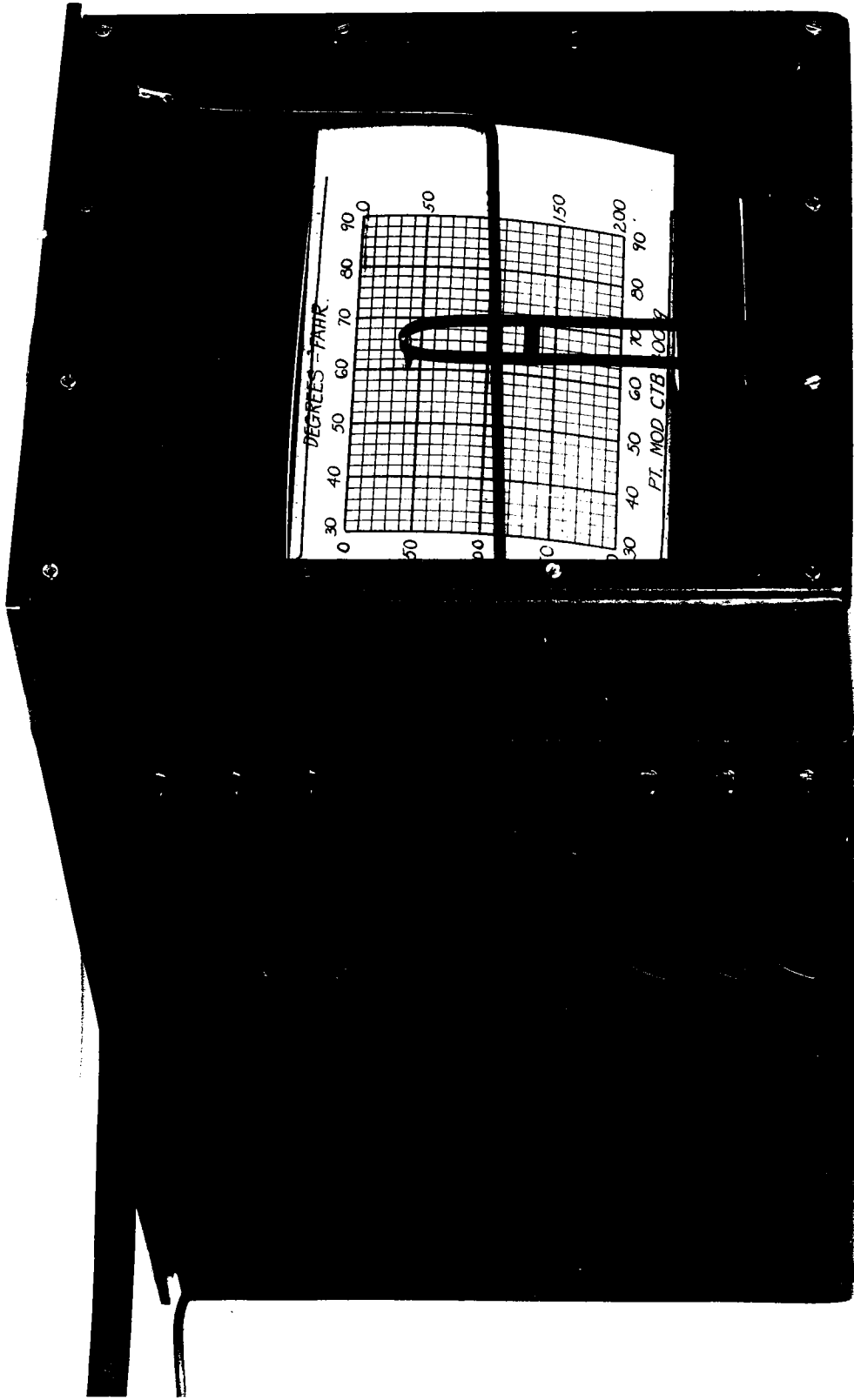


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NEW YORK UNIVERSITY



A BATHYTHERMOGRAPH

By ATHELSTAN F. SPILHAUS

CONTRIBUTIONS FROM THE
COLLEGE OF ENGINEERING

1937-38

No. 16

BILL DUNKLE

A BATHYTHERMOGRAPH

By

ATHELSTAN F. SPILHAUS

*New York University**

In the study of the homogeneous layer in the ocean, Rossby¹ found it desirable to have an instrument which would provide a continuous record of temperature against pressure in the surface layers of the ocean. A preliminary instrument named an "oceanograph" was constructed and used during the summer of 1934. The manifold uses to which such an instrument could be put presaged a widespread employment of the apparatus. This, however, did not come about because of certain inherent difficulties in Rossby's design. The record was made on a large smoked foil, and thus entailed the attachment of multiplying linkages to the actuating elements for pressure and temperature. Such multiplying linkages are uncertain in action in sea water, and, furthermore, the size of the instrument to accommodate them must necessarily be fairly great. At Prof. Rossby's suggestion, the author attempted to modify the oceanograph so that it would be more suitable for routine use. The modifications were made with the following aims in view:

