity to be made. The intercept of the line of best fit to time axis is called the intercept time. The depth to a refractor is a function of the velocities in the underlying and overlying layers, and their respective intercept times.

For the simple case of a single layer (velocity V_o) overlying a bedrock refractor (velocity V_1) the depth to bedrock, Z_o, is given by:

$$Z_o = \frac{TV_1 V_o}{2\sqrt{V_1^2 - V_o^2}}$$

where T is the intercept time.

For the general case of multiple layers overlying the bedrock refractor, the thickness of the n^{th} refracting layer, Z_n, is given by:

$$Z_n = \tfrac{1}{2}\left[T_{n+1} - \sum_{m=o}^{m=n-1}\left(\frac{2Z_m}{V_{m,\,n+1}}\right)\right]V_{n,n+1}$$

where T_{n+1} is the intercept time of the underlying refractor,

Z_m is the thickness of an overlying layer,

$V_{m,n+1} = \dfrac{V_{n+1} \cdot V_m}{\sqrt{V^2_{n+1} - V^2_m}}$ is the velocity conversion factor for the m^{th} of the (n-1) overlying layers,

and $V_{n,\,n+1} = \dfrac{V_{n+1} \cdot V_n}{\sqrt{V^2_{n+1} - V^2_n}}$ is the velocity conversion factor for the n^{th} layer.

The depth to a particular refractor is then obtained by summing the thicknesses of each of the overlying layers. The method of computation is given by Hawkins (1961).

There are two main limitations of this method:

(a) it will not detect a low-velocity layer underlying a high-velocity layer.

(b) it is difficult to resolve a thin layer between a low-velocity and a high-velocity refractor.

4. SYSTEMS USED BY BMR

BMR has been carrying out development of a reflection profiling system for obtaining high-resolution records in shallow water for engineering and shallow-marine geological investigations. The depth of investigation required was at least 30 m of sediment in water depths from 30 m to 1 m or less.

Existing seismic profiling systems were found to be inadequate, principally because they had been designed for deep penetration and lower resolution than our requirements, and as a result the duration of the transmission pulse was longer and predominantly low frequencies were used.

As part of the development program a number of different types of transducers were examined. One transducer which has been modified and used successfully is the 'sparker'.

The sparker uses an electric discharge in the water to produce the pressure pulse. This pulse is due to the sudden production of 'vapour' resulting from the high current density and the electrolytic and heating effects at the discharge electrode (Caulfield, 1962). This discharge is produced by a bank of capacitors charged up to 4 kV.

The waveform of the pressure pulse as a function of time produced by the sparker is determined principally by the amplitude and duration of the discharge current. The sparker used by BMR for high-resolution work in shallow water discharges 0.4 kJ and produces a peak pressure of the order of 100 kPa at 1 metre. The duration of the event is about 1 ms and the predominant frequencies are between about 0.1 and 4 kHz.

The energy transmitted by a sparker is a series of pulses rather than a single pulse. The additional pulses are caused by the collapse of vapour bubbles and surface reflections. The extra pulses result in a single horizon giving rise to a number of reflections, thereby confusing the data. Multiple reflections in shallow water add to this confusion.

Methods of reducing this bubble effect were investigated in an attempt to produce a single pulse of short duration. This would enable both high resolution and easier discrimination of multiples from primary reflections.

An effective means of reducing this effect and producing essentially a single, sharp pulse for low energy levels was found by placing the sparker in a fabric-reinforced rubber tube. The reduction in the bubble pulse was due principally to loss of energy of the expanding vapour bubble by inelastic deformation of the rubber tube.

To produce a single short pulse it is important to tow the sparker so that its depth is equal to ¼ the wavelength of the transmitted pulse. This will result in the surface reflected wave, (which undergoes phase reversal on reflection) reinforcing the second half of the pulse.

A linear array of hydrophones rather than a single element was used. By selection of a suitable spacing and length the array will enhance signals at right angles to the vessel's track and reduce the noise from the vessel and turbulence.

For high resolution and enhancement of the reflected signals the depth of the hydrophone is critical. The depth of the hydrophone should be ¼ the wavelength of the reflected signals. This will result in the shortest signal length without destructive interference.

