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Underwater Acoustics: Paper 2aUW9

Underwater acoustics research at the Woods Hole Oceanographic Institution, 1930-1960

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The Woods Hole Oceanographic Institution (WHOI) was founded in 1930, and throughout its history has had a strong involvement in research into the science and applications of sound in the ocean. In terms of a brief history, three eras stand out: (1) pre-WWII, (2) WWII, and (3) the postwar years. This manuscript will focus on the history of the most influential and colorful, individuals and stories that arose during the war years. Provided are personal reminiscences, technical report details, and photos illustrating the achievements, and importance, in underwater sound research at WHOI during that time.

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1. Introduction

The people who work at well-known places which have been in existence for awhile, like the Woods Hole Oceanographic Institution (WHOI), often know very little about the early history of their place of employment, much to their loss. I think that was true of the authors when we started working on this talk for the "Historical Perspectives on the Origins of Underwater Acoustics" session at the Acoustical Society of America meeting. However, given the impetus of the talk, and the wonderful resource of the WHOI Archives (http://dla.whoi.edu), we soon learned much about WHOI's rich and interesting history, from its inception in 1930 up to about 1960. (There is, of course, some very interesting history past 1960 as well, but we put this year as the post-WWII cutoff.) We are hoping that our WHOI history narration will be an important thread for understanding the history of underwater sound research that is being put together via these POMA archives from the Special Session. And we also hope the reader will be as entertained as we were by the rather rollicking and freewheeling characters that populated that period of history and their scientific adventures.

2. In the beginning…

WHOI's story begins with two visionaries: Henry Bryant Bigelow (Fig. 1), who became WHOI's first director, and Frank R. Lillie, who was president of the Marine Biological Laboratory (WHOI's older neighbor in Woods Hole village) and the true "founding father" of WHOI.

Figure 1. *WHOI's first director, Henry Bryant Bigelow, piloting US Bureau of Fisheries vessel Grampus in 1914. (Courtesy of WHOI Archives) His experiences as a seagoing oceanographer studying the Gulf of Maine give him strong qualifications as a leader in the field.*

The younger Bigelow and the more senior Lillie both shared the vision of an oceanographic laboratory on the east coast of the U.S. that did all types of oceanography and had a full-ocean capable ship. Previously, researchers working the Atlantic Ocean used vessels of opportunity, which were often range-limited and less capable of doing the types of tasks needed for diverse fields of oceanographic research. A dedicated laboratory and a capable ship would cure that lack.

Both being men of influence, the dream began to materialize, and in 1930 “The Oceanographic” initiated operations in Woods Hole, Massachusetts. The building for the Oceanographic formally opened its doors in the summer of 1931. This was a “mostly summer” facility at first, although current events soon changed that. Bigelow had two big tasks to accomplish in his first year as Director: 1) assemble a first rate staff for the new Institution and 2) formulate specifications for the new research vessel. The former he accomplished by scouting the universities for researchers in a wide assortment of specialties, most outside his own area in marine biology. The latter he accomplished by combining his own great seagoing expertise with that of his student, Columbus Iselin, who would skipper the new vessel on its maiden voyage to Woods Hole from its shipyard construction site in Copenhagen. The research vessel *R/V Atlantis* (Fig. 2) arrived in Woods Hole on August 31st, 1931, and the Woods Hole Oceanographic Institution was now staffed and grandly equipped for ocean research in the Atlantic Ocean and beyond.

Figure 2. *The R/V Atlantis in 1931. (Courtesy of WHOI Archives)*

WHOI's first full year of research was 1932, with a staff of sixteen research assistants and numerous visiting summer investigators arriving from all over the world. But aside from a newfangled "sonic sounding machine" (fathometer) aboard the *R/V Atlantis* [1], the research fare didn't have much to do with acoustics. Biology, geology, geophysics, physical oceanography and marine chemistry were the main topics of interest. But that was about to change drastically and soon, thanks to a young, ambitious Lehigh University professor named Maurice Ewing.

