NAVAL APPLICATIONS OF MARINE ACOUSTICS

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ABSTRACT

Both communities have interests (or requirements) that can be described by the parameters of time and space. The science and technology of Marine Acoustics, dependent on specific investigators and their focus, is not limited in it's interest. Navies, on the other hand, have constrained requirements and most usually, constrained equipments/resources. While there is often coincidence of interest, there is also competition for National resources; the outcome can lead to frustration on all sides. An additional issue has to be recognized; if the Navy believes it has developed an operational advantage by exploiting a particular oceanic behavior, it will (and should) protect that information, which is counter to the needs of a scientist, whose metric for success is publication. Balancing those competing issues can be difficult. From the perspective of Naval needs (requirements), several examples of the juxtaposition of sonar characteristics and Naval Operations onto the "world" of Marine Acoustics will be given, with an emphasis on ocean physical properties.

INTRODUCTION

The object of this paper is to provide the reader with an understanding of the interaction between two groups that work in the marine environment; one to understand it's properties over all time and space scales (and develop tools to work in those conditions) and the other to recognize the limits the marine environment places on the operational requirements for defense. The introduction looks at the past 100+ years at an altitude of 8000 m, but provides the context of defense requirements. A major link between operational Navies and the marine science and engineering folks is the undersea sensor called a "sonar". At the end of the 19th century, the sciences of piezoelectricity and electronics were known, but applications were in their infancy. A cogent example: Fessenden's "oscillator" (Figure 1), (Scientific American, 1915) was in fact, an electric motor driving a metal plate in contact with the sea to provide an acoustic signal to search for iceberg keels. World War I and the impact of the submarine accelerated the development of the first sonar devices, but no systems were in place until after the war. Work on sonars continued between the World Wars, but not at a pace consistent with the development of the submarine as a weapon of war. With the advent of WWII, that platform became so effective that enormous resources were devoted to the defeat of it. Though AntiSubmarine Warfare (or ASW) had a large role during the war, the individual "battles" were, in fact, short range affairs, typically of order of 3-8 km. The cold war began during, but reached high levels of intensity soon after the end of WWII. Two paradigm shifts occurred shortly after that: the first, exploitation of the underwater deep sound channel (Figure 2), (Ewing and Worzel, 1948), predicted by Lichte (Lichte, 1919) in the early 1900's, measured in the 1930's; and the operational deployment of nuclear submarines, with ICBMs (InterContinental Ballistic Missiles; (Figure 3), (USN). The result of this was the elevation of ASW to one of the top national defense priorities. Initially, there was debate over means of long range detection of submarines—active versus passive; tests during a project called "Artemis" led to the conclusion that active methods were too big, and expensive, (Figure 4), Massa Products Corporation Website) and not covering sufficient area, leading to passive methods and the system called "SOSUS" (SOund SUrveillance System). This particular time (the early 50's to early 60's) is when a degree of divergence between the communities began; in part, it was due to the success of Navy systems, which resulted in an attitude of "if it ain't broke, don't fix it", coupled with a desire to keep the success out of the news media. With the (more or less) end of the cold war, Naval interests shifted to littoral regions, where operational ranges were reduced to the extent that higher frequencies could be used for their work. In this time era, (90's to date) also marked the re-convergence of the two communities. The final paradigm shift (and admittedly speculative on the part of the author) is the reality today of the costs to maintain an effective Naval defense force in light of competing requirements in every National budget. Succinctly; the requirements have not changed; but the funds available to equip and maintain effective forces have effectively been reduced. The consequences are to search for ways that fit within a budget structure: a cogent example is the increasing use of the AUV (Autonomous Undersea Vehicle), which, in a piquant way, is putting the Navy back to the space and time "dimensions" of WWI/WWII. The body of the paper is a set of four examples of Naval applications of specific oceanic (and/or ocean boundary) properties.

