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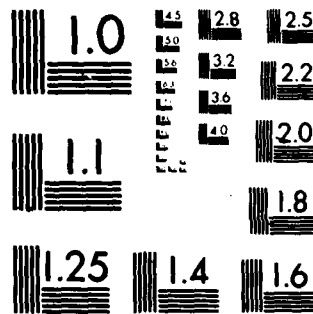
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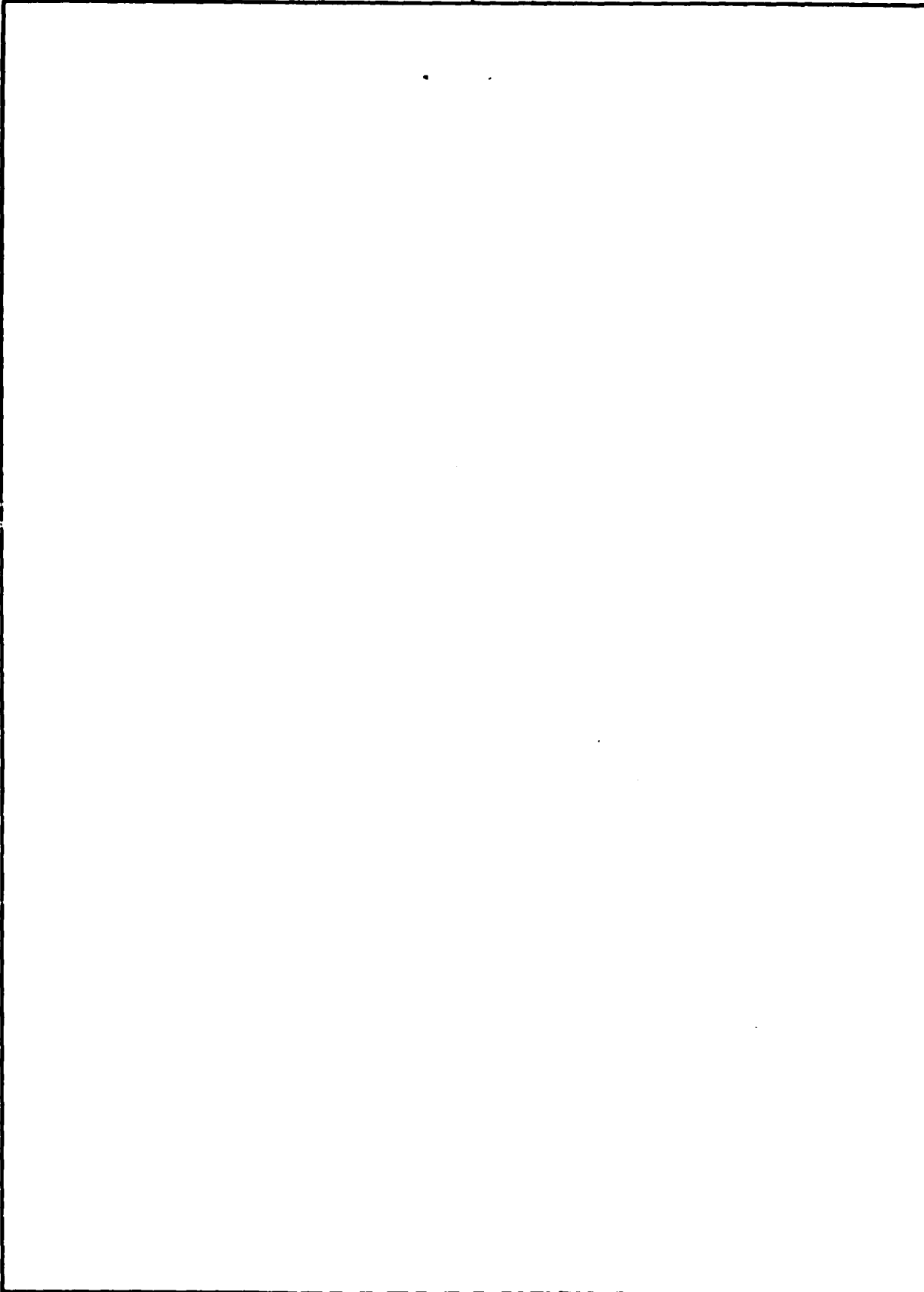


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INTRODUCTION

The relationship between free-air gravity anomalies and sea-floor bathymetry is one of the most important problems in marine gravity. For purely practical reasons, deciphering the nature of such a relationship is vital to predicting quantitatively the gravity field in oceanic areas in which only bathymetry is known. Closely related to this practical problem is the question of the physical basis for any observed or proposed dependence of gravity upon topography. Such a question bears on the mechanisms for creation and evolution of oceanic crust and lithosphere and on the possible interaction of the lithosphere with motions in the asthenosphere.

