SEPARATE from

GULF OF MEXICO

ITS ORIGIN, WATERS, AND MARINE LIFE

Prepared by American scientists under the sponsorship of the Fish and Wildlife Service, United States Department of the Interior

Coordinated by Paul S. Galtsoff

FISHERY BULLETIN 89

FISHERY BULLETIN OF THE FISH AND WILDLIFE SERVICE
VOLUME 55

UNITED STATES DEPARTMENT OF THE INTERIOR, Douglas McKay, *Secretary*
FISH AND WILDLIFE SERVICE, John L. Farley, *Director*

WASHINGTON : 1954

This separate is one of the 71 articles that comprise Fishery Bulletin 89 (604 pp.). The complete volume is available, at $3.25, from the Superintendent of Documents,
U. S. Government Printing Office,
Washington 25, D. C.

PHYSICAL OCEANOGRAPHY OF THE GULF OF MEXICO[1]

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Oceanography may be defined as the study of the oceans in all their aspects, including the interrelationships between the seas and their boundaries—the atmosphere, the shoreline, and the sea bottom. Physical oceanography consists of the analysis of the physical properties of sea water, the study of motions in the oceans such as those associated with ocean waves, tides, and winds, and examinations of the various mechanisms for the transfer and interchange of energy.

The nature of physical oceanography differs from that of the other aspects of the subject in that certain investigations may be conducted somewhat independently. The other generally recognized aspects of oceanography are the biological, the chemical, the geological, and the meteorological. Investigations in these are usually dependent upon physical oceanography and upon each other. It is desirable that work in the physical aspect be planned jointly with that in the other aspects in order that maximum utilization may be made of results which are obtained. The physical oceanographer must pay particular attention to the problems in the other branches of the work since one of the primary objectives of his own researches is the development of information needed for the solution of some of these problems.

There are many unique opportunities in the study of physical oceanography in the Gulf of Mexico. There is an offshore oil industry facing many problems related to construction and operation in the shallow waters over the wide continental shelf, there is a huge chemical industry which has an output depending heavily upon the varying longshore currents which alter the salt content of the water at the position where it is taken into the plants, and there are many characteristic weather features such as hurricanes, squalls, and fog which result from effects of the oceans upon the atmosphere. Further, the large oyster and shrimp fisheries are markedly affected by currents, turbulence and the physical characteristics of the sea water. Also, in reduction of beach contamination, prevention of beach erosion, reduction of dredging costs in marine channels, increasing the efficiency of marine transportation, development of recreational areas on the beaches, and in providing oceanographic information critical to the defense of our coastline, physical oceanography plays a most important role in the Gulf of Mexico.

The Gulf, being nearly enclosed, provides a model ocean in which much may be learned about processes operating in the larger oceans which are not so readily adaptable to comprehensive and systematic analysis. The presence of fixed platforms far from shore may make it possible for the first time to make such determinations as that of the effect of the wind in changing the slope of the sea surface in the open sea. Such information is needed for further development of the theories of wind stress upon the sea surface and for the more complete understanding of the manner in which the winds drive the ocean currents and set up ocean waves.

Despite the need for physical information in the Gulf, relatively little has as yet been done to survey the region systematically and to provide information in a form which is generally available. Recently there have been increased efforts in this direction, and within the near future it may be expected that knowledge of this highly important oceanic region will be greatly increased.

OCEAN CURRENTS

The primary problem in the physical oceanography of any region is the determination of the ocean currents. In the Gulf of Mexico it is particularly difficult. To provide a background for a discussion of this problem it is well to consider

[1] Contribution from the Department of Oceanography of the Agricultural and Mechanical College of Texas, Oceanographic Series No. 16; based in part on investigations conducted for the Texas A. and M. Research Foundation, through the sponsorship of the U. S. Navy Office of Naval Research.

briefly the general nature of the currents which may be expected in such a region.

The general nature of currents in the Gulf of Mexico

Sverdrup (1942) [2] lists three different groups of currents each of which is represented in the Gulf of Mexico. These are:

(1) currents that are related to the distribution of density in the sea,

(2) currents that are caused directly by the stress that the wind exerts on the sea surface, and

(3) tidal currents and currents associated with internal waves.

