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TIDES AND TIDAL CURRENTS IN THE GULF OF PANAMA

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The following discussion deals with two specific problems: first, the increase in the range of tide between the entrance and the head of the Gulf of Panama; and second, the variations in the tidal current velocities between the entrance and the head of the Gulf. Both phenomena are shown to be related to the bottom topography. The profile of the bottom across the continental shelf plays an important role in determining the distribution of tidal current velocities in such an area, and the maximum velocities are shown to occur at or near the edge of the shelf. Treating the tide of the Gulf of Panama as a standing wave, the current velocities in the Gulf have been related to the range and phase of the tide. Although the numerical examples are restricted to the Gulf of Panama, the same methods may be applied to other regions.

Range of tide and time of tide in the Central American Pacific.—The average range of tide in the Central American Pacific region is shown in Figure 74. An insert of the Gulf of Panama (Fig. 74A) shows additional tidal data for the stations within the Gulf. These figures were prepared from data in the Tide Tables for the Pacific and Indian Ocean, 1938 (U. S. Coast and Geodetic Survey). The upper value in the insert map is the average range of the tides, the lower value the average range of the spring tides, in feet. The tides are of the semi-diurnal type. The tides in the Gulf of Panama vary from 5 feet at minimum neap tides to over 22 feet at maximum springs (Kirkpatrick, 1926).

In the Central American Pacific area the average tidal range is greatest in the innermost portion of the Gulf of Panama. It decreases to 9 feet along the South American coast and there is a general decrease northward along the Central American coast. The insert map shows that even within the Gulf of Panama there is considerable variation in the average range of the tide. The maximum values for both average and average spring ranges are found at Balboa where the values are 12.6 and 16.4 feet respectively. At the entrance to the Gulf the values on the west side, Cape Mala, are 10.3 and 13.0 and on the east side, Piñas Bay, 10.8 and 13.8 feet. That is, the range of tide at the head of the Gulf is about 2.5 feet greater than at the


(192)
entrance. The values in parentheses (Fig. 74) are the lunitidal intervals expressed in terms of Greenwich Meridian Time for the respective stations. From these it is apparent that the time of tide is almost the same over the entire area. The greatest difference in time of tide, in the area shown in this map, is 1 hour 20 minutes. When it is noted that some stations are on the open coast and others in bays and inlets, where the tide will be somewhat retarded, the differences are strikingly small.

As the time of tide is so constant over such a large portion of the coast, it is obvious that the tide in this region must have the character of a standing
wave. Whether this is of the form discussed by Harris or whether it is due to
the interference of a series of progressive waves need not concern us at
this time. The general form of the coast line of the Pacific coast of the
Americas must have an important bearing on the nature of the tides in this
area. From Figure 74 it can be seen that the coast forms a large bight
approximately semicircular in shape. The Gulf of Panama proper forms a
secondary indentation at the head of the bight. Two interesting points
arise; first, what causes the greater range in tide at the head of the Gulf and
second, why are the ranges along the coast of South America greater than
those along the coast of Central and North America?

These questions are undoubtedly associated with the properties of the
tidal wave and the form of the coast. The fact that the wave is restricted
by the converging coast line will result in an increase in range near the head.
The greater range in tide on the southern and eastern coast is probably
related to the orientation of the tidal wave and the form of the coast line,
although the deflective force of the earth's rotation may play some part.
In the Gulf of Panama we must again consider the form of the coast line and
the deflective force of the earth's rotation, and a third factor, namely: the
shallower depths in the inner part of the Gulf.

Effect of topography on range of tide.—Lamb (1932) discusses the effect
of changing depth and boundaries upon the form of tidal waves in canals.
If we assume that the Gulf of Panama is of constant breadth but of variable
depth we can apply certain equations from Lamb. The depths along a line
running from the head of the Gulf to the entrance on the meridian 79° 20'
W (Fig. 74B) are shown in Figure 75, curve I. From this profile it would
appear that the slope between the head of the Gulf and a point 120 km from
the head could be considered constant. If this is the case, we can use the
equation given by Lamb (1932, p. 276) for a canal of constant width but
linearly changing depth, that is where $h = h_a \frac{x}{a}$.