At the beginning of the survey a number of filter settings and two energy levels, 0.4 kJ and 1.0 kJ, were used in order to determine the best configuration for this area.

The higher energy level did give some improvement in depth penetration, but owing to the lack of resolution caused by the resultant bubble pulse it was not used any further. The filter settings used were in the band 0.1 to 2 kHz. In areas of shallow bedrock the higher frequencies 0.4 to 2 kHz produced adequate penetration and good resolution. In the northern part of the bay the best results, being a compromise between penetration and resolution, were obtained using a setting of 0.2 to 1.0 kHz. This setting also provided the best noise rejection in this environment.

Attempts were made to record the reflection signal on a Sanyo analog magnetic tape recorder. This is a commercial stereo tape recorder. One channel was used to record the unfiltered, amplified hydrophone signal, the other to record a reference signal from the EPC recorder. This reference signal is used to synchronize the EPC recorder to the tape recorder when the tape is being played back. Synchronization is essential to produce a coherent record.

These attempts were only partly successful. The hydrophone signal was recorded and recovered but the synchronization failed. This was due to noise on the reference signal recording, which caused distortion of the signal and loss of coherence on playback.

5. RESULTS

Plate 1 shows the survey location and Plate 2 shows the location of the sparker traverses and the refraction positions. Plate 3 shows a sample reflection record and Plate 4 some sample refraction records. Plates 5 and 7 show the sparker cross-sections. The vertical lines indicate position fixes. Table 1 gives the results of the refraction investigation.

Table 1

Results of Refraction Investigation

Position	Velocities (km/s) in refractor	Depths (m) to refractor rel. to Sea Level
A1	1.50	0
	3.82	39
B1	1.50	0
	1.66	11
	3.76	33
B2	1.50	0
	3.56	19

B3	1.50	0
	3.82	11
C1	1.50	0
	1.84	4
	3.2(?)	69
C2	1.50	0
	1.70	16
	1.92	65
C3	1.50	0
	1.77	4
	1.93	17
D1	1.50	0
	1.77	14
	1.84	63
D2	1.50	0
	1.81	11
	1.95	13
	3.92	240
D3	1.50	0
	1.79	3
	1.87	21
D4	1.50	0
	1.82	3
	1.96	22
E1	1.50	0
	1.89	21
	3.37	57
E2	1.50	0
	1.83	28
	3.40	104
	4.28	148

All the velocities quoted are apparent velocities (measured only in one direction). Over most of the area surveyed the dips in the sedimentary formations are so small (as shown by the reflection results) that they would not significantly affect the velocity measurements. Also the velocities are averaged over a distance of at least 100 metres. The velocity of sound in water was taken as the standard for the other velocity determinations.

A high-velocity refraction was noted at C1. The signals are very weak, which may indicate attenuation of the signal through the overlying formations or that the refractions come from a relatively thin layer underlain by low-velocity material. Apart from C1 and E2, where a deeper high-velocity refractor was identified, all the other seven high apparent-velocity determinations lie between 3.37 and 3.92 km/s. These variations could be due to variations in the true bedrock velocity or variations in the dip of the refractor. In the latter case the depth determinations, which are based on the true velocity, could be in error by an extra 5 percent. Errors in reading the intercept time and the apparent velocities from the records together with the error due to dip could combine to give a total error of 15 percent.

For convenience the bay is divided up into five zones based on the nature of the reflection results:

(A) The area bounded by Tankerton Jetty, Tortoise Head, Cowes, Point Grant, Flinders and Stony Point.

(B) The area bounded by Tankerton Jetty, Cowes, Newhaven, and Settlement Point.

(C) The area between Settlement Point and Sandy Point (French Island).

(D) The area north of French Island between Sandy Point and Scrub Point Trig.

(E) The area known as the north arm between Quail Island and Tankerton Jetty.

The results in each of these areas are described separately.

Area A

In this area (Plates 5 and 6) the records show a shallow reflector over all the area, with little or no sediment cover. No clear reflections are visible below it. The refraction traverse A1 indicates a high-velocity refractor immediately under the water, with a velocity of 3.82 km/s. Such a velocity would be expected in the weathered and jointed basalt which crops out on shore.