3. "Doc" comes to town

Maurice Ewing (Fig. 3), known universally as "Doc" Ewing, was from a large, Texas farming family, a background which made him both hardworking and resourceful. Being an extremely bright youth from Texas, it seemed only natural that he would attend one of Texas' elite schools, Rice University in Houston, where he received his BS, MS and PhD degrees in geophysics. He also worked a number of part time jobs there, including (no surprise) in the Houston "oil patch." His academic career as an independent young scientist started at Lehigh University in Bethlehem, Pennsylvania as a Physics professor. There he continued his interest in geophysics, to which he added his own twist – the use of explosive sources in water (or even in ice) above the solid earth. To pursue this new direction, Ewing enlisted students from Lehigh (most notably Allyn Vine and Joe Worzel) to spend their weekends blowing up lakes, quarries, ponds and marshes in nearby New Jersey, and developing novel, home grown source and receiver equipment.

Figure 3. *Chief Scientist Maurice Ewing on board the R/V Atlantis in 1949. (Courtesy of WHOI Archives)*

While the land based geophysics community wasn't so interested in Ewing's novel research, WHOI trustee William Bowie did take notice, and offered Ewing ship time and funding to see if Ewing's methods could be used to investigate the structure of the continental shelf. Ewing jumped at the chance, and in 1935, after calming the fears (in retrospect, well justified!) of WHOI director Bigelow about having high explosives aboard his beautiful new ship, Ewing and his students started going to sea on the *R/V Atlantis* to do seismic exploration of the sea floor and its deeper structure.

From 1935-40, Ewing's troupe worked the East Coast doing seismics, with summer *R/V Atlantis* trips being their primary at-sea opportunity. It would not be amiss to say that Ewing and his students added a huge infusion of energy to Woods Hole, with a 24/7/365 work ethic, an unflappable "can-do" attitude, and a disregard for personal comfort and danger that would probably be considered crazy nowadays. Ewing (in his car, "Floosey Belle", Fig. 4) and his students tracked back and forth routinely from Lehigh to WHOI to test gear and grab data at sea. Cars loaded with dynamite and delicate gear would careen down hills without brakes, outrun hurricanes, and (more often than not) teach Car Repair 101 to the students.

Perhaps the most entertaining description of the adventures of Doc Ewing and his students is the candid account of his life that Joe Worzel wrote for later WHOI Director Robert Gagosian [2]. This account has wonderful historical detail, but also some very funny and human personal stories about what life was like in the pre-war and WWII era as a student under Ewing. Worzel was recruited after selling a camera to graduate student Allyn Vine (Fig. 4) and Professor Ewing, and then cutting a class in 1936 to go with them on a "fun jaunt" to NJ to shoot some seismic lines. As Worzel later put it, "this minor decision settled the rest of my professional career" [2].

Figure 4. *(Left) Allyn "Al" Vine in 1940. (Right) Doc Ewing (on right) checks his "Floosey Belle" (with help from his brother John, also a geophysicist.)*

From 1936-38, Ewing and his band (Fig. 5) created totally novel seafloor seismic gear to be deployed from the *R/V Atlantis*. Deep explosions were a new development, and geophones were homemade. Data was often a photo record of the seismic trace. Deep-sea camera technology, magnetometer technology, pressure case technology, and mooring/deployment technology were all greatly advanced at WHOI during this "quiet" pre-war era.

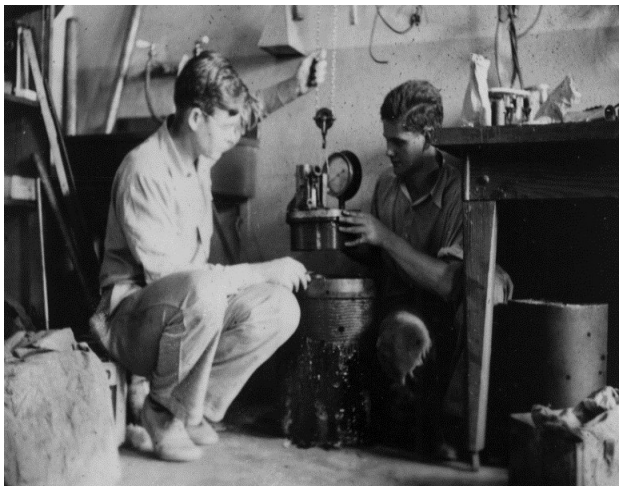

Figure 5. *"Doc" Ewing and Joe Worzel assembling an explosive device. (Courtesy of WHOI Archives)*

4. The War Years

By 1940, it was obvious to most that war was coming. As early as 1937, Columbus Iselin started work with the Navy off Cuba to study the "afternoon effect" (downward refraction of sound due to diurnal surface water heating.) Athelstan Spilhaus, who joined the WHOI staff in 1936, began development of the "Bathythermograph", which measured vertical temperature profiles (a good proxy for soundspeed), and which would prove invaluable to the Navy's submarine and anti-submarine warfare (ASW) efforts. And in 1940, Doc Ewing was participating with new WHOI Director Columbus Iselin to report ASW research directions, mainly the physics of sound transmission in top 100 fathoms of the ocean.