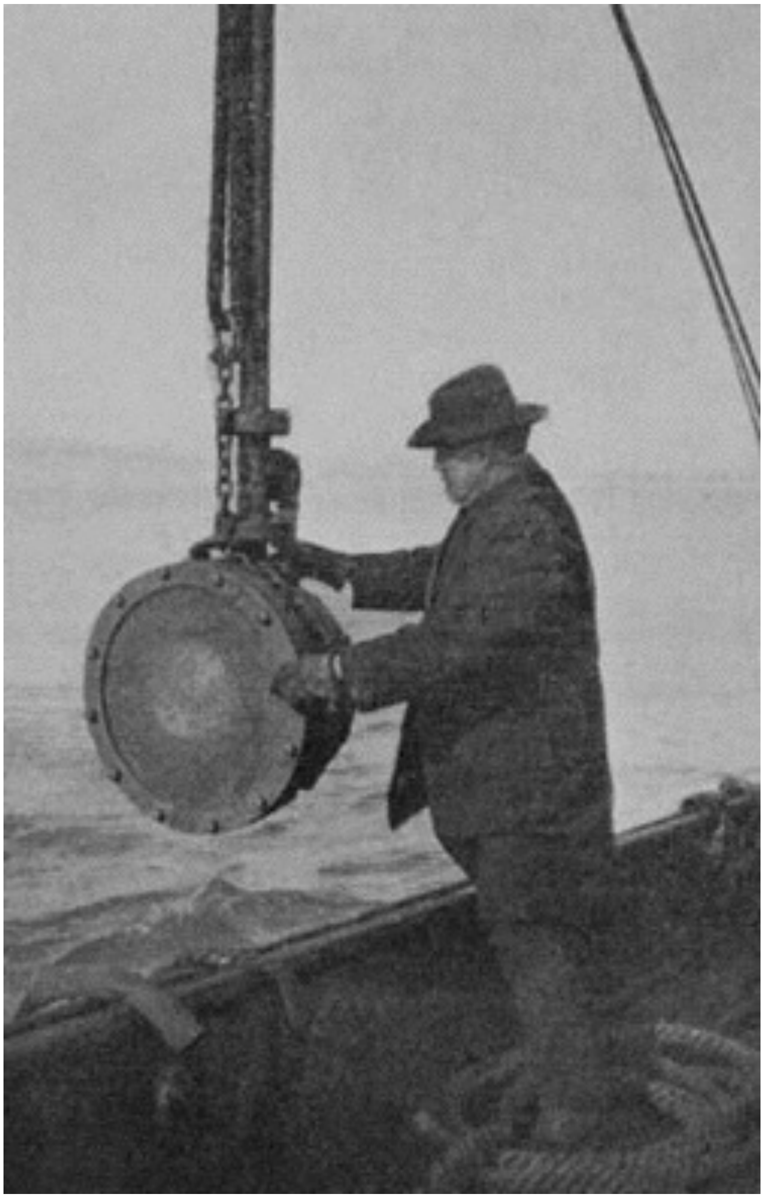

Figure 1: Reginald Fessenden, with his Oscillator

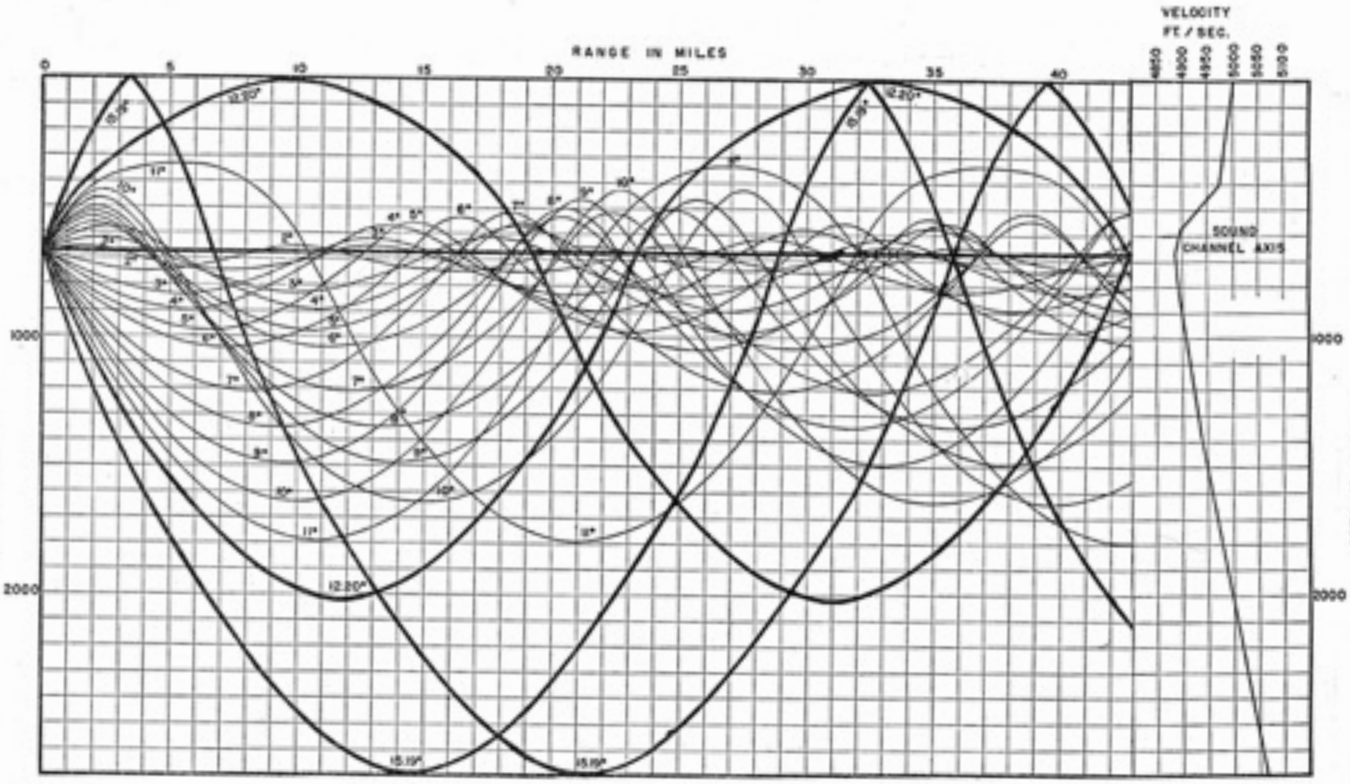

FIGURE 5.—*Ray diagram for typical Atlantic Ocean sound channel—sound channel and refracted surface-reflected rays*

Figure 2: The Sound Velocity Profile and an Illustration of the Deep Sound Channel