Area B

In the area between Rhyll and Cowes the deepest reflection recorded was from 18 m below bottom (Plate 6, 1220 to 1330 on 29/8). This reflector crops out on the bottom near Cowes and Red Bluff on French Island. The refraction results show a high-velocity refractor (3.56 to 3.82 km/s) underlying 22 m of sediment at B1 and cropping out at or near bottom at B2 and B3.

From 1230 to 1245 on 29/8, and 1105 to 1125 and 1225 to 1250 on 30/8 (Plate 6), there is a reflector which is almost horizontal over a long distance. It is generally at a level of about 12 m below sea level.

Between 1225 and 1305 on 30/8 there are weak irregular reflections from a depth of from 18 to 40 m below bottom. At 1305 this reflector crops out. It is considered to be the basalt.

Area C

A sudden change in the character of the records occurs going from area B to C at 1425 on 30/8 (Plate 6). The intensity of the signals decreased significantly, indicating a change in the bottom conditions. About 1 minute after this a deeper sub-bottom reflector was recorded from depths of about 30 m below bottom. The reflector rises to the east. Between 1445 and 1500 the only sub-bottom reflectors are shallow, but at 1510 a reflector was recorded at about 30 m below bottom; it dips to a depth of 50 m at 1520. From 1532 to

1545 a reflector rises from 50 m to 30 m. The refraction results show no clear refractions from bedrock except possibly at C1, indicating that bedrock is quite deep at C2 and C3, probably deeper than 100 m.

Area D

The records in this area (Plates 7 and 8) are characterized by several strong continuous reflectors, extending over long distances, generally gently dipping and as deep as about 130 m in water as shallow as 1 m. These reflections are remarkably strong, very continuous, and without any interference from multiples.

An energy level of 0.4 kJ and a filter setting of 0.2 to 1 kHz was employed. The long, continuous, gently dipping reflectors are considered to originate from boundaries between the different formations within the Cainozoic sequence. For example the boundary between the relatively unconsolidated Quaternary deposits and the more consolidated Tertiary sands and sandstones should provide a good reflecting surface, as should the boundaries between the Baxter sandstone and the Sherwood marl.

The less continuous weaker reflections beneath the other reflections are considered to be reflections from the Mesozoic basement or the volcanics.

Because of the continuous nature of most of the reflections it would be possible to trace a formation along most of the seismic cross-section once it has been identified clearly by two or three bores placed along the lines.

A number of possible faults and bedrock highs are indicated on the cross-sections.

The only refraction result which shows a refractor velocity greater than 1.8 km/s is at D2. This shows a depth of 240 m to a refractor with velocity of 3.92 km/s. The other records at D1, D3, D4 do not record the bedrock refractor.

Area E

In this area some of the reflectors recorded in area D crop out and an area of only shallow reflectors is again encountered near Tankerton Jetty. At 1522, 31/8 (Plate 7) near Tankerton a reflector rises steeply to the south. This may indicate the edge of a fault.

A number of boreholes are located in this area. One, BPM2, is almost on line 31/8 at 1322 (Plate 7) and shows a boundary between marl and basement at a depth of 24.4 m which correlates with a reflector at a similar depth. Under this reflector no others are observed.

The refraction results in the north of this area at E2 show a depth of 104 m to a refractor of velocity 3.4 km/s. This could correspond to the Silurian basement which occurs at shallow depth on shore.

The cross-sections presented have a vertical and horizontal time scale. To convert the vertical times to depth, halve the vertical time and multiply by the average velocity to the reflector. The velocity of the water is 1.5 km/s and the average for the sedimentary formations is generally between 1.8 and 2.0 km/s, based on the refraction work and analysis of reflector anomalies that correlate with water depth variations.

When a horizontal reflector underlies a deep channel cut into the sedimentary sequences it appears to bend downwards under the channel. This is due to the longer travel time through the low-velocity water. The velocity in the sediment is given by $V_s = V_w \cdot t_w/t_s$

where V_s = velocity in sediment

V_w = velocity in water

t_w = travel time through a section of water

t_s = travel time through a section of sediment with the same thickness.

