THE NAVY-PRINCETON GRAVITY EXPEDITION TO THE WEST INDIES IN 1932.

(Extract from the official Report, presented to the Bureau by the courtesy of the U.S. Hydrographer). (1)

NARRATIVE OF THE CRUISE.

by
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In preparation for the gravity cruise of the U.S.S. *S*-48, a new base station was established and the MEINESZ apparatus calibrated at the Naval Research Laboratory, Bellevue, Anacostia, D.C. The base station was located on the first floor of the annex, at an approximate elevation of 23 feet above mean sea level (2).

The gravity was determined to one part in a million, representing the average of several long runs under carefully controlled conditions. This station was also used to recheck the temperature constants of the pendulums. As the MEINESZ apparatus had been shipped from Holland, together with a new set of pendulums, it was necessary not only to assemble and calibrate the machine, but also to ascertain that no damage had occurred to the delicate working parts during transportation. This work was done in a small, well-insulated room, the temperature controlled by a thermostat on the heater circuit with the result that there was less than 1° C. variation throughout the day and night. Observations were made at 37° and 22° C., this range representing the limit of the thermostat. The variation in the period of the pendulums, due to expansion and contraction, was worked into temperature factors or constants, one for each pair of pendulums ; these were used in subsequent computations for the corrections of the observed period. Similar corrections were determined for atmospheric density by close readings of the standard barometer and hygrometer. The error in the recorded tilt of the swinging plane of the pendulums was likewise determined ; this was done by placing the apparatus on the concrete floor, accurately leveling the agate planes by means of the adjustable screw legs and making a short record ; the trace of the true zero would then appear on the developed film and the correction could be measured directly.

At the base station in the Naval Research Laboratory the time intervals of 1 second, used in determining the period of the pendulums, were supplied as electric impulses from the crystal controlled high-frequency clock of the laboratory. The rate was so remarkably constant as to make it superior to any escapement chronometer. The impulses actuated the magnetic shutter of the recording apparatus. Unfortunately, no minute designations, such as the omission of the sixtieth or zero second, were automatically sent out by the clock ; these had to be inserted manually by a key in the clock circuit. The method was difficult and tiring, subject to a certain risk of error and was finally employed only at the beginning and ending of the record to identify the minutes. The observations at the base station covered a period of about two weeks.

Upon completion of the cruise the gravity apparatus was again set up in Washington. It would have been desirable to have returned to the established base station at the Naval Research Laboratory and to have checked against the original results ; this would have revealed directly any change in the instrument, such as that resulting from warping of the pendulums or damage to the agate planes or knife edges. Such return, however, was considered inadvisable because of lack of time and available space. The equipment, therefore, was set up in the newly constructed constant temperature and vibration insulated vault of the United States Coast and Geodetic Survey in the Depart-

(1) *See also :* Hydrographic Review, *Vol. IX, N° 2, November* 1932, *page* 124.

(2) *The excavation for the foundation for the extension of the annex, then under construction, was completed before any gravity observations were made, so that it was not necessary to make any corrections for the removal of a significant mass close to the instrument.*

ment of Commerce Building. Nothing was lost by reason of the change; local gravity surveys conducted by the Department connect the base station at the Naval Research Laboratory with that in the Commerce Building, so that it was not essential to return to the original station. The recheck, though indirectly accomplished, was fairly satisfactory and revealed no serious instrumental change. The new pendulums had not been quite stable during the trip, but the changes were small and they were obviously gradual, and so the supposition, used for the deduction of the results, that the changes had occurred proportional to the elapsed time cannot have been far from the truth. The control observations made at Guantanamo before and after the separate legs of the expedition are in good harmony with these assumptions and so we may feel sure that this question has not introduced any appreciable uncertainty in the results.

Transportation of equipment.