Figure 4: The Artemis Active Array

Figure 3: The Business End of a SSBN

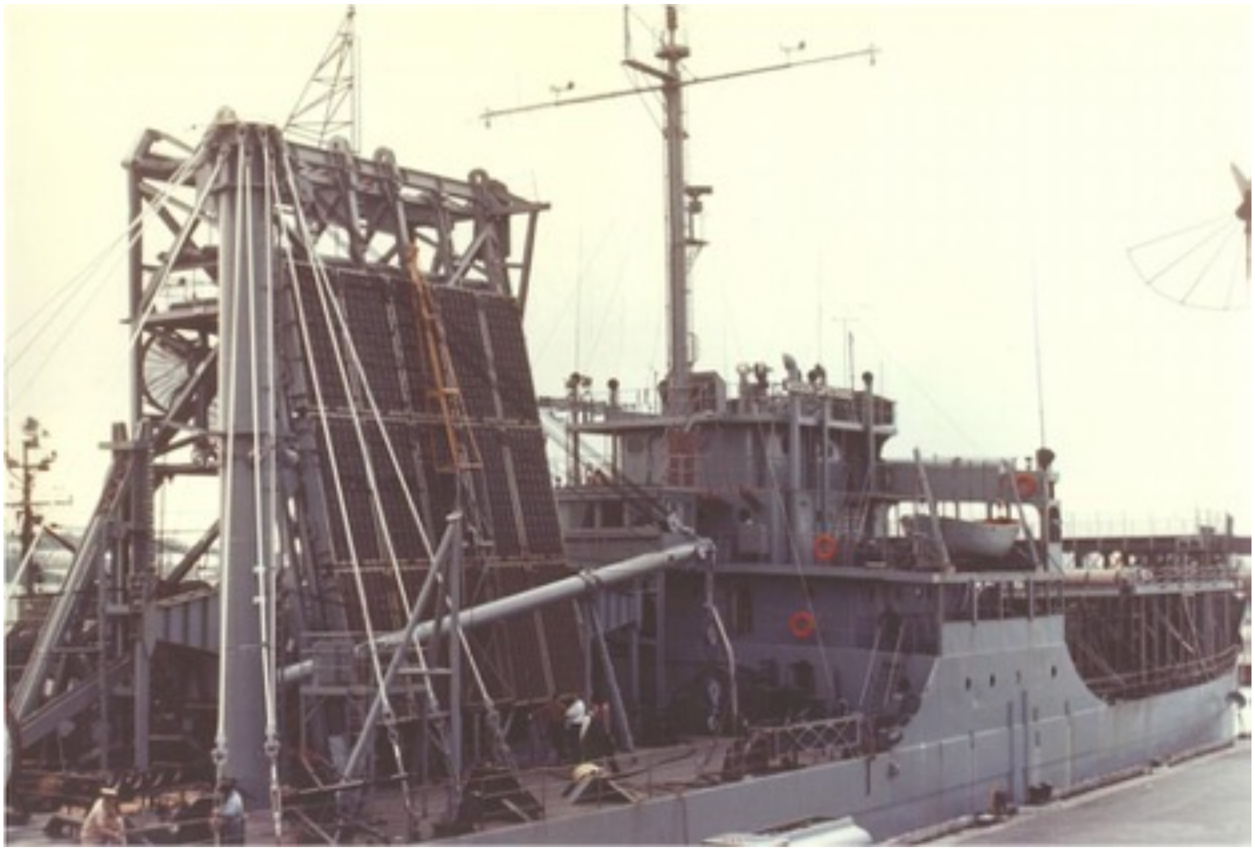

Figure 4: The Artemis Active Array

THE SQS-26; A SURFACE SHIP HULL MOUNTED SONAR

In the early 50's, destroyer skippers found themselves in a peculiar position: their hull-mounted sonar, still at frequencies of 10's of kHz could "see" 2-5 km in front of the ship and, with modest vertical angular depression, see a 2-5 km wide strip 55 plus km away (at least, in the North Atlantic), due to the deep sound channel created Convergence Zone (CZ); leaving them blind for approximately 48 km (Figure 5), (Dosits Website) not a good situation for a Navy ship facing a submarine with (now) fairly long range torpedoes. Solution? Lower the sonar frequency, increase the power and depress the vertical angle even more; burn through the loss due to bottom reflection and light up that 48 km "dead" zone. This was the birth of the SQS-26. (Figure 6), (Bell, 2003) Problem solved? Not quite; The original tests to aid in the sonar design were conducted in an area that was both flat (abyssal plains), and compacted (low(er) acoustic reflection loss). The first deployment quickly discovered this fact, and led to about a 5 year program, called the Marine Geophysical Survey(s), (Watson and Johnson, 1969) to categorize the sea floor physical characteristics and the consequent acoustic reflection loss for a broad range of frequencies and various Continuous Wave (CW) pulse types. Frequencies from low hundreds of Hz to more than 10 kHz were used; seafloor footprints varied from 100's of square meters to 1000's. Cores were obtained and a great deal of effort was made to identify the seafloor makeup. However, enormous pressure was present to provide bottom loss curves (Figure 7), (Urick, 1979) for various areas that could be used by the Navy operationally. Again, an example of close cooperation between the scientific community and the Navy, harking back to the days of WWII, though a clear indicator of the divergence of interests.