6. CONCLUSIONS

A BMR shallow-water high-resolution sparker profiling system was used in Westernport Bay to obtain high-quality records of the sedimentary sequence under the bay to depths up to 120 m. The records were obtained in water as shallow as 1 m and achieved a resolution of 1 m. The records defined positions where some of the formations crop out under the bay. Areas of shallow and deep bedrock were defined using a combination of reflection and refraction methods.

The BMR 0.4 kJ modified sparker system proved capable of penetration deeper than 100 m in Westernport while still achieving high resolution.

7. RECOMMENDATIONS

It is recommended that some cores of the sedimentary sequence be obtained along surveyed lines. These cores are necessary in order to accurately assess the capabilities of this system. The type of sediment penetrated and the nature of the boundaries that give rise to the reflections recorded are needed for this assessment.

These holes should be located on the northern part of the bay, for example at 1450 on 11/9. At this locality a number of reflectors were recorded and deep penetration was achieved.

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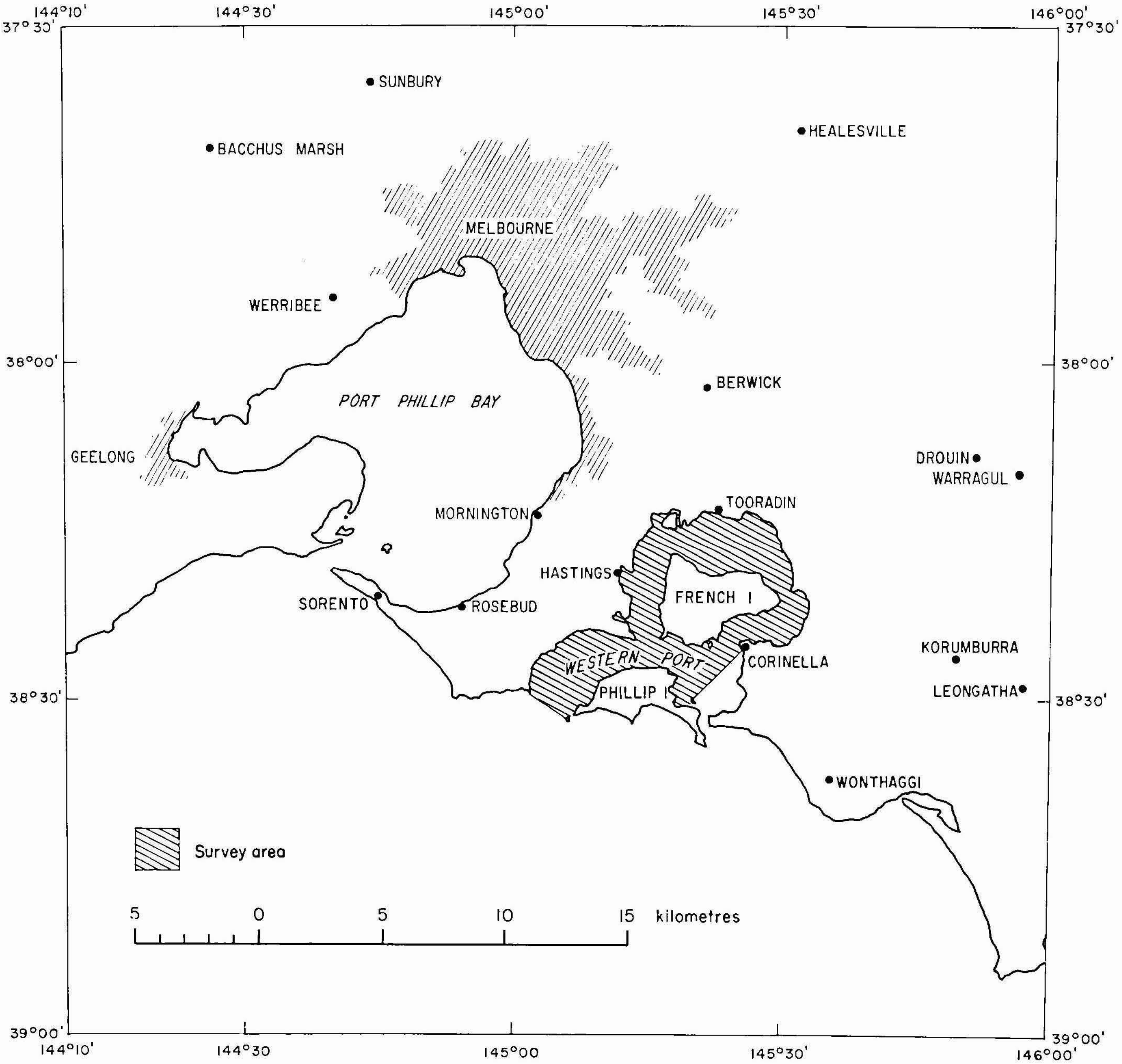
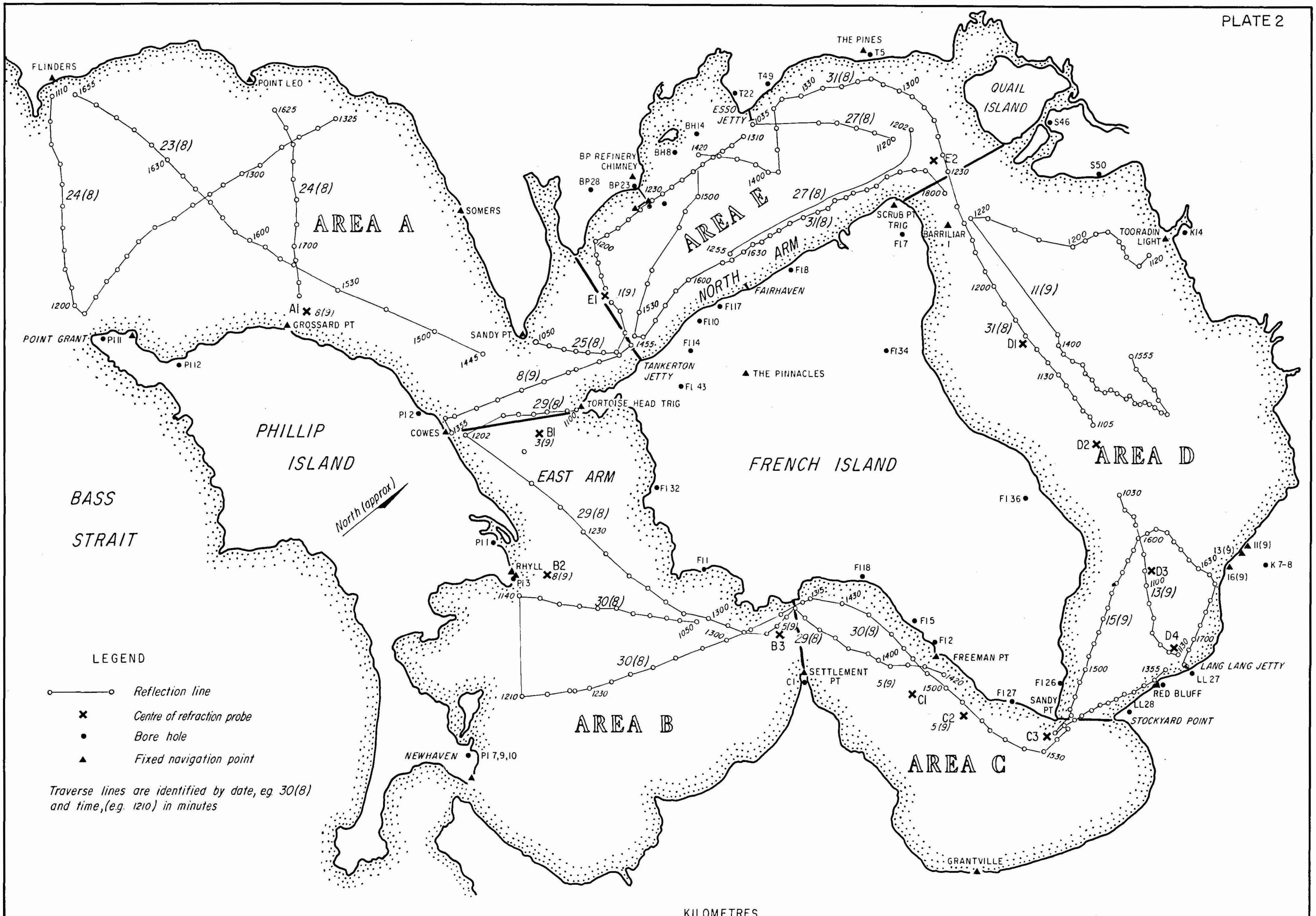
PLATE 1