Tidal currents [3] are caused by the tide-producing forces. These forces result from differences between the constant centrifugal force which acts on any particle on the earth and the varying gravitational attractions between the earth, the moon, and the sun. These attractions are proportional to the masses of the bodies and inversely proportional to the squares of the distances between them. Because of its very short distance from the earth the attraction of the moon is large. The sun, on the other hand, although it is at a much greater distance from the earth, is so large that a tide-producing force results which is as much as 46 percent of that of the moon.

The direct result of tide-producing forces acting upon the rotating earth is to raise and lower periodically the level of the ocean's surface, i. e., to create tides. Water which is required to raise sea level at a particular location must be furnished by horizontal movements within the ocean. These are the tidal currents. Since the sun and moon change their position with respect to a given part of the earth's surface in a periodic fashion, the tides and tidal currents are periodic. Because the rotation of the earth affects movements of water the tidal currents do not oscillate back and forth on a straight line but rotate. In the Northern Hemisphere this rotation usually is in a clockwise direction except where modified by other factors. At times, interference between tidal waves or the influence of other forces is such that the rotation may be counterclockwise.

Along the Gulf coast there are many bays and lagoons which have relatively restricted outlets to the sea. If the water level in these bays is to be raised by tidal action, all of the water required for the change in level must flow into the bay through these restricted channels. Therefore, the tidal currents in such channels may be quite large, particularly at certain stages of the tide.

The great width of the shallow continental shelf along the Gulf coast results in tidal current velocities which are relatively high considering the small range of tide. This is because the change of water level of this large area over the shelf must be brought about by flow across the shallow shelf. Since the depth of the moving water is small, its velocity must be relatively great to provide the volume needed for change in sea level. The high velocities and the changing direction and speed of these tidal currents may lead to considerable turbulence and stirring in certain localities.

Oscillating currents related to internal waves may be important in this region, but little information now is available on this subject.

Currents caused by the stress of the wind upon the sea surface are particularly important on the Gulf coast. The most widely known phenomenon which results from the action of such currents is the storm tide or general rise in water level which precedes winds of hurricane velocities. Storm tides are discussed by Cline (1920) and Tannehill (1927). Some of their results are summarized in the chapter on meteorological phenomena.

When a wind starts to blow over the ocean it exerts a frictional force or drag upon the sea surface. If the wind persists the surface layers of the water start to move and they in turn act upon the deeper layers and set these in motion also. The two forces which are involved in setting up such currents are the frictional force, and the Coriolis force which is the apparent force due to the rotation of the earth. If the wind blows long enough for a state of equilibrium to be reached, the surface waters away from the influence of the coast will be moving in a direction approximately 45° to the right of the wind direction in the Northern Hemisphere. A north wind sets up a surface current toward the southwest. The surface velocities may reach 1 to 2 percent of the wind velocity. Currents at greater depths will flow at greater angles to the wind and at speeds which decrease with depth.

[2] References are listed at the end of the chapter.

[3] Tides in the Gulf of Mexico are discussed separately in the article by H. A. Marmer, pp. 101–118.

