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Anomalous diurnal tidal currents on the Yermak Plateau

by Kenneth Hunkins

ABSTRACT

Recent observations made over the Yermak Plateau, a 100 x 200 km submarine feature northwest of Svalbard, show that ocean currents in that area are dominated by diurnal tidal currents although semidiurnal tidal displacements of the surface always exceed diurnal tidal displacements along the coast in the Arctic Ocean. Currents were recorded with meters suspended below two drifting ice stations, FRAM III in 1981 and FRAM IV in 1982, as they traveled over several weeks from a region of abyssal depths onto the western flank of the Yermak Plateau. Ice drift velocity was calculated from satellite positions and then vectorially added to the recorded data to produce current velocity relative to the bottom. Diurnal tidal currents with spectral peaks greater than semidiurnal peaks were observed in both years with current speeds reaching 30 cm/s over the edge of the Plateau. Semidiurnal tidal currents over the middle and lower slope were principally alongslope which is consistent with Kelvin wave motion. Diurnal tidal currents on the middle and lower slope were across-slope, and on the upper slope they had a clockwise rotary motion suggestive of topographic vorticity waves. These unusually large diurnal tides are apparently vorticity waves which have been resonantly forced by weak deep-sea diurnal tides.

1. Introduction

Tides in the Arctic Ocean, as in the North Atlantic, are predominantly semidiurnal in character. It is therefore remarkable to find diurnal motions dominating current records made over the Yermak Plateau, a submarine plateau extending from the coast of Svalbard northward for 400 km into the Arctic Ocean. Diurnal tidal currents recently observed there exceed the semidiurnal currents by a factor of 3 or 4, although observations of tidal heights along the north coast of Svalbard have shown semidiurnal amplitudes exceeding diurnal by factors of 4 to 10 (Hornbaek, 1954).

Four other regions have been reported in which diurnal tidal currents dominate offshore motion despite a semidiurnal regime along the nearby coast. Two of the examples are in the Atlantic, a shelf region about 100 km in extent around the island of St. Kilda off Scotland (Cartwright, 1969) and the southern end of Rockall Bank, a submarine plateau west of the British Isles (Huthnance, 1974). The other two areas are in the Pacific, one off Vancouver Island, Canada, (Crawford and Thomson, 1982), and one on the Campbell Plateau near New Zealand (Heath, 1983).
In each of these four cases, the explanation offered is that weak diurnal tides extending over an entire basin are selectively enhanced as topographic vorticity waves over steep slopes. The interpretation given for the anomalous diurnal currents reported in this paper is generally similar, but the question remains as to why the phenomenon occurs in only a few localities although topographic vorticity waves are theoretically possible at the diurnal period for latitudes poleward of 30°. For barotropic waves the actual latitude limitation will be somewhat greater than 30°, but this still leaves a large area of the globe over which such a resonance might be possible. The particular details of latitude and bottom topography that contribute to this resonance in the Arctic are examined here to help resolve this paradox.

2. Observations

Two research camps, FRAM III and FRAM IV, were established on drifting sea ice for two months each in the spring of 1981 and 1982, respectively, to serve as bases for oceanographic and geophysical measurements (Manley et al., 1982; Johnson, 1983). Both camps were set up north of Svalbard at about 84° latitude and then drifted southwestward with winds and currents (Figs. 1 and 2). The camps were located over water depths of about 4,000 m when first occupied and drifted over shallower depths on the flank of the Yermak Plateau during later stages of their occupation (Fig. 3).

Ocean currents relative to the drifting ice were recorded with Aanderaa RCM-5 meters suspended on weighted cables through holes cut in the ice. Records were
obtained at two levels, 25 and 104 m, from FRAM III, and from FRAM IV at five levels: 29, 55, 104, 153, and 303 m. The current meters were calibrated in the laboratory before and after their deployment. As the camps drifted their location was monitored with the Transit satellite navigation system. Since Transit satellites are in polar orbit, at these high latitudes nearly all satellite passes were received producing 17 to 21 fixes per day with an estimated accuracy of better than ±50 m (Hunkins et al., 1981; Tiemann et al., 1982). Ice velocity was obtained by differencing the smoothed position data. These fixes were at irregular intervals and a Kalman filter was used for smoothing. This filter reduced amplitudes at semidiurnal periods to 95% of their unfiltered value and had little significant effect on diurnal periods.