- (a) The instrument should if possible be small enough so that it can be lowered on an ordinary log line by hand if necessary, thus enabling it to be utilized on vessels not equipped with a hydrographic winch.
- (b) The instrument should be sufficiently rapid in its response such that regardless of the rate at which it passes through the water no errors due to the lag of the thermometric element will be apparent.
- (c) Care should be taken to eliminate hysteresis of the pressure element.
- (d) The plates on which the record traces are made should be easily inserted and removed and easily evaluated.

DESCRIPTION OF THE INSTRUMENT

The instrument finally evolved consists essentially of a pressure element comprising an hermetically sealed siphon inside of which is a guide and compression spring to give the requisite pressure range. Mounted on the movable end of the pressure element is a straight bi-metal strip, and thus

*Joint contribution from Woods Hole Oceanographic Institution (No. 167) and New York University.

¹C.-G. ROSSBY AND R. B. MONTGOMERY. "The Layer of Frictional Influence in Wind and Ocean Currents." *Papers in Phys. Oceanography and Meteorology of the Mass. Inst. of Tech. & Woods Hole Oceanographic Inst.*, Vol. III, No. 3, p. 73.

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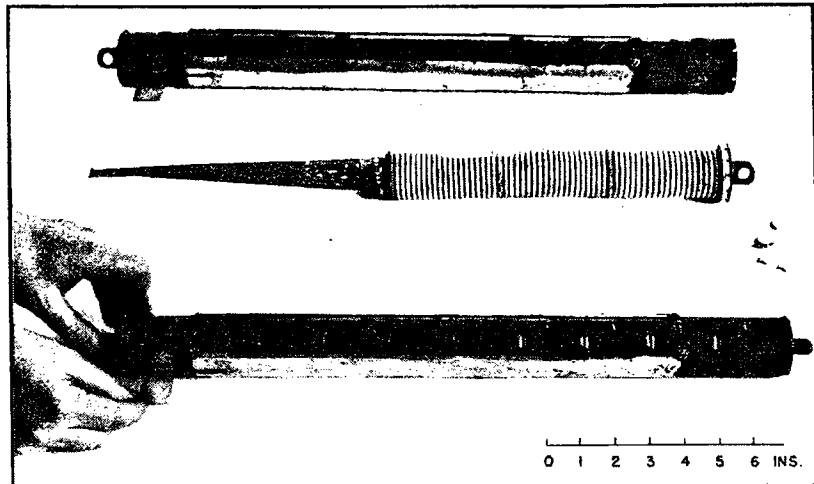


Figure 30. The bathythermograph.