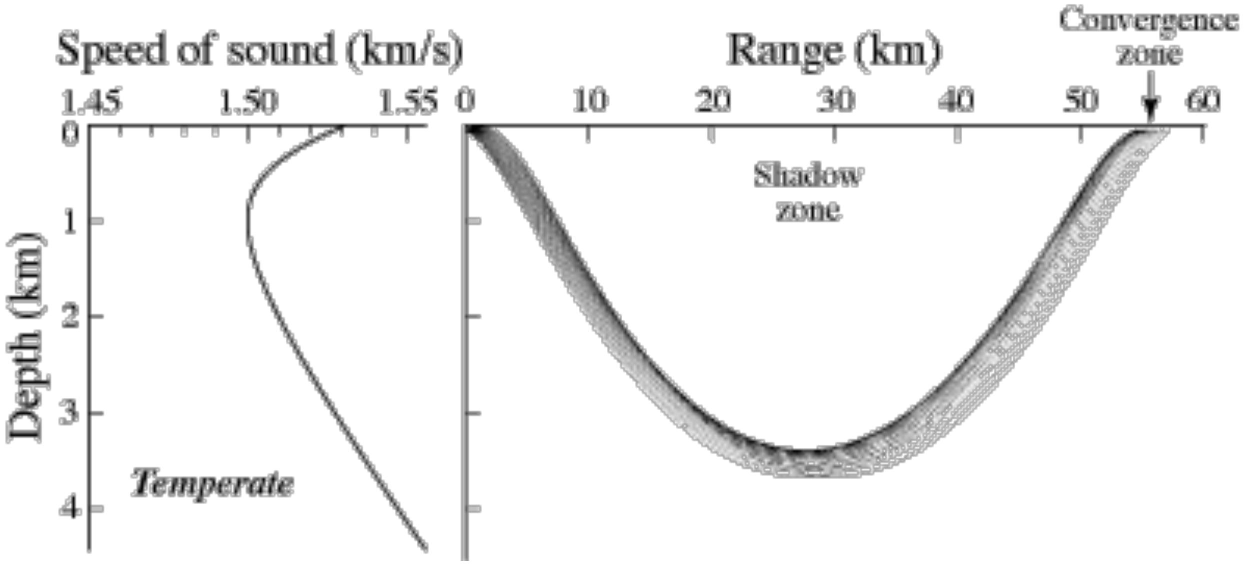

Figure 5: Direct Path, Convergence Zone and the Gap Between

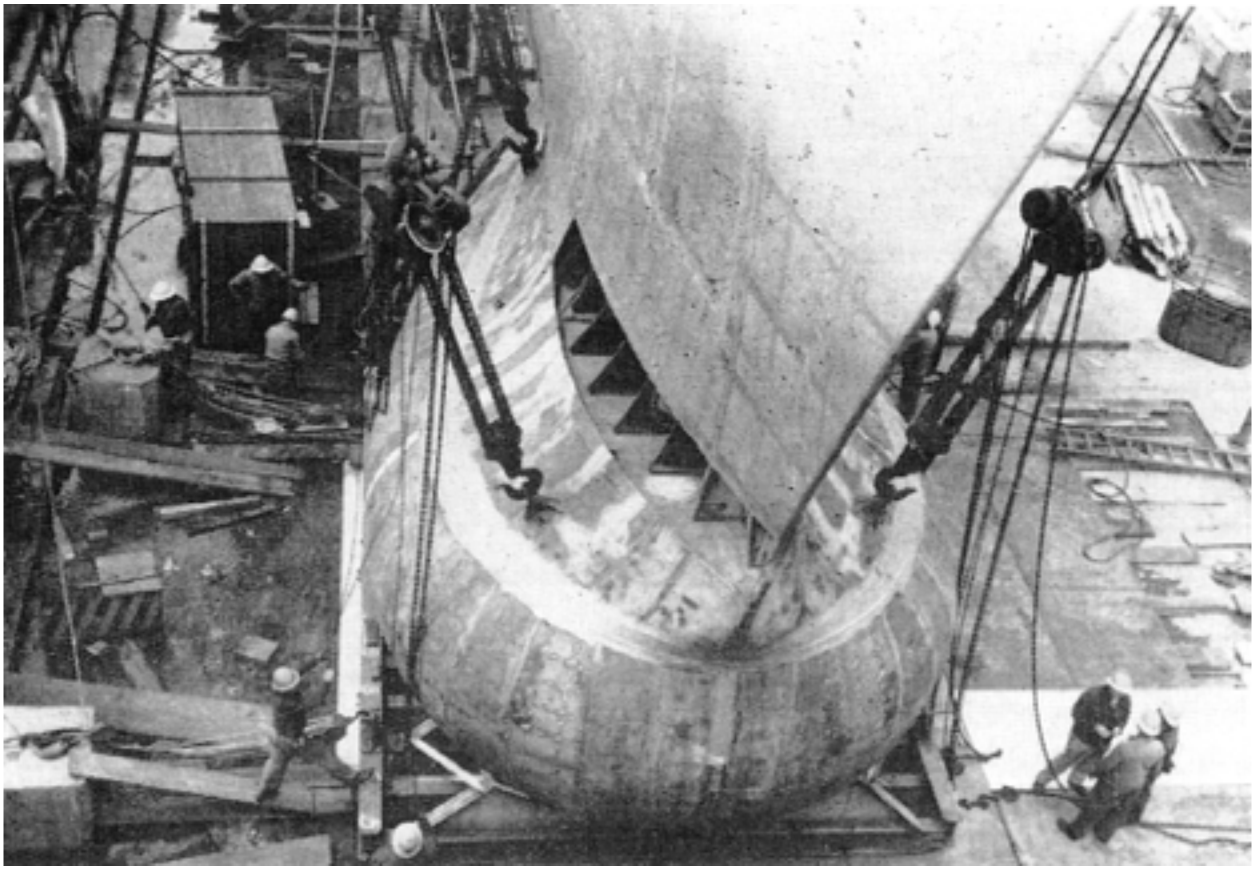

Figure 6: A SQS-26 System during Installation

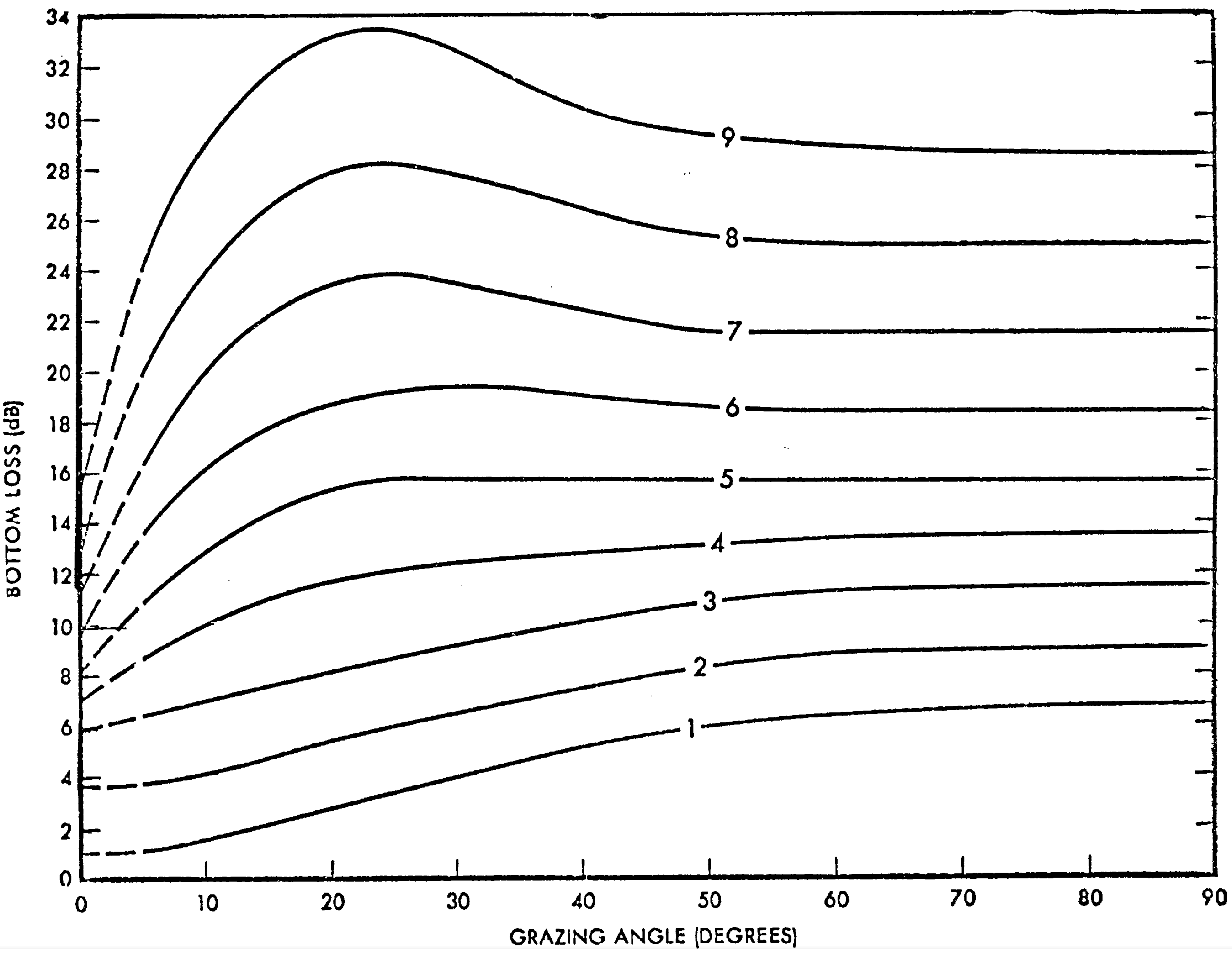

Figure 7: Generic Bottom Loss Curves

ABSORPTION

The movement to low frequencies for long range submarine detection shifted the dimensions of ASW from a few kilometers to ocean basin size (1000's of km). An immediate question was raised: how far could one see, given a specific target source level? Given the energy was traveling in the sound channel, the geometric spreading loss is easily calculated, but losses were also expected due to absorption. At the end of the WWII, it was known that sea water absorption losses were higher than pure water, but the reasons why were unknown. Two approaches were undertaken to resolve this issue: the first was laboratory (and some limited at-sea measurements); from this work, the contribution due to magnesium sulfate was identified in 1949 (Francois and Garrison I,1982) and the contribution due to Boric Acid in 1972 (Figure 8), (Francois and Garrison II, 1982). The second effort involved extensive at-sea measurements in all the major world ocean basins, again taking advantage of the deep sound channel (Figure 9),(Kibblewhite and Hampton, 1980); the reason for the latter effort was the concern that variations in large scale ocean properties would not be reflected in laboratory or small scale data collection. As an aside, there were also measurements in large fresh water bodies (Lake Tanganyika, in Africa; Lake Superior in North America); to compare with known pure water absorption and to act as a check on the oceanic measurement technique. An issue that received considerable debate was the uncertainty of whether or not the sound channel did indeed, trap the energy totally, so a correct calculation of absorption could be made, or were there losses from the channel along 8-10,000 km pathway that would be incorrectly interpreted as absorption loss? An extremely useful study of this question was made by Alick Kibblewhite (Kibblewhite and Hampton, 1980), of New Zealand, in 1980. A key question that has not been put to rest is: at what frequency does the sound channel trapping concept break down? In any case, oceanic scale measurements of sound absorption, that reflect varying salt content of the major seas have been completed, (Figure 10), (Mellen and Browning, 1977).