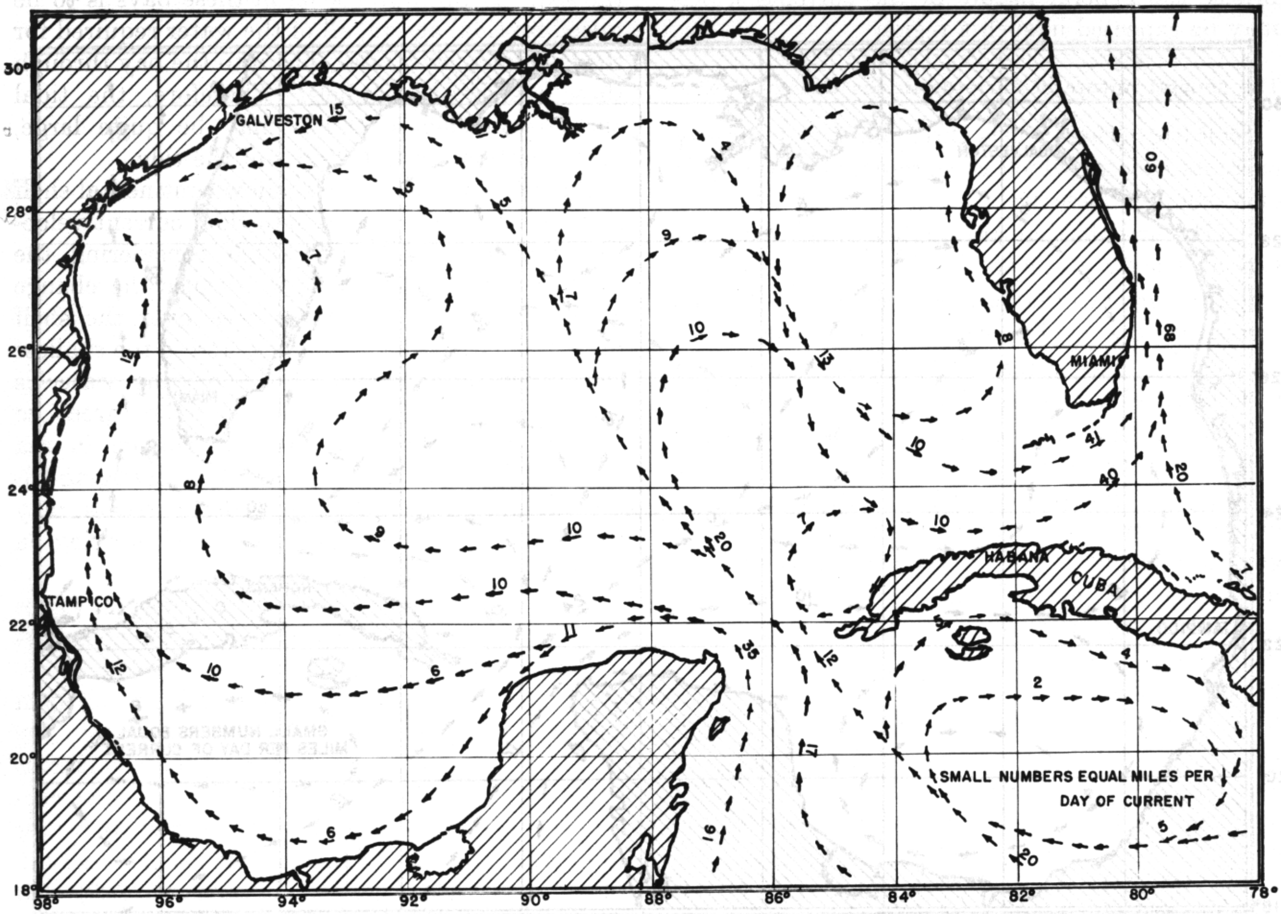

FIGURE 34.—Surface ocean currents in the Gulf of Mexico in June.

Conclusions concerning currents set up by the wind are mostly based upon theoretical considerations. A few observations have been made in landlocked bays to show the piling up of water by the wind. However, in the open ocean no systematic data are available. The drilling platforms off the Gulf coast permit the accumulation of data which will make possible a practical analysis.

The currents related to the distribution of density are the major semipermanent currents of the oceans. Little is known about these currents in the Gulf of Mexico. The chief source of information is the pilot charts of the United States Navy Hydrographic Office (figs. 34 and 35). These are based upon the navigation records of the ships sailing in the Gulf over many years. They do indicate the general drift in various regions, but the individual observations upon which they are based are subject to many errors. For example, the deviation of a ship from its course may be caused by the wind rather than by the current. Also, it is difficult to determine positions at sea accurately. A survey of the pilot charts for the Gulf indicates that these may not describe all of the currents present. They show waters flowing into the western part of the area at all latitudes but no water flowing out. This situation cannot exist unless there is a submarine return current of equal magnitude, which seems unlikely.

