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WSRL-GD-48/88

AR-005-439

SIGNIFICANT DEVELOPMENTS IN THE DEFENCE OCEANOGRAPHY OF AUSTRALIA'S AREA OF INTEREST

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Approved for Public Release

NOVEMBER 1988

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DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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DSTO WSRL

GENERAL DOCUMENT
WSRL-GD-48/88

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M.V. Hall

ABSTRACT(U)

Over the past 3 decades, Australian Defence Departments have sponsored significant research effort on aspects of the marine environment that affect the performance of sub-surface defence systems. The reasons for this effort on "Defence Oceanography", and its achievements to date, are discussed and related to changes in the requirements of the Maritime defence forces. Sonar surveillance is discussed as an application of Defence Oceanography, and the environmental parameters that have an impact on this aspect of maritime defence are described. The progress that has been made by research into understanding these parameters is summarised with emphasis on the ocean areas around Australia. The two main objectives of the research have been (i) to contribute to a data base or climatology (mainly useful for parameters that vary predictably with time): and (ii) to develop algorithms from which randomly-varying parameters (that are remote in either space or time) may be predicted from observable conditions. As has happened in the past, advances in Defence Oceanography will stimulate technological innovations that will, in turn, generate new and unexpected questions about the marine environment.

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1. INTRODUCTION

The first matter to address is the meaning of the term "Defence oceanography". Despite its grammatical structure, it does not refer to a distinct "branch" of oceanography, such as "biological oceanography". It is simply used as a concise method of referring to the numerous topics within the various branches of oceanography that are regarded from time to time as being of some significance to the operation of Defence systems on and in the ocean. With equal logic, one could use terms such as "Defence meteorology" or "Defence optics". The reasons that the term for oceanography has gathered a following are probably that a huge effort is going into studying oceanography around the world for various reasons; and of this effort, the various Defence organisations in industrialised nations around the world sponsor a significant proportion.

There has been a great "technological change" in maritime warfare over the past few decades, stimulated of course by the second World War and the subsequent "Cold War", and made possible by the advances in electronics that have been a feature of the 20th century. Prior to this century there was no capability for underwater surveillance and the main form of remote sensing was the telescope, which assisted the human observer to detect, localise and classify significant objects within the field of vision. Advances in the science of electromagnetic propagation brought about radio and radar, while progress in piezoelectricity and acoustics enabled the introduction of underwater sonar, initially stimulated by the need to detect icebergs following the collision of the *Titanic* in 1912, some decades before radar was developed (It is an interesting coincidence that a search with a deep-towed side-scan sonar located the same vessel during 1985, at a depth of 4 km). Sound, rather than electromagnetic waves, is used for detecting underwater targets however (except for a few special cases) because, at useful wavelengths and frequencies, it is absorbed by sea-water far less than is any electromagnetic transmission. Sound has some disadvantages however:

(i) it travels far slower than light. The average speed of sound in water is only around 1.5 km/s, compared with 2×10^5 km/s for light. The echo from a target at a distance of say 5 km takes around 7 s to return to the echo-sounder/sonar; and

(ii) a sound wave is readily scattered or absorbed by the irregular surfaces of the ocean and many of the objects that exist in it.

Radar and sonar have both played important parts during maritime warfare over the past few decades, and are expected to remain important for the foreseeable future. Their importance to Australia has recently been reported in the following terms: "Australia requires a manifest ability to detect, identify, and track potentially hostile forces within our area of direct military interest ..... modern technology in the form of over-the-horizon radar (OTHR) offers the prospect of broad-area real-time surveillance of our air and sea approaches out to 1500 nautical miles. Another promising new surveillance technology is the towed acoustic array, which is especially useful against submarines in favourable water conditions ....."[1]. Radar and related research is sponsored by the DSTO Surveillance and Electronics Research Laboratories.

Since late 1987, sponsorship of most of DSTO's oceanographic research on parameters relevant to underwater weapons (such as mining and mine clearance) has been the responsibility of the Materials Research Laboratory. Systematic DSTO work in this field commenced early in 1988 and is expected to increase significantly over the next year or two.

Over the past few decades there has been a steady emphasis in the DSTO Maritime Systems Division (and its preceding organisations such as the Royal Australian Navy Research Laboratory) on predicting the performance of sonars within a given situation, and also on improving performance, by design changes, wherever possible. A conclusion drawn from these endeavours has been that the marine environment needs to be understood in considerable detail. In the Australian context, for example, this conclusion has been recently re-phrased as: "Australian hydrographic and oceanographic knowledge of our maritime environment is crucial to military operations in our own defence"[2]. Oceanographic parameters are

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[1] Dibb P (1986) "Review of Australia's Defence Capabilities" Aust Govt Publ Service, Canberra. Page 6.

[2] Ibid. Page 64

complicated functions of space; many of them fluctuate significantly with time (particularly in the upper layers of the water column); and some of them can have critical effects on sonar performance and mining operations.

2. OCEANOGRAPHIC PARAMETERS RELEVANT TO SONAR AND NAVAL MINING

In discussing "significant developments" in Australian defence oceanography it is reasonable to concentrate at this time on parameters relevant to sonar, and to simply list the parameters that affect naval mining. The scope of the sonar-related work is described in figure 2. The oceanographic parameters that are relevant to sonar performance are listed in figure 3; and in figure 4 are listed the particular aspects of sonar operations (or a more directly connected parameter) that are affected by the designated parameter.

The oceanographic parameters that are relevant to naval mining are listed in figure 5; and in figure 6 are listed the particular aspects of mining operations (or a more directly connected parameter) that are affected by the designated parameter.

The majority of the important parameters belong to the field of "underwater acoustics". The sea surface, the sea floor, and many of the objects within the water column are strong sound reflectors, since their acoustic impedances are quite different to that of sea water. Sound energy is therefore significantly reflected in ways that depend on the precise shape of these reflectors. Even within the water column, and in the absence of reflectors, sound waves travelling quasi-horizontally (which is usually the case for sonar) follow paths (refract vertically) in a manner that is very sensitive to the exact shape of the "sound-speed profile" (SSP), which in turn depends on the temperature and salinity gradients. Sound travelling quasi-vertically (from and to a depth-sounder for example) is not so sensitive.

A feature of early sonars was that, in the absence of a demonstrated requirement to do otherwise, the dimensions of the transducers (projectors and receivers) were comparable with the wavelength of the carrier signal (which was generally some tens of centimetres). As a result, the width of the transmitted beam was large (say 30°). The phenomenon of background noise; either reverberation (the reception of large numbers of small random echoes from inhomogeneities in the medium), or ambient noise, was therefore significant but could be studied in terms of averages over comparatively large regions. Initial research into the properties of the ocean therefore emphasized a coarse-scale approach. To *reduce* the background noise, and hence improve the performance of these sensors, the beamwidth was decreased by increasing the transducer sizes. The effect of this has been that, in order to be able to predict the larger sensor's background noise level, the noise or reverberation producing properties of the ocean must be re-examined in finer detail. The noise problem was not *"solved"* by reducing the beamwidths, since with increasing capabilities by platforms and weapons to act at great distances, it has become necessary to detect targets at longer ranges (that is, still at low signal-to-noise ratios). Thus, although decades have elapsed, the need for environmental information has not (yet) diminished.

The word 'sonar' is applied to either a passive (listening) system or an active (echo-ranging) system; and both types have been in use since before World War II.

Active sonar

In order that they could be of convenient dimensions, early active sonars operated at carrier frequencies of around 25 kHz (an "ultrasonic" frequency, just above the usual human audio-band). At this relatively high frequency, sound is strongly absorbed and scattered, with the result that the average detection range of submarines was only about 1 km. The average detection range was subsequently increased in the post-war period, partly by reducing the carrier frequency (to improve the signal to noise ratio). To maintain a comparable directionality, the size (and hence mass and cost) of the systems was increased commensurately.

The signal-to-noise ratio at an active sonar is determined by the following factors:

source strength (loudness) of the pings emitted by the projector;

transmission loss that occurs from the projector to the target. Transmission loss is the ratio of the power output of the projector to the intensity at a given point and is a function of range from the transmitter;

target strength (scattering cross-section) of the target;

transmission loss from the target back to the projector (which is generally the same as the outward transmission loss unless the vessels are over a steeply sloping bottom);

self-noise of the sonar; and

reverberation, a decaying noise-like signal heard by a receiver after every ping. Reverberation is caused by backscattering from sound-reflecting inhomogeneities.

With the advent of long-range guided torpedoes and submarine-launched missiles, it has become desirable to detect submarines at long ranges. The limited detection ranges that are achieved by modern active sonars in some circumstances are due to a combination of the following factors:

At typical sonar frequencies, beamwidths of realistically-sized transducers are such that significant reverberation is generated by biological scatterers such as deep-sea fishes with gas-filled swimbladders (in deep-water), or by the roughness of the sea-floor and sea-surface (in shallow water). An important consequence of reverberation being the effective background noise is that there is nothing to be gained by increasing the output from the projector (The reverberation also increases and the signal-to-noise ratio remains unchanged).

Since the transducer is affixed to the keel of the ship (it is very expensive to deploy otherwise), the following problems occur:

the receiver's self-noise is increased by the proximity of the ship with its moving parts;

propagation in the horizontal direction is liable to degradation by scattering and attenuation by gas bubbles generated by the moving ship and/or the wind; and also by downward refraction, when the water near the surface is heated and a negative sound-speed gradient is generated ("afternoon effect"). The effective horizon of the sonar can come in to a range of less than 1 km.

it is relatively easy for a submarine to remain partially hidden from the sonar by descending to the thermocline beneath the surface mixed-layer (the reasons for this phenomenon are discussed later).

the strength of the echo is decreased by twice the transmission loss that applies to the distance between the sonar and target.

Passive sonar

With the realisation that the detection ranges of active sonars appeared to be limited, there has been an emphasis (especially since about 1970) on making the best possible use of passive sonar, which is basically an "array" of hydrophones (underwater microphones). A passive sonar simply listens for noises radiated by vessels (usually from their propulsion systems), and can be either mounted on the sea-floor, affixed to a submarine hull, towed by a vessel, or dropped into the sea by an aircraft (the "sonobuoy", of which BARRA is a modern Australian example).

The signal-to-noise ratio at a passive sonar is determined by the parameters listed in figure 7.

For stationary sonars, the noise is generally the ambient noise due to the effects of wind-driven surface-roughness, biological organisms or distant shipping. For moving sonars, flow noise is also a contributing factor, especially at the lower frequencies. Ambient noise can be reduced by designing a (large) directional system that responds only to sounds from a particular (but controllable) direction.

Frequencies low in the audio band are often used (rather than higher or lower frequencies), for the following reasons:

sound at these frequencies travels long distances in the ocean since the frequency is low enough that the effects of absorption, scattering, and bottom reflectivity on transmission loss are small;

the wavelengths are small enough that it is feasible to build a highly directional array of hydrophones; and

ships and submarines radiate substantial amounts of noise at these frequencies.

3. GEOGRAPHIC PRIORITIES

The areas in which DSTO oceanographic research has been conducted have tended to reflect defence significance as perceived by the government of the day. Prior to 1980 there were emphases on (i) "focal areas" (areas where the concentration of shipping is relatively high) close to busy Australian shipping ports; and (ii) sea lines of communication. Oceanographic surveys (or more correctly, underwater acoustic and oceanographic measurements) were made at the sites shown in figure 8.

The "Radford-Collins" Memorandum of Understanding between the USA and Australia, which had been commenced and amended during the 1950's and 1960's, provided that Australia would be responsible for protection of "allied" trade during a global conflict over a large ocean area centred on Australia. The ramifications of such a policy were brought to the attention of DSTO oceanographers in the late 1970's. As a consequence, a program of oceanographic surveys was planned for the particular trading routes that had been overlooked during the first major phase. This program, "Project SEAMAP", was designed to conduct a survey along each of the routes shown on the map in figure 9, during both the oceanic summer and winter. The parameters that were measured are listed in figure 10. The first SEAMAP survey took place during summer early 1984; and by winter 1987 the surveys along the Pacific Ocean routes had been completed.

The publication of "The Defence of Australia 1987" (the Defence white paper) brought about a re-appraisal of geographic priorities. This document defined an ADMI (Area of Direct Military Interest) and also an APSI (area of Primary Strategic Interest). The map in figure 11 shows a cartographic interpretation of these two areas based on definitions contained in the White Paper. According to that document, global conflict is a remote contingency. The corollary of this judgment is that the ADMI is more important than the APSI to Australia's defence capability. Project SEAMAP, which gives emphasis to the APSI, has therefore dropped to a relatively low priority, and conduct of further SEAMAP surveys has been deferred indefinitely. Instead, DSTO oceanographic surveys will be conducted within the ADMI for the foreseeable future. Two were conducted in early 1988, and a third was scheduled for November 1988.

4. SOUND-SPEED PROFILES

The primary determinant of acoustic propagation is the shape of the Sound-Speed Profile (SSP) in both the water column and the sea floor, and whether or not the SSP varies significantly with horizontal position. A typical SSP in the ocean, an example of which is shown in figure 12, exhibits the following features:

(1) From the surface to a typical depth of several tens of metres (although occasionally zero), there is an isothermal (constant temperature) surface mixed-layer (SML) in which the sound-speed slowly increases with depth. In the Tasman Sea, for example, the Mixed-Layer Depth (MLD) has a median (50 percentile) value of 40 m, the 16 percentile value is 0, and the 84 percentile value is 55 m (the distribution is highly skewed).

(2) Beneath the SML, there is a "thermocline" in which the temperature, and hence sound-speed, both have negative gradients. At medium and low latitudes, the thermocline extends to several hundred metres in depth.

(3) At around 1 km depth, the temperature gradient becomes very small, the sound-speed gradient increases to zero, and the sound-speed has its minimum value (the depth at which this occurs is called

the "SOFAR" axis). Below the SOFAR axis, the sound-speed gradient continues to increase and approaches a value of 0.018 m/s/m at abyssal depths. At great depth (4 to 5 km, depending on the surface value) the sound-speed can increase to its value at the surface so that, providing the sea floor is sufficiently deep, the upper 4 to 5 km of the ocean layer is a refracting acoustic duct.

Seasonal and geographic variation

The shape of a typical SSP varies with both time and geographic position. At positions remote from fronts between different water masses, the major temporal variation is with time of year, except for a small (but nevertheless important) degree of daily near-surface heating. In the southern hemisphere, the temperature of the SML is a maximum during February and March (whence the "cyclone season" during that period), and the minimum occurs during August and September. The amplitude of the seasonal variation varies markedly with latitude, as may be seen in figure 13. At high latitudes (say 45°), SST (Sea-surface Temperature) ranges between 12 and 17° C, for which the corresponding range in Sound-speed is between 1498 and 1514 m/s. At low latitude (say 10°), SST ranges between 26 and 28°C, and the corresponding Sound-speed range is between 1537 and 1542 m/s.

The shape of the SSP tends to be related to the "dynamic height anomaly" of the sea surface, which is approximately the actual height of the surface relative to the geoid (the idealised sea surface of a placid homogeneous ocean). The dynamic height is approximately determined by the average density of the water column. For example, the warmer and/or thicker the SML, the higher is the dynamic height. A region of high dynamic height, such as a warm-core eddy, is a "high pressure" in the ocean weather pattern, and its associated currents are similar to (but slower than) the winds associated with an atmospheric high pressure. Results for dynamic height such as those measured by Scully-Power (1973) in the Coral Sea may therefore be used to estimate the geographic variation of the MLD. The limitation on such a correlation is that for a fixed dynamic height (average density of the water column), the MLD is also affected by the local wind history. For a given dynamic height (which will usually be quasi-constant in shallow water), MLD may vary depending on the local history of storms, which is usually a function of season. High winds and/or cooling generate turbulence that increase MLD, whereas the cumulative effect of near-surface solar heating and mixing is to generate new (thin) SML's. Jones (1985) and Padman and Jones (1985) have reported preliminary work on modelling these processes in Australian waters.

Near-surface temperature profiles

Transient thermoclines (small temperature rises) near the ocean surface occur as the result of two separate effects: high solar heating together with moderate wind-speed cause near-surface temperature rises as a result of vertical diffusion; and in fronts between water masses, the horizontal change in SST is also accompanied by such temperature rises.

(i) Solar Heating:

A set of temperature profiles measured during the course of a sunny day is shown in figure 14. This "afternoon effect" (as the Navy terms it) causes rays from a shallow sonar to pass through the surface-duct rather than to be trapped by it. A computer model of vertical thermal and mechanical diffusion has been developed (Hill, 1983). This model has been applied to regions in the deep ocean where horizontal variation is unlikely. (In practical terms, this means far from ocean fronts). The variable calculated was the probability that "afternoon effect" would occur for a period of some hours during an afternoon. It was found (Hill, 1983) that afternoon effect is unlikely to occur at latitudes higher than 40°S (due to the high average wind speed); whereas it is reasonably likely to occur in regions and seasons where the average wind-speed is moderate.

(ii) Fronts:

The assumption that diffusion is confined to the vertical direction is liable to be inapplicable in frontal regions between water masses. In such regions there are horizontal gradients in the water temperature, together with the associated currents. In the Tasman Sea, where large-scale eddies are continually formed, "steep" horizontal gradients of sea surface temperature are commonly found, and, on the cold side of a front, the vertical temperature profile can exhibit a near-surface temperature rise in addition to any solar heating effect.

Large Scale Variations

Fronts between water masses are often identified by their associated oceanic boundary currents, of which the East Australian Current (EAC) is our local example (Andrews, Lawrence and Nilsson, 1980). The EAC meanders like an unstable river of southward travelling warm water in a "landscape" of cool water. The temperature difference across the EAC is likely to range from several Celsius degrees at the surface to around 1 degree at depths of 1 km. The positions of the meanders, which are horizontal oscillations in a planetary wave (with an amplitude of the order of 100 km), fluctuate with a time scale of the order of a month. At a frequency of around 3 times each year, a meander "nips" off to create a ring eddy, which then tends to move south-eastward and dissipate in the southern Tasman Sea (Nilsson, Andrews and Scully-Power, 1977; Nilsson and Cresswell, 1981). An individual eddy is quasi-symmetric in shape (Andrews and Scully-Power, 1976), and comparatively predictable in its movement once it clears the EAC and prominent sea-floor features such as sea-mounts and high ridges.