After the first base station measurements were completed the gravity apparatus was carefully packed for transportation to the submarine. The cases were handled with utmost care, every precaution being taken to guard them against possible shock which might affect the adjustments; in every instance the handling was supervised by a member of the scientific party. From Washington to Norfolk the shipment was made by river steamer, a large Navy lighter met the steamer upon arrival and carried the scientific party and the apparatus to the U.S.S. *Tarbell*, waiting at the Navy Yard. Here the apparatus was carefully hoisted aboard the *Tarbell* and secured in a protected place for the long voyage. The destroyer, under the command of Lt.-Comdr. H.K. Fenn, made excellent time in spite of heavy seas and on the morning of the fourth day arrived at Guantanamo Bay, Cuba.

The submarine, then leaving the Canal Zone, would arrive at Guantanamo as scheduled, February 4. The gravity apparatus was unloaded from the destroyer and stored at the office of the commandant and during the succeeding three days Dr. Meinesz, Messrs. Hess and Brown were engaged in computing the records made at the base station in Washington.

The Santiago earthquake.

An earthquake of considerable violence shook Santiago on February 3, 1932 at 1.17 a.m. The main shock lasted approximately 54 seconds. A minor shock had been felt the preceding afternoon, and shocks continued with generally decreasing intensity after the main quake. The scientific personnel of the expedition were in Santiago at the time of the earthquake but they had the good fortune both to be able to observe its effects and escape injury to themselves. The chronometers left at the Guantanamo Naval Station, where the shocks were less intense, were tested and found undamaged. The gravity apparatus was still unassembled and in the packing cases, and thus completely protected.

Narrative of the cruise.

After the arrival of the *S*-48 and the submarine tender *Chewink* at Guantanamo, several days were required to install the gravity apparatus and to test the depth finders. In order to check the operation of all equipment under actual sea conditions, both ships were taken successively on a short test cruise about the mouth of the harbor. Late in the afternoon on February 7, the expedition sailed from Guantanamo Bay on the first leg of the journey.

The course led to the south and eastward, crossing the extension of the Bartlett Deep immediately off the south coast of Cuba. Here the depth was indicated at 2,800 fathoms. Continuing southward, we arrived at the predetermined position for the first undersea gravity station. The dive was made at night, 10.30 p.m. The dives were spaced at about 60-mile intervals, or from 4 to 5 hours, according to the speed maintained. Night diving, of course, was unavoidable in such a concentrated program, and, as it turned out, over 50 percent of the stations were occupied after dark. The arduous life aboard a submarine at sea is not conducive to study or any activity other than the daily routine.

In the following narrative of the cruise of the U.S.S. *S*-48 the gravity stations at sea are numbered consecutively, beginning with No. 50. In 1928 the gravity survey included 49 sea stations, and it is for the sake of convenient reference in using the tables that the gravity stations of the two naval expeditions are numerically connected.

After the first submergence the course changed to south-westerly direction and included three dives (51, 52, and 53) on February 8, around the south shore of the island of Jamaica in the main body of the Caribbean Sea, reaching the point farthest south of the entire trip, approximately 17°45' N.

Turning westward and slightly to the north, the expedition headed again for the Bartlett trough, but this time for the central and deepest part; stations 54 and 55 were occupied on February 9 and stations 56 and 57 on the morning of the 10th. On the afternoon of the 10th the echo soundings revealed a depth of 4,000 fathoms (24,000 feet), the maximum depth for the Bartlett trough. An accurate gravity determination over this region was deemed important; therefore station 58 and station 59 were also occupied.

On February 11, stations 60, 61, 62, and 63 were spaced roughly equidistant across the remaining sea toward the western extremity of Cuba.

While passing to the westward of the cape, curious submarine echoes were returned from the ship's oscillator. Ordinarily there would be one distinct echo, but occasionally it would be followed by a second and weaker echo caused by surface reflection; the second one would have exactly twice the age of the first (1). However, for a distance of 10 miles or more, near the Cape, the echo lacked distinctness and appeared to be made up of 8 or 10, perhaps more, separate echoes accompanied by a loud roar ; the roar itself would continue more than 15 seconds. The whole effect was that of a loud train whistle in a narrow canyon. The apparent explanation is that the bottom of the sea is here broken up into numerous mountain ranges and rocky valleys ; these are probably the undersea extensions of the Cuban ranges, Serrania de Guaniguanico and Sierra Acostas.