The general equation for tidal movements in a canal, disregarding the
effect of the rotation of the earth, is given by Lamb (1932, p. 275).

$$g \frac{\partial}{\partial x} \left( hb \frac{\partial \eta}{\partial x} \right) + \omega^2 \eta = 0$$

where

$\eta_a = C \cos (\omega t + \varphi)$.

g = gravitational constant.
b = breadth of the canal.
h = depth at distance $x$ from the end. $h_a = depth at distance x = a$.
$\eta$ = level of the tide at time $t$.
$C$ = amplitude of the tide at $x = a$. 
\[ \sigma = \frac{2\pi}{T}, \text{ where } T \text{ is the tidal period, } t \text{ some fraction of } T \text{ and } \varepsilon \text{ some fraction of } 2\pi \text{ which is used when it is necessary to correct for phase differences. In the present case it may be disregarded. In the case under consideration } b \text{ is constant and } h = h_a \frac{x}{a}. \]  

Therefore,

\[ (2) \quad \frac{\partial}{\partial x} \left( x \frac{\partial \eta}{\partial x} \right) + k\eta = 0, \text{ where } k = \frac{\sigma^2 a}{gh_a}. \]

The solution can be written as a Bessel function.

\[ (3) \quad \eta = \frac{J_0(2k \frac{1}{2} x \frac{1}{2})}{J_0(2k \frac{1}{2} a \frac{1}{2})} C \cos(\sigma t). \]

Only the first three terms of the expansion need be considered and if we omit \( C \cos(\sigma t) \) we may write

\[ \eta = \frac{1 - \left( \frac{1}{2} \cdot 2k \frac{1}{2} x \frac{1}{2} \right)^2 + \frac{1}{4} \left( \frac{1}{2} \cdot 2k \frac{1}{2} a \frac{1}{2} \right)^4}{1 - \left( \frac{1}{2} \cdot 2k \frac{1}{2} a \frac{1}{2} \right)^2 + \frac{1}{4} \left( \frac{1}{2} \cdot 2k \frac{1}{2} a \frac{1}{2} \right)^4}. \]

In this case \( a = 120 \times 10^3 \text{ m, } h_a = 120 \text{ m, and, considering a semi-diurnal tide, } T = 4.48 \times 10^4 \text{ sec. Therefore:} \]

\[ k = 2.00 \times 10^{-6}. \]

If we solve for the value of \( \eta \) when \( x = 0 \), that is, at the head of the Gulf and reintroduce the term \( C \cos(\sigma t) \):

\[ \eta_0 = 1.30 \ C \cos(\sigma t). \]

That is, the range in tide at the head of the Gulf should be 30% greater than at the entrance. Actually the difference is much less than this and consequently we must find some other expression that gives a better agreement. From a study of the profiles of other shelves and from other sections in the Gulf, it appeared that a parabolic curve more nearly approximated the profile of the bottom. The expression for the bottom profile could then be written \( h = h_a \sqrt{\frac{x}{a}} \). This curve fitted to \( h_a = 120 \text{ m and } a = 120 \text{ km is shown in Figure 75, curve II. The parabolic curve gives depths somewhat greater than the actual depths of the section in the inner portion of the Gulf. In this case } b \text{ is constant and } h = h_a \sqrt{\frac{x}{a}}, \text{ consequently} \]

\[ (4) \quad \frac{\partial}{\partial x} \left( \sqrt{x} \frac{\partial \eta}{\partial x} \right) + k\eta = 0. \quad k = \frac{\sigma^2 \sqrt{a}}{gh_a} = 5.77 \times 10^{-9}. \]
The solution can again be written as a Bessel function which expanded yields

\[ \eta = \frac{1 - \frac{2}{3} k\alpha^{3/2}}{1 - \frac{2}{3} k\alpha^{3/2}} \ldots C \cos (\omega t). \]