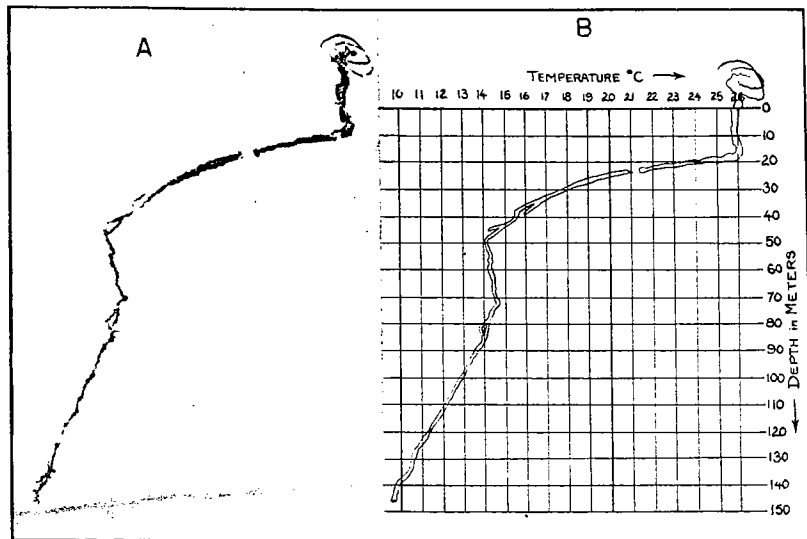


Figure 31. Photographic enlargement (A) from an original record of the bathythermograph, with key diagram (B) showing trace superimposed upon calibration chart.

motion with pressure is at right angles to the deflection of the strip with temperature. At the end of the bi-metal strip a fine needle point is arranged to inscribe a trace on a small glass slide. The slide is prepared for the record by coating it with a thin layer of oil and then smoking the glass to slightly blacken it. The function of the oil is to prevent the smoked film being washed off by the sea water. In view of the fact that the motion of the inscribing point is in two dimensions, the plate which receives the record is held perfectly rigidly in the body of the instrument, and thus insertion and extraction of the plates are entirely independent of the sensitive actuating elements. Figure 30 shows the complete instrument in the lower photograph and indicates the method of insertion of the glass slide to take the trace, while the upper part of the illustration gives a view of the instrument partly disassembled to show the simplicity of the actuating elements. Figure 31 is a photographic enlargement of an original record from the small slide, and the accompanying key diagram shows the trace superimposed on a calibration grid. It can be seen that the record consists of two lines—one made during the descent of the instrument, and the other during the ascent. It can be easily shown that hysteresis of the pressure element and lag of the temperature element both act in such a way as to separate the ascent and descent traces; so that if either pressure hysteresis or thermal lag are present to a marked degree, two distinct traces would have been recorded. The coincidence of the two curves, however, insures that the instrument is functioning correctly. From the standpoint of thermal lag the record is particularly remarkable when it is realized that in the case of the particular test in the photograph the instrument was sent down and brought up through the water at a rate of 100 meters per minute. Thus the whole test down to a depth of 150 meters was completed in 3 minutes. Evaluation of the record obtained is simply accomplished by projecting it by means of a miniature camera projector on to a calibrated screen. Tests were made by lowering the bathythermograph on the end of a log line and it was found that good records could be obtained by an ordinary seaman.

SOME RESULTS OF MEASUREMENTS MADE WITH THE BATHYTHERMOGRAPH

On a cruise made by the "Atlantis," research ship of the Woods Hole Oceanographic Institution, measurements with the bathythermograph were carried out almost hourly for a period of two days, and remarkably sudden discontinuities in the thermocline and inversions of the thermocline were revealed. Figure 32 is a plot showing the temperature variation with depth on the horizontal and vertical axes respectively, while the time changes are set off along the oblique third axis. The bathythermograph records were traced directly on to this diagram from photographic enlargements of the original traces. This figure served to illustrate several points.