Stations 64, 65, 66 and 67 were occupied progressively between Cape San Antonio and Key West, Fla.; the course, for the most part, followed approximately the axis of the Gulf Stream. Station 67, divided into two separate measurements, was combined in one submergence, the first being on course 90° and the second on 270°, the purpose being to determine, by comparison of gravity values, the speed of the ship. The method considers the rotation of the earth and the difference in centrifugal force introduced by the east-west movement of the ship, but can be employed only to give the relative movement of the ship with respect to the water. It is regrettable that the data will give no idea of the velocity or direction of the current; this relatively important information could only be deduced from determinations of the ship's position and from charts and other navigational data issued by the Hydrographic Office of the Navy. In the notes of each gravity station an approximation of the error was included.

Early on the morning of February 13 the expedition arrived at Key West. After a strenuous 5 days at sea everyone was relieved to again set foot on solid ground. The scientists began immediately the work of developing the 19 photographic records of the gravity observations; the facilities of the Marine Hospital at the Navy Yard were kindly afforded for the purpose. Some of the records, principally those taken near the Bartlett Deep, were computed provisionally.

On the evening of February 15, heading south-eastward, the expedition reached the entrance to Nicholas Channel, about 15 miles west of Cay Sal Bank, and occupied station 68 shortly after midnight. Turning abruptly northward and eastward, we followed the Gulf Stream to stations 69 and 70, in latitude 25°; here we left the Straits of Florida and followed Santaren Channel, skirting the western edge of the Great Bahama Bank. Stations 71 and 72 were occupied on the course south. Turning south-eastward, the ships followed the Old Bahama Channel along the northern coast of Cuba.

Continuing down the north coast of Cuba, the submarine occupied stations 73, 74, 75 and 76, rounded Cape Maisi at sunset the third day, and arrived at Guantanamo Bay at 6 o'clock the following morning, thus completing the first loop of the expedition. The succeeding five days were spent in the customary development of records and in making preliminary computations. The development of the films was made possible by the use of the X-ray dark room in the Naval Dispensary.

Again leaving our base at Guantanamo, the expedition started on the second loop early in the morning, February 25. As on the entire trip around Cuba, the weather was fine and the hatches could be left open while cruising on the surface, affording plenty of fresh air to all parts of the ship. The comparatively large deck space allowed

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(1) *See :* Hydrographic Review, *Vol. X, No. 2, page* 172. (*I.H.B.*).

everyone to partake of a moderate amount of exercise by walking to and fro. Confined as it seems, it was a great relief as compared to the crowded conditions below.

Traveling eastward along the southern coast of Cuba, the expedition again passed Cape Maisi, this time turning north-eastward toward Great Inagua Island. Continuing to a point in the Windward Passage about midway between Inagua and Cape St. Nicolas Mole, Haiti, station 77 was established late that same night. On the next day, February 26, station 78 was occupied a few miles east of Great Inagua Island ; here the expedition headed almost directly north to Caicos Passage, between Mariguana Island and Caicos Bank, and occupied stations 79 and 80 successively about 60 miles apart.

At station 81 the expedition turned to the south and passed the western limits of the Caicos Bank, beginning then to trace the southern and return-half of the loop. At station 82 the course pointed for Turks Island Passage ; station 83, perhaps the most difficult of all the dives, was executed in the center of the passage.

From Turks Island the expedition headed toward Cuba, passing close to Tortuga Island and Cape St. Nicolas Mole, and occupied station 84 in the passage midway between Haiti and Cuba, in sight of both. On February 29, the loop was successfully completed at Guantanamo Bay.