An infra-red photograph of the Tasman Sea is shown in figure 15. A large warm-core eddy is indicated by the dark circular feature ESE from Sydney.

The SSP near a front is complicated and variable: the effective MLD (as perceived by a sonar at a small depth) may even vanish as the front is traversed, even though there may be a significant SML on either side.

The "Leeuwin Current" off the south-west coast also produces eddies (Andrews, 1977), although the temperature variations across them are not as great as they are across the EAC eddies.

In addition to effects on a SSP as such, currents may in principle have a direct influence on sound propagation because the "effective" sound speed is approximately equal to the stationary sound speed plus the component of the current velocity in the direction of the sound wave. Changes to the gradient of the SSP are therefore proportional to the Mach Number of the current[3] . As a rule, currents in the ocean have little direct effect on sound propagation, even in frontal regions. Their Mach number is typically of the order of only 0.001 (Andrews and Scully-Power, 1976). Frontal ocean currents usually are greatest at the surface and decay quasi-exponentially with a depth-constant of the order of several hundred metres. The current gradient is therefore usually negligible in relation to the gradients in the SSP.

5. ACOUSTIC PROPAGATION

The ocean is an acoustic waveguide whose boundaries are usually rough. In cases where the boundaries are smooth and flat (horizontal), the solution to the acoustic wave equation may be expressed as a series of "normal modes", each of which has a characteristic outgoing horizontal wave and a standing wave in the vertical direction (which does not vary with range). Since the vertical standing waves are mutually orthogonal, there is no coupling of energy amongst them and the summation is relatively straightforward. (The difficult part of the calculation is determining the characteristic values of the normal modes). If the boundaries are only slightly rough and/or sloping, then a useful method is to consider range-dependent modes. Since such modes cannot be mutually orthogonal at all ranges, there is mode-coupling and energy does transfer amongst the modes.

The number of modes present is proportional to the thickness of the waveguide measured in terms of acoustic wavelength, and increases with the product of the reflectivities of the two boundaries. If the frequency is sufficiently high that there are *many* normal modes, then the normal mode series may be accurately transformed into the sum of several "arrivals", each of which has the character of a ray, a geometrical path in the range-depth plane that may be determined by applying "Snell's Law".

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[3] In the atmosphere, wind has a noticeable effect on sound propagation. The Mach number of wind is typically of the order of 0.03, and there is always a significant positive gradient near the ground. Sound travelling down-wind is therefore refracted back to the ground, whereas sound travelling upwind is refracted upwards and lost.

A summary of the methodology for current studies in acoustic propagation is shown in figure 16. 'SUS' are underwater explosives ('Signal Underwater Sound'); and the names in uppercase lettering are acronyms for large computer propagation models (most of the examples shown were developed in the USA).

Surface-duct propagation

The acoustic ocean surface-duct is analogous to the radar atmospheric humidity duct. A surface-duct has an acoustic cut-off frequency that decreases with increasing MLD. At frequencies below cut-off the acoustic wavelength is too large for normal modes to exist within the duct, and in effect the sound wave does not notice that there is a duct present. At frequencies well above cut-off, there are many normal modes present and it is usually convenient to discuss surface-duct propagation in terms of sound rays. Within the SML, sound rays refract upwards (with a radius of curvature of around 90 km) to reflect off the surface. The SML therefore forms an acoustic surface-duct. For any particular depth in the thermocline there is a certain range beyond which it is not possible for a direct ray to arrive from a near-surface projector. Much of the thermocline therefore constitutes an acoustic "shadow zone", into which sound from a near-surface projector may enter only by the (relatively weak) processes of scattering or diffraction. A diagram of rays emanating from a shallow projector in an isothermal SML is shown in the upper graph in figure 17.

The main environmental parameters that determine transmission loss in a surface-duct are the mixed-layer thickness, surface-roughness, and when it occurs, near-surface solar heating.

Mixed-Layer Thickness (MLD)

Acoustic transmission improves as the MLD increases. In terms of Ray theory, the angular spread of rays that are trapped in the SML increases with MLD; and in terms of mode theory, the number of trapped modes also increases.

Afternoon Effect

The diurnal surface heating described earlier can have a dramatic effect on the ability of the SML to trap rays. The centre graph in figure 17 shows a mild example of the effect, in which the sound-speed at the projector is less than the sound-speed at the bottom of the duct. Some of the rays that emanate from the projector are trapped within the duct. The lower graph shows that no ray is trapped by the duct if the sound-speed at the projector is greater than the sound-speed at the bottom of the SML. (The number at the middle of each graph is a representative time of day at which the particular profile is liable to occur, subject to there being little wind or cloud cover.)

Surface-Roughness

Acoustic surface-duct transmission is degraded as wind-speed and surface-roughness increase. Scattering of sound by both the rough surface and its associated bubble layer cause sound energy to leak from the duct (Hall, 1980). Since MLD and roughness are both wind-generated (although MLD reflects the history of the wind over a period of several days) it is plausible that these two variables could be correlated. If the correlation were significant, there could be interesting effects on the probability distribution of transmission loss. For cases considered to date however (Hall and Sandy, 1985), the correlation between roughness and MLD is only about 10%, and the consequent effect on the probability distribution of transmission loss is insignificant.

Deep-water acoustic propagation

In most ocean areas of interest to Australia, underwater acoustic propagation is largely determined by the reflective properties of the sea-floor. An illustration of the bottom-reflected rays that travel from a projector to a receiver at short range is shown in figure 18. For each order of bottom reflection, there are 4 paths from projector to receiver: the bottom-only reflected path (B); the surface and bottom reflected path (SB); the bottom and surface reflected path (BS); and the surface-bottom-surface reflected path (SBS). The significance of these paths is that even in a straightforward measurement of bottom reflectivity, care must be taken to resolve the separate arrivals (so as to avoid mutual interference).

At long ranges, the SML will be important if of sufficient thickness; but whether or not there is a thick SML, bottom bounce arrivals will always be important, as is shown schematically in figure 19.

In general terms, deep water propagation is well understood, especially for cases where scattering near the sea-surface is unimportant, where variation in the horizontal plane is very gradual (so that mode-coupling is small), and where bottom roughness is not important. Under these conditions, well-established approximations to the acoustic wave equation can be used to study the acoustic effects of oceanographic features such as mesoscale eddies. Examples are "adiabatic" mode theory (which neglects mode coupling) or the "parabolic equation" theory (which includes mode coupling, but assumes the significant energy is always travelling almost horizontally). These studies have shown that such features have important effects on long-distance propagation, such as altering the range at which zones of high intensity occur (Lawrence, 1983). An example of the way in which an eddy (the main immediate effect of which is to vary MLD) affects the acoustic propagation pattern at a frequency of 100 Hz is shown in figure 20. In the case depicted in the upper graph there is no range variation (ie no eddy) and the MLD is fixed at 300 m. Since the acoustic cut-off frequency for this MLD is 35 Hz, sound at 100 Hz propagates in the duct quite well, as may be seen in the graph. In the case depicted in the lower graph a projector is placed at the centre of an eddy. The MLD decreases from 300 m at the projector to around 50 m at the rim of the eddy (a range of 35 km). Outside the eddy, the cut-off frequency of the SML is 550 Hz with the result that sound at 100 Hz is not trapped within the layer in that region.

Eddies also refract sound horizontally to produce a "bearing deviation". An example of how the bearing deviation varies with range as the receiver passes through an eddy is shown in figure 21.

Convergence-zone propagation

At low frequencies (for which the surface-duct has no effect), long range propagation occurs via upward refraction at depths of 4 to 5 km. For a shallow sound-projector, this phenomenon gives rise to "convergence -zone" propagation in which the sound rays (in the vertical plane) return to the surface, and partially re-focus there, at ranges of 60 km and multiples thereof. This effect may be seen in figure 20. In the horizontal plane, convergence zones are annuli centred on the sound projector. In the vertical plane, sound rays refract towards the SOFAR axis, which generally occurs at depths from 1.3 to 1.0 km. The waveguide formed by the SSP in deep water is referred to as the "SOFAR channel". This channel is able to contain acoustic normal modes, the number of which is approximately equal to the frequency in Hertz.

Acoustic properties of the sea-floor

Sea-floors are two-phase media in which the solid particles have variable properties such as chemical composition, grain-size distribution and degree of compaction (related to "porosity"). One approach to predicting their acoustic properties has been to treat them as a one-phase solid and to directly measure *in situ* the speeds and attenuation rates of the compressional and shear waves, and the density. With these quantities available, both the acoustic reflectivity (at any frequency and incident angle) and the behaviour of energy that penetrates the sea-floor, may be calculated.

The geographical variation of bottom interaction properties, using the simple procedure of near-surface explosive charges and hydrophones, has been the subject of oceanographic surveys for around 20 years. These measurements determine the loss of acoustic energy on reflection as a function of angle and of frequency. Results obtained from the deep sea-floor of the Tasman Sea, at several frequencies, are shown as a function of grazing angle in figure 22.

A noticeable development in the quality of instrumentation available for studying the roughness of the sea-floor has been the "Stabilised Narrow Beam Echo-Sounder" fitted to HMAS COOK. A contour map of the sea-floor topography over an area approaching a sea-mount is shown in figure 23. When more data of this type becomes available, we will be able to give far more detailed descriptions of the reflective properties of the sea-floor.

From the results of seismic profiling and core-sampling surveys, sub-bottom profiles of the sound-speeds and density may be derived. An example of such a profile is shown in figure 24. Based on such information gathered over wide areas, charts showing a variety of features including bathymetry, sediment type, and sediment thickness are being produced.

Under the auspices of project "ADOBE" (Acoustic Deep Ocean Bottom Experiments), measurements have commenced of the acoustic interaction in the deep ocean using projectors and receivers placed near the sea-floor, so as to provide a wide range of interaction angles, a stable predictable water environment above the sea-floor, and an absence of any effect due to the sea surface. For a typical ADOBE measurement, a ray diagram and a projector/receiver configuration diagram are shown in figures 25 and 26 respectively. The concepts used in obtaining a geo-acoustic profile from ADOBE data are illustrated in figure 27. An example of the signal amplitude and phase measured as a function of range during an ADOBE measurement is shown in figure 28. Providing the phase results are sufficiently accurate (there are indications that this may not yet have been achieved), direct mathematical inverse schemes may be applied to such data to obtain the geo-acoustic profiles. If the phase measurements are not sufficiently accurate, then indirect iterative schemes (Lawrence, 1985) may be employed as an alternative. This type of experiment deals with the top few hundred metres of sediment (more important to sonars), in contrast to the deeper depths that are examined by seismic profiling (more important to mineral exploration).

Shallow-water acoustic propagation

The term 'shallow-water' usually refers to regions over the continental shelf, where the depth of the sea floor is less than around 200 m. In general, shallow-water propagation is not as predictable as for the deep-water case, mainly for the reason that the sound-speed profile in the sea floor, which is now the dominant factor, is difficult to predict to the required precision.

Other factors that lead to a high variability in shallow-water propagation are:

(1) the importance of the shape of the sea-floor. Large scale roughness leads to horizontal refraction of the sound paths (Kamenyitsky,1971) and coupling between acoustic normal modes (Hall, 1986). Small scale roughness yields bottom scattering and loss of coherence;

(2) the importance of the shape of the sound-speed profile in the water column. A zero gradient (typical of winter) leads to long skips between successive bottom reflections; whereas a negative gradient (as occurs in summer) leads to short skip distances between reflections. Thus the reflectivity of the sea-floor is a strong determinant under summer conditions, but is less of a limitation under winter conditions. The complement of this situation is that sea-surface roughness can be significant under winter conditions, but less important when the sound-speed gradient becomes negative.

Contours of propagation loss in the range-depth plane are shown for typical winter and summer sound-speed profiles in figures 29 and 30 respectively. The depth of the sea-floor is 100 m, and a 100 Hz projector is at a depth of 20 m.

In general, for the reasons listed above, acoustic propagation losses in shallow water are higher (over the same horizontal range), and detection ranges of targets are correspondingly less, than occur in deep water.

6. ACOUSTIC SCATTERING

Backscattering is the process that occurs at the boundaries of the ocean, or at inhomogeneities within the ocean, that results in echoes ("reverberation") from an emitted signal being received in the neighbourhood of the projector.

Volume backscattering

Volume backscattering occurs at inhomogeneities within the ocean water column. For shallow projectors in deep water, volume backscattering is usually more significant than the backscattering from either the surface or the sea-floor. The major scatterers in the ocean medium include gas-filled swimbladders in fishes, and (for the higher frequencies) bubbles and the various crustacea. Bubbles and swimbladders have a resonance frequency that varies inversely with their average radius.

Bubbles

Bubbles scatter sound strongly, especially at their resonance frequency, and therefore scatter and attenuate sound significantly when prevalent. A reasonable number of measurements of wave-generated bubble size spectra have been obtained photographically under various wind conditions. The main results are (Walsh and Mulhearn 1987): very few bubbles are observed at wind speeds (W) less than 6 m/s; above that speed the number of bubbles increases as $W^{3.4}$ while the volume fraction of air to water increases as $W^{4.9}$; and the bubble-size spectrum has a r^{-4} slope (r = bubble radius). Walsh's work was for deep ocean conditions beyond the NSW continental shelf. These results are in good agreement with results already obtained overseas using photography, which also showed that the bubble populations decrease quasi-exponentially with depth[4].

Since the concentrations of bubbles increases with wind-speed, reverberation from wind/wave generated bubbles will increase with the "sea state", even though it is not a result of backscattering from the actual surface.

Biological Scattering

Mesopelagic (deep-sea) fish and crustacea are distributed throughout the world oceans, although their population densities tend to depend on resupply of nutrients. Most mesopelagic fishes form a "Deep Scattering Layer" (DSL) at depths of several hundred metres by day, and rise to the upper layers by night (to feed on the near-surface plankton). A simplified diagram of the scattering regions that contribute to reverberation (at two particular times subsequent to the emission of an acoustic transient) is shown in figure 31.

In the Australasian area, stations at which volume backscattering spectra were measured prior to 1980 are shown in figure 32. A summary of the relative values of the day and night values of volume backscattering strengths in areas around Australia is shown in figure 33. Since 1980, further measurements have been made along the Pacific Ocean SEAMAP routes(fig.9). Some night-time values near both New Zealand and Sydney are shown in figure 34. The lowest levels of biological backscattering occur in the Coral Sea basin (Hall, 1973), while the highest values are found near the Chatham Rise south-east of New Zealand, an important commercial fishery area (Hall and Bell, 1986).

An interesting DSL has been observed near the Equator, over the Ceylon Abyssal Plain south of the Bay of Bengal. This DSL was 1.7 km deep (Hall, 1971) and from its resonance frequency (of 3.5 kHz) the mass of the individual fish is estimated to be around 150 g.

The exposed swimbladder of a dissected (Myctophid) mesopelagic fish is shown in figure 35. Fish swimbladders scatter sound strongly at their resonance frequency, which for large bladders is similar to that for a similarly sized free bubble. The normalised spectrum of the scattering strength of a single swimbladder is shown in figure 36. For small swimbladders however (such as those of young fish), friction within the bladder tissues (Hall, 1981) causes the resonance peak to merge into the dashed curve and hence become unnoticeable.

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[4] Overseas acoustic measurements in shallow water have indicated that the bubble population does not appear to decay with depth. Mulhearn (1981) developed mathematical models to explain the results of acoustic measurements of bubbles in coastal waters (off California) at low wind-speeds as being due to one population of bubbles attached to small particles in the water and stabilised by surfactant skins, and a second population arising from decaying matter on or in the sea-floor. It is not known at present whether such bubbles are distributed widely or only in specific localities over continental shelves.

Surface Backscattering

Surface Backscattering occurs at the sea-surface when rough. High Frequency surface backscattering (acoustic wavelengths up to around 10 cm) is associated with the variation in the slope of the surface and is therefore dependent on the instantaneous wind-speed. The leeward side of a long gravity wave is steeper than its windward side; and capillary waves tend to ride on the leeward, rather than the windward, side of long waves. The leeward side therefore returns a stronger reflection to a near-horizontal sound beam than a windward side. HF surface backscattering is therefore anisotropic, in that the reverberation for a sonar pointing upwind is less than that for a sonar pointing downwind.

LF Backscatter (long acoustic wavelength), to a first order approximation, is associated with the larger-scale roughness at the corresponding "Bragg-resonance" wavelength of the surface waves. Since the surface waves are moving, the backscatter exhibits Doppler shifts. A sonar wavelength of 20 m for example is in resonance with surface waves that have a wavelength of 10 m. (The phase speed of these gravity waves is 4 m/s, and the frequencies of the Bragg peaks in the Doppler spectrum are 0.4 Hz above and below the carrier frequency.)

Sea-surface roughness is less important to sonar than it is to radar because wave troughs have smaller slopes than do wave crests. Backscattering by the rough sea surface is usually less significant than either Volume or Bottom backscattering because the grazing angle of the sound rays to the surface is very small (less than 2°). The grazing angle is small because projectors are usually deployed near the sea surface, since it is expensive to operate a high-powered projector at any significant depth.

Bottom Backscattering

Reverberation from a deep sea-floor is often negligible since, for a near-horizontal beam, it is due to backscattering at very long ranges (depending on the exact bottom-depth). In shallow water however, bottom backscattering is usually the environmental limiting factor to the performance of short-range Very High Frequency mine-hunting active sonars.

Sediments consisting of clay and silt are smooth and cause less backscattering than do sand or pebble sediments. Very few data are available on bottom backscattering strengths in the ocean areas around Australia. Although one series of observations has been published (Hall, 1973b) there is insufficient information available on the fine-scale roughness of the sea floor areas sampled during the survey to correlate with the acoustic results.

7. AMBIENT NOISE

Ambient noise levels in the ocean are consistently high because the low attenuation of sound allows sources at large distances (both natural and man-made) to contribute. Ambient noise is considered to comprise three distinct categories: noise from (man-made) ship-traffic; sounds from biological organisms; and noise from motions associated with the ocean surface waves. An overview of the methodology of current DSTO studies of ambient noise is shown in figure 37. Sites of major measurements prior to 1980 are shown on the map in figure 38.