1940 was also a significant year for his Ewing's two prize students, Worzel and Vine. In that year, Worzel was accepted as a Lehigh grad student, and Vine was finishing up his PhD work. Both would be significantly assigned into the war efforts. Most notably for Vine during the war, he and Ewing worked on Bathythermograph (BT) improvements for the Navy. The improved device was given to Navy submariners, prompting one skipper to write back to WHOI "God Bless Allyn Vine" [1]. Worzel, on the other hand, kept working on coastal propagation studies under Ewing. Also in that year, Ewing moved Vine and Worzel to WHOI for the duration of the war. Their ultimate lodging, the rectory of the nearby Methodist Church, became a lively bachelor quarters for about fifteen single men working at WHOI during the war [2].

Another important date for WHOI acoustics was Jan 1, 1941, when the National Defense Research Committee (NDRC) was formally established. WHOI received its first Division 6 (Underwater Sound) war contract, and the "Sound Transmission in Sea Water" became its first publication [3]. Columbus Iselin wrote the oceanography section and Doc Ewing wrote the physics, with major contributions from Allyn Vine, Joe Worzel and Alfred Woodcock. This work became the Navy's underwater sound manual and was only superseded decades after the war.

WHOI, of course, had many other specialties that the Navy was interested in, and some forty different projects involving all the aspects of oceanography were pursued through a large "blanket contract" under NDRC auspices. Of the most interest to ocean acoustics were its second project, entitled "Sound transmission in sea water" ("Navy 2") and its seventh project, listed as "Development and application of underwater explosives" ("Navy 7") [4].

One big project in 1943 was on shallow water acoustics. WHOI was asked (at first blindly) to totally understand sound propagation in 10-20 fathoms, for all frequencies, and for all bottom types, and so they soon found out why. It turned out that the Germans could set off (disable) an entire acoustic mine field, simply by remotely using the ground wave from an explosive shot. In this case, the low frequency ground wave rumble arrives first, and sounds very much like a ship. To remedy this, they inserted a delay into the mine to wait for the water wave to pass to verify whether it is a shot or a ship!

As with the minefield problem, there was a basic need to understand acoustics on the continental shelves, for ASW and many other reasons. Thus, Ewing and Worzel sailed all over East Coast setting off shots and acquiring data. They saw the ground and water waves mentioned above, and many other of the dispersive features of broadband pulses in shallow water. However, one thing that was desired was a "full wave" (as opposed to ray) theory of the acoustic propagation that explained their unique data. There was a fellow based at Columbia University (though his exact whereabouts during WWII were really somewhat of a mystery), named Chaim Pekeris, who had just such a theory of shallow water propagation, but had no data to back it up.

Figure 6. *Chaim Pekeris, from Worzel, Ewing, Pekeris (1948). Propagation of Sound in the Ocean, Contribution #415 from the Woods Hole Oceanographic Institution.*

One of Worzel's more interesting "sea stories" was about the fun (?) he had chasing a German submarine with SUS charges from a small coastal boat while taking acoustic data [2]. Dangerous? Nah, the U-boats weren't going to waste a torpedo on a small research vessel. But we suspect that if the U-boat captain knew just how valuable Joe Worzel was to the war effort, he might have thought twice.