Five days were set aside to refuel and provision the ships for the next and longest loop. The scientists employed the time, as usual, in developing the records of the previous trip.

On March 5 the expedition started on the last loop around and through the islands of the Bahamas, out into the Atlantic and back into the Tongue of the Ocean.

The course, therefore, was altered from the original plan and station 85 was added at the appointed place. Turning northward, the expedition passed Cape Maisi for the last time and headed for Crooked Island Passage, occupying stations 86 and 87 en route, No. 87 lying almost directly west of Acklin Island. Traveling in a zigzag course to avoid the closely grouped islands, the expedition entered Exuma Sound. Dive 88 was made opposite the north end of Long Island and No. 89 shortly after entering the sound.

After diving at station 88, the U.S.S. *Chewink*, by prearrangement, left the company of the submarine and cruised toward Devil's Point on Cat Island, running a depth profile to supplement that obtained by the submarine. The vessel returned prior to the next dive.

At the upper end of Exuma Sound the sea appeared so quiet that it seemed possible a submergence would not be required. No chances were taken, however, as the loss of the record would have been irreparable. This is mentioned to emphasize the extreme importance of consistency in making the observations ; the fact that no records were lost during the entire trip speaks well of the method.

Following station 90, which was made in the usual manner, the ships again separated in order to run independent depth profiles ; the *Chewink* cruised south-westward to Shroud Cay, eastward across the entire width of the sound to Eleuthera Point ; the submarine continued to the north end of the sound and returned to the point. In this way, the ships jointly secured the depth profiles, running both lengthwise and crosswise.

Between Eleuthera Point and Little San Salvador Island there is a broad bar covered by only 60 feet of water. After crossing the bar the bottom dropped almost vertically to a depth of 1 mile in a horizontal distance of less than one halt mile. The steep slope represents the true eastern border of the Bahamas, the edge of the continental shelf ; further out to sea the depth increases rather slowly to about 2,650 fathoms (15,900 feet) and remains the same thereafter, with the ocean floor noticeably flat.

The course was then laid in a north-easterly direction out into the Atlantic ; the short loop out to sea was made to determine anomalies of gravity east of the continental shelf, with the expectation that the data, by comparison, would help in determining the structure of the Bahamas ; station 91 was established only a few miles at sea, followed by 92 and 93 early the next morning.

Station 94 was occupied under rough weather conditions.

Station 95 was established shortly after sighting the lighthouse of Elbow Cay ; though the wind was still strong, the island somewhat protected the spot and the dive was made without any unusual occurrence. From this point we headed for Northeast Providence Channel and occupied station 96 at the entrance. Continuing along the channel past Nassau, the next dive, No. 97, was made about 5 miles west of the island of New Providence, after which the expedition entered the Tongue of the Ocean.

Poor visibility and the resultant uncertainty of position made it inadvisable to dive that night, instead the ships cruised to the lower end of the Tongue of the Ocean and by daybreak had approached within a few miles of the sandy flats which mark the extreme lower boundary. Here station 98 was established.

The ships again separated and steered widely different courses in returning north, the purpose being to obtain depth readings over as great an area as possible. The courses were so planned as to construct several continuous depth profiles extending from one shore to the other by combining the observations of the two ships. The ninety-ninth dive and gravity reading, the last of this series, was made half way up the Tongue of the Ocean, about 10 miles off Andros Island.

The ships docked at Nassau early on the morning of March 12.

The second contingent of the expedition under the direction of Dr. R.M. FIELD aboard the yacht *Marmion* arrived two days earlier. They had moved their gravity apparatus from one island to another and had completed 12 observations at representative geological positions. All members of the expedition were cordially received and entertained by the Governor of the Bahamas and the officials and citizens of Nassau.