Traffic noise

Ships distributed over an ocean basin produce a low frequency background noise referred to as traffic noise. Regions of high shipping such as the Tasman Sea show underwater sound pressure levels that are comparable to those of a busy city street. In regions of low shipping densities and poor propagation on the other hand, such as the Timor Sea, traffic noise levels are 20 to 30 dB lower (Cato, 1976). This comparison is illustrated by the "Traffic" curves in figure 39.

Wave-generated noise

Although this is the most important source of underwater noise, it is difficult to predict accurately, because a number of complex mechanisms of noise generation are involved and these are not yet quantitatively understood. Some of our recent theoretical work, which has calculated the noise generated by interaction between opposing surface-waves, has been successful in accurately predicting noise at frequencies up to around 5 Hz (Cato, 1983). In figure 39, the opposing wave interaction curve decreases with frequency and shows no dependence on wind-speed. The reasons for this are: (i) unless the wind-speed is less than around 2 m/s over a wide area (which is very rare) the resonance frequency of the surface wave spectrum is less than 1 Hz; and (ii) the "high-frequency" (capillary wave) portion of the wave spectrum is "saturated" at a similarly low wind-speed.

The current hypothesis on the origin of "wave-generated" noise at frequencies higher than around 5 Hz is based on the concept of two broad, and yet distinct, peaks in the noise spectrum. These are illustrated in figure 39. The noise levels (which persist to the depths of the ocean) exceed traffic noise levels in most areas once wind speeds rise above about 7 m/s. The peak at around 20 Hz is considered likely to be due to oscillations of bubble-clouds within the wave-action zone; and the peak at around 500 Hz is considered to be due to breaking waves. In order to test these theories and to improve our understanding of the noise generation mechanisms, sophisticated experiments are being conducted in laboratory tanks and at sea.

Recently, work related to describing the directionality of ambient noise has commenced. This requires that the sources of the sounds be identified and their source strength and radiation beam patterns determined. Burgess and Kewley (1983) have described aspects of the effective source strength of the sea surface roughness in the Tasman Sea, while Ferguson and Wyllie (1987) have shown that the radiation pattern of the surface produces the same directionality pattern at a receiver as would a vertical classical dipole.

Biological noise

Marine animals produce a wide variety of sounds which although intermittent can at times dominate the background noise. In particular, there are regular choruses at sunset, and, to a lesser extent, sunrise, when the sounds of countless fish and invertebrates cause the ambient noise to rise by 20 to 30 dB (Cato 1978). Typical examples of choruses in shallow tropical waters are shown in figure 39. The occurrence of these choruses is sufficiently regular to be reliably predicted once the sources and their behaviour and distribution have been established. Work on this topic is currently underway.

The sounds of large whales are of sufficient intensity to affect sonar performance even though only relatively small numbers of individuals are involved. The intense clicking sounds of sperm whales, which are plentiful in deep water, result in choruses of similar level to those of fish and invertebrates. However, they are far less predictable because of the nomadic behaviour of these whales. Herds of humpback whales produce a variety of intense sounds during their annual migrations along the Australian Coastlines (Cato, 1984). Sonar operators need to be aware of the characteristics of these sounds so that when detected they can be recognised for what they are. One of the problems about quantifying these characteristics is that the sounds change from one year to the next.

8. CONCLUSIONS

An overview of the conclusions that may be drawn from this paper is presented in figure 40. Two of the aspects listed there may be described in more detail as follows:

A. The nature of 'Defence Oceanography' ("what?")

There are many parameters that are relevant to the performance of the various types of sonar systems. For each of these parameters, it is desirable to know its spectrum (if applicable) and how it varies with position in space, and time (such as season, or time of day, depending on the parameter). Some parameters are determined by, or affected by, other environmental conditions that are easily monitored (such as surface roughness, or the sea-surface temperature). Many parameters are affected by conditions that are not easily monitored (such as size and depth-distributions of deep-sea fishes, or the detailed structure of the deep-sea floor); and in these cases it is easier to measure the acoustic parameters directly (namely, volume backscattering strength and acoustic bottom reflectivity, for the above examples) than to measure the causative parameter and then deduce the acoustic effect. It is fortunate that the significant parameters that fluctuate in an apparently random manner (eg mixed-layer thickness) generally do so at depths that are not too great.

B. Methodology ("how?")

A substantial body of knowledge has been gathered on the descriptive oceanography of the waters around the east and west coasts of Australia, especially in the Coral Sea and off the southern segments of these coasts. The next major step is to extend this program to important areas in waters to the north.

Physical modelling of important parameters has also progressed, but there is still room for significant progress to be made, especially for predicting: (1) acoustic propagation over the continental terrace; and (2) near-surface sound-speed profiles.

9. ACKNOWLEDGEMENTS

Dr D.H. Cato contributed to the section on Ambient Noise. Dr P.J. Mulhearn contributed to the sub-section on Bubbles.

BIBLIOGRAPHY OF DSTO PUBLICATIONS

This bibliography is confined to publications in refereed journals, except for some cases where conference proceedings or reports are the only publications on a particular topic.

Authors who have not been members of DSTO are signified with [ ]

DESCRIPTIVE AND PHYSICAL OCEANOGRAPHY

Andrews J C (1977) "Eddy structure and the West Australian Current" Deep-Sea Research 24, 1133 - 1148

Andrews J C, Lawrence M W, and Nilsson C S (1980) "Observations of the Tasman Front" J Phys Oceanography 10, 1854 - 1869

Andrews J C and Scully-Power P (1976) "The structure of an East Australian Current anticyclonic eddy" J Phys Oceanography 6, 756 - 765

[Godfrey J S], Jones I S F, [Maxwell J G H], and Scott B D (1980) "On the winter cascade from Bass Strait into the Tasman Sea" Aust J Mar & Freshwater Res 31, 275 - 286

Hamilton L J (1986) "Statistical features of the oceanographic area off South-western Australia, obtained from bathythermograph data" Aust J Mar Freshwater Res 37, 421-436

Hill J W (1983) "The structure and dynamics of oceanic transient thermoclines." Eighth Australasian Fluid Mechanics Conference, Uni. of Newcastle, N.S.W., pp. 4A.13 - 4A.16

Jones I S F (1980) "Tidal and wind-driven currents in Bass Strait" Aust J Mar Freshwater Res 31, 109 - 117

Jones I S F (1983) "Richardson Number profiles over the continental shelf" J Phys Oceanography 13, 1829 - 1835

Jones I S F (1985) "Some statistics of the temperature profile through the base of the ocean mixed layer", Deep-Sea Res 32, 1255 - 1272

Jones I S F and [Kenney B C] (1977) "The scaling of velocity fluctuations in the surface mixed layer" J Geophys Res 82, 1392 - 1396

Jones I S F and Mulhearn P J (1983) "The influence of external turbulence on sheared interfaces" Geophys Astrophys Fluid Dynamics 24, 49 - 62

Jones I S F and [Padman L] (1983) "Semidiurnal internal tides in eastern Bass Strait" Aust J Mar Freshwater Res 34, 159 - 171

Mulhearn P J (1981) "Distribution of microbubbles in coastal waters" J. Geophys. Res 86 (No. C7), 6429-6434

Mulhearn P J (1982) "Use of the Japanese satellite GMS for following the East Australian Current" Aust J Mar Freshwater Res 33, 1097 - 1101

Mulhearn P J (1983) "On the climatology of warm-core rings from the East Australian Current" Aust J Mar Freshwater Res 34, 687 - 692

Mulhearn P J (1983) "Deep currents of the northern Tasman Sea Basin" Deep-Sea Research 30, 1119 - 1126

Mulhearn P J (1987) "The Tasman Front: A study using satellite infrared imagery", J Phys Oceanography 17, 1148 - 1155

Mulhearn P J, [Filloux J H, Lilley F F M, Bindoff N L and Ferguson I J], "Abyssal currents during the formation and passage of an East Australian Current warm-core ring" Deep-Sea Research 33, 1563 - 1576 (1986)

Nilsson C S, Andrews J C, and Scully-Power P (1977) "Observations of eddy formation off East Australia" J Phys Oceanography 7, 659 - 669

Nilsson C S and [Cresswell G R] (1981) "The formation and evolution of East Australian Current warm-core eddies" Prog Oceanography 9, 133 - 183

[Padman L] and Jones I S F (1985) "Richardson Number statistics in the seasonal thermocline", J Phys Oceanography 15, 844 - 854

Scully-Power P D (1973) "Coral Sea flow budgets in winter" Aust J Mar Freshwater Res 24, 203 - 215

[Walsh A] and Mulhearn P J (1987) "Photographic measurements of bubble populations from breaking wind waves at sea", J Geophys Res 92, 14553 - 14565

UNDERWATER ACOUSTICS

Burgess A S and Kewley D J (1983) "Wind-generated surface noise source levels in deep water east of Australia" J Acoust Soc Am 73, 201 - 210

Cato D H (1976) "Ambient sea noise in waters near Australia" J Acoust Soc Am 60, 320 - 328

Cato D H (1978) "Review of ambient noise in the ocean: non biological sources" Bull Aust Acoust Soc 6, 31 - 36

Cato D H (1978) "Marine biological choruses observed in tropical waters near Australia" J Acoust Soc Am 64, 736 - 743

Cato D H (1980) "Some unusual sounds of apparent biological origin responsible for sustained background noise in the Timor Sea" J Acoust Soc Am 68, 1056 - 1060

Cato D H (1983) "Theoretical and measured noise from water wave orbital motion" Proc. 11th International Congress on Acoustics, Paris, July 1983, Vol 2, pp 449 - 452

Cato D H (1984) "Recording humpback whale sounds of Stradbroke Island" In *Focus on Stradbroke* , [R J Coleman, J Covacevich and P Davie] (Editors), Boolarong, Brisbane, pp 283 - 290

Ferguson B G and Wyllie D V (1987) "Comparison of observed and theoretical responses of a horizontal line array to wind-induced noise in the deep ocean", J Acoust Soc Am 82, 601 - 605

Hall M (1971) "Volume backscattering in the South China Sea and the Indian Ocean" J Acoust Soc Am 50, 940 - 945

Hall M (1973a) "Volume backscattering in the Tasman Sea, the Coral Sea and the Indian Ocean" J Acoust Soc Am 54, 473 - 477

Hall M (1973b) "Bottom backscattering in the Java Trench Area and the Tasman Sea" J Acoust Soc Am 54, 730 - 734

Hall M (1976) "Mode theory of wave propagation in a bilinear medium: The WKB approximation" J Acoust Soc Am 60, 810 - 814

Hall M (1979) "The influence of a submerged duct on sound propagation in a surface duct" J Acoust Soc Am 66, 1102 - 1107

Hall M (1980) "Surface-duct propagation: an evaluation of models of the effects of surface roughness" J Acoust Soc Am 67, 803 - 811

Hall M (1981) "Measurements of acoustic volume backscattering in the Indian and Southern Oceans" Aust J Mar & Freshwater Res 32, 855 - 876

Hall M (1982) "Normal mode theory: The role of the branch-line integral in Pedersen-Gordon type models" J Acoust Soc Am 72, 1978 - 1988

Hall M (1984) "Application of two-variable Taylor series to the ray theory of propagation in an unbound medium" J Acoust Soc Am 75, 1433 - 1442

Hall M (1986) "The effects of variations in sound speed on coupling coefficients between acoustic normal modes in shallow water over a sloping bottom", J Acoust Soc Am 79, 332 - 337

Hall M and Bell M J (1986) "SEAMAP 1 Data Report: Volume Backscattering in the Tasman Sea and the west South Pacific Ocean", Technical Note No. 2/86, R A N Research Laboratory, Sydney

Hall M, [Gordon D F, and White D] (1982) "Improved methods for determining eigenfunctions in multi-layered normal-mode problems" J Acoust Soc Am 73, 153 - 162

Hall M and Quill A F (1983) "Biological sound scattering in an ocean eddy" Aust J Mar & Freshwater Res 34, 563-572

Hall M and Sandy R T (1985) "An investigation into the effect of the correlation between sea-surface roughness and duct-thickness on the distribution of acoustic propagation loss". Technical Memorandum No. 5/85, RAN Research Laboratory, Sydney.

Kamenyitsky A J A (1971) "Some aspects of shallow water sound propagation" Ph.D. thesis, School of Physics, University of NSW, Sydney.

Kelly L J, Kewley D J, and Burgess A S (1985) "A biological chorus in deep water northwest of Australia", J Acoust Soc Am 77, 508 - 511.

Kewley D J (1984) "Using eigenvalue analysis to identify interference in ambient sea noise vertical directionality measurements", J Acoust Soc Am 75, 826 - 833.

Lawrence M W (1983) "Modeling of acoustic propagation across warm-core eddies" J Acoust Soc Am 73, 474-485.

Lawrence M W (1985) "Ray theory modeling applied to low-frequency acoustic interaction with horizontally stratified ocean bottoms" J Acoust Soc Am 78, 649-658

SIGNIFICANT DEVELOPMENTS IN THE DEFENCE OCEANOGRAPHY OF AUSTRALIA'S AREA OF INTEREST

by

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Figure 1. Significant developments

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

MARITIME DEFENCE SUBPROGRAMS

SCOPE OF ENVIRONMENTAL COMPONENT

Research and applied studies into those aspects of underwater acoustics and oceanography that affect the performance of underwater defence surveillance and platform systems. At present there is an emphasis on sonar surveillance.

The work comprises:

(a) descriptive surveys that produce information for maritime environmental data banks; and

(b) physical modelling of the ocean to produce algorithms from which remote variables may be determined when the relevant observable parameters are specified.

For sonar surveillance, the main parameters are underwater acoustic propagation, scattering, ambient noise, marine geophysics, and sound-speed profiles. For submarine operations, the main parameters are ocean dynamics and density profiles.

Figure 2. Environmental component of maritime defence subprograms

OCEANOGRAPHIC PARAMETERS RELEVANT TO SONAR

UNDERWATER ACOUSTICS

Shallow Water Backscattering
Volume Backscattering
Propagation Loss
Bottom Reflectivity
Ambient Sea Noise

PHYSICAL OCEANOGRAPHY

Temperature and Sound-Speed Profiles of the Water Column
Sea-surface Roughness and Wave-generated Bubbles

MARINE GEOLOGY

Sub-bottom Sound-Speed Profiles
Sea-Floor Large-Scale Topography
Small-Scale Roughness
Sediment Density

MARINE BIOLOGY

Fish and Plankton Population Densities

Figure 3. Oceanographic parameters relevant to sonar

SPECIFIC APPLICATIONS OF THE OCEANOGRAPHIC PARAMETERS RELEVANT TO SONAR

Marine Geology:
Bottom Reflectivity

Bottom Roughness:
Bottom Reflectivity and Backscattering

Sea-surface roughness and Wave-generated bubbles:
Ambient Noise, Backscattering, and (HF) Propagation Loss

Marine Biology:
Noise (eg croakers, snapping shrimp)
Backscattering (biological scattering)

Sound-speed profiles and Bottom Reflectivity:
Predicting Propagation Loss

LF Noise and Propagation Loss:
Detection of submarines by passive sonar (towed array, sonobuoy);
and detection of shipping by submarine-mounted passive sonar

HF & VHF Backscattering and Propagation Loss:
Detection of submarines, torpedoes and mines by active sonar

Figure 4. Specific applications of the oceanographic parameters relevant to sonar

OCEANOGRAPHIC PARAMETERS RELEVANT TO MINING

PHYSICAL OCEANOGRAPHY

Pressure fluctuations at sea bed (eg due to sea swell)
at depths < 90 m

Currents within 5 m of the sea bed
in depths > 180 m in straits

Currents at heights > 5m above the sea bed in depths 90-180 m in approaches to selected ports and in selected straits

Currents within 5 m of the sea bed in depths 90-180 m in approaches to selected ports and in selected straits

Currents in approaches to ports and depth < 90m

Currents in straits in depths > 90m

Turbidity

UNDERWATER ACOUSTICS

Acoustic propagation to 100 m, at 10-2000 Hz in depths < 90m

Sea bed reverberation at 100 kHz in depths < 90m

Ambient noise at 10-2000 Hz in depths < 90m

Ambient noise at 100 kHz in depths < 90m

MARINE GEOLOGY - SOIL MECHANICS

Sediment penetrability

Sediment Strength

MARINE BIOLOGY

Plankton Blooms

Figure 5. Oceanographic parameters relevant to mining

SPECIFIC APPLICATIONS OF THE OCEANOGRAPHIC PARAMETERS RELEVANT TO MINING

Currents:
Clearance Divers swimming about 2 m above sea bed
(depths < 60 m)

Remote Observation Vehicles operating about 2 m above sea bed
(depths < 180 m)

Mine Disposal Drones operating about 2 m above sea bed
(depths < 90 m)

Stability of Tethered buoyant mines, that are about 3 m long,
oriented vertically, and about 3 m above the sea bed

Control of deep trawl sweeps operating about 3 m above sea bed
in mineable straits (depths around 200 m)

Plankton Blooms and Turbidity: Optical visibility

Low-Frequency Noise, Fluctuations, and Propagation:
Pre-setting the Detection Threshold for acoustic and pressure mines

High-Frequency Noise and Reverberation:
Interference with mine-hunting sonars

Sediment Penetrability: Rate of burial of objects
(in depths < 90 m)

Sediment Strength: Stability of Mine-anchors

Figure 6. Specific applications of the oceanographic parameters relevant to mining

ENVIRONMENTAL ACOUSTICS

The acoustical performance of a passive sonar array depends on:

- Target frequencies and levels.

- Signal propagation through the ocean and the horizontal/vertical arrival angles at the receiver.

- Background noise sources (such as non-target vessels, winds and storms, and biological noises) and their horizontal/vertical angles at the receiver.

- Flow-generated noise close to the hydrophones.

At the Marine Studies Composite (DSTO Salisbury, SA), research studies have been undertaken primarily in the last three areas. This activity includes experiments and theoretical work.

Work at DSTO Sydney has emphasised the second and third areas.

