Gravity Expedition of the U.S. Navy.

By Dr. F. A. VENING MEINESZ.

IN the course of 1928 an invitation from the Carnegie Institution of Washington was received and accepted to go to the U.S.A. with the apparatus for maritime gravity survey of the Netherlands Geodetic Commission. The U.S. Navy, having received a communication on this subject from the International Union of Geodesy and Geophysics, wished to organise an expedition for determining gravity in the Gulf of Mexico and the Caribbean Sea. The Secretary of the Navy, the Hon. Curtis D. Wilbur, designated the Naval Observatory for making the arrangements.

The expedition took place in the autumn of 1928. It consisted of the U.S. Submarine *S-21*, on board of which the observations were made, and two surface ships, the U.S. *Eagles 35* and *58*. The expedition was under the command of Lieutenant T. L. Nash, Captain of the U.S. *Eagle 35*, while Lieutenant J. L. Fisher had command of the U.S.S. *S-21*; officers of the submarine were Lieuts. F. S. Hall, F. D. Hamblin, and A. R. Sodergren. The scientific staff on board the *S-21* consisted of Dr. Fred. E. Wright, of the Geophysical Laboratory of the Carnegie Institution, Mr. Elmer B. Collins, principal scientist of the Hydrographic Office of the U.S. Navy, and myself.

The expedition started from Washington on Oct. 2 and completed the following schedule:

Leave.	Arrive.	Number of Observations.
Oct. 1. Washington	Oct. 2. Hampton Roads	0
Oct. 4. Hampton Roads	Oct. 8. Key West	3
Oct. 10. Key West	Oct. 14. Galveston	7
Oct. 19. Galveston	Oct. 23. West Key via Mississippi Delta	7
Oct. 29. Key West	Nov. 2. Guantanamo (Cuba) via Bartlett Deep	8
Nov. 5. Guantanamo	Nov. 9. St. Thomas via Nares Deep	9
Nov. 15. St. Thomas	Nov. 19. Guantanamo via Caribbean Sea	6
Nov. 21. Guantanamo	Nov. 27. Washington	5

In addition, observations were made in all the harbours, of which Hampton Roads, Guantanamo, San Juan (during trip from Guantanamo to St. Thomas), and St. Thomas, were gravity stations, which have not been occupied before. The total number of new stations amounted therefore to 49.

The pendulum apparatus was mounted in the central control room of the ship; this was a favourable spot for making the observations, as it is near the meta-centre of the ship, so that the rolling and the pitching cause only small translations of the apparatus. The apparatus is hung in gimbals, which makes it possible to work it even if the rolling or pitching is very great; a few observations have been made with a roll of 7° to both sides of the vertical, and with a slight modification of the gimbals it is hoped that in the future observations may be made with still larger angular movements. In this way it was often possible to work at periscope depth. During the return, however, from Guantanamo to Washington, the Atlantic was so rough near Cape Hatteras that the two observations which had been planned above the top and above the bottom of the continental slope could not be made, as the ship's movement at 100 feet depth exceeded the limit of 7° .

The apparatus used has been constructed at the workshop of the Meteorological Institute at De Bilt (Holland) by the chief mechanic L. M. van Rest; begun in 1925, it received its final shape in the spring of 1928 by the rearrangement of the photographic recording apparatus. It consists of a pendulum apparatus and a recording apparatus, combined in one unit hung in gimbals.

The pendulum apparatus contains three half-second

pendulums swinging in the same plane; in order to avoid magnetic influences, brass pendulums are used, although of course their temperature constants are great. An insulating cover reduces the changes of temperature inside the apparatus. As, however, the central control room of the U.S.S. *S-21* showed less variation of temperature than the control rooms of the submarines with which I made previous voyages, the temperature inside the apparatus was likewise more stable; it seldom showed greater fluctuations than a few hundredths of a degree.

The pendulums are not recorded separately but combined in two pairs. For each pair the difference of the angles of elongation is recorded, and this angle may be considered as the angle of elongation of a fictitious pendulum of the same period as the original pendulums. It can be shown—and this is the fundamental principle of this method for determining gravity at sea—that the movement of this fictitious pendulum is free from the principal disturbing effect of the ship's movements: the effect of the horizontal accelerations. The records of the two pairs which the apparatus provides are therefore nearly regular; there remain only small disturbances by the vertical accelerations of the apparatus and by the tilt of the swinging-plane. The first is practically eliminated by taking the mean pendulum period over a sufficiently long period of observation; for this purpose half an hour is more than enough. The second makes it necessary to apply a certain correction to the result, which can easily be computed if the tilt is known. The apparatus is therefore provided with an auxiliary pendulum, which can move in a plane perpendicular to the swinging-plane and is damped in order to prevent its proper oscillations. The position of this pendulum with regard to the apparatus is recorded. This correction amounts only to a few units in the seventh decimal place of the second if the tilt is small, for example, not more than $10'$; the gimbal suspension easily keeps it below this limit.