At the head of the Gulf, where \( x = 0 \),

\[ \eta_o = 1.19 \ C \cos (\omega t). \]

That is, on these assumptions the range of tide at the head of the Gulf should be 1.19 times greater than that off the entrance to the Gulf. At Piñas Bay on the eastern side of the mouth of the Gulf, where the shelf is very narrow, the average range of tide is 10.8 feet and the average spring range is 13.8 feet. At Cape Mala, on the western side of the entrance to the Gulf, the average ranges are 10.3 and 13.0 feet respectively. As the differences between Cape Mala and Piñas Bay may be due to the effect of the earth’s rotation, we may assume that the average ranges in tide at the central part of the entrance to the Gulf are about 10.5 feet and 13.4 feet. If we multiply these values by 1.19 we obtain 12.5 feet and 16.0 feet for the averages of the tide at the head of the Gulf. At Balboa the actual values are 12.6 feet and 16.4 feet.

If we adjust the theoretical average tidal amplitude so that it agrees with the observed amplitude at Balboa, we obtain the curve shown in Fig. 75, curve IV. The amplitude of the tide which was computed by considering the slope of the bottom as constant is also shown (curve III). The apparent contradiction in the results obtained, namely that the bottom profile is almost a straight line and that the tidal range at the head of the Gulf is much smaller than would be expected from this, is undoubtedly due to the effect of friction. This is the reason why the parabolic function which gives depths greater than the actual profile yields an expression for the tidal amplitude which agrees more closely with the actual conditions. The fact that the parabolic function gives such a good agreement at Balboa must then be considered as more or less accidental. The average amplitudes at the various stations in the Gulf are also shown and, although the agreement with the parabolic expression is good near the head of the Gulf, it does not fit very well for Rey Island. In this case the value obtained using the straight line function is somewhat closer. In order to facilitate calculations the parabolic expression for the tidal amplitude has been used in the following discussion.

Characteristics of tidal currents.—In a study of the oceanographic conditions in any area the horizontal water movements associated with the rise and fall of the tide are usually of much greater significance than the vertical movements. The tidal range in the Gulf of Panama is large and it is obvious that associated with the tides there must be strong tidal currents. Tre-
mendous volumes of water must enter and leave the Gulf during each tidal period. There are many references to the strong tidal currents in the Gulf of Panama (over 1 knot in many instances) in the Coast Pilots and the newer charts published by the United States Hydrographic Office, particularly in the region of the Perlas Islands Archipelago (U. S. Hydrographic Office Charts No. 1019, 1410, 5580, 5584, etc.).
As the tidal range in the Gulf of Panama varies from 5 feet to over 22 feet there must be wide variations in the maximum velocities. This may account, in part at least, for the many statements that the Gulf is an area of extremely variable currents. Also, as the tidal currents will reach maximum velocities twice during the tidal period of about 12.5 hours, and approach zero velocities twice during the same period it is obvious that the movements in the Gulf will be very variable. Although the tidal currents may reach high velocities, they are reversing currents and therefore bring about no actual transport of water, consequently their effect upon the oceanographic conditions can only be that of mixing of the waters already present. The point which must be emphasized is that the non-tidal circulation which determines the general oceanographic features in the Gulf is probably rather steady over relatively long periods and that the currents reported as variable are associated with the tides. They are of a periodic nature and depend upon the phase and range of the tide.

It has been shown in the preceding section that the tides in the Central American region and in the Gulf of Panama can be treated as standing waves. Therefore the maximum current velocities will be found at half tide. Certain other factors must be taken into consideration, such as the effect of the earth’s rotation and the effect of the bottom configuration. In the absence of the effect of the rotation of the earth the horizontal movement of a particle associated with the tides would be in a straight line oscillating back and forth. However the effect is such that any particle in motion tends to be deflected to the right of the direction of progress in the northern hemisphere and to the left in the southern hemisphere. Only on the equator is this effect zero and there the tidal currents should be rectilinear. The effect increases as the sine of the latitude and consequently the tidal currents are not rectilinear but trace ellipses of increasing width as the latitude increases until at the poles the movements will be circular. One ellipse will be completed in each tidal period.