Currents observed from the ice represent the vector difference of ocean currents and ice velocity. To obtain the desired currents relative to the bottom, ice velocity was added vectorially to the observed currents. These corrected or absolute currents are the ones used throughout this paper. They were resolved into orthogonal components with the y-axis directed 60°T, parallel to the bathymetric contours of the northwest flank of the Yermak Plateau and the x-axis directed toward 150°, across the slope.

Currents at a depth of 104 m are shown for both camps in Figures 4a and b along with a profile of ocean depth along each track. The two camps followed similar but not identical tracks which allows some comparison between records. In both cases there is a section of record in the vicinity of the steep slope of the Plateau dominated by diurnal motions. In the 1981 record from FRAM III the tidal currents are clearly diurnal over...
the upper slope in the depth range of 800 to 2,000 m. In this record there is a large velocity excursion between days 110 and 114 which is associated with temperature and salinity changes which are not shown here. This excursion probably represents a frontal crossing and is not of central interest to this paper. The early part of the FRAM III record over deep water has a noisy character with some evidence of semidiurnal tides. Again in the latter part of the record over the top of the Plateau semidiurnal motion predominates. The drift of FRAM IV in 1982 carried it only over the lower slopes of the Plateau where strong diurnal tidal currents were observed over depths between 1,800 and 3,500 m. The early part of the 1982 drift in depths greater than 3,500 m shows considerable noise with a weak semidiurnal signal. The diurnal current vector over the upper slope in 1981 described a clockwise, nearly circular rotation. Diurnal motions in 1982 over the middle and lower slope were, however, nearly rectilinear and aligned in the cross-slope direction. Previous observations of diurnal period motions are from shallow regions, and these relatively strong diurnal currents are surprising over as deep a feature as the Yermak Plateau.

These current velocities are a function of both time and position. The average net drift rate for FRAM III was 6.3 km/day and for FRAM IV it was 5.5 km/day. The
Figure 4a and b. Absolute current velocities along the tracks of FRAM III and FRAM IV at a depth of 104 m. Axis orientation: $+u$ at 150°; and $+v$ at 060°. Ocean depth along tracks plotted at bottom. Days are numbered beginning January 1, 1981.
Figure 5. Ice velocity and absolute cross-slope currents, $u$, at five levels during the FRAM IV drift.
Figure 6. Temperature and salinity statistics for a 24-day period at FRAM IV. (Mean shown by heavy solid line, standard deviation by light solid line, and extreme by dashed line.)

daily movements are relatively small in comparison with the width of the slopes surrounding the Yermak Plateau. So over a single cycle the amplitude of measured currents can be considered the amplitude at a particular location, and the envelope of the tidal maxima along the drift track is a representation of tidal current amplitudes in relation to topography. The dominance of diurnal tidal currents over the flank of the Yermak Plateau contrasts with the semidiurnal tidal regime observed in tide gauge measurements at coastal sites around the Arctic Ocean. It also contrasts with the semidiurnal regime found in the few moored current records from areas just south of the Yermak Plateau. A semidiurnal current regime is evident in moored current records off West Spitzbergen (Hanzlick, 1983) and in the center of Fram Strait (Hunkins, 1984).

Currents were recorded for five different levels in the upper layers at FRAM IV permitting a comparison of current changes with depth (Fig. 5). It is evident that both amplitude and phase change little between the surface and 300 m. Over this same depth range there is a marked change in density as can be seen in Figure 6 where salinity and temperature statistics are plotted. Both parameters increase rapidly with depth in the upper layers. Inflection points representing the centers of the halocline and thermocline occur at a depth of about 100 m. Salinity is the controlling factor for density in these cold waters and the density profile closely follows the salinity profile. The density structure is thus much shallower than ocean depth in this region. The lack of significant tidal shear through this strong stratification is taken as evidence that the tides are primarily barotropic. It is interesting to note in Figure 5 that the ice also has a tidal motion but with an amplitude less than that of the underlying water.