- (a) Abrupt changes in the thermocline are shown, and it should be stressed that these changes must be actually present because they are in every case substantiated by the coincidence of the up and down trace of the bathythermograph.
- (b) The temperature depth structure below 50 meters is quite complicated, especially for those tests between 1900 and midnight. Thus it is

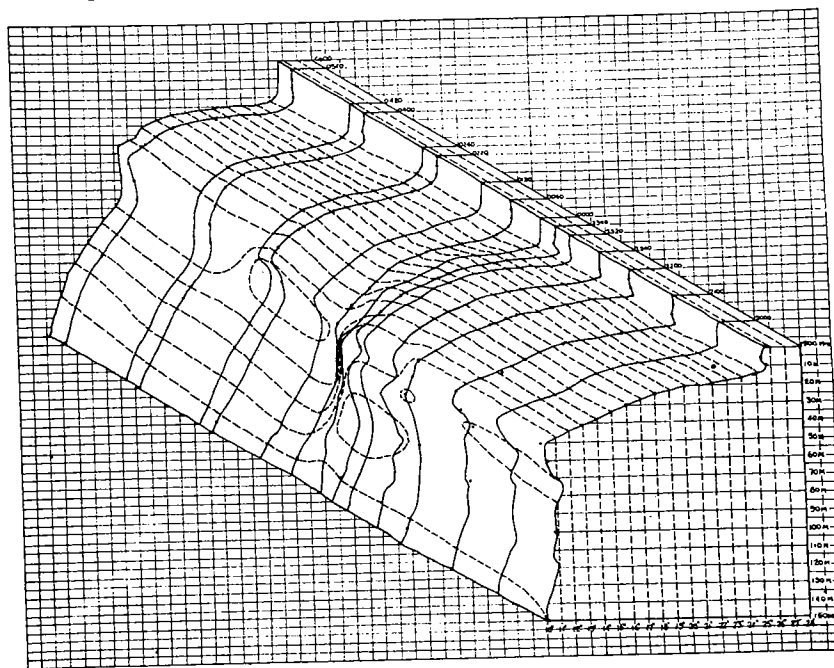


Figure 32. The variation of the temperature-depth profile with time, as determined from the bathythermograph traces and water bottle temperatures.

evident that if water bottles were used these intricacies of the temperature curve would be entirely overlooked, owing to the necessarily wide spacing of the bottles below 50 meters.²

² This was actually the case. At Station no. 18 (Aug. 26, 1937, 2203 hrs.) of the cruise on which the instrument was tested the water bottles were spaced at 1, 5, 10, 15, 20, 40, 70, 150, 200, 300, and 400 meters and the smooth curve, drawn by Mr. C. O'D. Iselin through the points thus obtained, completely missed an abrupt change from the summer thermocline to isothermalcy which the bathythermograph indicated to exist at about 60 meters. Accordingly, at Station no. 19, one hour and forty minutes later in the same water, the spacing was altered to: 1, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 100, 150, 250, and 350 meters and the discontinuity of the thermal

- (c) The sudden change in the character of the temperature depth curve below 50 meters between the hours 0000 and 0040 is very remarkable, for the "Atlantis" could not have drifted very far in this short space of time.³
- (d) The traces shown at the following hours were taken with the bathythermograph. 1900, 2000, 2100, 2240, 2320, 0000, 0120, 0240, 0420, and 0600, while the curve obtained from water bottle thermometer readings are shown at 1900, 2100, 2200, 2340, 0040, 0220, 0400, and 0540. Thus, comparison between the bathythermograph readings and the thermometer readings may be made directly for the two times 1900 and 2100 when both series were taken nearly simultaneously.

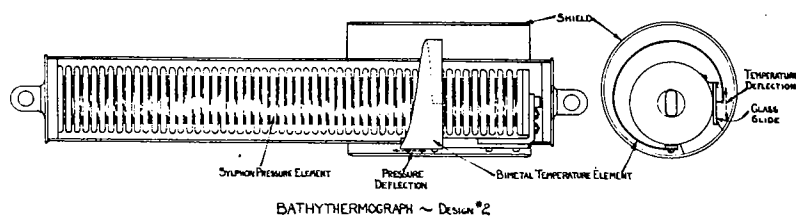


Figure 33. Design No. 2 for improved bathythermograph.

Such small differences (never more than 0.2° Centigrade) as are evident may easily be accounted for by the difference in time between the water bottle temperature station and the bathythermograph test.