On March 17, after developing all records made during the previous cruise, the ships sailed again, this time on the final and shortest leg of the journey. Following independent and wide sweeping courses, the two ships surveyed the depths through Northwest Providence Channel toward the Florida coast; stations 100 and 101 were positioned in the channel, about 35 miles apart and directly to the south of Bahama Island; continuing westward, station 102 was placed in the Straits of Florida opposite the mouth of the channel. The concluding measurement at station 103 was made practically in the axis of the Gulf Stream, only 25 miles from Miami, Fla.

The expedition ended at Miami, the equipment was packed and shipped to Baltimore, thence by truck to Washington, D.C. The film records of the last four gravity stations were developed and the final notes entered. After a brief rest at the home of Lt. Hugh MATHESON, owner of the yacht *Marmion*, the scientific party returned north by train.

Echo Soundings.

The U.S.S. *S*-48 and the U.S.S. *Chewink* were equipped with sonic depth finders, consisting essentially of 500-cycle submarine oscillators and sensitive under-water microphones for picking up the reflected sound waves. Merely by observing the interval between the transmission of the signal and the reception of the echo; multiplying this by the speed of the wave; correcting slightly for the estimated temperature gradient, the depth could be computed with fair degree of accuracy. The timing was done by means of a stop watch reading to hundredths of the second; the accuracy, however, depended more on the operator and was limited by the human element. It was found that the operators, after becoming acquainted with the characteristics of the echo, grew very proficient in judging time and in computing the depth, the variation due to error falling within the tolerable limits of the real variation in the ocean bottom.

Soundings were made by both ships almost continuously throughout the entire cruise. During periods of submergence excellent clear echoes would be received by the submarine. This undoubtedly was due to reduction in local noise about the submarine, such as the stopping of Diesel engines, pumps, and incidental machinery. Soundings were made at regular intervals, from 5 to 30 minutes, depending upon the value of the information. The expedition encountered certain regions, notably the section of the Bartlett Deep south of Guantanamo Bay, where the echo would fade out and become inaudible probably without an accompanying change of depth; the echo would reappear in several minutes indicating the same depth as that at which it disappeared. The cause of this phenomenon was not determined. Since the effect was noticeable in shallow as well as deep water, it was suggested that an explanation would be found in the diffraction effect of extreme temperature gradients, in irregularities of the ocean bottom or, perhaps, in thick absorbing deposits of mud or silt.

The United States Navy Hydrographic Office has prepared a detailed outline of the route of the expedition with notations of the depths observed by both ships; this is incorporated on H.O. charts 373, 2145, 948 and 944.

Gravity observations and chronometer corrections.

In installing the gravity apparatus aboard the submarine it is desirable to place it as near the meta-center of the ship as possible to reduce movement of the apparatus due to the rolling and pitching of the ship. In the U.S.S. *S*-48 the apparatus was mounted on a center stanchion in the control room; a system of gimbals with heavy counterbalances supported the actual pendulum framework in a vertical position so that a roll of as much as 7° to either side would not affect the gravity observation.

For the sake of convenience the three chronometers were placed in the radio room; this is to facilitate comparison with the radio time signals sent from the Naval Observatory in Washington. The two main chronometers are then connected with the electromagnetic shutters of the gravity apparatus by extension wires. This arrangement was also satisfactory for the reason that the chronometers could be mounted in padded frames in a fixed position and did not need to be disturbed throughout the trip. Actual electrical connection with the gravity unit was made only while an observation was under way.

The two main chronometers are needed for the pendulum observations themselves. The periods of the pendulums are expressed in the seconds of these chronometers and so it is necessary to know their rates for reducing these periods to true time.

The rates are determined by observing time signals, but as a great accuracy is needed, no ordinary time signals can be used and it is necessary to revert to rhythmic time signals and to a special method of receiving them. This method permits an accuracy of one hundredth of a second in each time comparison. A certain amount of skill and natural keenness of hearing is required so that anyone who anticipates doing the work at sea should first become thoroughly acquainted with the method by diligent practice ashore.