Besides the records which have been mentioned, two others are made; one of the temperature inside the apparatus and another of the middle pendulum alone. This last record is necessary for computing the reduction of the pendulum periods to infinitely small amplitudes; it is irregular because the movement of each pendulum is strongly disturbed, but as it is only used for the computation of a small reduction, this gives no special difficulties for the computations.

The records are provided with two series of time-marks by means of two shutters, which are actuated by electrical circuits opened and shut by two chronometers. Each shutter passes during a fraction of a second before the light-source which is used for recording purposes.

The rate of these chronometers is found by taking wireless time-signals; during the recent voyage the signals of Annapolis were used. Reception was effected by means of an auxiliary chronometer, provided by the Naval Observatory at Washington, the rate of which had been strongly deranged, so that every 65 seconds a full second coincidence could be observed with the signals, of which the rhythm is the same as of mean time. These coincidences were observed by ear through the well-known method of putting the contact of this chronometer in series with the telephone of the wireless. The appearances and the disappearances of the signals in the telephone have both been used.

The rates of the chronometers have been satisfactory, so that the uncertainty resulting from the fact

that the rate during the observation may deviate from the mean rate deduced from the time-signals will probably not amount to more than 2 or 3 millidynes in the result for the gravity.

The programme of the expedition was chosen with an eye to the numerous geophysical and geological problems in that part of the earth's crust. We may mention the question if isostasy prevails in the Gulf of Mexico in general and near or above the Mississippi delta; further, the problem of the Bartlett Deep south of East Cuba and the Nares Deep north of Porto Rico; the question of isostasy in the Caribbean Sea and in the Atlantic between Cape Hatteras and the West Indies, and, lastly, the gravity field above the continental slope for that part of the coast of North America.

Thanks to the whole-hearted co-operation of Captain Fisher, who ordered all the dives necessary for the measurements, this programme was fully accomplished. This involved a great deal of diving, often several times a day—once even five times in seventeen hours—which meant an additional strain for everybody. The helpful assistance of the captain, officers, and crew during the whole voyage in all circumstances may here be thankfully acknowledged.

Besides the pendulum observations a great number of soundings were taken. The submarine was provided with the sonic depth-finder of the U.S. Navy, which has given excellent results; not only during submergence, but also at the surface soundings were possible, so that the whole route could be covered. Over the ocean deeps the soundings were taken at short intervals, so that a detailed profile could be obtained.

The results of the gravity observations were provisionally computed during the voyage, and at the same time the isostatic reductions of the stations were made at the bureau of the U.S. Coast and Geodetic Survey, so that the complete provisional results were available a few days after the return of the expedition. The final computations are now being made at the Naval Observatory at Washington. Pending these, a definite interpretation is not advisable, but a few remarks concerning the provisional results may be given. It is not probable that the final results will change these conclusions.¹

The Gulf of Mexico has shown a curious positive anomaly of about 60 millidynes over nearly its whole extent; only north of Yucatan it is somewhat less, but the anomaly is still positive. Towards Key West and Galveston this anomaly disappears. Returning from Galveston to Key West a special series of observations was made over the Mississippi delta in two profiles perpendicular to the contour lines of the sea bottom, in order to investigate the isostatic equilibrium of the earth's crust in that neighbourhood. It might be thought likely that deviations of equilibrium would occur because of the great load of material deposited by the river in the Gulf, but the results have not given any evidence in this direction. The slight positive anomaly which has been found seems rather to be in accordance with the general trend of anomalies in the Gulf, so that there is no reason to bring them in connexion with the delta and to assume a lag in the re-establishment of equilibrium.