FURTHER DEVELOPMENT:

Though the result shown may be considered as very satisfactory, it is proposed to improve the instrument further by an attempt to utilize a design such as indicated in Figure 33. The improvement which such a design would incur is that the temperature element would be exposed directly to the flow of water and that all thermal lag by it would be eliminated. Furthermore, the size of the instrument, if constructed according to the design in Figure 33 will be cut down considerably and, though in the first design the coordinates are very nearly rectangular (because the length of the bi-metal strip is great compared to the deflection of its end), in the

gradient as indicated by the bathythermograph was established. The latter distribution of water bottles was thereafter maintained for subsequent stations in the same region.

³ In a personal communication, Mr. Iselin informed the author that the T-S correlation also changes at the same time and, as the drift of the ship could not have been more than a mile or two, he concludes that the mixing in the neighborhood of 100 meters depth was very incomplete.

second design the coordinates will be perfectly rectangular. Finally it is thought that vibration will be entirely eliminated by the second design, and that, therefore, a finer trace and greater accuracy will be obtained.

It is hoped that this instrument can be produced, if demand is sufficient, cheaply enough to obtain it widespread application, not only by biologists and oceanographers, but also in the fishing industry—the apparatus being such that it can be handled by entirely untrained personnel.

On Reaching 50: An Early History Of the Bathythermograph

*This Remarkable Invention Led the Study of the Sea
Out of the Expedition Stage and into Synoptic Oceanography*

By Dr. Athelstan Spilhaus

The bathythermograph is 50 years old this year. It seems an appropriate time to recall its history. It started in June 1936 in Pretoria, South Africa, when a cablegram arrived from my great professor and mentor, Carl Gustav Arvid Rossby. His message was that he had made arrangements with Woods Hole Oceanographic Institution to pay my salary as research assistant and return to work with him at Massachusetts Institute of Technology in Cambridge.

On arrival in Boston, it was revealed that Rossby, who was then involved in his great work relating to jet streams and vorticity, wanted a rotating model ocean with a jet stream somewhat like the Gulf Stream in it. The counterclockwise rotation was to provide the model's Coriolis force.

To house the resulting 6-foot-diameter dishpan, the only space MIT had was an infrequently used men's room in the basement of the Mechanical Engineering Building. Here the laboratory was set up and the only interruptions were students with other pressing hydrodynamic problems.

Some of these smart MIT guys didn't know the difference between Coriolis and urinal—so it would sometimes be discovered upon arrival at work in the morning a two-layer "ocean" in the six-foot-diameter dishpan.

The features in which Rossby was interested were the eddies on both sides of the jet stream. Not only was he doing his theoretical studies but he was also trying to delineate the real eddies on the edge of the Gulf Stream, eddies that were well known to bring unusual warm water close in to Nantucket.

For an earlier *Atlantis* cruise during the summer of 1934, he had had built a great box-like contraption he called an "oceanograph" in an attempt to get continuous tracings of temperature versus depth in the surface layers of the ocean more conveniently than with the then-standard procedure of lowering a string of reversing thermometers attached to Nansen bottles.

But Rossby's oceanograph was not practical; it was cumbersome, full of multiplying linkages that got fouled with seaweed, and it vibrated, making the recordings unusable.

Nevertheless, the idea of an instrument that could be rapidly lowered and pulled up to give a record of temperature versus depth was en-

labeled to the length of the tubular casing, while the bimetal curved with temperature along the X-axis across the diameter of the tube—just two deformable parts.

Working at off-times in the machine shop of the Guggenheim Aeronautical Building—with great help from a machinist, Mr. Maddox, provided out of friendship without MIT's official sanction—the first bathythermograph was built.

Woods Hole, in the wonderful *personae* of Columbus Iselin and Dr. Henry Bigelow, the director, became intrigued enough with the first crude model that they provided the opportunity to sail on a number of cruises on late 1936 and early 1937 to test the gadget.



Allan Vine's engineering genius transformed Spilhaus' Bourdon tube BT design into this streamlined, practical projectile that now could be deployed from high speed Navy destroyers.

tracing. One design, conceived during a year in South Africa, became a project back at MIT, where it was built on a bootleg basis.