In the deep waters, direct observation of current velocities has been almost impossible until recently because of difficulty in anchoring vessels. Accordingly, few such observations have been made. Instead, oceanographers have developed a method based upon principles of physics. By use of this method the ocean currents present may be inferred from the distribution of density as determined by relatively simple observations of temperature, salinity, and pressure. Two forces again

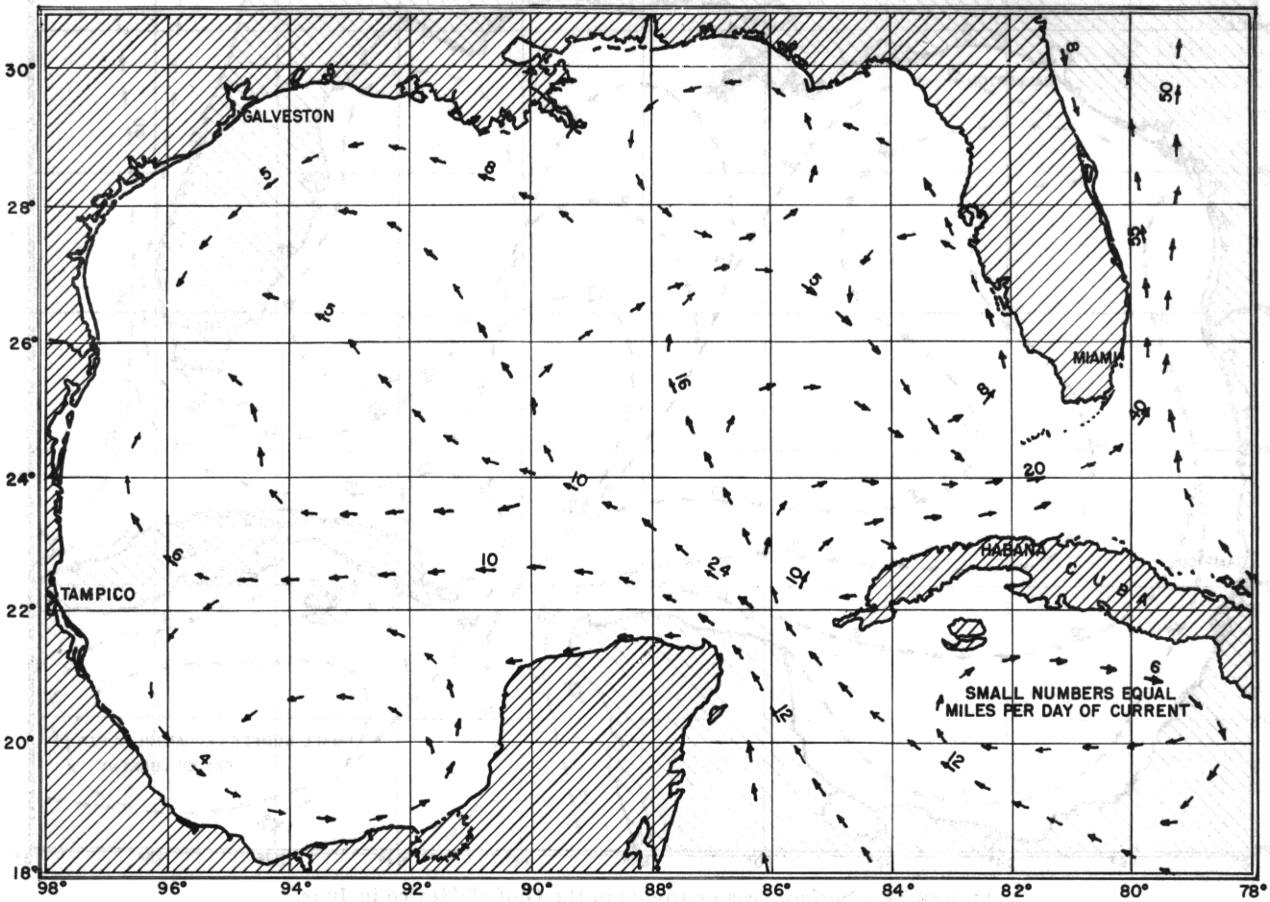

FIGURE 35.—Surface ocean currents in the Gulf of Mexico in December.