Kinetic energy spectra confirm that diurnal current amplitudes exceed semidiurnal amplitudes. From FRAM IV the spectrum of along-slope velocities at 330 m has a diurnal peak only slightly greater than the semidiurnal (Fig. 7a), but for cross-slope velocity the semidiurnal peak is lost in background noise (Fig. 7b) and the diurnal peak exceeds the semidiurnal by over one order of magnitude. Polarization of the motion
differs for the two tidal periods. The diurnal tidal ellipse is aligned in the cross-slope direction, while the semidiurnal is aligned along-slope. In order to investigate this polarization more closely, the velocity data were resolved into various orthogonal axes with each set rotated by 15° from adjacent sets. Spectra for the v-component were then computed for each set and the peak values at the two tidal periods were determined and plotted versus the orientation of the y-axis (Fig. 8). There is a broad diurnal peak centered near 150° and sharp minimum at 060° indicating that motion at that period is essentially normal to the slope. The semidiurnal motions are nearly parallel to the slope however with a broad peak near 060° and somewhat sharper minimum near 150°. This alignment of the semidiurnal currents with the bottom contours is not unexpected since it agrees with the predicted orientation of the current ellipse in Kowalik and
Untersteiner’s (1978) numerical model of the $M_2$ tide for the Arctic Ocean. It is consistent with an interpretation in terms of Kelvin waves (Kowalik, 1979). The cross-shelf diurnal currents, however, suggest that topographic vorticity waves may be important for that tidal period.

3. Topographic vorticity waves

The strong diurnal tides found near St. Kilda, Rockall Bank, Vancouver Island, and Campbell Plateau have been attributed to resonant forcing of topographic vorticity waves by the divergent diurnal tides extending over the whole basin. Such forcing is theoretically possible at latitudes poleward of 30° where the Coriolis period is 24 hours.
Figure 8. Peak amplitudes of kinetic energy for the diurnal and semidiurnal frequencies plotted as a function of current axis orientation. FRAM IV, 303 m.

The original identification of anomalous diurnal tides with vorticity waves was made by Cartwright (1969) who used the barotropic free wave theory of Buchwald and Adams (1968) for an exponential shelf profile bounded landward by a vertical coast and seaward by a semi-infinite deep ocean with constant depth. With parameters chosen to fit the topography off St. Kilda, the diurnal frequency occurs near the frequency maximum of the first mode which was interpreted as evidence for resonant enhancement at this frequency. Any combination of frequency and wavenumber on the dispersion curve will exhibit resonance under forcing, but at the frequency maximum, which is coincidental with zero group velocity, wave energy will not leave a site and there will be an additional enhancement. Resonant forcing of topographic vorticity waves by weak diurnal tides has continued to be the explanation favored by other investigators. Huthnance (1974) suggested that direct gravitational forces drive the strong diurnal tides at the southern end of Rockall Bank. Smith (1975) proposed alongshore variations in topography as the important factor in trapping vorticity waves near St. Kilda. Later, more extensive measurements near that island prompted an explanation for the diurnal wave as a superposition of a Kelvin and a vorticity wave in anti-phase (Cartwright et al., 1980).

Off Vancouver Island diurnal currents exceed the semidiurnal by factors ranging from 2 to 4 even though the tidal height ratio there is only 0.6 and semidiurnal tides dominate the surrounding coast and deep water regions. This anomaly was attributed
to vorticity waves by Crawford and Thomson (1982) who showed that first mode barotropic waves could exist at the diurnal frequency for the shelf profile near Vancouver Island. Later analysis and comparison with baroclinic models resulted in the conclusion that these diurnal currents were first mode baroclinic vorticity waves (Crawford and Thomson, 1984).

Heath (1983) suggested trapped vorticity waves as an explanation for the large diurnal currents over the Subantarctic Slope of the Campbell Plateau with interpretation in terms of the Buchwald and Adams model (1968) with an infinitely wide shelf.

The anomalous diurnal currents observed on the Yermak Plateau in the Arctic Ocean are also apparently due to diurnal tides resonantly forced over steep topography. The occurrence of diurnal currents in the same region during visits of several weeks in separate years suggest that this is a permanent feature of the tidal regime in this area. The association between the Plateau margin and these current anomalies also suggests topographic vorticity waves. These data stimulate new interest in the question asked by Cartwright et al. (1980) as to “... why the phenomenon of large diurnal currents should be apparent only in this small area (St. Kilda vicinity in their case) of shelf sea?” Five localized areas in three different oceans have now been found to exhibit strong diurnal tides despite a semidiurnal regime outside each small anomalous area. Free diurnal shelf waves may theoretically exist over sufficiently steep topography poleward of 30° but for barotropic motion over realistic shelf topography the latitude limit will be higher. For example, the Buchwald and Adams (1968) dispersion curve used by Cartwright (1969) shows a frequency maximum which corresponds to the diurnal frequency at 52° latitude. With stratification, free waves may occur at any period greater than the Coriolis period (Chapman, 1983). Diurnal resonances have been reported only for the five mentioned areas although it is true that many shelf regions remain to be surveyed. The question of remote versus local forcing is also yet to be answered. Are the diurnal currents driven by the basin-wide divergent tidal wave as originally suggested by Cartwright (1969), are they driven by the direct action of the diurnal gravitational forces (Huthnance, 1974), or are they generated by tidally-induced Reynolds stresses in a bottom boundary layer (Thomson and Crawford, 1982)? The details of the forcing question are not pursued here, rather the problem of the particular aspects of topography which favor this resonance is examined with a simple analytical model for free waves.