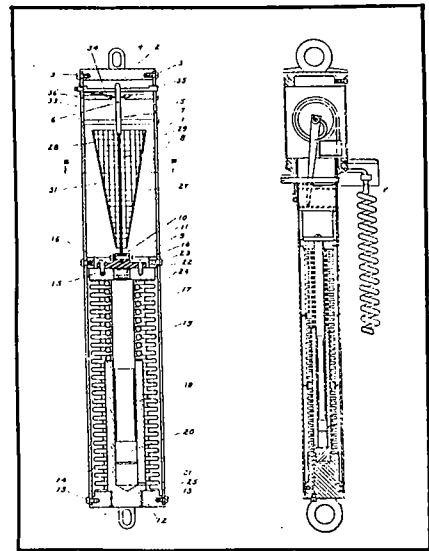
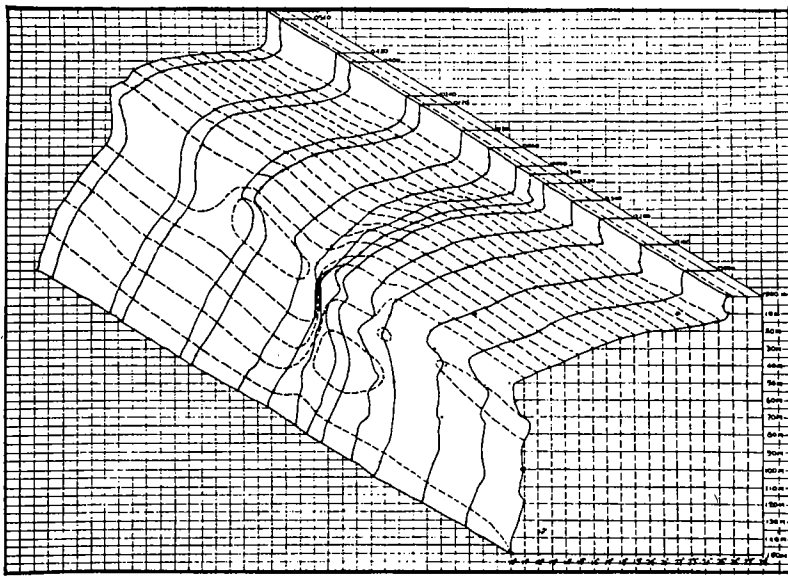
A Bootleg Beginning

All multiplying linkages and pivots were eliminated and the instrument was made small and rugged. It became simply a compressible metal bellows within a tubular casing to which it was attached at one end with a straight bimetal strip on the free end. The end of the bimetal strip was a stylus that scribed on a smoked-glass microscope slide held in the other end of the casing. Thus, the bellows compressed with pressure along the Y-axis, paral-

On these cruises, more time was spent in the engine room redesigning the instrument than on deck testing it. By early 1937, a workable instrument was tested on the *Atlantis I* and the bathythermograph's small glass record slides showed remarkable discontinuities and inversions of the thermocline in the surface layers of the ocean hitherto unknown.

The instrument was ready to be christened and named. It recorded temperature against pressure, but the word barothermograph was already in widespread use for a meteorological station instrument which recorded atmospheric temperature and barometric pressure on a chart. So it was

(Continued on page 20)



For the first time, the BT yielded data resulting in this temperature-depth versus time (far left) profile. Two patent application drawings at right show Spilhaus' original BT design (left drawing) and a later version—built and tested in 1937 at Woods Hole—that incorporated a Bourdon tube. In the original design, a compressible metal bellows (14) in a tube controls a stylus that scribes temperature changes on a smoked glass slide (5). The Bourdon tube version reduced temperature lags inherent in his first design and eliminated vibration as well.

settled that the device be named, "bathythermograph," from the Greek root for depth, "bathos." Later, the bathythermograph came to be universally called the BT.

The first paper entitled "A Bathythermograph" was written for the *Journal of Marine Research*, Vol. 1, No. 2, 1937-38. This paper ended

with the statement: "It is hoped that this instrument can... obtain widespread application, not only by biologists and oceanographers, but also in the fishing industry—the apparatus being such that it can be handled by entirely untrained personnel."