The principle of the method is to determine coincidences of the beats of the time signal with the beats of the chronometer and this requires a certain difference of period. So, in case the American type of rhythmic signal is used, which has the rhythm of ordinary mean time, it is necessary to bring along a special chronometer with a deranged rate. For this purpose the third chronometer, Negus No. 590, lent by the Naval Observatory was used.

To determine the coincidences with the Washington time signals, this chronometer was arranged in conjunction with the radio receiver of the submarine so that its contacts are in series with the headphones in the output of the receiver. Due to the fact that the chronometer rate is deranged the contacts are closed at intervals greater (or less) than the intervals of the signals indicating true seconds of the Naval Observatory clock; consequently, due to the fact that the incoming time signals and the chronometer contact intervals are not isochronous the signals as heard in the headphones appear to occult, to disappear entirely, to reappear as almost instantaneous dots, slowly lengthening to their maximum or real duration, slowly to become shorter again and finally to disappear entirely; the moments of appearance or disappearance of the signal are readily discernible. If the chronometer has a rate deranged in positive direction the disappearances of the Washington signal represent positions where the actual beginning of the Washington signal coincides with the exact second as indicated on the chronometer; if the chronometer has a negative rate the moment of appearance indicates the actual beginning of the Washington signal. In any event, it is the beginning and not the end of the Washington signal which must be observed in determinations where an accuracy of one hundredth of a second is demanded. Various mechanical lags in the observatory relay system and residual currents in the transmitters which change with weather conditions and other variables make the cessation of the signal unreliable.

The time signals from the Naval Observatory last for 5 minutes; ordinarily, 4 or 5 coincidences can be obtained in this space of time if reception conditions are favorable. A mean value can be computed which extends the accuracy still further.

For reducing the rates of the two main chronometers, sideral time Nardin No. 212 and mean time Nardin No. 2081, these chronometers have to be compared with the third chronometer with which the time signal was observed. This leads to the following procedure for each time comparison: (*a*) Comparison of the two main chronometers by means of one or two coincidences; (*b*) comparison of one of the main chronometers and the third chronometer by means of a number of coincidences; (*c*) the observation of the time signal with the third chronometer by means of the above method; and finally (*d*) the repetition of (*b*) in order that the mean of the times of the comparisons (*b*) and (*d*) approaches the time of the observation of the time signal. In this way the rate of the third chronometer does not enter into the result.

Thus is found the mean rate of the main chronometers between two time signals. This is not exactly what is needed. For reducing the periods of the pendulums to true time, it is necessary to know the rate during the pendulum observation and this may deviate more or less from the mean rate that has been determined. This source of error may be reduced by using good chronometers with a uniform rate; in this regard the Nardin chronometers are fairly satisfactory. Second, this error may be reduced by observing time signals at more frequent intervals. In order to allow the expedition to obtain this added accuracy the Naval Observatory was kind enough to send out several extra time signals a day, bringing the total number up to seven, as follows: 3 a.m., 9 a.m., noon, 4 p.m., 7 p.m., 10 p.m., midnight. This increase in the number of time signals has materially helped to increase the accuracy of the results of the expedition.

Nearly as important as the determination of chronometer rates is the accurate observance of changes in temperature, pressure, and humidity. During submergence the hatches, of course, must be closed; high-pressure air escapes from numerous valves and vents and the barometric pressure within the submarine rises. The engines no longer can be ventilated outboard and the heat they retain circulates throughout the ship, consequently the temperature rises rapidly and the humidity increases. In order to smooth out the temperature and humidity effects, a thick heat-insulated cover is supplied for the pendulum unit; the cover is faced with heavy sheet brass both inside and out to offer additional thermal lag and at the same time to promote a regular distribution of the temperature.