Figure 7. Environmental acoustics...performance of passive sonar

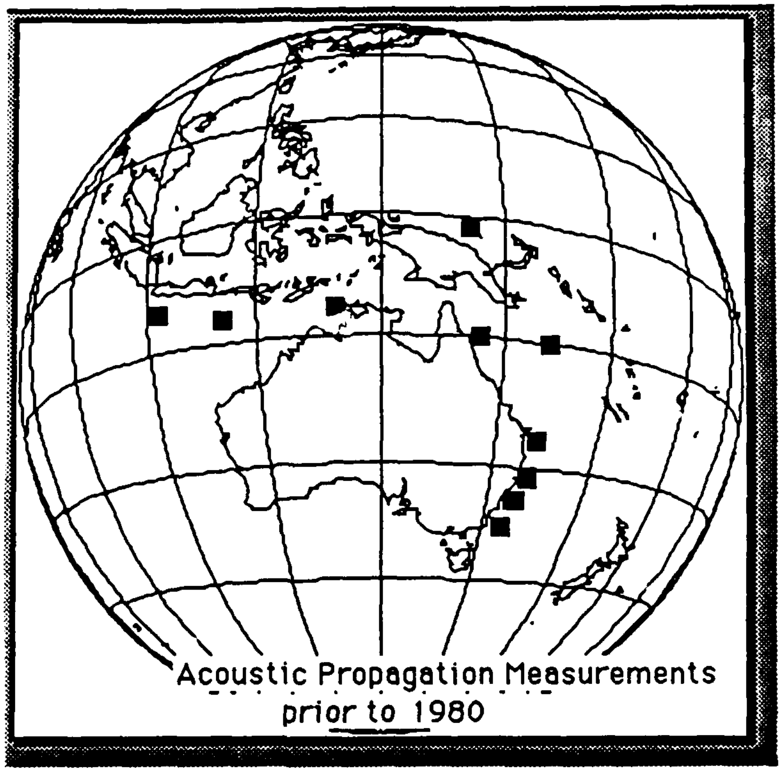


Figure 8. Acoustic propagation measurements prior to 1980

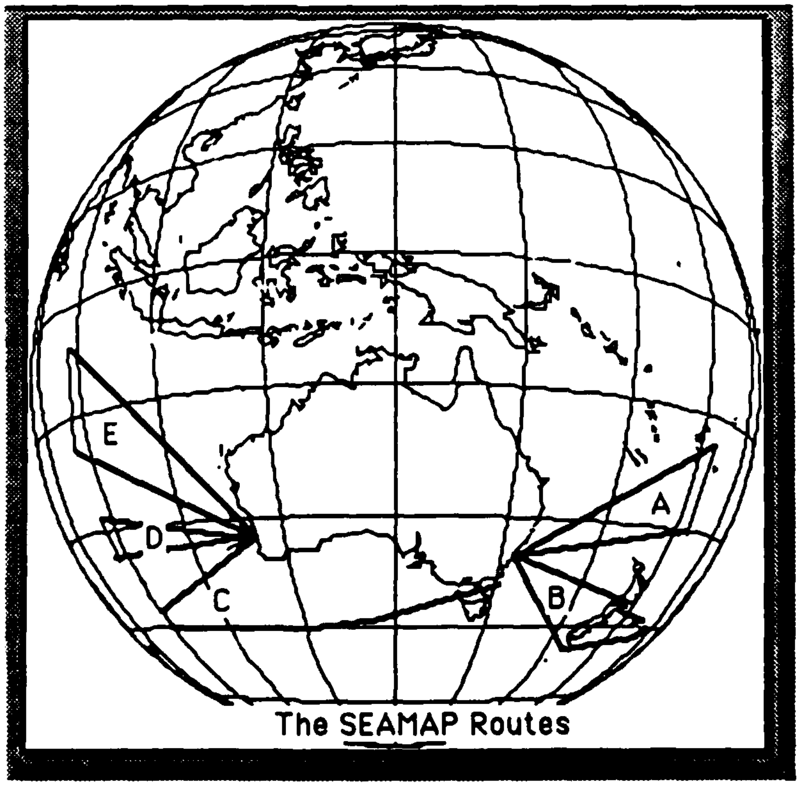


Figure 9. The seamap routes

THE SEAMAP PARAMETERS

UNDERWATER ACOUSTICS

Long-range bottom-bounce propagation (explosives and sonobuoy)

Bottom reflectivity (explosives and sonobuoy)

Volume backscattering (explosives and hydrophone)

Deep-water ambient sea-noise (sonobuoy)

PHYSICAL OCEANOGRAPHY

Sound speed profiles within the ocean (velocity probe)

Sea surface roughness (visual estimate)

MARINE GEOLOGY

Composition of sea floor (bottom cores)

Topography (photographs and echo-sounder records)

Sub-bottom sound velocity profile (low frequency seismic system)

MARINE BIOLOGY

Abundance and sizes of mesopelagic fishes (mid-water fish nets)

Figure 10. The seamap parameters

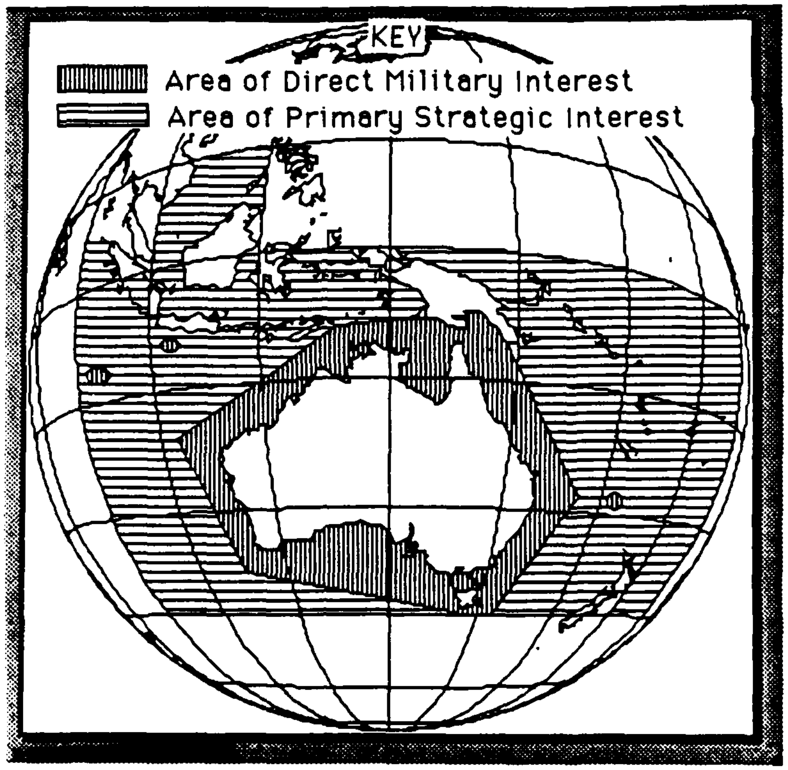


Figure 11. Areas of direct military and primary strategic interest

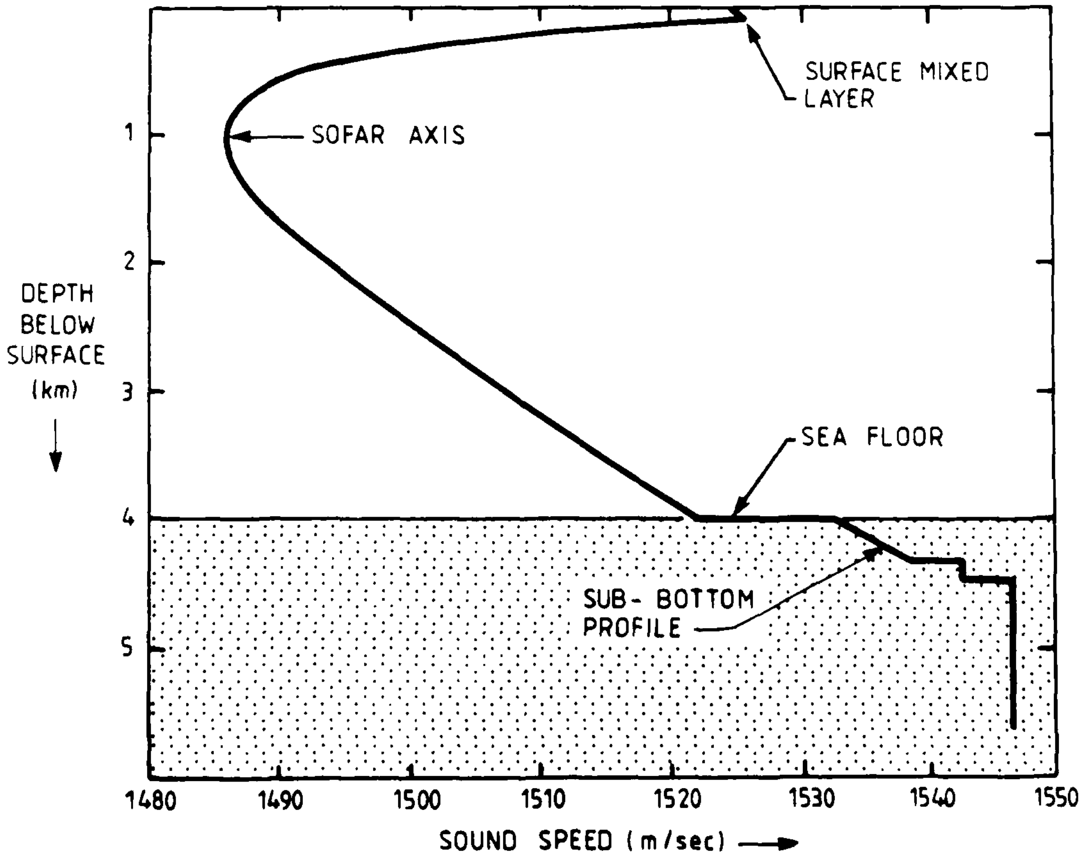


Figure 12. Sound-speed profile (in eastern Indian Ocean)

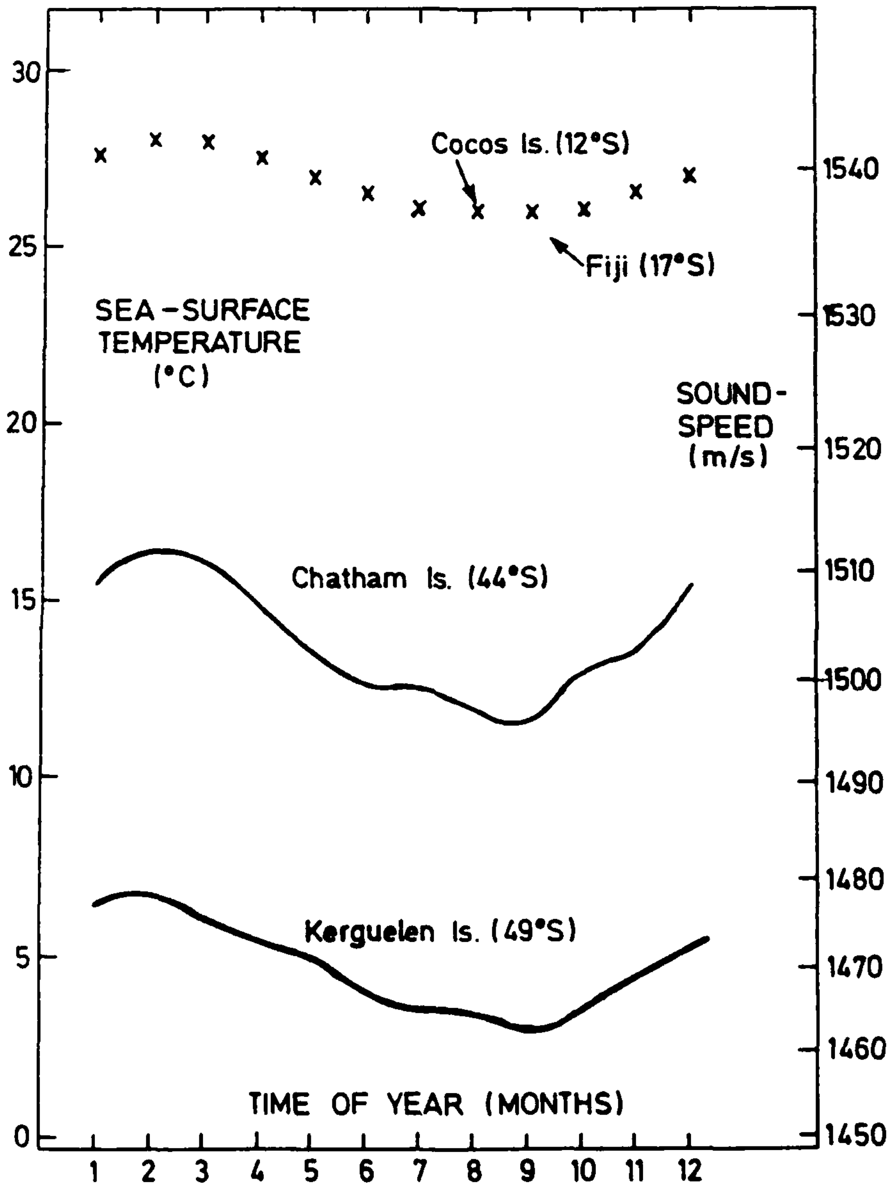
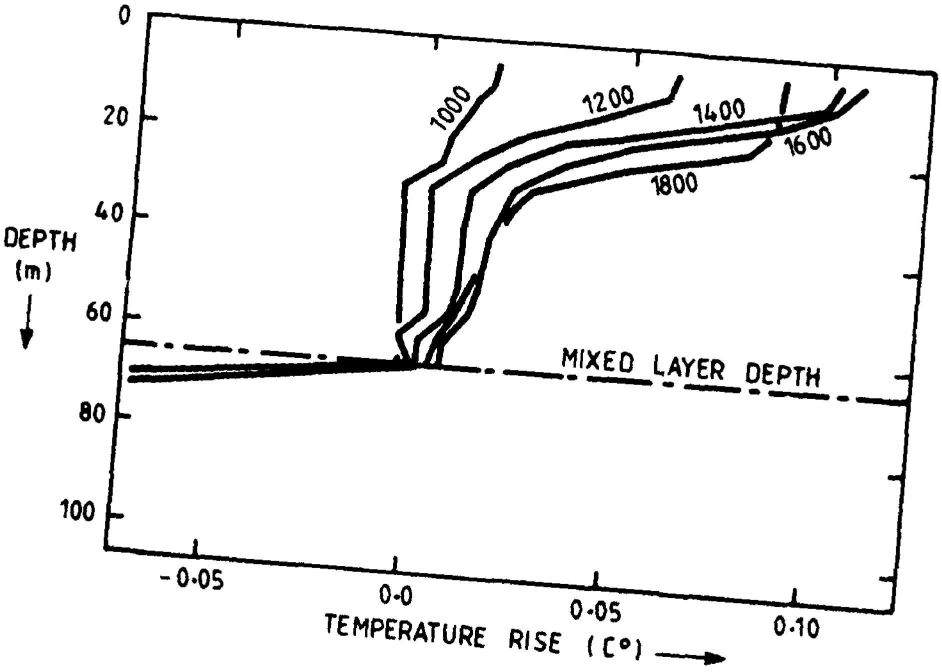


Figure 13. Seasonal variations of sea-surface temperature and sound-speed



Figures 14 . Diurnal heating near the surface

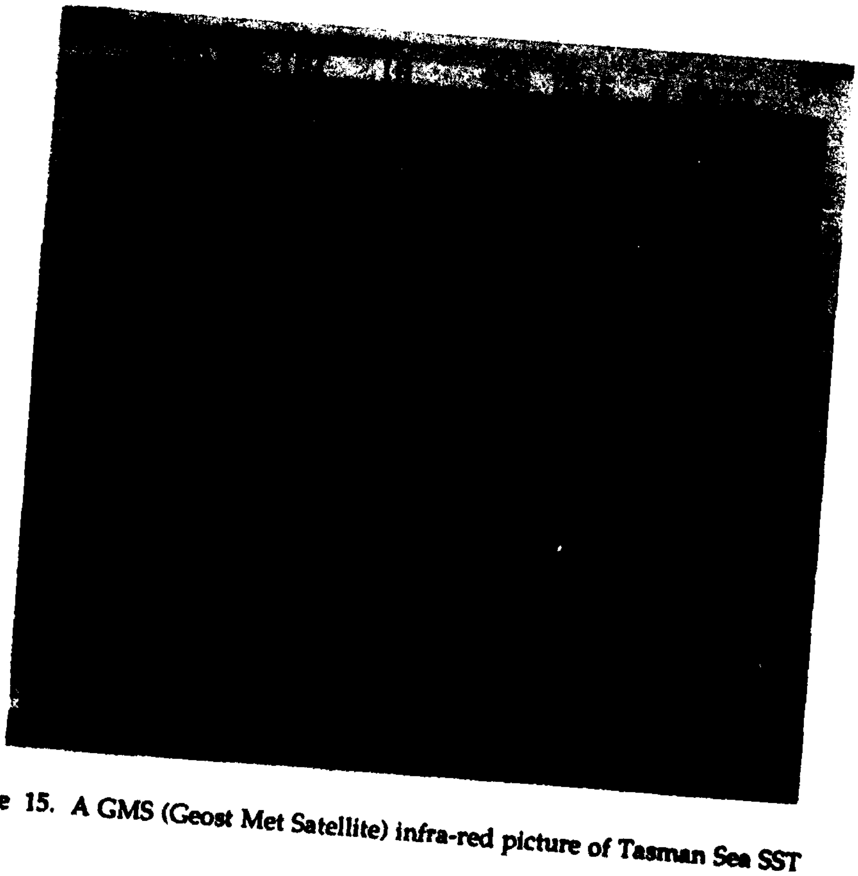


Figure 15. A GMS (Geost Met Satellite) infra-red picture of Tasman Sea SST

ACOUSTIC PROPAGATION STUDIES

Experimental and theoretical work involves:

- Air-deployed SUS charges or ship-deployed sound projectors.
- A heirarchy of increasingly complex computer models (Raytracing, shallow-water mode theory, HF surface-duct, FACT, RAYMODE, PAREQ, IFD, SNAP, and FFP)

Ongoing activities include:

- developing geoacoustics models for the Australian area
- developing 3D models
- acoustic fluctuation models
- creating a verified propagation loss computer-based database for systems studies