are involved, one of these being the Coriolis force and the other the "pressure force" which is a force that depends upon the water density distribution in the earth's gravitational field. The pressure force tends to make water flow from a region of high pressure toward a region of low pressure just as water poured into less dense oil will flow outward from the point at which it is poured. When the movement related to the pressure gradient has begun, the Coriolis force acts toward the right of the movement in the Northern Hemisphere and the resulting equilibrium between the two forces is associated with a steady current flowing almost perpendicular to a line connecting the regions of high pressure and low pressure. This flow is such that in the Northern Hemisphere the more dense water is on the left of a person standing with his back to the current and the less dense water is on his right. Since temperature is one of the major factors influencing density, it may be inferred that the cold water is on the observer's left and the warm is on his right when he is standing as described above with relation to the current. Thus, he can tell something about the currents if he knows the distribution of temperature, or he can tell something about the temperature if he knows the distribution of currents.

There are a number of difficulties which arise in applying the current computation method. These occur partly because the basic assumptions underlying the theory are not always fulfilled. However, despite these difficulties the method has been found to be the one which provides the most information for a reasonable amount of work. It is not known how accurately the Gulf currents in deep water may be determined by this method, but there is reason to believe it to be the most accurate of the methods now in use. Used in conjunction with the geomagnetic electrokinetograph, it probably provides the best complete picture of the current patterns in the open Gulf. Determination of the flow over the broad, shallow continental shelf remains a difficult problem.

Some processes by which the distribution of density is caused to change are evaporation, conduction, and the movement of masses of water by the winds. Since the total transport of water due to the winds in this hemisphere is toward the right of the wind, and since this transport consists of waters in the surface layers which are warm and of low density, the low density waters are piled up at the right of the wind flow, which is in the center of anticyclones, regions of good clear weather. The warm waters are removed from the low pressure storm areas at the left by the wind action. These movements are called the wind-driven currents. Their primary effect is to pile up water of small density in areas of anticyclonic winds and to leave waters of greater density in areas of cyclonic winds. This leads to a secondary effect, namely, the maintenance of a different ocean current related to this distribution of density. Since such currents flow nearly perpendicular to a line connecting the regions having the different water densities, the associated currents form a pattern quite similar to the pattern of the winds. This may readily be recognized on charts showing the distribution of ocean currents with prevailing winds superimposed.

Investigations of ocean currents in the Gulf of Mexico

There is probably no part of the oceans of the world of comparable size to the Gulf of Mexico where there is such a wide difference of opinion concerning the specific current regime. This difference is brought out by Sweitzer (1898). He quotes Isaac Vassius who, writing about the year 1663, tells how the currents through the Yucatán Channel "turn obliquely" and pass through the Straits of Florida. The issue of the Encyclopedia Britannica available in 1898 states that "a portion of it (the current—DFL) passes directly to the northeast along the shore of Cuba; but by far the larger part sweeps around the Gulf." Sweitzer himself concludes that, at times "the channel of Yucatán pours its waters into the Gulf so that they spread out in all directions moving on its center," while at other times the currents flow "in a northeasterly direction around the extreme west coast of Cuba." These last results were based upon studies of the distribution of specific gravity of the surface waters, United States Coast and Geodetic Survey, Lindenkohl (1896), and upon modification of currents by the prevailing winds.

Sweitzer also reported considerable agitation of the waters covering an area of about 100 square miles occurring off the coast of Texas about 40 miles south and 20 miles east of Aransas Pass which could only be accounted for by the meeting of two opposing currents. Other evidence of converging currents has since been found, and this area has become known as the graveyard of ships.

Measurements made in the years 1885 to 1889 by the United States Coast and Geodetic Survey vessel *Blake*, commanded by Pillsbury (1889), determined the currents in the Straits of Florida. Since the ship was anchored, direct current observations could be compared to computed values, and the comparison provided one of the best examples illustrating the validity of the method for computing relative currents which is now so widely used.

Agassiz (1888) published temperature and salinity data collected by the *Blake* in 1878. These data, together with others collected by the *Bache*, Bigelow (1917), were used by Wüst to compute the transport of the water through the Florida Straits as 26 million m^3/second. Associated with this transport is a water level difference of 19 cm. between the southeastern Gulf and the Atlantic at St. Augustine, Florida, which is discussed by Montgomery (1938). A theory of piling up water in the "Bay of Mexico" was advocated by Benjamin Franklin about 1770.