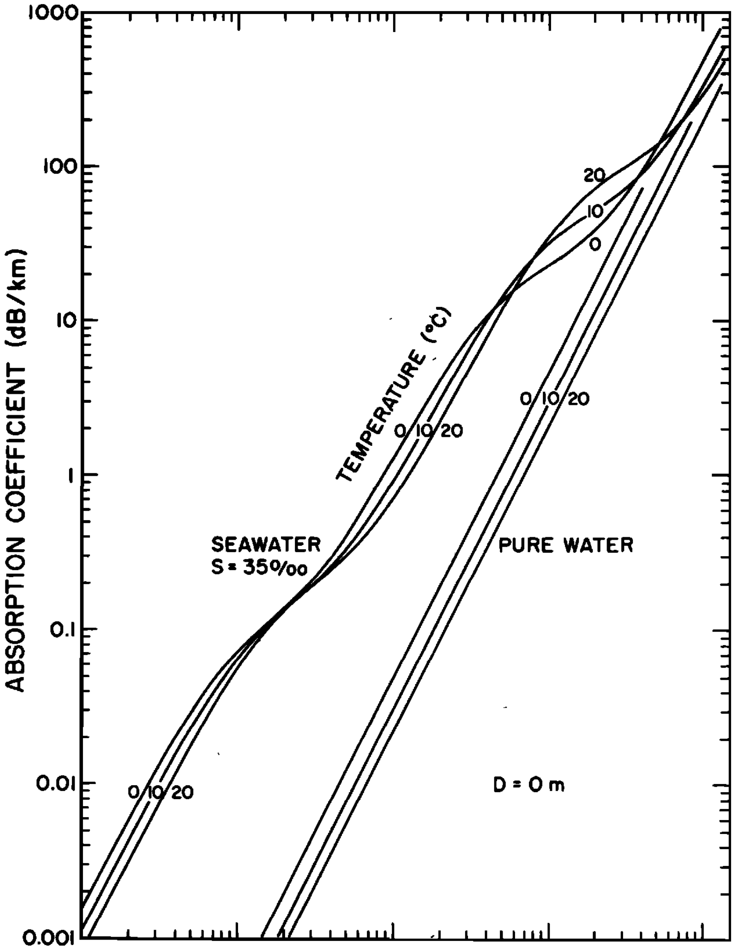

Figure 8: Absorption in Seawater

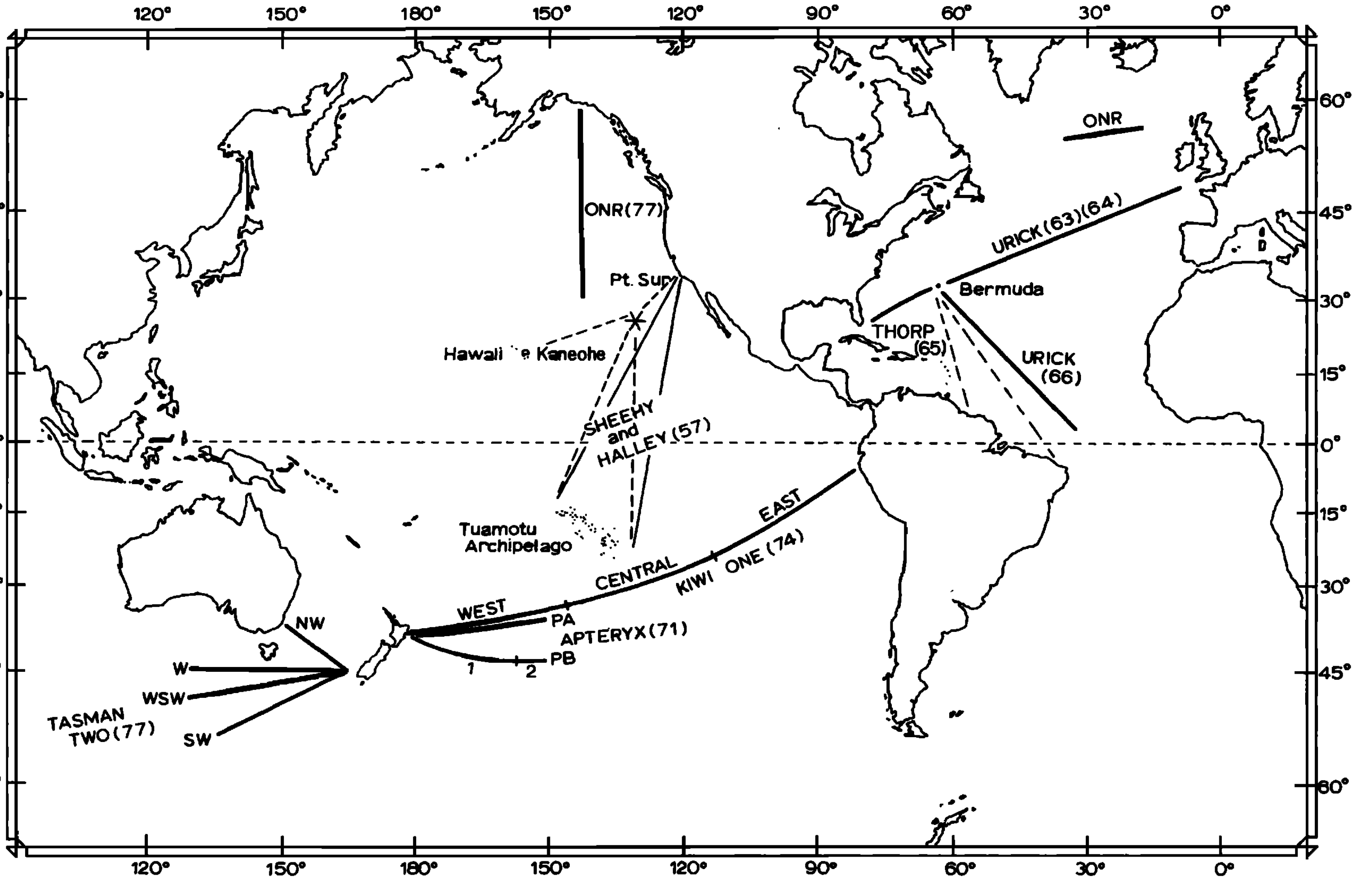

Figure 9: World Wide Attenuation Measurements

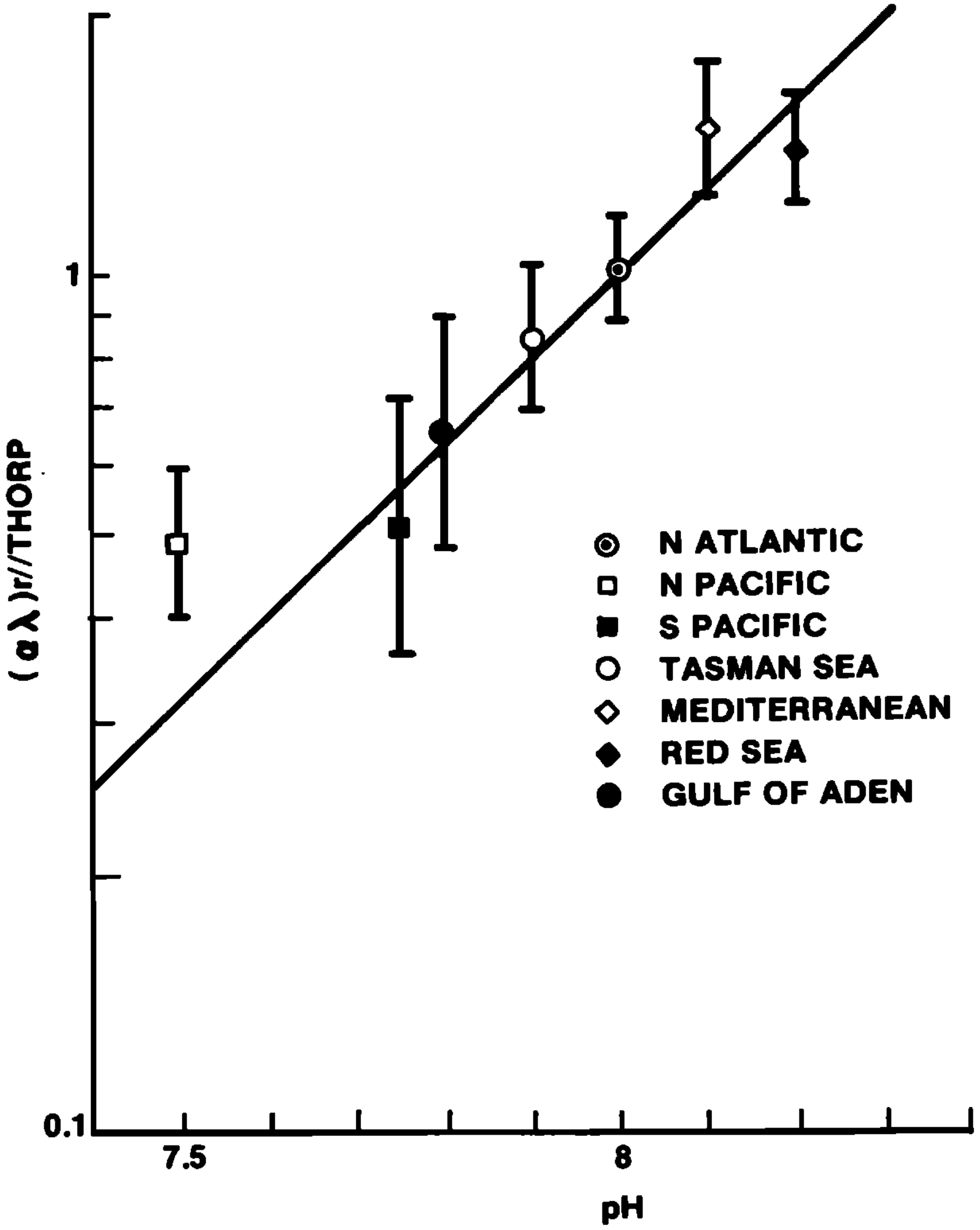

Figure 10: pH Dependence of Attenuation

SIGNAL VARIATION

A feature of every sonar signal received (no matter what frequency is used; no matter what signal type is used; no matter how long the signal is examined) is the frustrating variation in amplitude with time, that does not have any obvious explanation. Setting aside large scale circumstances such as the Lloyd's Mirror (boundary image interference) phenomena, the general cause is micro-path differences leading to phase shifts that result in both constructive/destructive interference. Then one is left with the question: what caused the path differences? That question has as many answers as there are ocean dynamic features the sound field traverses. The spatial and temporal scales are extreme; ranging from seconds to months and from centimeters to kilometers. Features such as internal waves, boundary currents, gyres to tiny temperature patches, fresh water cells in the Arctic and bubble plumes from breaking waves are a few examples from a very long list of possibilities. Two examples are detailed: Project MIMI and the Cobb Seamount tests. MIMI (University of Miami/University of Michigan) transmitted 420 Hz signals from near Miami, Florida to Bimini, in the Bahamas (Figure 11), (Steinberg and Birdsall, 1966) approximately 70 km in distance, but across the funnel that the Gulf Stream flows through. The acoustic path did encounter the sea floor, so the causal(s) for change were the dynamics of the water column and the sea floor encounters. The second sea test,Cobb Seamount; (Figure 12), (Ewart, 1984) was from one seamount to another, approximately 18 km miles apart off the US west coast 500 km from the Washington State coastline; a path that only traveled through the water column and included frequencies from 2 to 13 kHz. The results have published in a number of articles and were the first to link specific ocean dynamic processes to signal variation.