Figure 16. Acoustic propagation studies

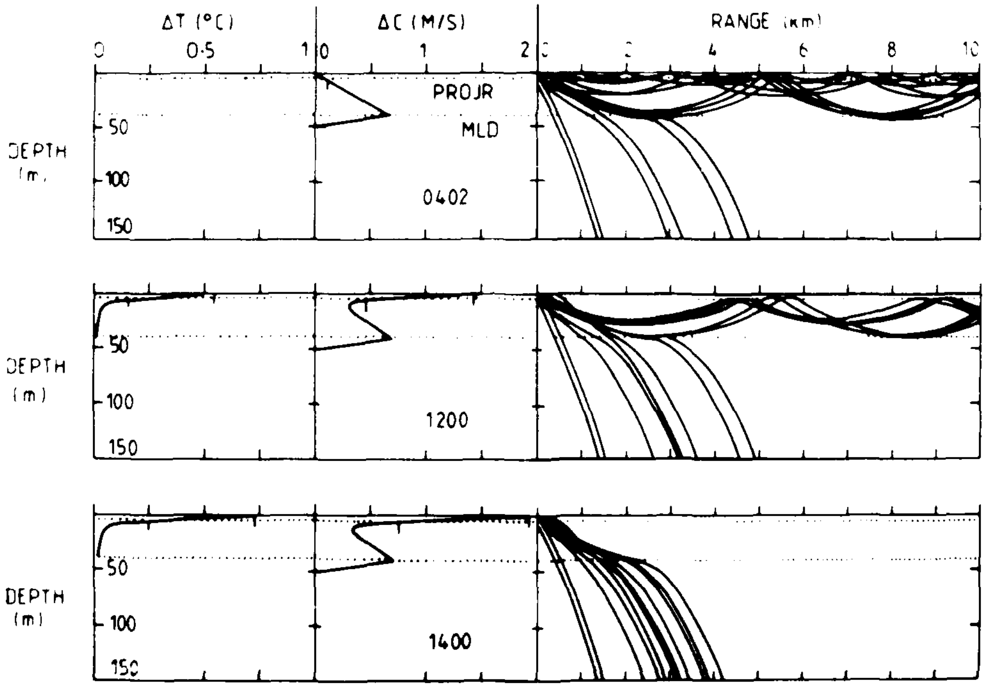


Figure 17. Acoustic ray diagram of surface-duct propagation with and without diurnal surface heating ("afternoon effect")

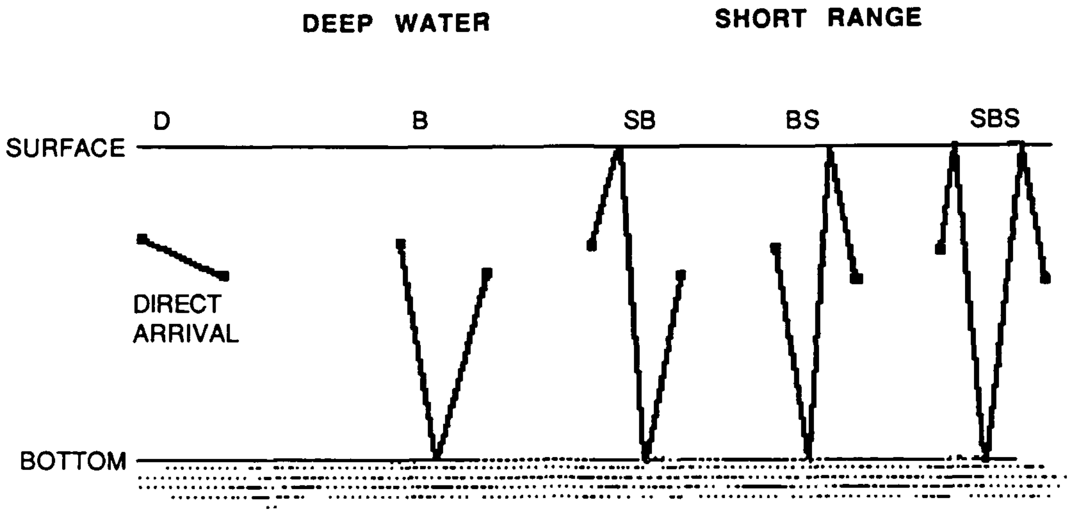


Figure 18. Explosion at close range in deep water

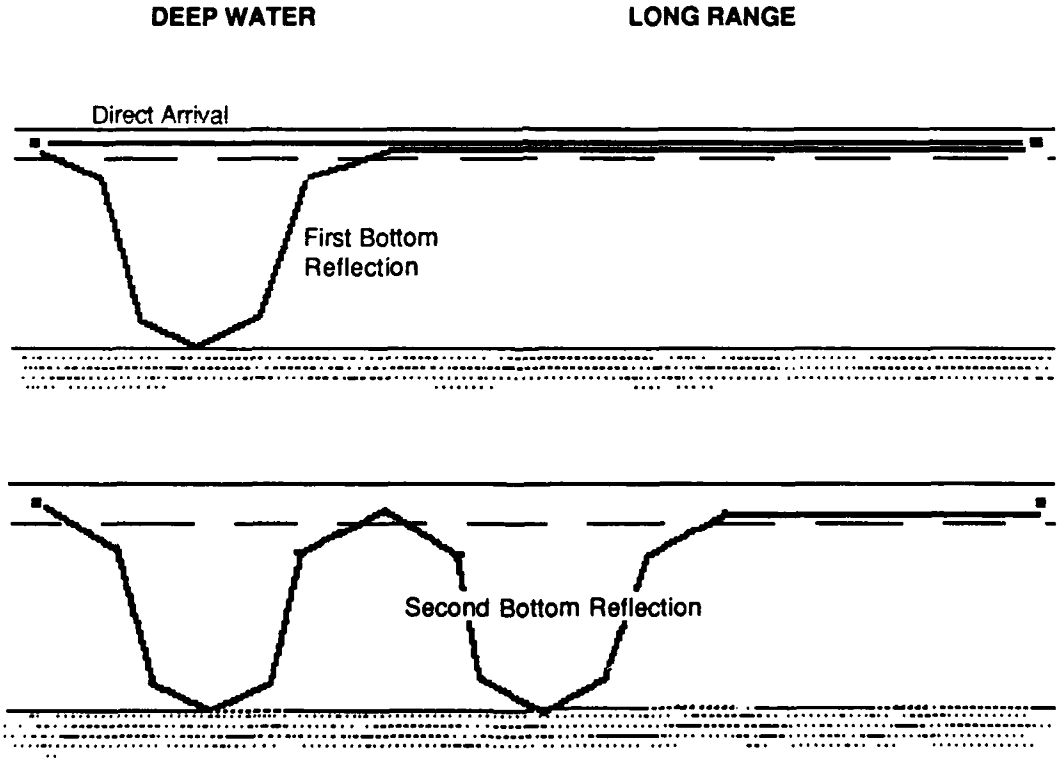


Figure 19. Explosion at long range in deep water

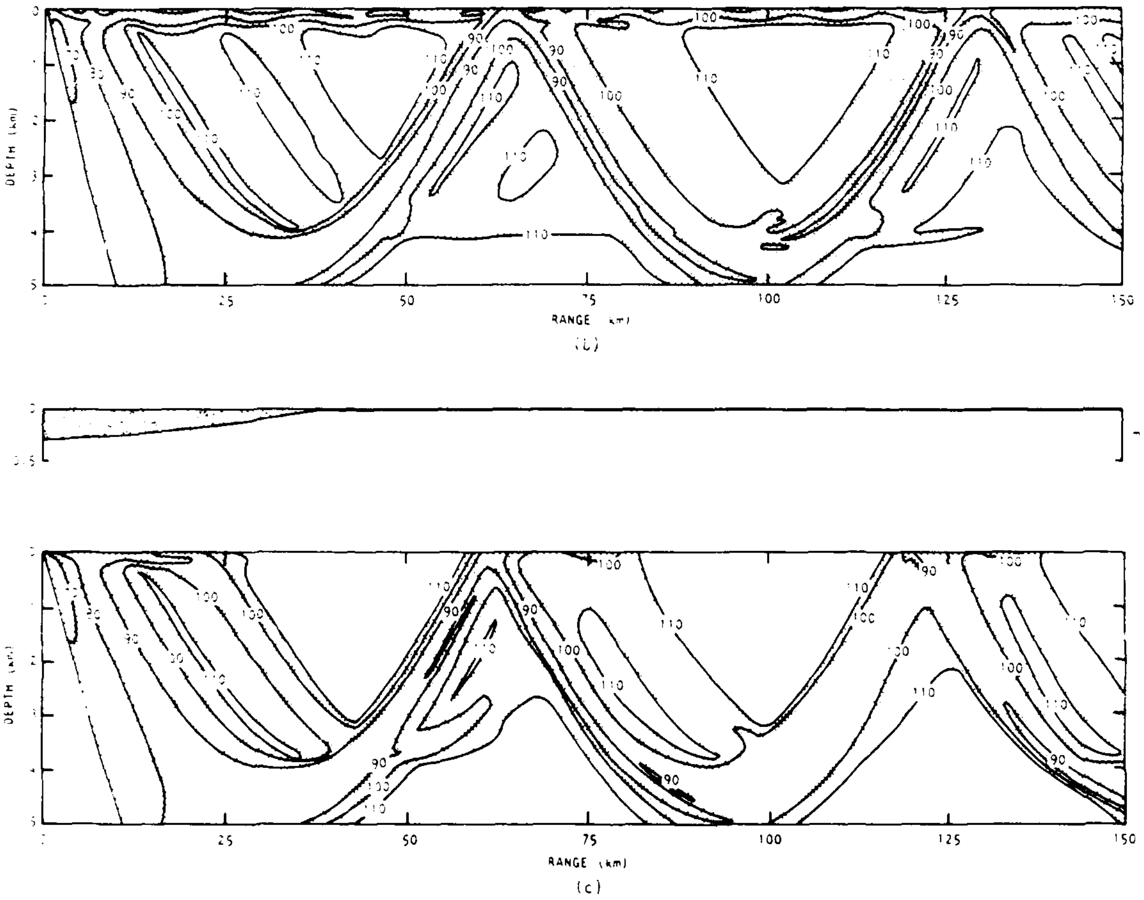


Figure 20. Effect of a warm-core eddy on vertical refraction of deep water low-frequency sound propagation