The Yermak Plateau is actually a submarine peninsula extending northward from the Svalbard shelf for about 400 km in a broad arc (Fig. 3). Depths along the crest are 500 m or less within 100 km of Svalbard and then deepen to 700 m for the next 200 km. The cross-section normal to the crest is convex with the northern and western slopes descending to abyssal depths of greater than 3,000 m. On the enclosed eastern and southern sides, there is an enclosed basin with a floor at 2,200 m. No simple geometry can closely represent such a complex topography, the circular submarine plateau with convexly sloping sides was chosen here to provide topography which is analytically convenient.
4. Vorticity waves trapped over a circular submarine plateau

The simplest three-dimensional shape for which vorticity wave behavior can be analyzed and which bears some resemblance to the Yermak Plateau is a circular flat-topped feature with convexly sloping sides surrounded by an ocean with a flat bottom. The shape chosen here is a truncated paraboloid resembling an inverted bowl (Fig. 9). The use of a circular form as an approximation to a submarine peninsula might be questioned but its use receives some justification from the laboratory experiments of Caldwell and Eide (1978). They showed that resonances of vorticity waves around circular islands were not altered appreciably by the introduction of radial barriers. Longuet-Higgins (1970) developed a theory for vorticity waves around a circular island with sides sloping according to a power law. In this paper the theory is developed for a submarine plateau or seamount rather than for an island. The mathematical development here generally follows that of Longuet-Higgins except for differences in the boundary conditions.

The equations for conservation of potential vorticity and conservation of mass may be written in cylindrical coordinates as

\[
\frac{\partial}{\partial t} \left[ \frac{\partial}{\partial r} (rv) - \frac{\partial u}{\partial \theta} \right] + f \left[ \frac{\partial (ru)}{\partial r} + \frac{\partial v}{\partial \theta} \right] = 0
\]  \hspace{1cm} (1)

and

\[
\frac{\partial}{\partial r} (rhu) + \frac{\partial}{\partial \theta} (hv) = 0
\]  \hspace{1cm} (2)

where \(r\) and \(\theta\) are the radial and azimuthal distances, respectively, with corresponding velocity components, \(u\) and \(v\). Time is symbolized by \(t\), ocean depth by \(h\), and the local Coriolis parameter by \(f = 2\Omega \sin \phi\) where \(\Omega\) is the earth's angular frequency and \(\phi\) is
latitude. When the topography is radially symmetric, the last two equations may be combined into the single equation

$$
\frac{\partial}{\partial t} \left[ \frac{\partial}{\partial r} (rv) - \frac{\partial u}{\partial \theta} \right] - fr \frac{h}{\partial r} = 0 .
$$

(3)

Introduce a stream function for volume transport defined by

$$
hu = \frac{1}{r} \frac{\partial \psi}{\partial \theta} \quad \text{and} \quad hv = - \frac{\partial \psi}{\partial r}
$$

(4)

and consider wave solutions

$$
\psi = \Psi(r) \ e^{i(n \theta - \omega t)}
$$

(5)

where $n$ is a positive integer.

The radial equation is

$$
\frac{d^2 \psi}{dr^2} + \left( \frac{1}{r} - \frac{1}{h} \frac{d}{dr} \frac{d \psi}{dr} \right) \left( \frac{n^2}{r^2} + \frac{nf}{\omega} \frac{1}{h} \frac{d}{dr} \right) \psi = 0 .
$$

(6)

The submarine plateau is described by

$$
h_1 \quad 0 < r/a < 1 \\
h = h_1 (r/a)^2 \quad 1 < r/a \leq b \\
h_2 \quad b \leq r/a < \infty .
$$

(7)

Cross-sections through the plateau are shown in Figure 9 for two different values of the constant $b$. For the level regions (6) becomes

$$
\frac{d^2 \psi}{dr^2} + \frac{1}{r} \frac{d \psi}{dr} - \frac{n^2}{r^2} \psi = 0
$$

(8)

while for the slope region it becomes

$$
\frac{d^2 \psi}{dr^2} - \left( \frac{n(n + 2f/\omega)}{r^2} \right) \psi = 0 .
$$