WESTERN PORT SPARKER SURVEY
LOCALITY MAP

PLATE 2



LAYOUT OF TRAVERSES

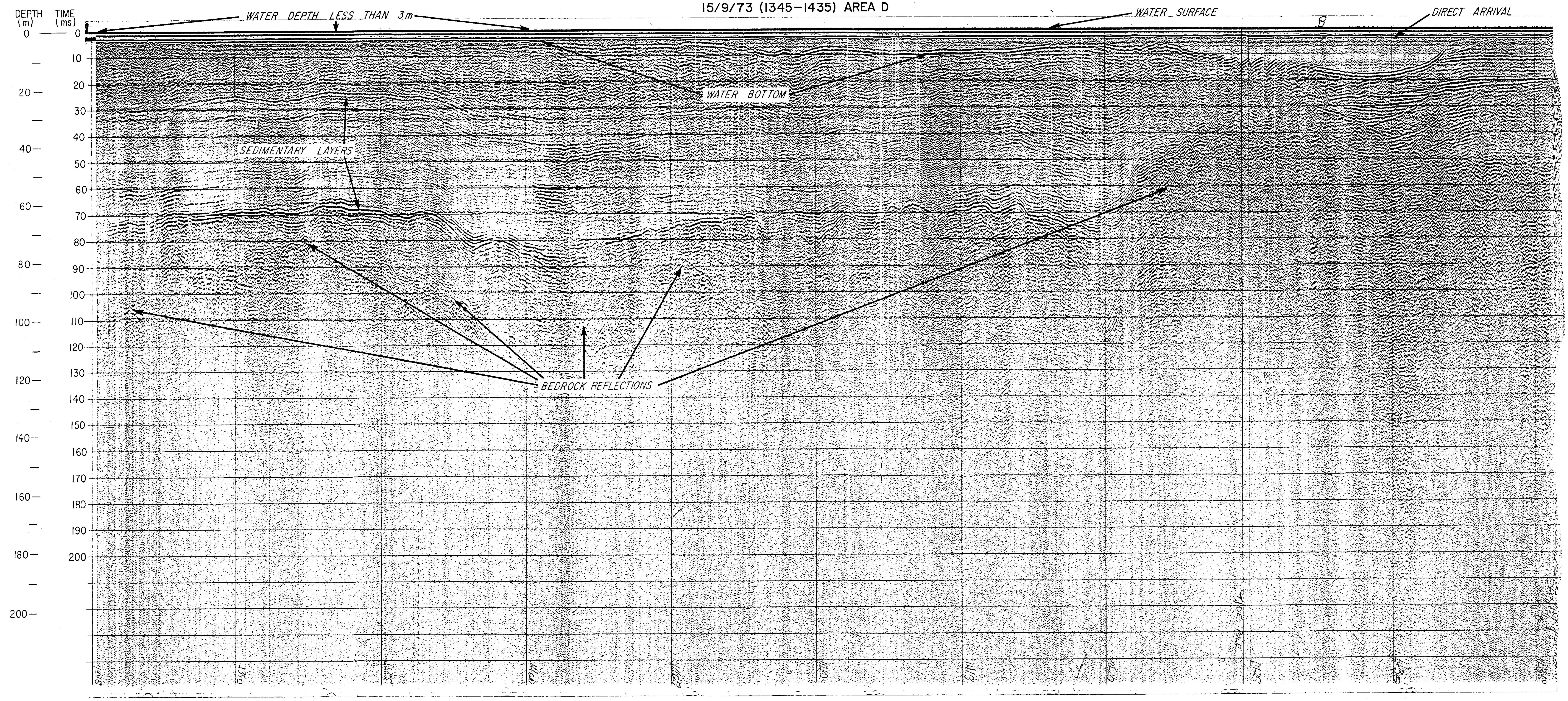
Record No 1975/122

J55/B5-116

PLATE 3

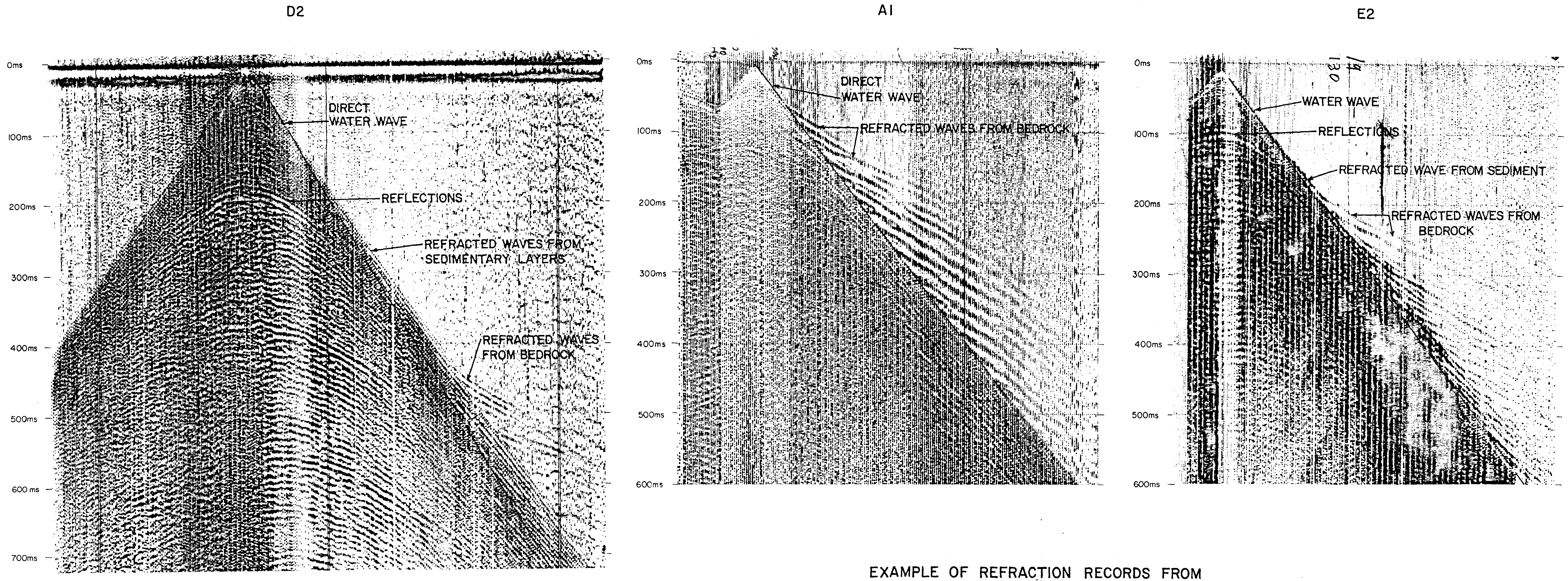