The relationship of maximum and minimum velocities under a given set of conditions in the open ocean is that:

\[ S = \frac{V_{\text{min}}}{V_{\text{max}}} = 2 \sin \varphi \frac{T}{T'} \]

when \( T \) = the period of the tide, \( T' = 24 \) hours and \( \varphi \) = latitude.

For a semi-diurnal tide, \( T \) is approximately equal to \( \frac{1}{2}T' \).

Therefore, \( S \approx \sin \varphi \).

For the lower latitudes the values of \( S \) are given in the following table:
From the above figures it can be seen that the effect of the earth’s rotation upon tidal currents must be slight in the Central American region as the maximum velocities will be many times as great as the minimum velocities. In the Gulf of Panama, itself, there is undoubtedly some effect but it will be so slight compared to the flow in and out of the Gulf that we need not give it much consideration. Furthermore the proximity to land will result in the development of gradients which will tend to reduce the lateral deflection. However, it should be emphasized that the tidal currents will at no time be zero; but will instead decrease to minimum velocities at high and low water.

Tidal currents over the continental shelf.—As stated above, the topography of the bottom has an important role in determining the velocity of tidal currents. It is not the depth alone which enters when we are considering the water movements associated with a standing wave; but also the relationship of the depth and the distance from shore.

Let us examine the case where a standing wave is oriented at right angles to the coast line and where the level at the tide of time \( t \) and point \( x \) is represented by
\[
\eta = C_x \cos (\sigma t)
\]
where \( C_x \) is the amplitude of the tide at the point \( x \). Substituting for \( \eta \), in equation (1) we obtain
\[
\frac{\partial}{\partial x} \left( h \frac{\partial \eta}{\partial x} \right) = - \frac{\sigma^2}{g} C_x \cos (\sigma t).
\]
\[
g \frac{\partial \eta}{\partial x} = - \frac{\sigma^2}{h} \cos (\sigma t) \int_0^x C_x \, dx.
\]
Now
\[
\frac{\partial u}{\partial t} = - g \frac{\partial \eta}{\partial x}.
\]
(7) Therefore
\[
\frac{\partial u}{\partial t} = \frac{\sigma^2}{h} \cos (\sigma t) \int_0^x C_x \, dx.
\]
(8) and
\[
u = \frac{\sigma}{h} \sin (\sigma t) \int_0^x C_x \, dx.
\]
From this we see that the velocity will vary inversely as the depth \((h)\) at the point \(x\) and directly as the volume of water represented by the integral of the level of the tide over the distance from the shore to the point \(x\). If the level of the tide was constant, this would merely represent the product of the level of the tide and the distance \(x\).

Let us examine the velocity of the tidal currents over shelves of certain types. If we consider only the maximum velocities, that is when \(\sin(\sigma t) = 1\), then,

\[
U_{\text{max}} = \frac{\sigma}{h} \int_{0}^{x} C_{x} \, dx. \tag{9}
\]

Let us further assume that \(C_{x}\) is constant, then

\[
U_{\text{max}} = \frac{\sigma}{h} C_{x}.
\]

Certain striking relationships can then be readily seen. First: if the depth is constant, the velocity will vary as the distance from shore. Second: if the slope is constant and passes through \(x = 0\), that is \(\frac{x}{h}\) is constant, then the velocity is constant and independent of \(x\). Third: if the slope is constant over a certain stretch of the shelf, the velocity over that stretch will decrease on approaching the coast if the slope is \(< \frac{h}{x}\) but \(>\) horizontal, and will increase if the slope is \(> \frac{h}{x}\). Fourth: the velocity will be maximal where \(\frac{x}{h}\), that is the distance from shore divided by the depth, is greatest.