(9)

Boundary conditions to be satisfied are

$$
\Psi \text{ is finite as } r \to 0 ,
$$

$$
\Psi \text{ and } d \psi/dr \text{ are continuous at } r = (a, b) ,
$$

and

$$
\Psi \to 0 \text{ as } r \to \infty .
$$

In Longuet-Higgins' model there is vertical wall at $r = a$ and no inner region. Eq. (9) has an equidimensional form and the general solution for the slope region is

$$
\Psi = r[P_1 e^{i\beta r} + P_2 e^{-i\beta r}]
$$

(10)
where \( P_1 \) and \( P_2 \) are complex constants,
\[
\beta = (n^2 + 2nf/\omega + 1)^{1/2},
\]
and radial distance \( r \) is now scaled by the radius, \( a \), of the flat top. In the slope region these solutions must be oscillatory to satisfy the boundary conditions. This requires that \( \beta \) be imaginary,
\[
\beta = i |\beta| \text{ for } a < r < b,
\]
and it follows from (11) that \( \omega/f \leq 0 \) so that these waves must propagate in a clockwise direction around a plateau in the northern hemisphere. Eq. (10) may be rewritten as
\[
\Psi = r [B \sin |\beta| \ln r + C \cos |\beta| \ln r]
\]
where \( B \) and \( C \) are real constants. The solutions of (8) for the level regions which satisfy the boundary conditions are
\[
\Psi = Ar^n \text{ for } 0 \leq r \leq 1
\]
and
\[
\Psi = Dr^{-n} \text{ for } b \leq r.
\]
A set of four equations is obtained by substituting (12), (13), and (14) into the boundary conditions at \( r = (1, b) \). Elimination of the four constants then gives the dispersion relation
\[
\tan (|\beta| \ln b) + \frac{2n |\beta|}{n^2 - |\beta|^2 - 1} = 0
\]
which has an infinite number of roots for each value of azimuthal mode number \( n \). The current pattern has \( 2n \) cells in the azimuthal direction and \( m \) cells in the radial direction. The relationship between dimensionless frequency, \( \omega/f \), and the ratio \( b \) of outer to inner slope radii is shown in Figure 10 for the lower modes. Inspection of Yermak Plateau bathymetry shows that application of this model requires a value of \( b \) in the range between 2 and 3. The only diurnal modes which exist in this range are \((1, 1)\) with \( b = 2.0 \) and \((1, 2)\) with \( b = 2.47 \) and the depth profiles for these two values of \( b \) are plotted in Figure 9. Values of \( a = 70 \text{ km} \) and \( h_1 = 800 \text{ m} \) were chosen as appropriate for application of this model to the Yermak Plateau. Constants for the stream function are found by substituting (12), (13), and (14) into the boundary conditions and the velocity components are then found from the definitions (4). The gravest mode \((1, 1)\) is trapped over the flat top of the plateau (Fig. 11a). For the \((1, 2)\) mode there is trapping of the radial velocity \( u \) over the upper break in slope but the azimuthal velocity is constant over the flat top (Fig. 11b). Rotation of the current vector is clockwise on the shallow water side of the node in \( v \) and counter-clockwise offshore of the node.
5. Discussion

This circular shelf model is seen to have free vorticity wave solutions at the diurnal frequency when topographic constants and latitude are chosen to be appropriate for the Yermak Plateau. In a forced wave model, these free wave solutions would be associated with resonance conditions and the model is capable of generally explaining the large observed diurnal currents in terms of resonant amplification of weak basin-wide diurnal tides over steep slopes. Only the fundamental cross-slope mode has free wave solutions at the diurnal frequency. Higher modes occur at lower frequencies well outside the diurnal range.

For a given mode, the circular plateau must have a particular ratio of diameters $b$ or, equivalently, a ratio of depths, $b^2$, to be tuned to the diurnal frequency. For the $(1, 1)$ mode at the diurnal frequency the ratio of diameters is $b = 2$, so the ratio of depths is $b^2 = 4$. In terms of actual dimensions this may be taken to correspond to a plateau depth of 800 m and a depth of 3,200 m for the surrounding ocean or, equivalently, to inner and outer diameters of 140 and 280 km, respectively. For the $(1, 2)$ mode at the same frequency, $b = 2.47$ and $b^2 = 6.10$. For a plateau depth of 800 m, the surrounding
Figure 11. (a) Stream function and velocity component amplitudes as a function of dimensionless radius for the (1, 1) mode with $b = 2.0$ and $\omega/f = 0.5$. (b) Stream function and velocity component amplitudes as a function of dimensionless radius for the (1, 2) mode with $b = 2.4766$ and $\omega/f = 0.5$.

ocean will be 4,800 m deep which is greater than the actual depth, so the topographic fit is better for the (1, 1) resonance.