Both shallow and deep water sound propagation were important to understand, and while at WHOI, Ewing and his team contributed greatly to both. Ewing had theoretically predicted the deep sound channel in the "Sound Transmission in Sea Water" memo [3], and in 1943, he proposed the Sound Fixing and Ranging (SOFAR) channel propagation as useful for locating downed fliers [2]. He tested this prediction off the Bahamas with 4 lb TNT charges (Fig. 7). In addition to finding out that it worked, he also predicted that the sound could likely be heard halfway around the world! These long distance transmissions would provide the foundation for basin scale thermometry, and they happened fifty years before that application was ever pursued. Regarding the WWII SUS bombs, however, fliers didn't want them on their planes, and so that particular application never took root. In a rather historical paradox pointed out by famous oceanographer Walter Munk, Soviet acoustician and noted theorist Leonid Brekhovskikh found the SOFAR axis independently via experiment, and not by theoretical prediction, as did experimentalist Ewing. [5]

Figure 7. *Worzel and Ewing assembling charge for submarine SOS location signal. (Courtesy of WHOI Archives)*

5. Other early ocean acoustics pioneers at WHOI

While Ewing, Vine and Worzel might have been the dominant figures in the war and postwar years, there were a number of bright stars of acoustics shining at WHOI as well. Four of them that we will mention here are: Arnold Arons, Betty Bunce, Mary Sears and Brackett Hersey.

Arnold Arons (Fig. 8) was a staff member of the WHOI Underwater Explosives Research Laboratory, the "Navy 7" group, conducting explosives research for the U.S. war effort. He served as the WHOI research group leader that made shock wave measurements on the first atomic bomb tests at Bikini Atoll in 1946. After doing reflection of acoustic pulses work, he was lured to physical oceanography and meterology research by Hank Stommel, where he did quite well with his (along with Stommel) discovery and theory of salt fingers.

Figure 8. *Arnold Arons WHOI photo (Courtesy of WHOI Archives)*

Betty Bunce (Fig. 9) was a member of the WHOI underwater explosives group starting in 1944. Betty's research included marine seismology, acoustic reflection and refraction, and underwater acoustics associated with seafloor studies. In 1959, she was the first woman to officially go to sea on a American research vessel for more than a day trip. She was also the first woman ever to serve as chief scientist on an American oceanographic vessel. Long-time WHOI scientist Mike Purdy wrote, "The place today that women scientists rightfully hold in oceanography, are due in no small part to Betty's example" [6].

Figure 9. *Betty Bunce on the R/V Atlantis II in 1977. (Photo by Vicki Cullen)*

Mary Sears (Fig. 10) was one of the first 10 researchers appointed at WHOI in the 1930s and served on the WHOI scientific staff from 1940 to 1963. Also a Navy WAVE during World War II, she provided intelligence reports, "Submarine Supplements to the Sailing Directions," which predicted the presence of thermoclines under which a submarines could hide to escape enemy detection by surface sonar. Another of Mary's major contributions to oceanography and underwater acoustics began in 1953, when she helped form and became the long-time editor of a brand-new journal, *Deep-Sea Research*.

During WHOI's 50th anniversary in 1980, Roger Revelle remarked ".. it is generally forgotten that the first Oceanographer of the Navy in modern times was a short, rather shy and prim WAVE Lieutenant... Mary Sears" [7]. Few also know that Mary was a retired Commander of the US Navy [8]. In 2000, the US Navy named a new naval research vessel, its sixth Pathfinder-class oceanographic survey ship, the *USNS Mary Sears*. This was the first time in its 225+ year history that the Navy named a research vessel for a woman.

Figure 10. *Mary Sears in her Office in the WHOI Bigelow Building, Room 206.(Courtesy of WHOI Archives)*

Brackett Hersey was another of Doc Ewing's brilliant students, who was hired in 1947 to run the underwater acoustics program. He was the first chairman of the new WHOI Geology & Geophysics department (1963-1966). Hersey's research included solid earth geophysics, underwater acoustics, physical oceanography, sound scattering by marine animals and marine geology. He worked to pioneer the development and use of towed instruments at sea, and received patents for methods of the study and applications in marine seismology and underwater acoustics. The best known and most-widely applied of these is the Continuous Seismic Profiler (CSP) for measurement of layered sediment beneath the ocean floor.

Figure 10. *Brackett Hersey in R/V Atlantis lab in 1949. (Courtesy of WHOI Archives)*

6. Concluding remarks

Perhaps the most fitting remark to finish this brief overview of the achievements in WHOI's early history in ocean acoustics is one made by Arnold Arons in a talk he gave to the WHOI Ocean Acoustics Lab in October 2000. "As you obsolesce as a scientist, if you live long enough, you turn into a historian. I guess that's what's happened to me" [9]. We authors are all a bit of the "older generation" of ocean acoustic scientists ourselves, so perhaps Arnold's comment applies to us as well. If so, we don't mind being in this company at all.

7. Acknowledgements

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