SAMPLE HIGH RESOLUTION RECORD FROM WESTERN PORT SURVEY

15/9/73 (1345-1435) AREA D



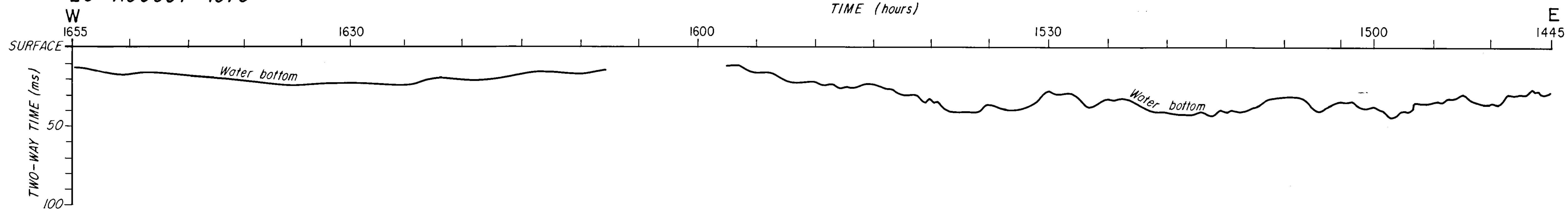
To accompany Record No. 1973/195 and 1975/122