The appearance of diurnal motion over the upper slope and outer shelf edge in the 1981 data (Fig. 4a) is consistent with the theory. Diurnal motion for the 1982 record (Fig. 4b) is over the lower slope which was the only part of the slope sampled in that year. This is not entirely consistent with theory which predicts low values over the lower slope. No explanation for this discrepancy is available at present.

Discrimination between the (1, 1) and (1, 2) modes could be made on the basis of current information near the center of the plateau if it were available. The azimuthal velocity has a level maximum over the flat top for both modes, however, the radial component is level over the top for the (1, 1) mode but has a sharp maximum over the shelf break for the (1, 2) mode. The 1981 record shown in Figure 4 does suggest a resumption of the semidiurnal tide near the top of the slope which could be taken to favor an interpretation in terms of the (1, 2) mode. Although the forced wave problem has not been addressed directly here, it is reasonable to assume that the response of the (1, 1) mode will be greater than that of any higher modes for forcing on a spatial scale.
as broad as the oceanic diurnal tide, and on this basis, as well as on the topographic agreement, the (1, 1) mode is the preferred choice.

In the 1981 record there was clockwise rotation over the upper slope in agreement with vorticity wave behavior. On the lower slope the data are too noisy to give a reliable rotation sense. In 1982 only the lower slope was sampled, and currents were primarily rectilinear with no clearly discernible sense of rotation since the alongslope component was below the noise level. In these models, currents at the nodal point, about mid-depth on the slope, are purely across-slope. The observed nearly rectilinear across-slope motion occurs over a considerable range of depths. Perhaps this is attributable to the irregularity of the actual bathymetry with nodal points varying along the slope so that waves produced by averaged profiles have a nodal point which is effectively broadened to cover a range of depths.

All of the observed cases of anomalous diurnal tides have been interpreted as topographically-trapped vorticity waves resonantly forced by weak oceanic diurnal tides. The study of diurnal tidal anomalies off Vancouver Island has benefited from an extensive array of moored pressure gauges and current meters. However, the explanation by Crawford and Thomson (1984) for their behavior differs from the interpretations for the other four areas. A shelf model with no alongshore variation was found to interpret the data best in terms of first mode baroclinic vorticity waves and Kelvin
waves. This contrasts with the barotropic vorticity wave interpretations given for the other areas although Kelvin waves also contributed to the St. Kilda interpretation. The importance of stratification off Vancouver Island may be due to the coincidence of the depths of the offshore seasonal thermocline and the shelf break which are both at about 250 m. On the Yermak Plateau, however, stratification is limited to the upper 200 m which is much less than its crestal depths of 500 to 800 m which evidently reduces the importance of baroclinic effects. Nondivergent vorticity waves are evidently of primary importance in all cases, but when the shelf is narrow, as off Vancouver Island and St. Kilda, Kelvin waves may also contribute to the motion, and when the shelf break and thermocline coincide, baroclinic effects may be important.

Each of the five areas is limited to a small region of 100 to 200 km in extent but it is not easy to find a common denominator for the topographic shapes. The Vancouver shelf is fairly linear; the St. Kilda shelf, curving; the Yermak Plateau, peninsular; and Rockall Bank, an isolated plateau. Yet diurnal anomalies are found over all of these features. The Vancouver shelf is straight and an unchanging shelf profile seems a justifiable first approximation as it may be for the Campbell Plateau also. The St. Kilda shelf curves convexly and has been modeled by a linear shelf (Cartwright, 1969; Cartwright et al., 1980) but a shelf with alongshore variation has also been suggested by Smith (1975) as a better representation. Rockall Bank is clearly a three-dimensional feature and has been modeled as such by Huthnance (1974). A circular plateau model of the Yermak Plateau has been favored in this paper. Each area still needs individual study since the general prediction of these diurnal resonances would require the combination of a global tidal model with detailed bathymetry and stratification, a type of modeling which is still in the future. Present global tidal models, such as that of Schwiderski (1980 and 1981) based on a combination of hydrodynamic theory and empirical data, are unable to resolve these anomalous areas of resonance.

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REFERENCES

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