The last mentioned point is one of general interest because of the characteristic form of the continental shelves. Although the width of the continental shelf varies greatly from place to place along the coasts it has, in practically all cases, a zone of relatively constant depths before reaching the continental slope. Consequently the value of \(\frac{x}{h}\) is greatest at or near the edge of the shelf, and therefore the tidal currents will attain their maximum velocities in this zone, provided that the tidal wave is not distorted by the outline of the coast. If we consider the greater range of the tide usually associated with the shoaling bottom, that is when \(C_{x}\) increases as \(x\) decreases, the volume of water passing \(x\) will be greater than if the amplitude is constant. Consequently the velocities will be greater.

It must be borne in mind that the foregoing considerations were based on certain assumptions, namely, that we had a standing wave oriented at right angles to the coast line. This case is probably not encountered in
very many areas in the ocean. However, the general conception concerning the distribution of velocities over the shelf will hold true whenever there is any transport of water across the shelf which is associated with the tidal movements. If the tidal wave is of the progressive type, the maximum velocities will occur at high and low water instead of at half tides as in the standing wave. If the tidal wave is reflected or otherwise affected by the proximity of the coast, the tidal currents may bear some other relation to the tidal cycle.

In the considerations above it has been assumed that the depth was uniform or sloped upwards continuously towards the coast. It has been shown that the velocity at any distance from the coast is a function of the depth at \( x \), and the integral of the amplitude of the tide over the distance \( x \). It should be noted that the depths inside of \( x \) have no effect on the velocity at \( x \), except as they may affect the amplitude of the tide.

**Tidal current velocities along 79° 20' W in the Gulf of Panama.**—It has been shown that the variations in the amplitude of the tide in the Gulf of Panama can be expressed in terms of a fictitious bottom profile having the form of a parabola coinciding with the actual depth at a point 120 km. from the head of the Gulf. In the previous section the relation of the maximum tidal currents to the amplitude of the tide, the distance from shore and depth was developed. Using equation (9) we can compute the maximum velocity of the tidal currents along the section in the Gulf of Panama. Curve IV in figure 75 represents the computed average amplitude of the tide along this section adjusted to agree with the amplitude at Balboa. Using tidal amplitudes obtained in this way the maximum tidal current velocities were computed for intervals of 10 km. using the actual profile of the bottom. The curve has been extended beyond the shelf by assuming that the tidal amplitude remained constant in the deeper water. The velocities computed in this way are shown in Figure 75, curve V. It can be seen that in deep water the tidal current velocities will be very small, but they increase rapidly over the continental slope and reach maximum values of more than 0.26 m/sec (0.5 knot) near the edge of the continental shelf. The velocities remain high and relatively constant for a considerable distance and then drop off on approaching the head of the Gulf. We might have expected such a velocity distribution as the profile of the bottom in this portion of Gulf is such that the slope is practically constant and equal to \( \frac{h}{x} \). As the general form of the bottom profile is parabolic rather than a straight line curve it was considered of interest to compute the velocities that would exist if the bottom was represented by the parabola used in computing the tidal amplitude. This was done and the values are shown in curve VI. In this case the velocities show the maximum at the edge of the shelf, but
decrease rather regularly with the decreasing depth and then drop off sharply near shore.

*Relation of tidal currents to range of the tide in the Gulf of Panama.*—In the foregoing discussion the maximum velocities along the section have been computed for the average range in tide. As there is such a difference in the neap and spring tidal ranges and as the tidal currents for any tidal period will depend upon the range of the tide, it is necessary to have an expression to relate the velocity distribution to the range of tide. The maximum tidal current velocities at any point along the section in the Gulf of Panama depend upon the integral of the amplitude of the tide between

![Graph showing the relation of the maximum tidal current velocities along 79° 20' W. in the Gulf of Panama to the range of tide at Balboa.](image)