Marine gravity and sea-floor topography cannot be related by a simple mathematical expression (e.g., a linear relationship) that has validity in all oceanic environments. A synthesis of submarine gravity data and bathymetry by Woollard and Daugherty (1970) demonstrated the necessity to divide oceanic regions by tectonic types and the difficulty in simply relating free-air anomaly and depth even within groups of tectonically similar environments. Degree averages of marine gravity anomalies and depths within selected regions were also correlated with varying degrees of success by Watts and Talwani (1974), Sclater et al. (1975), and Watts (1976).

A necessary step in improving what heretofore have generally been strictly empirical attempts to derive a rule relating gravity and bathymetry over a selected region is to take into proper account the findings of plate tectonic studies of the oceans. At mid-ocean ridges, the lithosphere is thin, perhaps no thicker than the crust (Francis and Porter, 1973; Solomon and Julian, 1974; Orcutt et al., 1975; Rosendahl et al., 1976), and sea-floor topography except at the shortest wavelengths is isostatically compensated with a shallow compensation depth (Dorman, 1975; McKenzie and Bowin, 1976; Cochran, 1979; McNutt, 1979). Sea-floor topography created by mid-plate volcanic activity is com-

compensated much deeper because of the substantially thicker lithosphere, and the compensation is regional (Vening Meinesz, 1941), involving flexure of the oceanic plate (Walcott, 1970; Watts and Cochran, 1974; Watts et al., 1975, 1980; Watts, 1978b; Detrick and Watts, 1979), the effective elastic thickness of which increases with sea-floor age (Caldwell and Turcotte, 1979). At trench systems, topography is not isostatically compensated owing to the large dynamic forces associated with lithosphere subduction (e.g., Vening Meinesz, 1954). Still controversial are explanations for frequent correlations in very long wavelength gravity and topographic anomalies in the oceans (Menard, 1973; Anderson et al., 1973; Weissel and Hayes, 1974; Sclater et al., 1975; Marsh and Marsh, 1976; Cochran and Talwani, 1977; Watts, 1978a), with asthenospheric flow the most exciting but still unproven hypothesis.

This report gives the mathematical framework for a simple relation between topography and gravity in two dimensions for stable ocean basins. The conceptual basis for the relation is flexure theory for thin elastic plates loaded from above. The evolution with sea-floor age of lithospheric temperature and rheology is abstracted to an effective elastic layer thickness which grows with plate age. In order to derive gravity from topography using this relation, both the lithospheric age and the age of any more recently superposed volcanic constructs (islands, seamounts, aseismic ridges) must be known. Guidelines are given for estimating these ages. The bathymetry-gravity relation is tested using data from the central Pacific basin. The test is not successful, for reasons which are described. A number of suggestions are given for future work.

THEORY

We seek a relation between bathymetry and gravity in stable ocean basins. We shall work explicitly in spatial dimensions, rather than use one- or two-dimensional wave-number representations, so as to permit consideration of regions of arbitrary geometry and spatial extent.

We shall assume that the sea-floor topography is composed of three parts: (1) the long-wavelength deepening of the sea floor with age due to thermal contraction of the lithosphere (Sclater *et al.*, 1971); (2) the volcanic topography emplaced as a load on top of the lithosphere; and (3) the lithospheric response to that load. We assume that the effect of (1) on the bathymetry may be removed with a suitable age-depth relation (Sclater *et al.*, 1975; Parsons and Sclater, 1977; Cochran and Talwani, 1977); its effect on gravity is negligible far from ridges (Lambeck, 1972). We discuss the validity of these assumptions further at the end of this report.

Let the lithosphere be modeled as a thin, spherical, elastic shell of thickness T , Young's modulus E , and Poisson's ratio ν , overlying a fluid interior of density ρ_m . Let R be the radius to the midplane of the shell, let g be the gravitational acceleration at radius $r = R - T/2$, and let D be the flexural rigidity of the shell

$$D = \frac{ET^3}{12(1 - \nu^2)} \quad (1)$$

Consider a uniform vertical load q (force per unit area) applied to a circular unit area on the surface of the shell. The vertical deflection (positive if downward) of the lithosphere is given by

$$w = \frac{-q}{2\pi(ET/R^3 + \Delta\rho g)} \text{ kei } \xi \quad (2)$$

(Brotchie and Sylvester, 1969; Brotchie, 1971), where ξ is

the distance from the load center, normalized by the radius of relative stiffness