G463-9



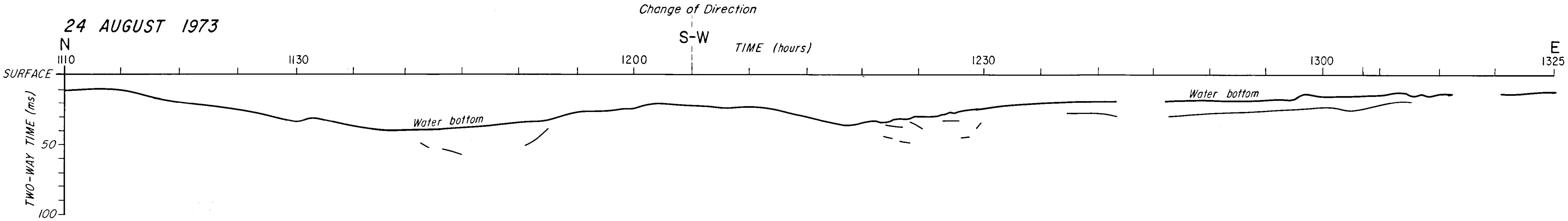
EXAMPLE OF REFRACTION RECORDS FROM WESTERN PORT SURVEY

23 AUGUST 1973



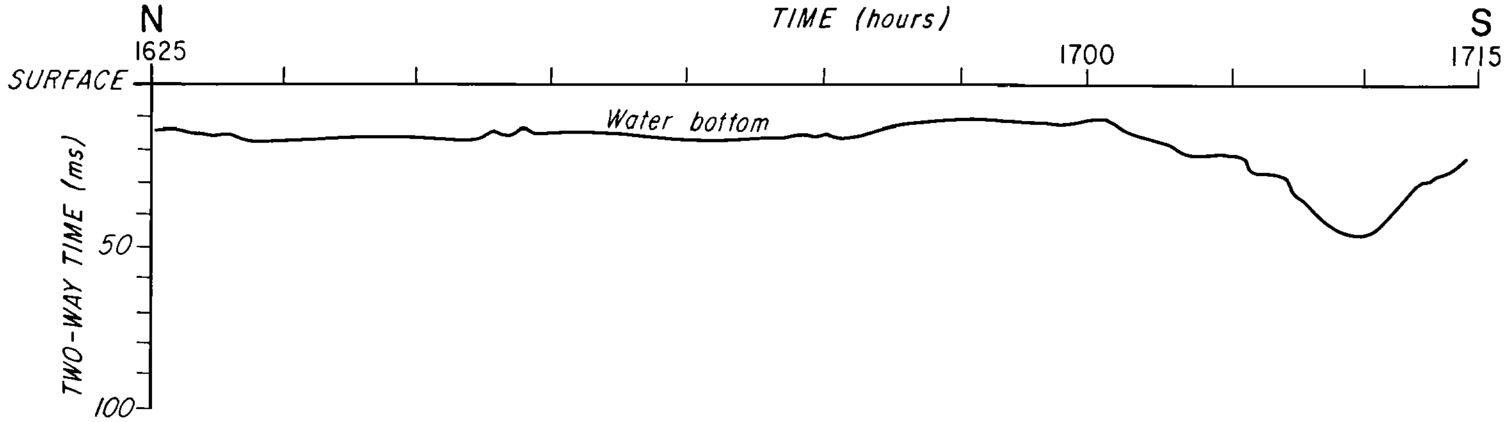
AREA A

24 AUGUST 1973



AREA A

24 AUGUST 1973



AREA A

Record No 1975/122

J55/B5-118

PLATE 7

Record No 1975/122

J55/B5-122

Record No. 1975/122

J55/B5-119