**Figure 76.** The relation of the maximum tidal current velocities along 79° 20' W. in the Gulf of Panama to the range of tide at Balboa.

that point and the head of the Gulf. The variations in the range of the tide within the Gulf is rather small compared to the range itself, namely about 19%. Therefore the use of a mean range of tide would not affect the calculation of velocities at any point along the section by more than 10%. From equation (6) we know that the amplitude 120 km for the head of the Gulf,

\[ C = \frac{r_o}{1.19} \]

when \( r_o \) is the range at the head of the Gulf. The mean amplitude on this section is \( \bar{r} = 1.11 \) \( C \) or \( \bar{r} = \frac{1.11 \times r_o}{1.19} = 0.934 \) \( r_o \). Using the relationship \( u_{max} = \frac{x}{h} \sigma \times 0.934 \) \( r_o \) the distribution of maximum tidal current velocities along the section was computed for various ranges of tide at Balboa. These are shown in Figure 76.
Relation of tidal current velocities to stage of tide.—In the previous discussion we have considered only the maximum current velocities attained during any tidal cycle and have shown how these vary with the range in tide. As the tidal wave in the Gulf of Panama has the character of a standing wave these maximum velocities are reached at half tide. At high and low water the velocities approach zero. The change in velocity during a tidal cycle follows a simple harmonic form as shown by equation (8). The average velocity of the tidal current for one-half the tidal period, that is between low and high water, or high and low water is \( \frac{2}{\pi} \) times the maximum velocity. Using the value of maximum velocities attained at 100 km from the head for mean range of tide, namely 0.26 m/sec, we find an average velocity of 0.17 m/sec which is equivalent to a movement of about 2 nautical miles during the half tidal period. During spring tides the movement will be of the order of 4 nautical miles in each direction.

Figure 77 shows the relation of the tidal current velocity to the phase of the tide. The velocity at any point along the section in the Gulf of Panama and at any phase of the tide and for any range of tide can then be determined from figures 76 and 77 by multiplying the maximum velocity for the necessary range of tide by the fraction appropriate for the phase of the tide. Positive values indicate inward flow, negative values flow out of the Gulf.

Vertical variations in velocity of tidal currents.—In the foregoing discussion it has been assumed that the horizontal velocities were uniform from the surface to the bottom. That is, that particles in a vertical plane normal to the orientation of the wave would remain in such a plane. That such conditions do not hold in nature has been shown whenever careful observations
have been made on the velocity of tidal currents between the surface and bottom (Sverdrup, 1929, for example). Maximum velocities are encountered at or near the surface and below this the velocities decrease towards the bottom. The form of the velocity curve varies considerably but approaches zero at or near the bottom. As our calculations concerning the tidal currents are based on the assumption of uniform horizontal velocities, it is obvious that the values obtained are smaller than those which must exist at and near the surface. The economy of the systems under consideration must be met; that is, a certain amount of water must pass through a given section and if the velocities are small near the bottom, they must be correspondingly greater near the surface.

Vertical components of tidal currents.—In a study of the tidal currents only the horizontal movements are considered as they are of much greater magnitude than the vertical movements. However, it is obvious that some vertical movements must be present, otherwise we could not have the changes in tide level.

Although we are ignoring statements made in the previous section, let us again assume that the horizontal velocities in a vertical plane normal to a standing wave crossing the shelf are constant. If the shelf is of uniform depth, the vertical component will then be zero at the bottom and at the surface equal to the rate of change of tide level. However, if the depth is shoaling, particles near the bottom must rise with the decreasing depths. The magnitude of the vertical change between high and low water will then depend upon the distance travelled by the particle and the slope of the bottom.

Let \( \frac{\Delta x}{t} \) = horizontal velocity component, then \( \frac{\Delta h}{t} \) = vertical component of velocity.