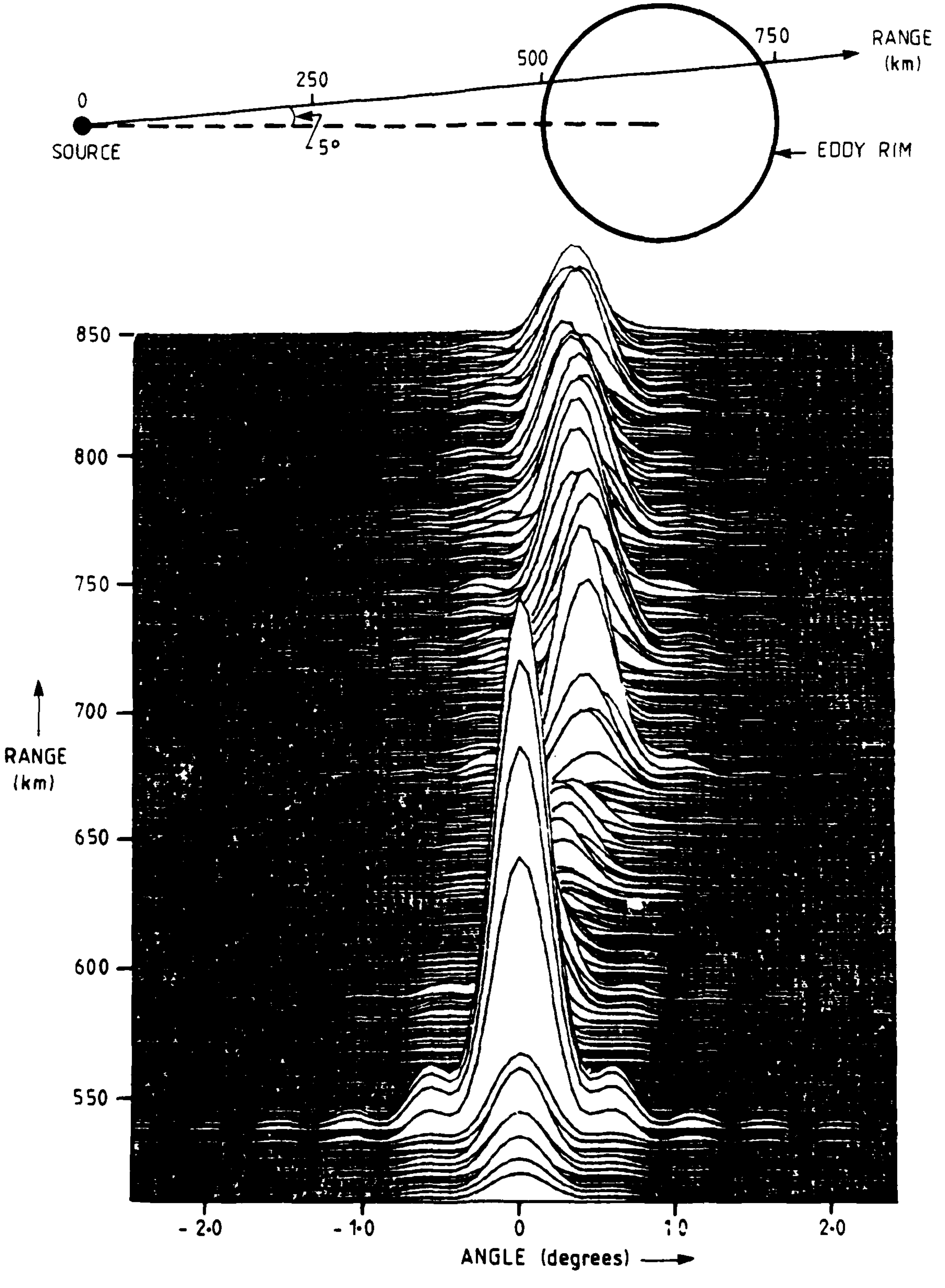


Figure 21. Horizontal refraction of energy by a (cold-core) mesoscale ocean eddy

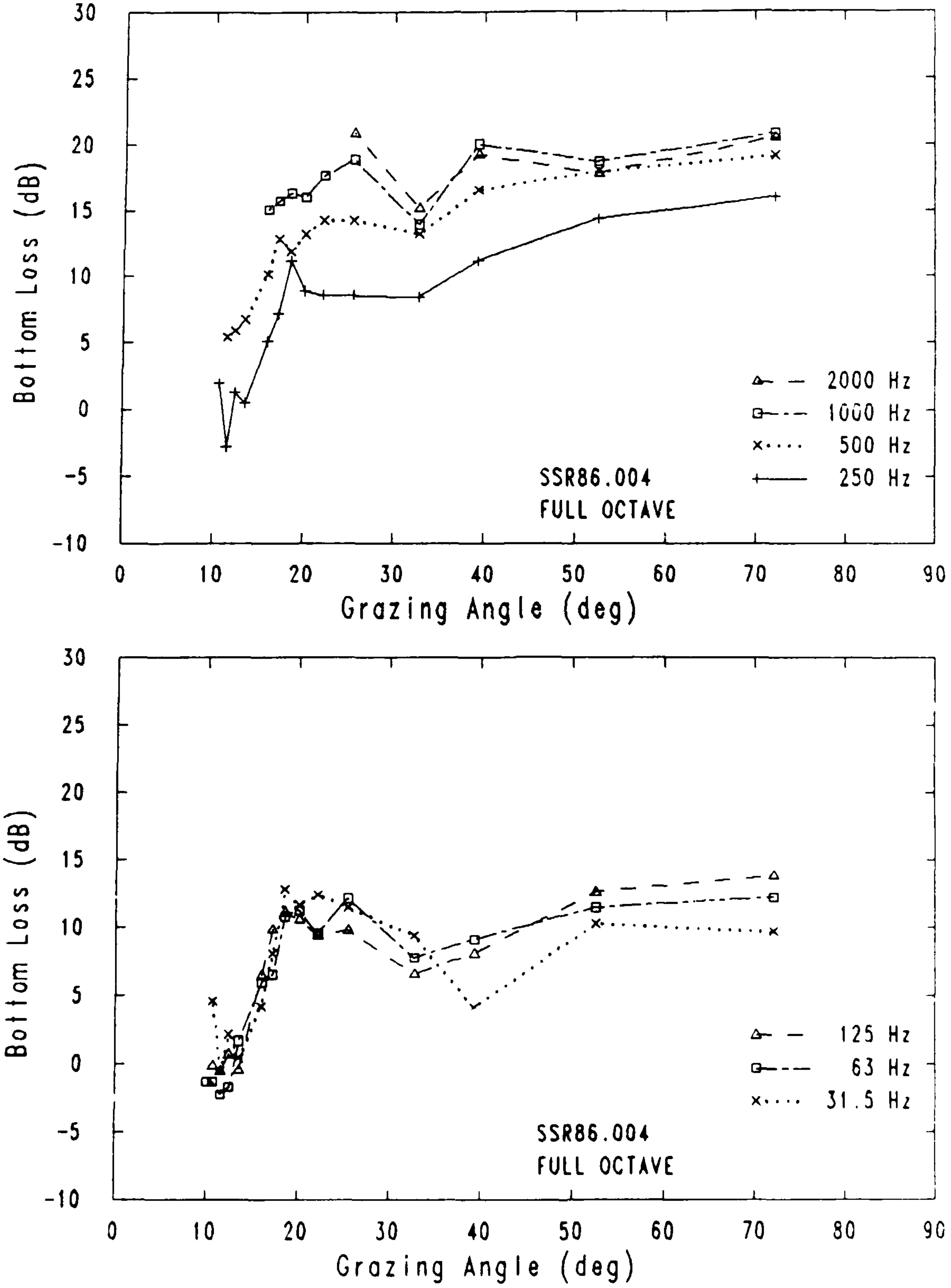


Figure 22. Examples of measured bottom reflectivities vs grazing angle

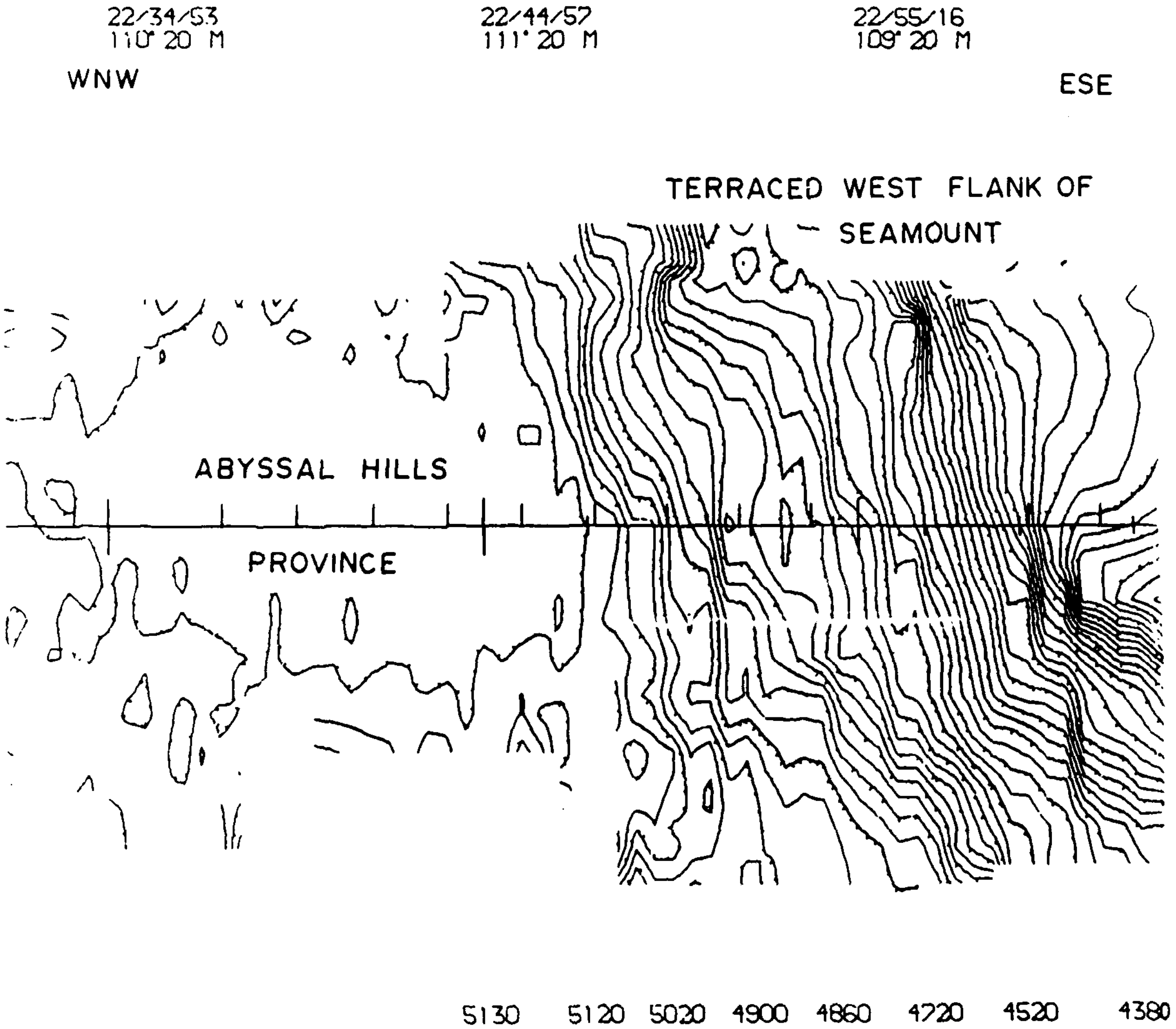
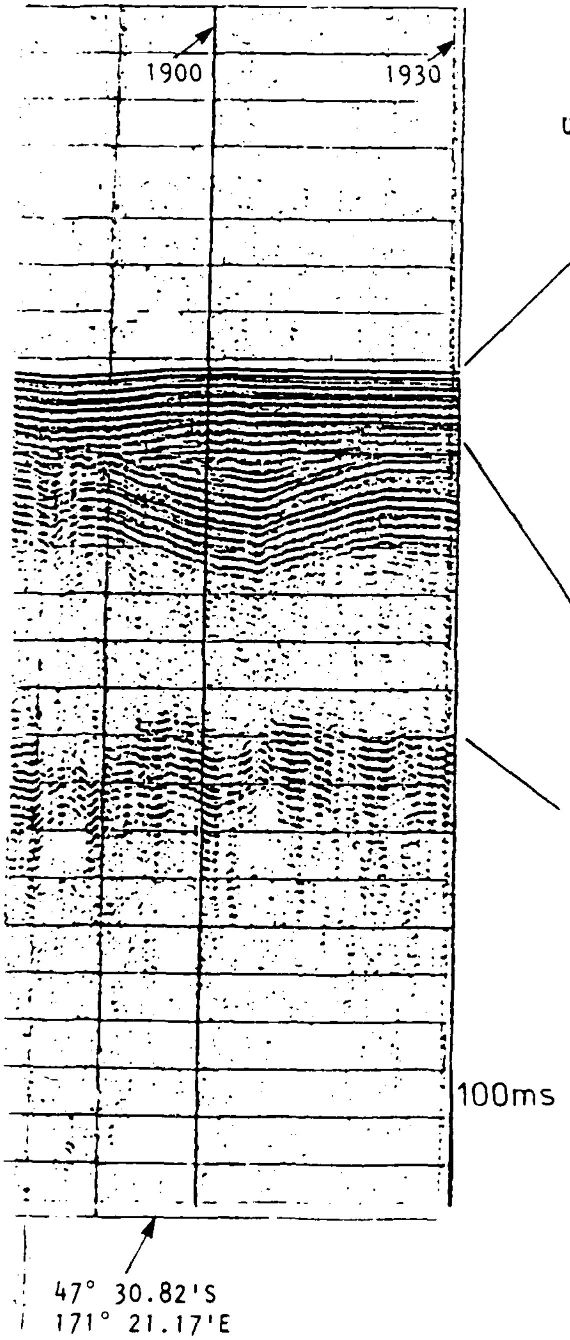


Figure 23. Seabeam Profile Heemskirk Seamount (20 m contours)

NORTH WESTERN CAMPBELL PLATEAU

47° 30.82'S
171° 21.17'E



Water 1388 m
$S_o/S_w = 1.03$

UNITS:
Depth of top:
Composition:
Parameters:

0 m
Impure calcareous ooze mud
$D = 1.5$
$V_p = 1.57T$
$V_s = 0.3$
$K_p = 0.1-0.4$

20 m
Semiconsolidated impure calcareous ooze mud
$D = 1.53T$ to $1.68B$
$V_p = 1.55T$ to $1.75B$
$V_s = 0.26T$ to $0.43B$
$K_p = 0.1-0.35$

140 - 230 m
Compacted calcareous ooze mud
$D = 1.8T$ to $1.93B$
$V_p = 1.87T$ to $2.7-2.8B$
$V_s = 0.5T$ to $1.2B$
$K_p = 0.1-0.35T$ to $0.1B$

760 - 930 m 'X'
Semilithified limestone and clastics
$D = 2.0-2.2$
$V_p = 2.7T$ to $3.2T$
$V_s = 1.0$ to $1.4B$
$K_p = 0.1$

?~800-1000 m
Lithified greywackes or schist
$D = 2.5-2.7$
$V_p = 5.0-5.6$
$V_s = 3.1-3.6$
$K_p = 0.03$

Special factors:
i) Very rough, very reflective basement surface at 760-930m.
ii) The Neogene sediment unit above 140-230m is closely layered, while the underlying Palaeogene is acoustically transparent.

Figure 24. (Geo-acoustic) Model 1. North Western Campbell Plateau

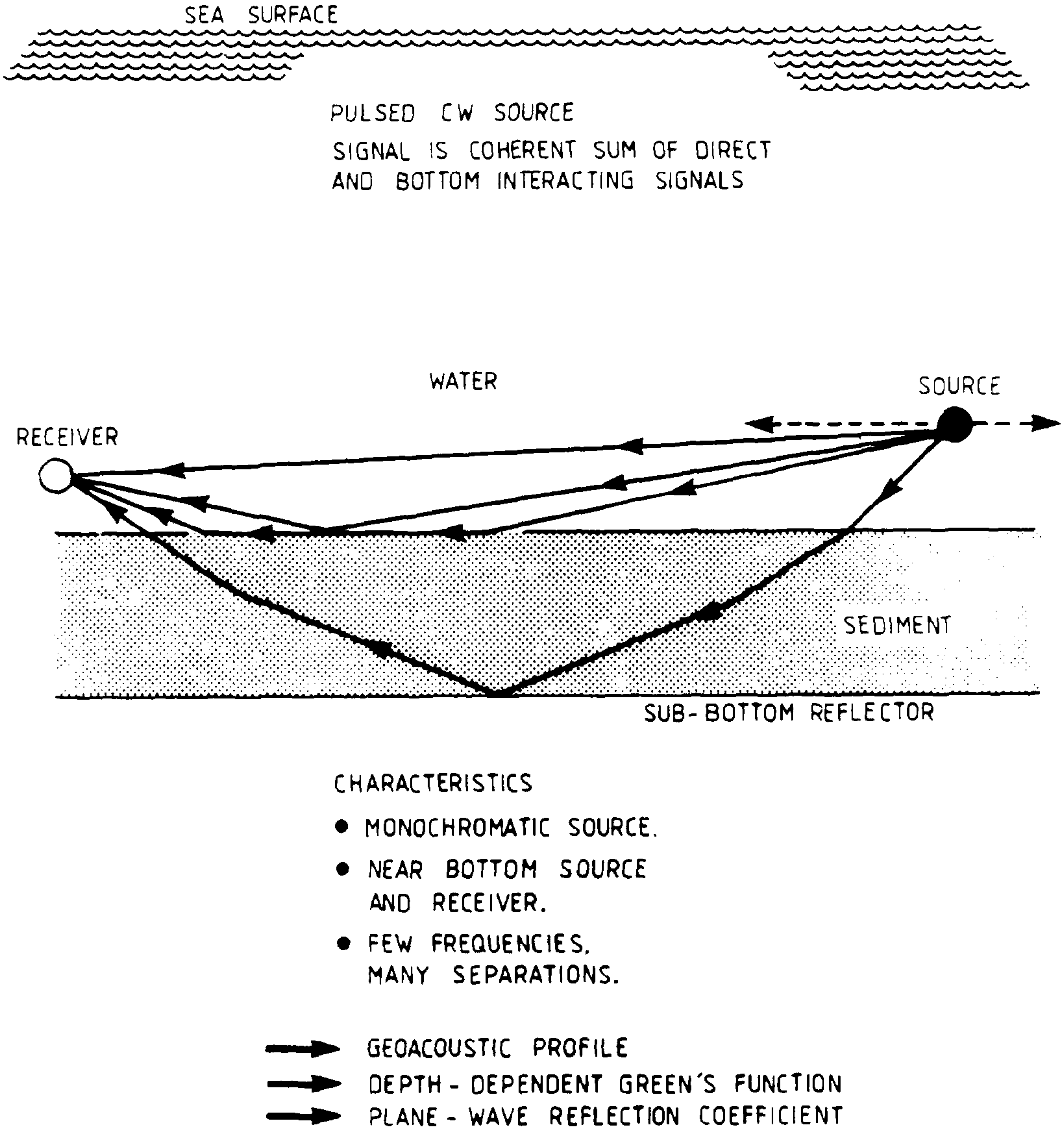


Figure 25. Ray diagram for ADOBE (acoustic deep ocean bottom experiment)