$$\ell = \left(\frac{D}{ET/R^2 + \Delta\rho g} \right)^{1/4}; \quad (3)$$

kei is a Bessel-Kelvin function of order zero (Abramowitz and Stegun, 1964); and $\Delta\rho = \rho_m - \rho_w$ where ρ_w is the density of seawater if the load is applied at the sea bottom and zero if the load is applied on land. Note that (2) is equivalent to the expression (Brotchie and Sylvester, 1969) for the response to a point force p since $p \approx q\pi d^2 \ell^2$ where $\xi = d$ is the radius of the circular unit area. Equations (2) and (3) may be simplified because for oceanic lithosphere $ET/R^2 \sim 10^1$ and $\Delta\rho g \approx 2 \times 10^3$ in c.g.s. units, so $\Delta\rho g \gg ET/R^2$ and

$$w = \frac{q}{2\pi\Delta\rho g} kei \xi. \quad (4)$$

We may generalize (4) to a distributed load. Let $q(x,y)$ be the force per unit area exerted on the lithosphere by topography. Then the deflection w is given by

$$w(x,y) = \frac{1}{2\pi\Delta\rho g} \iint q(x',y') kei(r'/\ell) dx'dy' \quad (5)$$

where $r' = [(x' - x)^2 + (y' - y)^2]^{1/2}$. Equation (5) may be thought of as the double convolution of q with the flexural response function

$$\phi(x,y) = \frac{1}{2\pi\Delta\rho g} kei \left[\frac{(x^2 + y^2)^{1/2}}{\ell} \right] \quad (6)$$

which in turn is a function of the local flexural rigidity D , or equivalently the effective elastic lithospheric thickness T , through

$$\ell = \left(\frac{D}{\Delta\rho g} \right)^{1/4}.$$

A single convolution of (two-dimensional) load with response function was also used by Roufosse and Parsons (1977) in their study of the Hawaiian ridge. If the load is emplaced in a time short compared to the lithospheric age and if viscous relaxation of stress subsequent to initial lithospheric flexure has been minimal, then ℓ is simply a function of the time difference between plate age and load emplacement age.

Unfortunately, the load $q(x,y)$ is not known a priori but rather the ocean floor elevation $h(x,y)$ with respect to some arbitrary datum is known. As noted above, h contains contributions from both the topographic load and the lithospheric response. We may resolve this difficulty, however, by iteration. Assume initially that $q(x,y) = \Delta\rho'gh(x,y)$ where $\Delta\rho' = \rho_t - \rho_w$ and ρ_t is the density of the major units constituting the topographic variations. Then use (5) to calculate $w(x,y)$. Now set $q(x,y) = \Delta\rho'g(h + w)$. Recalculate w from (5), and repeat the last two steps until q and w converge to a steady solution.

Once a self-consistent decomposition of h into load topography $q/\Delta\rho'g$ plus plate deflection w is achieved, the calculation of gravity is straightforward. Two terms contribute to the gravity: (i) the attraction of the topography and (ii) the deflection of the Moho and of any other density contrast interfaces within the lithosphere. Any density contrast between the base of the lithosphere and the asthenosphere would also contribute to (ii), but this contribution is probably negligible. For both (i) and (ii) the gravity anomaly may be written in the form of that due to a surface mass distribution $\sigma(x,y)$

$$g(x,y,z) = Gz \iint \frac{\sigma(x',y')}{[(x' - x)^2 + (y' - y)^2 + z^2]^{3/2}} dx'dy' \quad (7)$$

where G is the gravitational constant and $z > 0$ is the vertical distance between the observation point (x,y,z) and the

horizontal plane on which σ is evaluated. For the topographic contribution, $\sigma = \Delta\rho' h$ on the plane of the topographic datum ($h = 0$). For the plate deflection contribution, $\sigma = \Delta\rho w$ on the plane corresponding to mean Moho depth.

IMPLEMENTATION

The theoretical relationship between topography and gravity outlined above can be applied to any finite area over which bathymetry and age are specified as functions of position. We have applied these concepts to a region, described in the next section, in which degree averages of ocean floor depth (corrected for mean age) and free air gravity are known. Implementation of the theory as a usable algorithm requires estimates of volcanic load ages and of the evolution of the flexural response function with age, and calculational schemes for evaluating the convolution integrals in (5) and (7).

Some care must be exercised in deciding the age of a volcanic construct relative to the age of the surrounding seafloor. For islands this is not a serious problem as the exposed or cored (if a coralline island) bedrocks can be dated. For seamounts some simple rules will be helpful. One such rule is that an inactive topographic feature will sink with respect to sea level at the rate of its surrounding abyssal sea floor, a rate which is associated with thermal contraction of the lithosphere and which is a well known function of ocean-floor age (Sclater et al., 1971). On this basis, for instance, the Ninetyeast ridge can be shown to have been generated at the southeast Indian ridge (Sclater and Fisher, 1974). Much of the ocean floor topography, in fact, was apparently generated at or near ridge crests on very young oceanic lithosphere (McKenzie and Bowin, 1976).