A second result of importance has been found over the Nares Deep, north of Porto Rico. It is in harmony with the few values observed in that part during my former cruise with the Dutch submarine *K XIII* from Holland via Panama to Java. It shows great departures from isostatic equilibrium, which probably may

be ascribed to stresses working in the earth's crust in connexion with the formation of the deep. Over the deep is a great deficiency of gravity; before reduction, it was more than 300 millidynes, and after isostatic reduction about 190 millidynes. North and south of the deep the anomaly after isostatic reduction is small; north of the deep it is slightly positive (± 25 millidynes), and south of it on the north coast of Porto Rico slightly negative (-10 m.d.). The gravity in Porto Rico is yet unknown, but the U.S. Coast and Geodetic Survey is planning an expedition for supplying a series of land values in connexion with the results of the expedition, and a few stations on the island will be occupied so that in a short time the continuation of the gravity field through Porto Rico will be known. The importance of this land gravity expedition is obvious; it will complete the data which have been found. South of the island, positive anomalies of about 40 m.d. have been found, as has also been the case throughout the whole part of the Caribbean Sea which has been crossed. Summing up these results, we see that apparently the great deficiency of gravity above the deep is not accompanied by considerable positive anomalies in the neighbourhood, unless the values on Porto Rico should reveal any such anomalies.

Another result worth mentioning in connexion with the deep is that two stations north of the island of Haiti, both situated to the west of the Nares Deep, likewise show great negative anomalies (± -120 m.d.), and even farther to the west, in two stations north of East Cuba, the anomaly is still negative (± -40 m.d.). This seems to indicate that the stresses in the earth's crust which are causing the Nares Deep are not limited to the region of the deep itself, but continue much farther to the west. The topography itself does not reveal this.

The values of gravity found above the eastern part of the Bartlett Deep, south of East Cuba, show smaller anomalies after isostatic reduction than the Nares Deep; the greatest negative anomaly above the deep is -61 m.d., while most of the anomalies found to the north or the south of the deep are less than $+25$ m.d. This gives the impression that the stresses in this part of the crust are smaller than those near Porto Rico.

Lastly, we will mention the results found in the Atlantic Ocean on the way back from Guantanamo to Washington. The three stations above deep water, which are all situated near the bottom of the continental slope, show small positive anomalies of about $+10$ m.d., which contrast with the value of -26 m.d. in Crooked Island Passage at the top of the slope and with the values found along the part of the Atlantic Coast to the south-west of Cape Hatteras by the U.S. Coast and Geodetic Survey, which are likewise negative; their mean value is -24 m.d. We find here an analogous result, although somewhat less pronounced, to that found in 1926 by the *K XIII* on the west coast of Central and North America between Panama and San Francisco. In the latter case the values above the top of the slope were about normal and those above the foot positive, with a mean value of about 65 m.d.; the difference between the values above the top and the foot of the slope has the same sign, but is larger on the west coast than on the east coast.

Without wishing to enter into a premature interpretation of these results, we may mention two points. First, it seems difficult to explain these isostatic anomalies by a different location of the compensation masses from that assumed for the isostatic reduction, so that we appear to be forced to accept a deviation of equilibrium on these coasts. Secondly, an explanation of these disturbances of equilibrium on the west

¹ All the anomalies mentioned in this paper have been derived from gravity values, which are isostatically reduced according to the method of the U.S. Coast and Geodetic Survey.

coast by a westward drift of the American continent and a corresponding pressure on the ocean floor, seems not in harmony with the results which have now been found on the east coast; in this case the reverse might be expected—a negative anomaly above the foot of the continental slope behind the moving continent.

Before and after the expedition, base observations were made with the apparatus both in the gravity base station, Washington, of the U.S. Coast and Geodetic Survey, and in the Netherlands gravity base station, De Bilt. These observations provide, therefore, a new check on the comparison of Washington with the international base station Potsdam. The final computations and the application of the final corrections of the time-signals have to be awaited before any conclusions will be possible.

The expedition has doubtless meant an important step for geodetic and geophysical science: because of the immediate results of which a short sketch has been given in this article, but still more because of future possibilities should the U.S. Navy continue this research. Results of great importance and extent might then be expected. The expedition has been made possible by the co-operation of the U.S. Navy with the Carnegie Institution and the Dutch Geodetic Commission. Sincere thanks may be expressed to the Secretary of the U.S. Navy, the Hon. Curtis D. Wilbur; to Admiral Hughes, Chief of Naval Operations; to Admiral Leigh, Chief of the Bureau of Navigation; also to Captain Freeman, Superintendent of the Naval Observatory, for his indefatigable work in preparing the expedition.