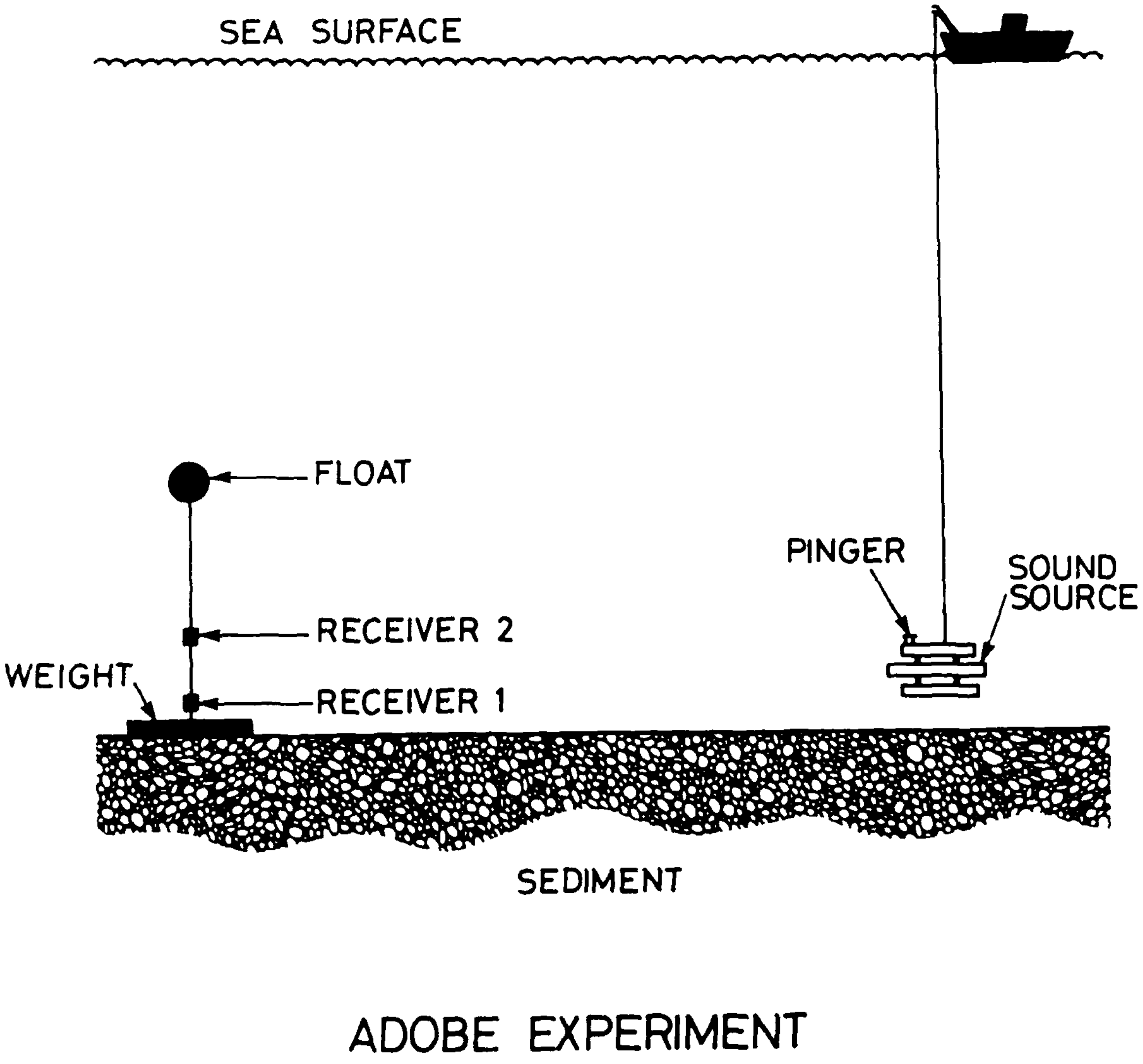


Figure 26. Source and receiver configuration for ADOBE

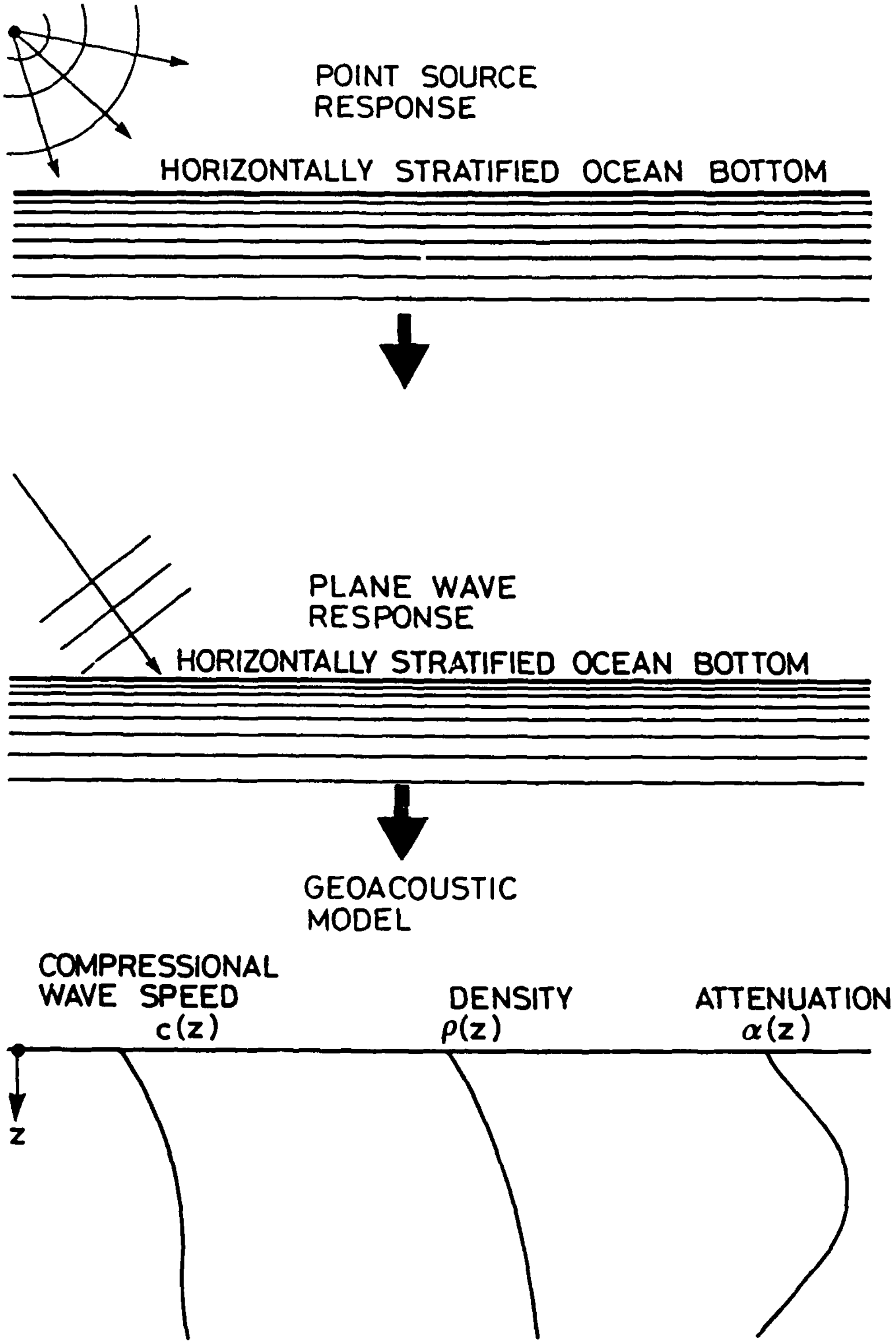


Figure 27. Concepts in obtaining a Geo-acoustic model from ADOBE data

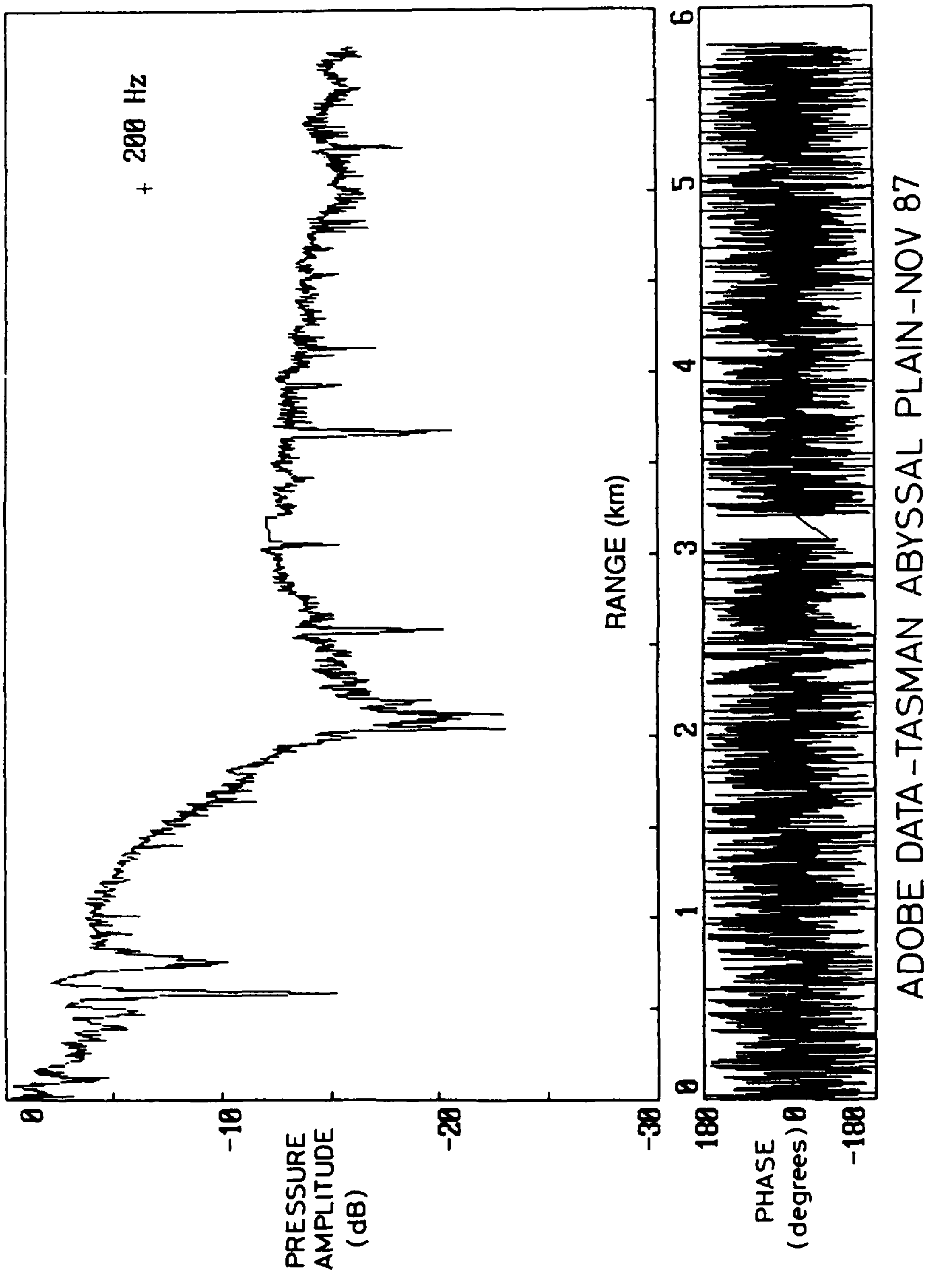


Figure 28. Example of amplitudes and phases of measured ADOBE data

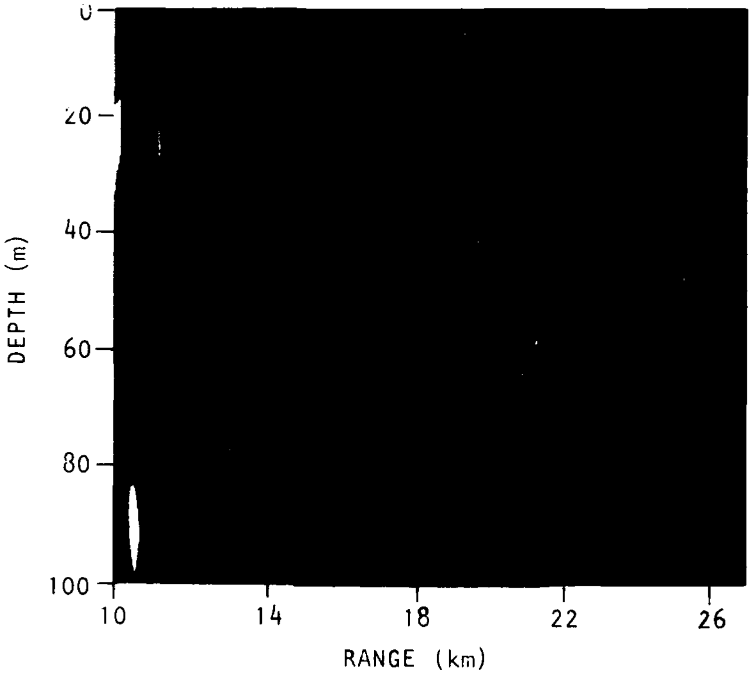


Figure 29. Acoustic propagation in shallow water: winter

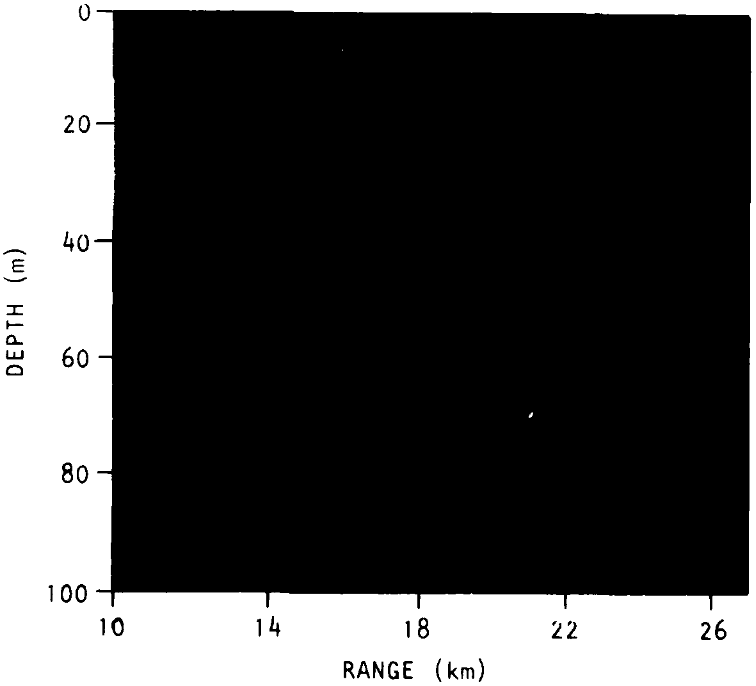


Figure 30. Acoustic propagation in shallow water: summer

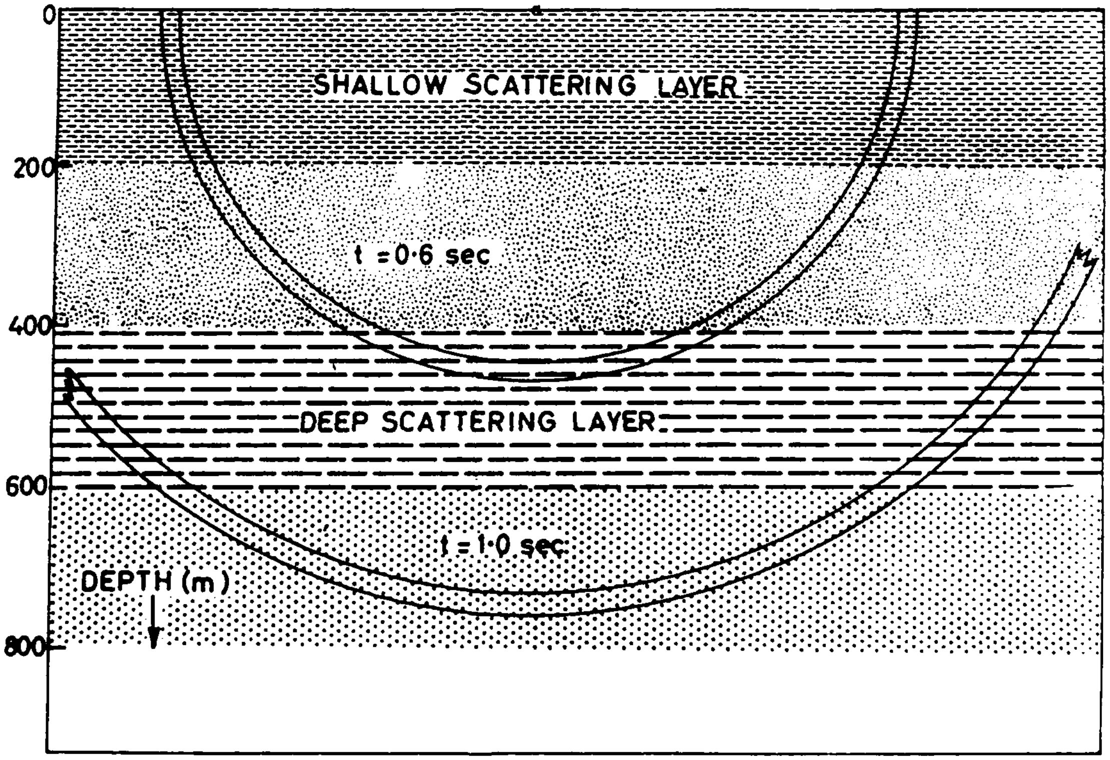


Figure 31. Acoustic scattering: volumes causing reverberation at times 0.6 and 1.0 s

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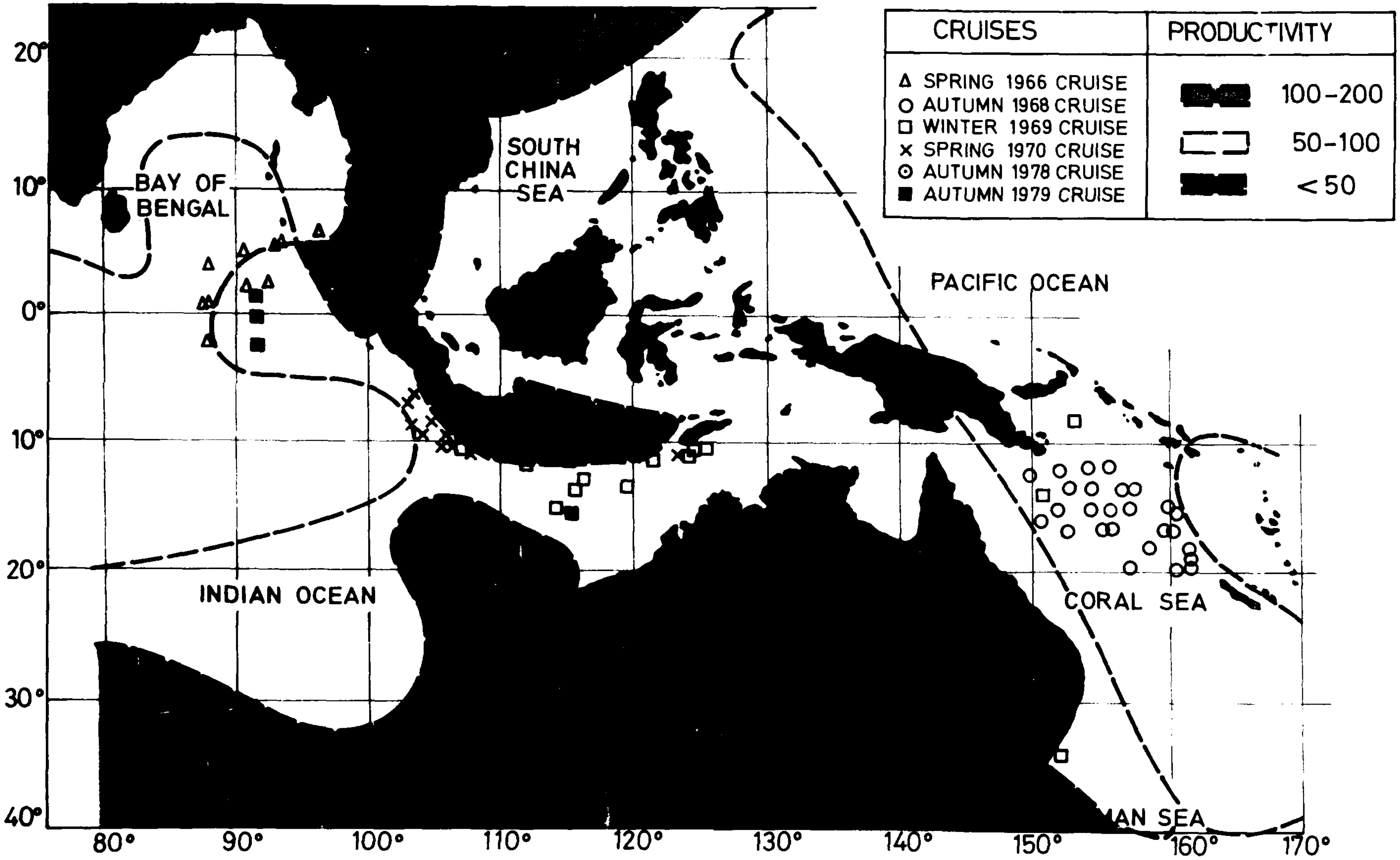

Figure 32. Stations at which volume reverberation was measured

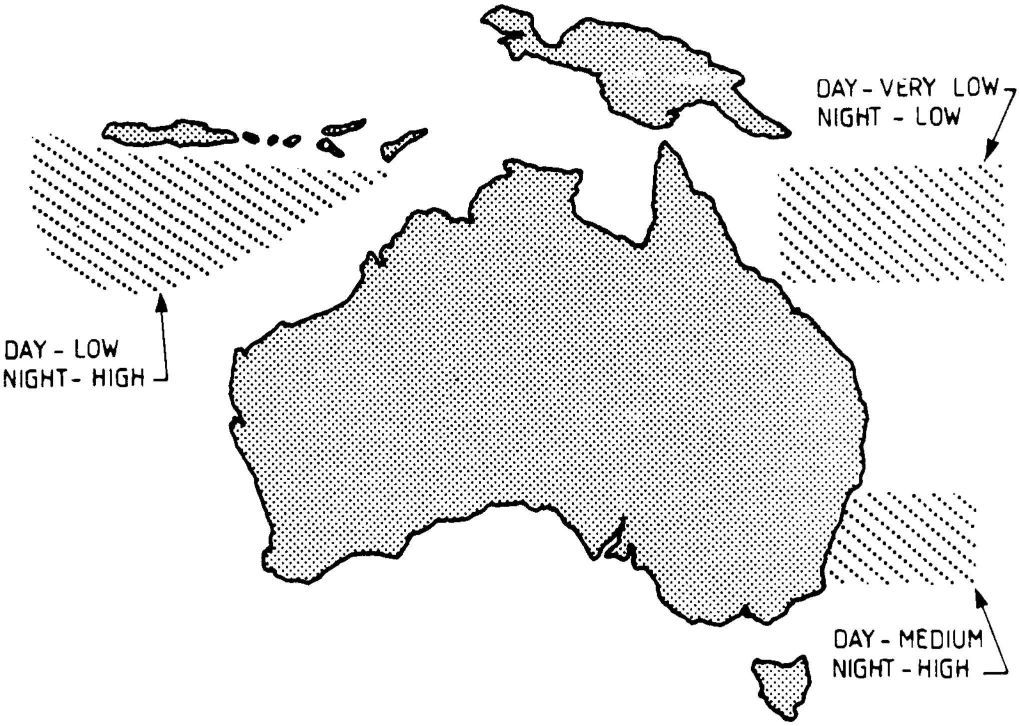

Figure 33. Volume backscattering strengths, day and night, in 3 areas

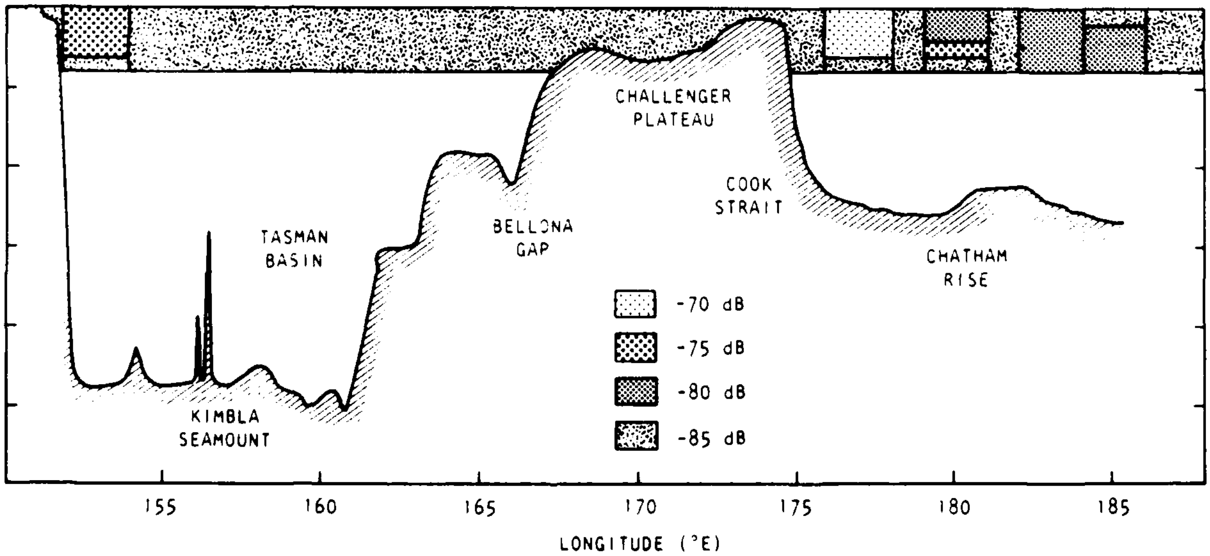

Figure 34. Night-time volume scattering strengths at 10 kHz during the northern leg of the summer survey along SEAMAP route B