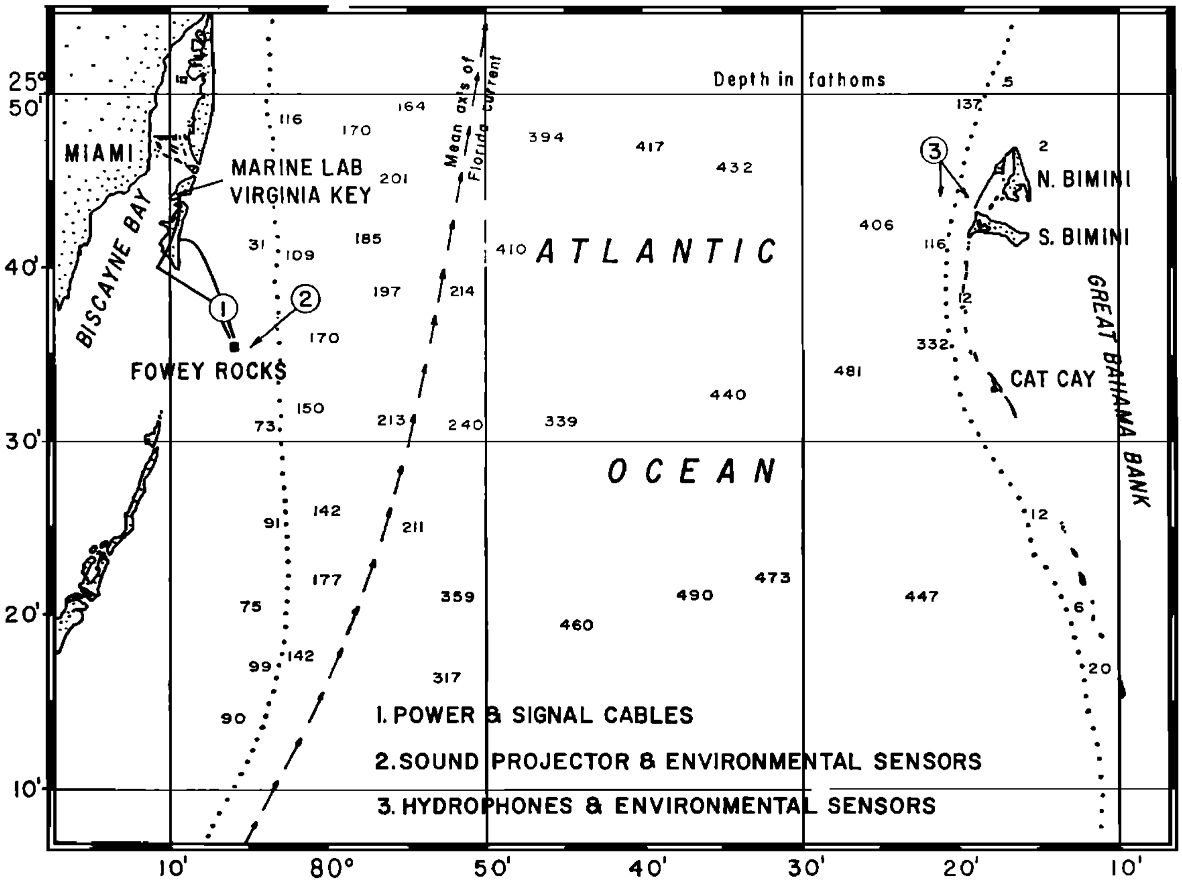

Figure 11: The MIMI Experimental Site

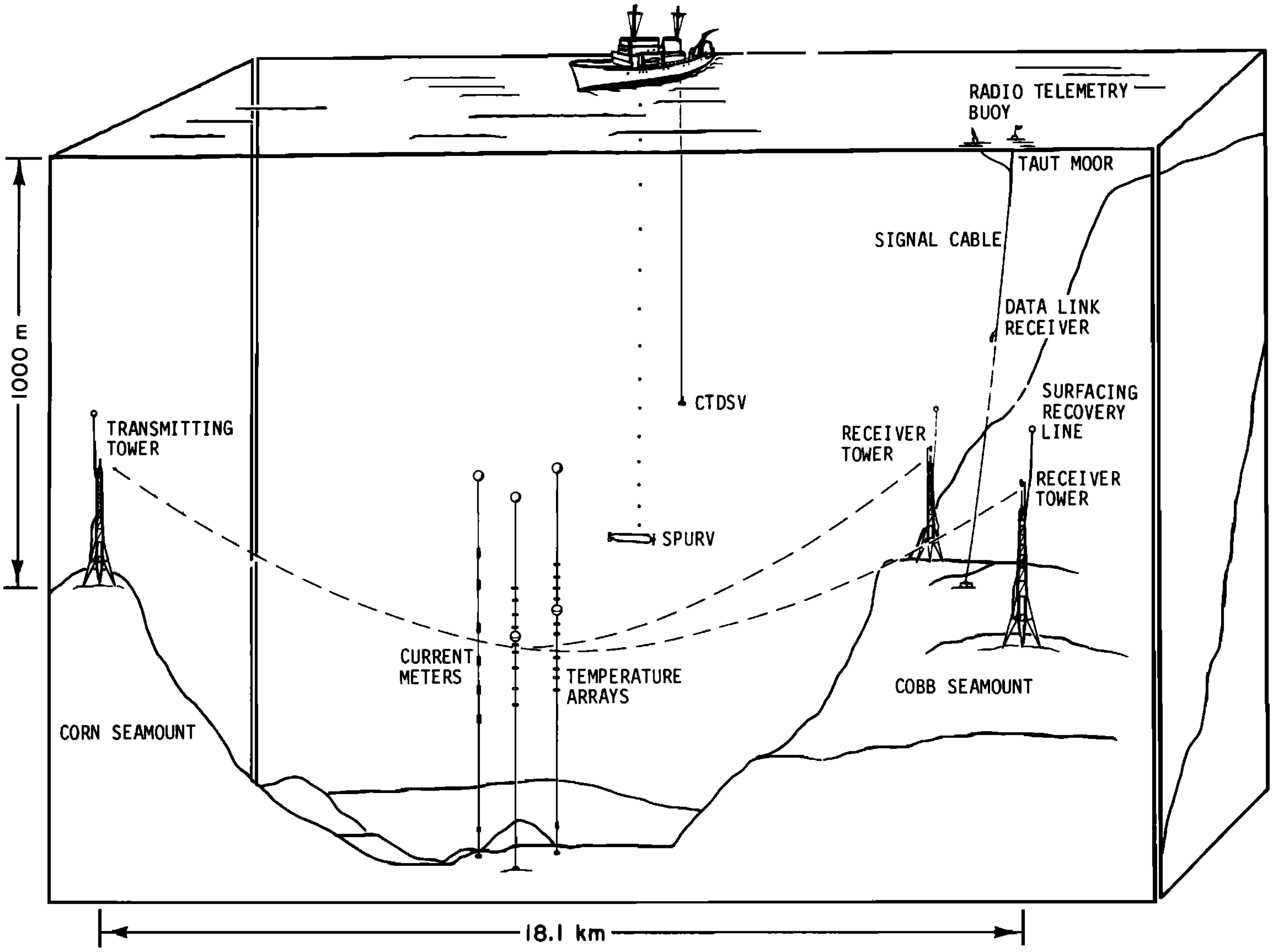

Figure 12: The Cobb Seamount Test Site

VHF ACOUSTICS

The Navy has two primary requirements for high resolution mapping of the seafloor: Navigation and Mine Countermeasures. The natural variation of the ocean bottom is high; add to that the debris deposited there by everyone and the result is a complex boundary that may present hazards, and if also littered with sea mines, extreme danger. Bathymetric mapping began with high frequency down-looking "fathometers" (10's of kHz), which soon gravitated to Side Looking Sonars (SLS's) (or Side Scan Sonars(SSS's)), that provide excellent, almost photographic images of the seafloor. As frequencies increased (to 100's of kHz) the size of "visible" objects dropped to less than a few cm, at least for shallower depths. There are various configurations of the SLS; with a "towed fish" (Figure 13), (NOAA Website) or a hull mounted unit being the two popular versions. The operational trade-off is a hull mounted system can be more powerful and sensor position can be well defined for mapping registration, but, as the water depth increases the desire to stay near the seafloor and use higher frequencies for better resolution often leads to the towed fish option. It should also be noted, that off-shore oil exploration and the logistic systems for handling the product lead to significant investment of this industry in the development of high resolution sonars, for equipment positioning, monitoring and repair work. Synthetic Aperture Radar (SAR) has been in use for some time; but it's counterpart, Synthetic Aperture Sonar (SAS), (Figure 14), (Kongsberg Maritime Website) took longer to develop; the requirement of exact sensor position location, together with a reasonable estimate of water column (sound speed) variability is necessary for it's successful use. The aperture increase allows return to lower frequencies and retain high resolution, which extends the water depth coverage. It is possible to "see" objects of order 3-5 cm. Configurations to date have been towed fish. A major application of the high resolution sonars, is (as expected) object identification, but research continues to take advantage of the complex reflected signal to study detailed physical properties of the seafloor. Additionally, mapping of the ocean bottom at these high resolutions leads to research of the evolutionary formation processes of the seafloor and predictive methods for estimating its composition.

Figure 13: Side Looking Sonar "Fish"

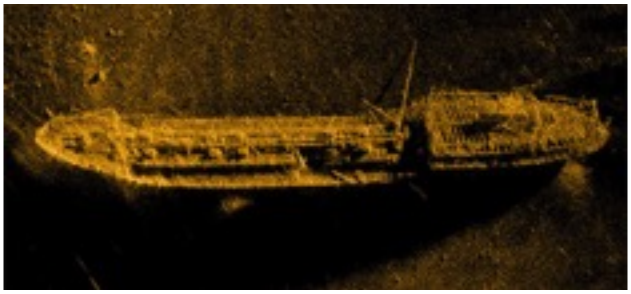

Figure 14: SAS Image

CONCLUDING REMARKS

As would be gathered from the above comments, the interaction between defense forces and the national science and engineering community has a mixed history. The focused requirements of a Navy, together with limited resources can cause divergence of interests; taken overall, the interaction has been valuable for both and will continue to be so.

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