In 1922, the *Dana* made some observations in the Yucatán Channel and in the Florida Straits, as shown in figure 36. These observations, as well as those of the *Mabel Taylor* in 1932, were summarized by Parr (1935) who concluded that "evidence thus obtained from the Gulf itself, although directly opposed to some of his premises, nevertheless serves to confirm the theory already advanced by Nielsen on the basis of observations in the Straits alone, that the so-called Gulf Stream only takes the shortest possible path from its entrance through the Yucatán Channel to its

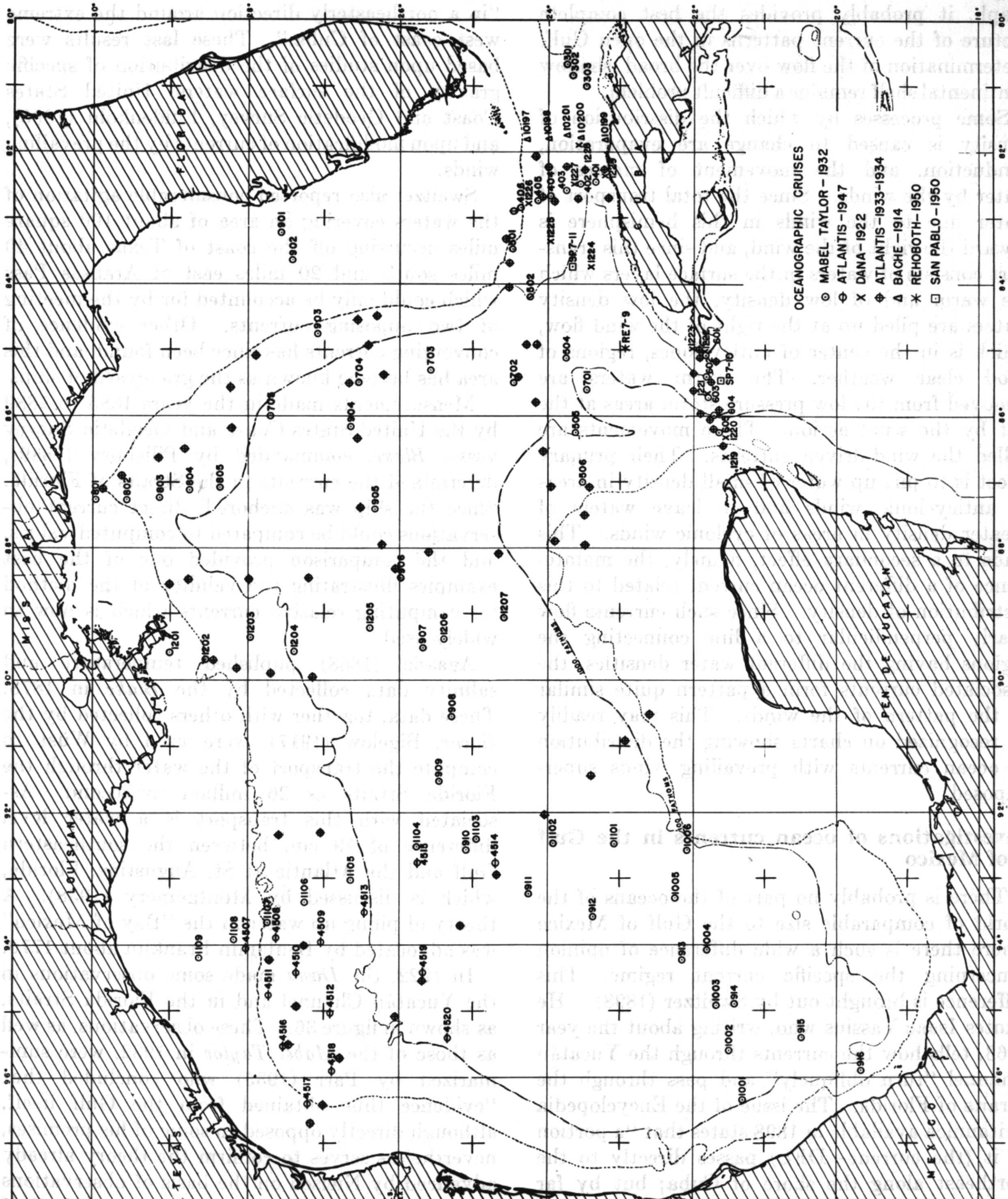

FIGURE 36.—Hydrographic stations in Gulf of Mexico.