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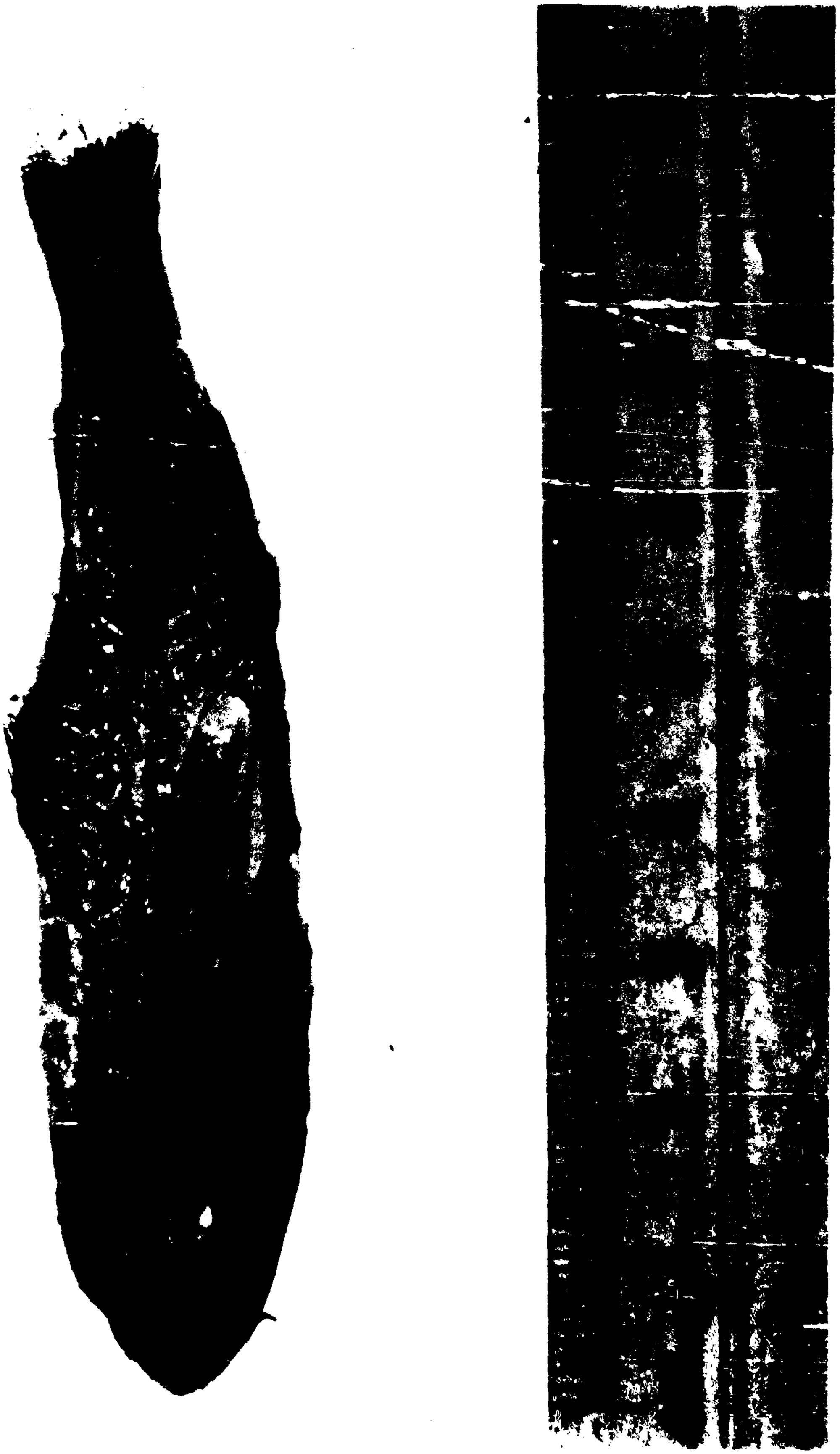

Figure 35. Dissected mesopelagic Myctophid ("lantern fish")

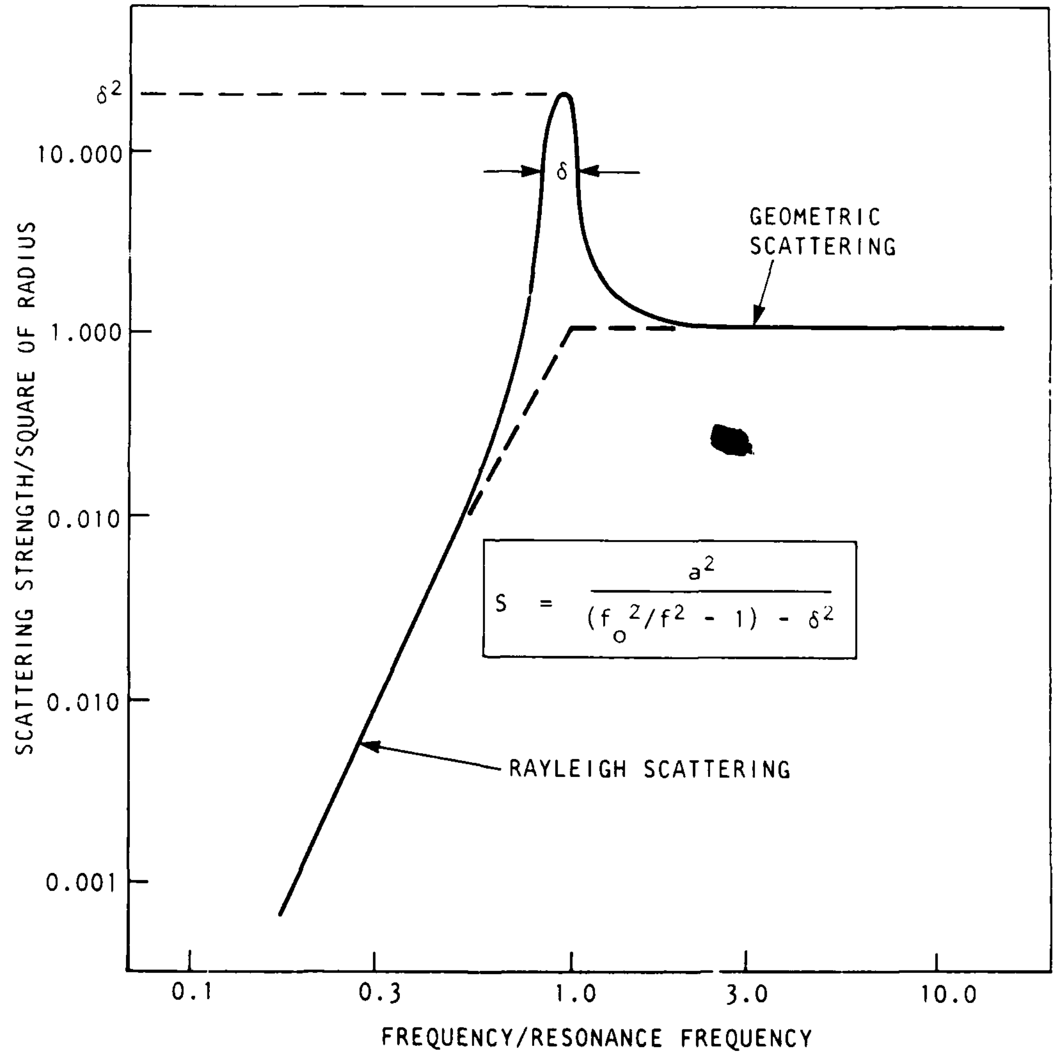

Figure 36. Theoretical scattering strength spectrum of a bubble/swimbladder

BACKGROUND OCEAN NOISE

Experimental and theoretical work involves:

- the horizontal and vertical directionality dependence upon frequency
- source levels for wind and ship noise
- determining the variation of overall noise levels for the Australian area
- identifying the incidence and duration of less common noise sources such as biological choruses, oil drilling activities, and seismic (volcano) noise.

Figure 37. Background ambient noise

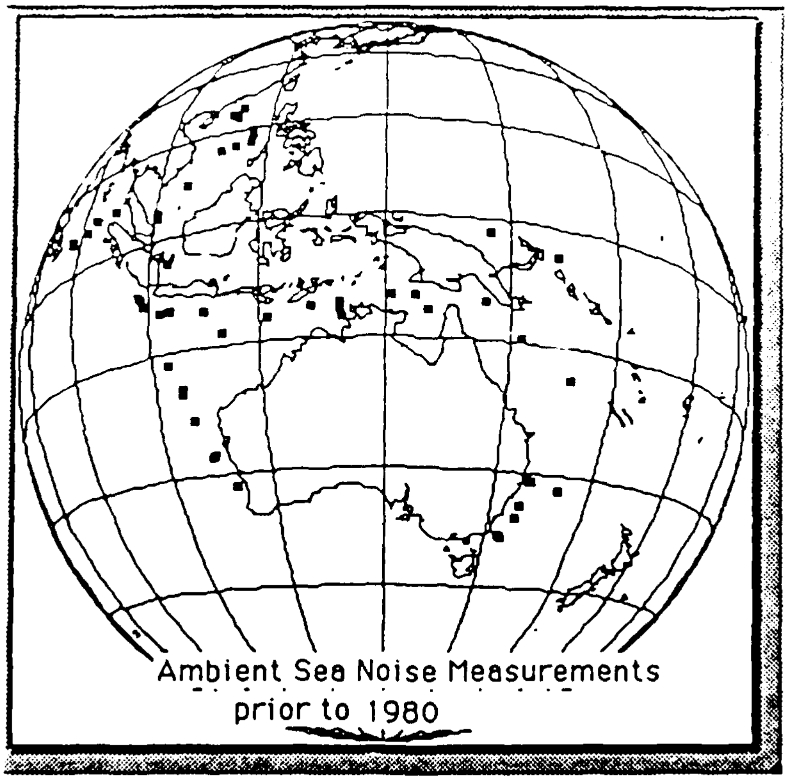

Figure 38. Ambient sea noise measurements prior to 1980

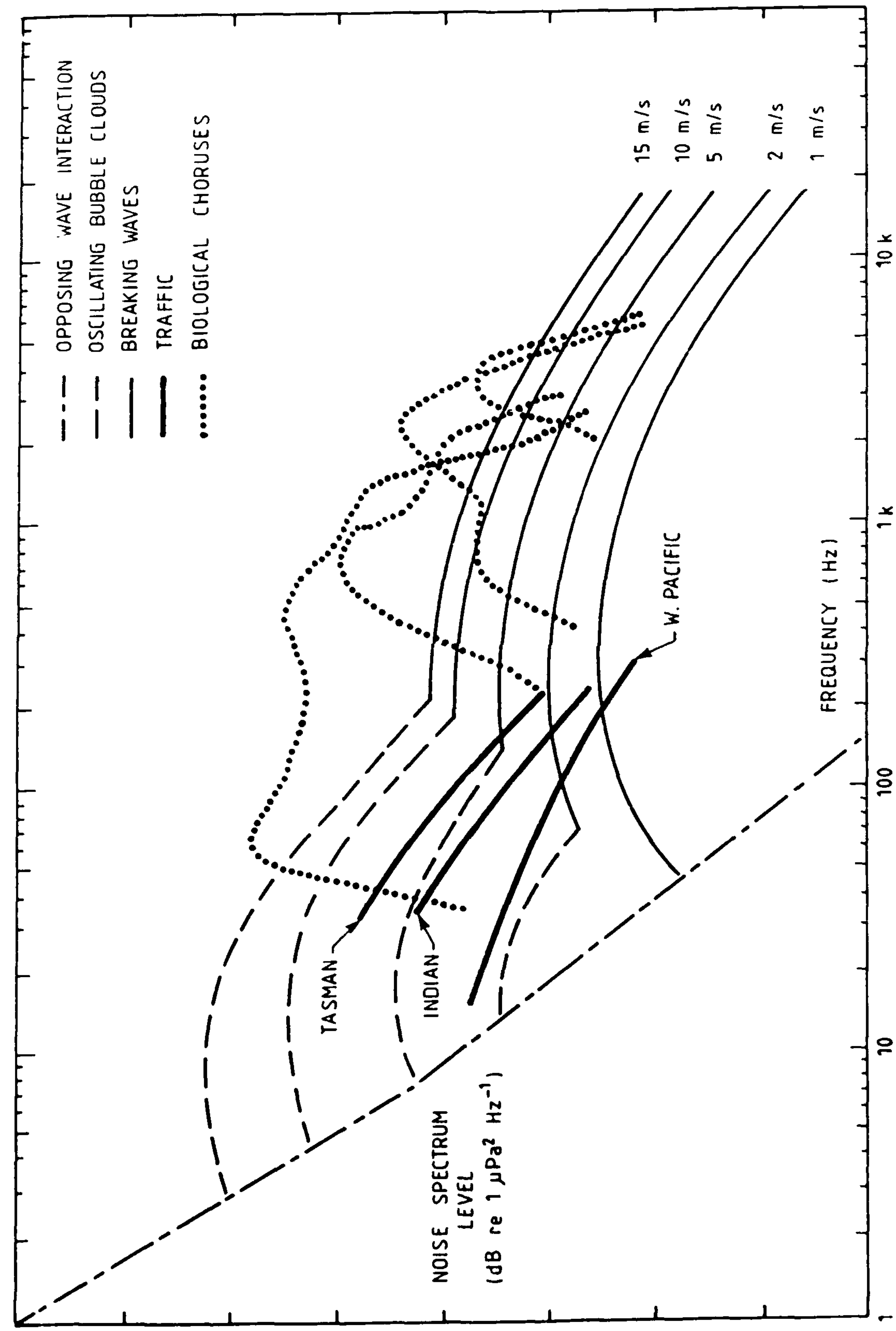

Figure 39. Spectra of wind, traffic and biological noises

CONCLUSIONS

Oceanography with defence applications

What?

Research and applied studies into oceanographic parameters that affect the performance of underwater defence systems.

Why?

To enhance Australian defence capability by providing oceanographic information necessary to prediction of performance.

How?

- Oceanographic surveys
- Mathematical modelling with experimental verification

Where?

- Australia's "area of direct military interest"
- The "area of primary strategic interest"

Who?

- Ocean Sciences Group of the Maritime Systems Division at DSTO Sydney
- Hydrographic branch of the R.A.N.
- Oceanographic institutions under contract and/or research agreements (to various DSTO Divisions and R.A.N. directorates.

When?

During oceanographic summer and winter (for surveys)

Figure 40. Oceanography with defence applications

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Security classification of this page : UNCLASSIFIED

1 DOCUMENT NUMBERS	**2 SECURITY CLASSIFICATION**
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Series Number : WSRL-GD-48/88	b. Title in Isolation : Unclassified
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	3 DOWNGRADING / DELIMITING INSTRUCTIONS

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SIGNIFICANT DEVELOPMENTS IN THE DEFENCE OCEANOGRAPHY
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5 PERSONAL AUTHOR (S)	**6 DOCUMENT DATE**
M.V. Hall	November 1988
	7 7.1 TOTAL NUMBER OF PAGES 52
	7.2 NUMBER OF REFERENCES -
8 8.1 CORPORATE AUTHOR (S)	**9 REFERENCE NUMBERS**
Weapons Systems Research Laboratory	a. Task : 86/142
	b. Sponsoring Agency : DST
8.2 DOCUMENT SERIES and NUMBER General Document 48/88	**10 COST CODE**
11 IMPRINT (Publishing organisation)	**12 COMPUTER PROGRAM (S)** (Title (s) and language (s))
Defence Science Technology Organisation Salisbury	

13 RELEASE LIMITATIONS (of the document)

Approved for Public Release.

Security classification of this page : UNCLASSIFIED

14 ANNOUNCEMENT LIMITATIONS (of the information on these pages)

No limitation

15 DESCRIPTORS

a. EJC Thesaurus Terms	Oceanographic parameters Military oceanography Towed sonar Underwater acoustics
b. Non - Thesaurus Terms	

16 COSATI CODES

0047B
0063A

17 SUMMARY OR ABSTRACT
(if this is security classified, the announcement of this report will be similarly classified)

Over the past 3 decades, Australian Defence Departments have sponsored significant research effort on aspects of the marine environment that affect the performance of sub-surface defence systems. The reasons for this effort on "Defence Oceanography", and its achievements to date, are discussed and related to changes in the requirements of the Maritime defence forces. Sonar surveillance is discussed as an application of Defence Oceanography, and the environmental parameters that have an impact on this aspect of maritime defence are described. The progress that has been made by research into understanding these parameters is summarised with emphasis on the ocean areas around Australia. The two main objectives of the research have been (i) to contribute to a data base or climatology (mainly useful for parameters that vary predictably with time); and (ii) to develop algorithms from which randomly-varying parameters (that are remote in either space or time) may be predicted from observable conditions. As has happened in the past, advances in Defence Oceanography will stimulate technological innovations that will, in turn, generate new and unexpected questions about the marine environment.