Personally, I wish to acknowledge the kind reception accorded me everywhere, in Washington, in naval as well as in scientific circles, on board the U.S.S. *S-21* and the other ships, and ashore in the different ports which have been touched, where the naval authorities or, in St. Thomas, the Governor of the Virgin Islands, gave me a most cordial welcome.

Zoological Exploration of Mongolia.

IN the summer, 1928, the Russian Academy of Sciences sent a zoological expedition to Mongolia, under the direction of A. Y. Tougarinov, who gives a short preliminary account of it in *Priroda*, No. 12, 1928. The problem of the expedition was the study of the Mongolian fauna to the east of Urga, a region which so far had not been zoologically investigated. The expedition took the route south-east of Urga. Plains, with occasional chains of comparatively low mountains, or individual peaks, distinguished by extreme poverty and uniformity of fauna, stretch east of Urga practically to Hingan.

The expedition was astonished by the great numbers of *Microtus brandti*, whose colonies stretch for tens of kilometres. There are no large mammals, with the exception of rare antelopes; at times colonies of tarbagans were met. The characteristic birds are *Halieetus leucorhynchus*, *Buteo hemilasius*, and the desert larks. Such poor landscape stretches up to Hingan, and only after 50 kilometres is a change observed. Owing to the humid conditions, the semi-desert is gradually transformed into a steppe, the herbaceous carpet is thicker, gramineous plants and other densely leaved steppe grasses are predominant. A grassy steppe takes the place of the xerophytic flora. The representatives of desert, such as the sandgrouse, disappear, and dwellers of steppe and forest begin to appear, which shelter in the elm forests of the valley of Chahin-gol. Representatives of Manchurian fauna such as *Xanthopygia tricolor*, *Pica*

sericea, *Circus melanoleucus* are met with. The expedition observed a great flight of birds across Chahin-gol, the species being characteristic of taiga and the tundra of eastern Siberia. It may be assumed that here around Mongolia and along Hingan lies the migratory route of east Siberian birds, the origin of which is known to have been in the south-east of Asia.

Summing up the character of the explored region, it may be said that besides the Mongolian and Manchurian provinces mentioned, the rest of eastern Mongolia may be considered as one district, the chief characteristic of which is the predominance of central Asiatic fauna. Series of species characteristic and usual to regions south of Urga are absent (for example, *Podoces hendersoni*, *Accentor fulvescens*, *Emberiza godlewskii*). Their absence cannot always be explained by the lack of suitable habitats. The Turanian elements and the forms of the southern Palaearctic are also absent. All this leads to the conclusion that recently the country has been exposed to conditions which have impoverished the fauna and hindered the spreading of forms from east and south. The extreme desert state and the xerothermic climate were probably the required conditions.

University and Educational Intelligence.

CAMBRIDGE.—Dr. N. E. Goldsworthy, of Clare College, has been elected to the John Lucas Walker studentship for three years. This studentship was founded for the furtherance of original research in pathology and is of the value of £300 a year for three years.

Smith's prizes have been awarded to H. D. Ursell, of Clare College, and J. M. Whittaker, of Trinity College. Rayleigh prizes have been awarded to J. Hargreaves, of Clare College, J. G. Semple, of St. John's College, and S. Verblunsky, of Magdalene College.

EDINBURGH.—At the meeting of the Senatus held on Mar. 14, it was announced that His Royal Highness Prince George has consented to visit the University on May 15 to open the new Department of Zoology.

At the same meeting the Senatus resolved to offer the honorary degree of doctor of laws to the following among others: Prof. E. S. Goodrich, Linacre professor of zoology and comparative anatomy, University of Oxford; Prof. A. V. Hill, Foulerton research professor of the Royal Society; Prof. C. E. Inglis, professor of mechanics and applied mechanics, University of Cambridge; Dr. A. P. Laurie, formerly principal of Heriot-Watt College; Sir James Walker, emeritus-professor of chemistry of the University of Edinburgh; and the Right Hon. Baron Woolavington of Lavington.

MANCHESTER.—Sir Ronald Ross, Director-in-Chief of the Ross Institute and Hospital for Tropical Diseases, the discoverer of the life-history of malaria parasites in mosquitoes, is among those on whom it is proposed to confer the honorary degree of D.Sc. on May 15.

ST. ANDREWS.—H.R.H. The Duchess of York has signified her willingness to be present at the opening on June 28 of the Graduation Hall gifted to the University of St. Andrews by James Younger, of Mount Melville, St. Andrews, and Mrs. Younger. After performing the opening ceremony, Her Royal Highness will receive the honorary degree of doctor of laws.