exit through the Straits of Florida, without deviating on the way, or diffusing any to itself significant amount into the Gulf of Mexico proper, or receiving any predominant contribution from the Gulf in return." This statement on the one hand and the current pattern shown in figures 34 and 35 on the other hand summarize the present divergence of opinion.

The *Mabel Taylor* cruise was made without unprotected thermometers or other reliable means of determining depth of observations. Parr cautions that particularly in the Yucatán Channel and Florida Straits there is sufficient uncertainty of the depths of the *Mabel Taylor* operations "to make it seem inadvisable to subject them to a form of analysis and comparison in which depth is an essential consideration." Similarly, the *Atlantis* cruise of 1934, Parr (1937), lacks subsurface data since the hydrographic cable was lost early in the survey. Thus, the oceanographic data available to Parr were meager.

Dietrich (1939) reviewed the currents of the Gulf, and his conclusions, although based upon essentially the same data as used by Parr, show considerably more influence by the Gulf Stream upon the general circulation in the Gulf. He discussed the sill depths showing that the Gulf circulation cannot affect the deep water circulation of the Atlantic below about 800 meters. However, the Florida current, which is shallower than this, has considerable effect.

In 1947 the *Atlantis* conducted a survey of the northwestern Gulf making 27 hydrographic stations (fig. 36) and 473 bathythermograph observations of temperature. These data have been analyzed by Fred B. Phleger (1951), now of the Scripps Institution of Oceanography of the University of California, and have been published by the Geological Society of America.

The first cruises of the *Alaska*, oceanographic research vessel of the Fish and Wildlife Service operating on a survey of the Gulf of Mexico with the cooperation of the Department of Oceanography of Texas Agricultural and Mechanical College and the United States Navy, Office of Naval Research, were completed in October 1951 (fig. 37). These provide the first complete coverage of the Gulf with information needed to compute the deep water currents. The data from these cruises have been distributed and prelimary analyses indicate that they support the main features of the current pattern shown in figure 34.

A brief description of the currents of the Gulf of Mexico is provided in the United States Coast Pilot (1949):

> Under normal conditions, at all seasons of the year, the great volume of water passing northward through Yucatán Channel into the Gulf of Mexico, spreads out in various directions. Surface flows set westward across Campeche Bank, the Gulf of Campeche, and the Sigsbee Deep; northwestward toward Galveston and Port Arthur; north-northwestward toward the Mississippi Passes; and eastward into the Straits of Florida.
>
> A straight line drawn from Buenavista Key, Western Cuba, to the Mississippi Passes forms an approximate boundary between movements having different directions. West of this line the drift is generally northward or westward, while east of it the drift is eastward or southeastward toward the Straits of Florida.
>
> There are northward flows along the west side of the Gulf between Tampico and Corpus Christi in the vicinity of the 100-fathom and 1,000-fathom curves, north of the Sigsbee Deep between the 2,000-fathom and the 100-fathom curves, and along the west coast of Florida.
>
> In general, the surface circulation is the same at all seasons. There is, however, some seasonal change in velocity, the flow being generally stronger in spring and summer than in the autumn and winter.
>
> The current near the Florida Keys is variable and uncertain.

This description is apparently taken from the Pilot Chart series of the Hydrographic Office (H. O. No. 3500, issued monthly). Another series, H. O. No. 10,690, 1 to 12, Current Charts of the Central American Waters, give resultant direction and velocity for each 1° quadrangle of latitude and longitude. This series has been used by Smith, et al. (1951), to show zones where seasonal convergence or divergence occur.

Many of the references cited above contain bibliographies pertinent to the Gulf of Mexico. Also, Geyer (1950) lists many useful works.

In summary, the currents of the Gulf of Mexico and their variations are not specifically known. Studies completed in the past indicate some unusual and interesting features and provide incentive and justification for continued intensive investigation.