Columbus Iselin was not only a scientist but, it seemed, one who

knew everything worth knowing about ships. Being conversant with the early developments of sonar in relation to the detection of submarines, he pointed out another sphere of application. He arranged for the two of us to take the *Atlantis* and conduct sonar-BT tests in conjunction with the *U.S.S. Semmes* and a Navy submarine out of New London (August 23-31, 1937) to demonstrate the importance of the bathythermograph in the detection of submarines by sonar.

The Navy scientist who accompanied us and who also saw the importance of the instrument was Dr. R. L. Steinberger of the Radio Laboratory, U.S. Navy Yard, Washington, D.C. At that early stage, detection of submarines was a hit-or-miss proposition. Sound engineers were attributing failures to deficiencies in the sonar equipment, whereas we were trying to convince them that it was the thermal layering of the oceans and the lens-like bending of the sound waves by the thermocline that were responsible for the misses.

In any case, the Navy Department's Bureau of Engineering started the paper work to order two bathythermographs to use on a southern cruise of the *Semmes*, which was to rendezvous with submarines out of the U.S. base in Guantanamo Bay, Cuba, in February 1938.

In October 1937, right after the *Semmes* tests, the Navy had asked to arrange for the manufacture of two bathythermographs. While at New York University at that time heading up the Department of Meteorology,

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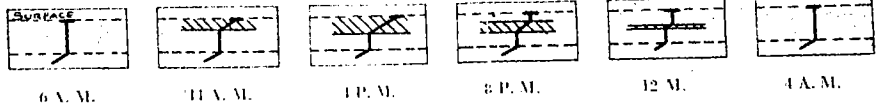
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When I

the immediate thought was of getting Sperry Gyroscope Company (which had given me my first job in the United States in the summer of 1933) to manufacture them. Sperry was willing to go ahead and received a requisition from the Navy with specifications by February 1938.

From Bimetal to Bourdon

The specifications were for the bimetal bathythermography; however further tests indicated a move to a Bourdon tube so that the moving



Series of traces shows diurnal heating and cooling of seawater layers with passage of time. Temperature reads left to right; depth from top downward. (Submarine Signal Co.)

temperature element was not exposed to the flow when used from a moving vessel.

Probably for this reason, the arrangement with Sperry never came to fruition.

A Bourdon tube BT was built and tested at Woods Hole that summer.

With eventual uses by biologists, oceanographers, and fishermen in mind, the first vice president of a well-respected old Boston company called the Submarine Signal Company was contacted. Mr. H. J. W. Fay, the vice president, resisted all eloquent attempts to excite his interest. In response to the claim that "every oceanographer will be wanting one," his laconic reply was, "Yes, all six of them."

Submarine Signal Company was well-known and respected in seafaring circles because it produced a sonic depth finder and submarine signalling devices, which had been developed by Reginald Aubrey Fessenden.

Fay agreed to develop the bathythermograph because his company wished to maintain its long-standing reputation in the ocean instrument field. His company filed for a patent on the BT in my name but assigned to the company on August 10, 1938.

[An interesting sidelight is the expense account for a special trip to Boston to meet with them where they had offered to pay expenses. I found in my files the letter I wrote itemizing the expenses for the trip from New York to Boston and return. It was \$10 up on the Merchants' Limited and \$5.73 return on the day train. Total expenses \$15.73—hardly padded.]

By September, Submarine Signal was already working and thinking about the Bourdon tube model. This device would show less lag with faster speeds through seawater and, as the moving part of the instrument was protected from the flow, would not be affected by vibration. In December, it was tested on the *Atlantis* with Mr. Hubbard of the Submarine Signal Company.

One amusing little problem involved the glass slides used to obtain the graph drawn by the stylus. From the very beginning, smoked-glass microscope slides were used, easily obtain-

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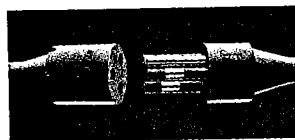
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