So that the

\[
\frac{\text{Vertical velocity}}{\text{Horizontal velocity}} = \frac{\Delta h/t}{\Delta x/t} = \frac{\Delta h}{\Delta x} = \text{slope}.
\]

Therefore the vertical velocity at any point on the bottom is determined by the horizontal velocity and slope of the bottom and the vertical range is determined by the horizontal distance travelled during one half tidal period multiplied by the mean slope of the bottom. Using data from Figure 75, the maximum velocities for the average range of tide at points 5, 15, 25, etc. km along the section were read off and the total horizontal movement for rising or falling tides computed. The average slopes at these points were then determined and from these the amount of vertical movement at the bottom. These are shown in Figure 75, curve VII. Along the stretch from the head to entrance of the Gulf the vertical movement near the bottom varies from less than 1 meter to over 50 meters. As the slope of the bottom
at any point is constant and the vertical range is a function of the horizontal movement at that point, the vertical range will depend upon the range of the tide and will, in the Gulf of Panama, vary from less than half the plotted values to nearly twice those shown, depending on the range in tide. It may be seen that, although the distance travelled is relatively small on the continental slope, the slope (Figure 75, curve VIII) is so great that the vertical movement must be great.

Near the edge of any continental shelf and on the continental slope there must be vertical movements of considerable amplitude directly associated with the tidal currents. It should be possible to detect such vertical oscillations by the changes in physical and chemical conditions. These vertical movements will be greatest near the bottom and will decrease towards the surface in direct proportion to the depth of observation to the total depth, if we disregard the convergence or divergence and change in tide level. It should be pointed out that these fluctuations are not the same as internal waves which are encountered in the open ocean.

_Tidal currents in the Gulf of Panama._—In the foregoing discussion the variations in the tidal currents in the Gulf of Panama are related to the variations in the range and phase of the tide. The velocity distribution is shown to depend upon the form of the Gulf and the shallow depths which extend a long way out in the Gulf. As the calculations were made on the assumption that the Gulf was of uniform breadth and as the velocity distribution was based on a single profile of the Gulf, it is obvious that the numerical values presented would be modified if the actual shape of the Gulf and the presence of the islands were taken into account. For example, the entrance to the Gulf is narrower than the central portions of the Gulf, and this will cause somewhat higher current velocities at the entrance. The Gulf of San Miguel and its tributary tidal waters will also increase the velocities in the central eastern portion of the Gulf. Around the islands we shall also have tidal currents of higher velocities. The numerical data presented are therefore approximations of the actual conditions arrived at by certain simplifications of the problem.

The tidal currents are independent of any non-tidal movements. During the greater part of the year there is apparently a counter-clockwise gyral within the Gulf which has a velocity of approximately 0.26 m/sec (0.5 knot). The tidal currents must then be superimposed upon this current. The resultant combination of the two will yield the following general result. On the flood tides the northerly movement will be increased in the eastern portion of the Gulf and the southerly movement reduced in the western part of the Gulf. On ebb tides the northerly motion will be reduced in the eastern portion of the Gulf and the southerly movement increased in the western portion. Whether or not the actual movements in any part of the Gulf will be reversed due to the changing tidal currents or will merely be
modified will obviously depend upon the relative strength and direction of
the tidal and non-tidal currents.

SUMMARY

1. The tides in the Gulf of Panama and along the Pacific coast of Central
America are of the semi-diurnal type associated with a standing wave.
2. The range of tide in the Gulf of Panama varies from 5 feet at neap
tides to over 22 feet at springs.
3. The increase in range of tide in the inner part of the Gulf (19%) is
shown to be due to the shoaling bottom.
4. A general expression for the effect of the profile of the continental
shelf upon the distribution of the velocities of the tidal currents is developed.
5. From the range in tide and the bottom profile of the Gulf of Panama
the distribution of current velocities along a section extending out from the
head of the Gulf has been computed.
6. The relation of the current velocities to the range and the phase of
tide is given.
7. It is pointed out that there should be detectable fluctuations in the
vertical distribution of properties near the edge of the continental shelf
which are directly associated with the transport of water by the tidal
movements.

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