SEA SURFACE TEMPERATURES

A large number of sea surface temperature observations have been collected at shore stations. Some of these data from locations shown in figure

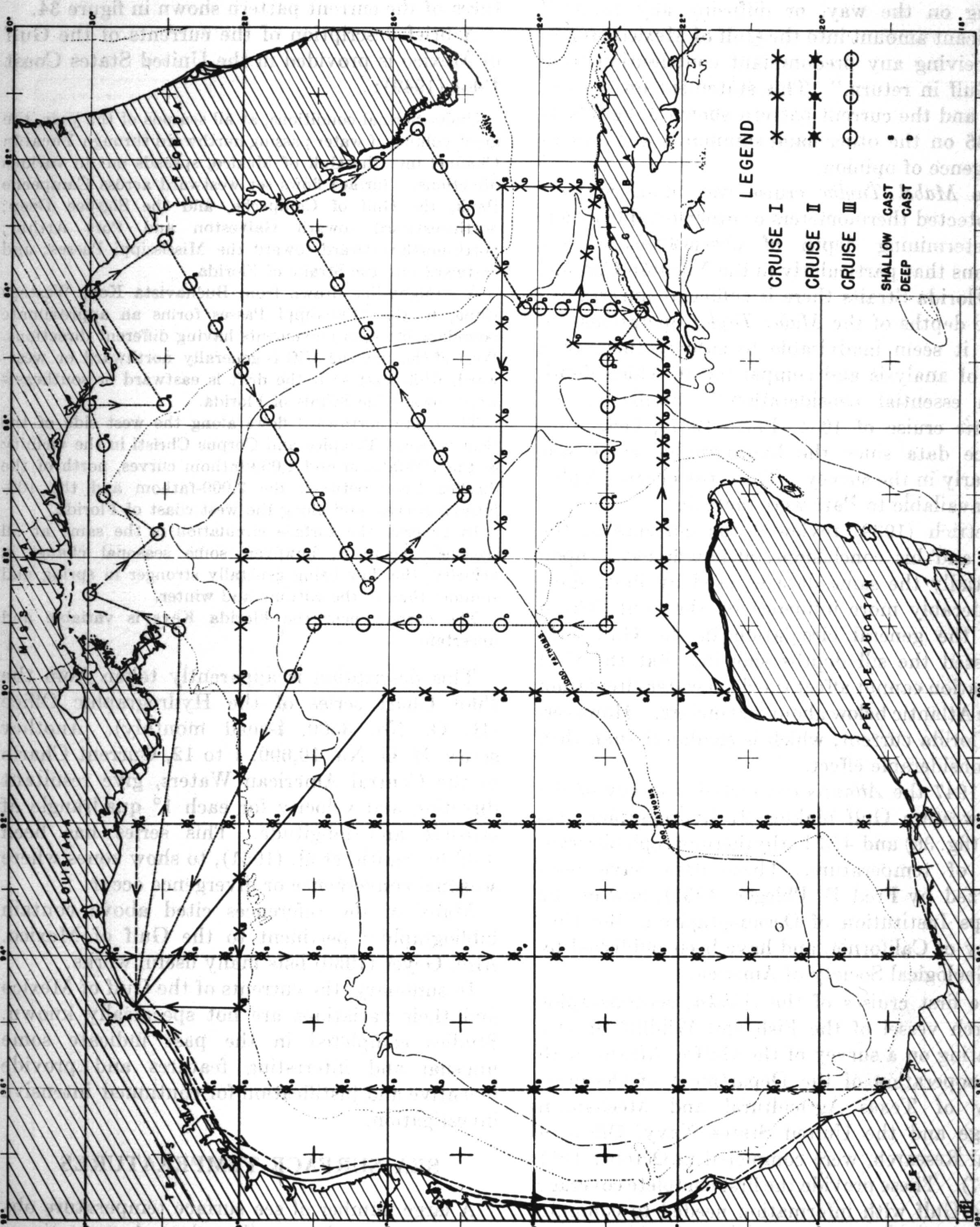

FIGURE 37.—Cruise plan for U. S. Fish and Wildlife vessel *Alaska*, September 1950.