Two thermometers are installed inside the case, one of the standard mercury type and the other a bimetallic strip equipped with a prism to give a photographic trace. The mercury thermometer is mounted inside the shank of a dummy pendulum in order to simulate as closely as possible the temperature condition of the main pendulums; this thermometer has a scale, visible through a window in the cover, which can be read easily in tenths of degrees and can be estimated to hundredths. The bimetallic strip is not observed while gravity records are being taken but its photographic trace serves as a recheck when the films are developed and final measurements are made. A mercury thermometer, located in some convenient place near the gravity outfit, is desirable in that it gives an indication of the magnitude of the external temperature change.

A carefully made hair hygrometer indicates the relative humidity inside the pendulum case; its scale, located immediately above the pendulum thermometer, is readily seen from the outside through the long glass window. At the beginning and end of the cruise this hygrometer is checked against a standard psychrometer and its correction noted; both at Washington and at Guantanamo this correction amounted to –5 per cent.

In observing the barometric pressure a compensated aneroid was used; great care was taken, however, to check the aneroid against a standard mercurial barometer as frequently as possible. Correcting the mercurial barometer for temperature in each instance the error of the aneroid was found to be consistently –0.08 inch throughout the expedition. Due to unavoidable friction in the aneroid mechanism it is considered good practice to tap the barometer face lightly with the finger nail before taking the reading.

An eastward or westward movement of the ship changes the observed gravity by reason of the EÖTVÖS effect. Since the earth is revolving to the eastward, an additional eastward movement of the ship results in further increasing the centrifugal force and in reducing the observed gravity; similarly, a westward movement tends to increase the observed gravity. It is apparent, therefore, that the value must be corrected according to the east-west component of the ship's velocity but certain complications arise which make this determination liable to error. Two factors must be known — the velocity of the ship through the water and the velocity of the ocean currents at that point.

In tropical waters the hull of a ship accumulates organic growth very rapidly. This condition increases the ship's resistance in the water and gradually reduces the true speed even though the propellers are turning at known and constant rate. After the ship has been drydocked and the hull cleaned, the ratio of screw revolutions to the actual speed is at a maximum and the ratio drops as a function of the time out of drydock, and the temperature of the water and the character of the service to which the vessel is subjected. Curves have been prepared which enable the navigator to make a correction but at best this correction is only a rough approximation.

The true velocity of the submerged submarine relative to the water may be determined by making use of the EÖTVÖS effect, by observing the gravity while the ship is running first directly eastward and then directly westward. The difference in the observed gravity (d_g) is then a means of determining the true speed of the vessel, as

$$2v = d_g / 0.0075 \cos \varphi$$

in which v is the speed of the vessel in miles per hour, d_g the difference in gravity in cms. per sec.^{2} and φ the latitude.

Unfortunately, the ocean currents are more difficult to determine, since they are irregular and changeable, varying from place to place and from one hour to another with the tides, winds, and general weather conditions; only meager information can be included in the hydrographic charts. The navigator can judge the current only after he has been set off his course by a given amount. Therefore in determining the east-west component of the ocean current one can only resort to what may be considered an approximation, governed by the data about the ship's positions, by the general location, the nature of the sea, and any other information that is available.

In making gravity-at-sea observations a definite routine must be outlined and followed, otherwise some important step may be overlooked which would result in the loss of the record. It is recommended, therefore, that anyone anticipating gravity observations using the Vening Meinesz equipment study the prescribed routine as given on page 17 of the report, *The Gravity Measuring Cruise of the U.S. Submarine* S-21, prepared by F.A. Vening Meinesz and F.E. Wright, a publication of the United States Naval Observatory, or on page 62, etc., of *Theory and Practice of Pendulum Observations at Sea,* by the first author (Waltman, Delft, 1929).

The results of the gravity measurements are assembled in a table on page 17 of the Report. In column 5 of the table (1) the observed value of the gravity deduced from the photographic record is given for each station; part of these values were first computed provisionally by Vening Meinesz, Brown, and Hess during the trip while the ship was in port. Later all the measurements were repeated and the computations completed at the Hydrographic Office.

(1) *Not reproduced here (I.H.B.).*