The flexural rigidity D and the effective elastic range thickness T are known to vary from values in the range 3×10^{27} - 2×10^{29} dyne-cm and 3 - 13 km, respectively, near mid-ocean ridges (Cochran, 1979; Detrick and Watts, 1979; McNutt, 1979) to values in the range 3×10^{29} to 10^{30} dyne-cm and 15 - 30 km, respectively, for older lithosphere (Walcott, 1970; Watts and Cochran, 1974; Watts et al., 1975, 1976; Caldwell et al., 1976; Watts, 1978b; Suyenaga, 1979). The

assumption that T scales as an isotherm depth is consistent with the data (Caldwell and Turcotte, 1979), so that a standard oceanic plate thermal model (Parsons and Sclater, 1977) and a few good measures of D and T are sufficient to define T as a function of lithosphere age minus load age.

Evaluation of the necessary convolution integrals has been conducted as follows. For each degree square we first subtract the mean bathymetric depth from the depth predicted from a spreading plate model for the appropriate region. This residual depth is then treated as a combination of lithosphere load and response to that load. For the Green's function for the loading problem we use the response of the lithosphere to a circular load of radius a such that πa^2 equals the area of the degree square:

$$w = \begin{cases} \frac{q}{\Delta \rho g} (\alpha \ker' \alpha \operatorname{ber} \xi - \alpha \operatorname{kei}' \alpha \operatorname{bei} \xi + 1) & \text{for } \xi \leq \alpha = \frac{a}{\ell} \\ \frac{q\alpha}{\Delta \rho g} (\operatorname{ber}' \alpha \ker \xi - \operatorname{bei}' \alpha \operatorname{kei} \xi) & \text{for } \xi \geq \alpha = \frac{a}{\ell} \end{cases} \quad (8)$$

(Brotchie, 1971), where $\ker$, ber and bei are additional Bessel-Kelvin functions of zero order and the prime denotes first derivative (Abramowitz and Stegun, 1964). The flexural length ℓ (or flexural rigidity D) can be taken appropriate to the lithosphere at the time of application of the load on the degree square in question. The convolution integral (5) is converted to a sum. Let w_i be the subsidence at the center of the i th degree square, let q_j be the load on the j th degree square and let w_{ij} be the contribution to w_i from q_j . Then each w_{ij} may be estimated from (8) after setting ξ to the appropriate (normalized) distance between the centers of the i th and j th square, and

$$w_i = \sum_j w_{ij} \quad (9)$$

As noted above, iteration is necessary to determine a self-consistent set of values for q_j and w_i from a given set of observed residual depths. In practice, about five iterations are required before the sum of the squared differences in w_i (or q_j) between successive iterations is less than 1 part in 10^3 .

Expression (7) for the predicted free-air gravity anomaly is evaluated using the Taylor series algorithm of Morrison (1976) for calculating the gravitational potential from a surface density distribution specified over a latitude-longitude grid. The contribution from each degree square is of the form

$$U(r, \phi, \theta) = \iint F d\phi' d\theta' \\ = \Delta\phi' \Delta\theta' [F_0 + \frac{1}{24} (F_{\phi\phi} \Delta\phi'^2 + F_{\theta\theta} \Delta\theta'^2)] \quad (9)$$

$$\text{where } F = \frac{G \sigma r'^2 \cos\phi'}{R} ,$$

the observation point is (r, ϕ, θ) in spherical coordinates (radius, latitude, longitude), the mass point is (r', ϕ', θ') , R is the distance between the two points and $\Delta\phi'$ and $\Delta\theta'$ are the dimensions of the degree square. In (9), F_0 , $F_{\phi\phi}$, and $F_{\theta\theta}$ are F , $\delta^2 F / \delta\phi'^2$ and $\delta^2 F / \delta\theta'^2$; respectively, evaluated at the center of the degree square. $F_{\phi\phi}$ and $F_{\theta\theta}$ may be obtained analytically:

$$\begin{aligned} \frac{F_{\phi\phi}}{G\sigma r'^2} = & -\frac{\cos\phi'}{R} - \frac{2\sin\phi'}{R^3} rr' [\sin\phi \cos\phi' - \cos\phi \sin\phi' (\cos\theta \cos\theta' \\ & + \sin\theta \sin\theta')] - \frac{\cos\phi'}{R^3} rr' [\sin\phi \sin\phi' + \cos\phi \cos\phi' \\ & (\cos\theta \cos\theta' + \sin\theta \sin\theta')] + \frac{3\cos\theta'}{R^5} (rr')^2 [\sin\phi \cos\phi' \\ & - \cos\phi \sin\phi' (\cos\theta \cos\theta' + \sin\theta \sin\theta')]^2 \end{aligned} \quad (10)$$

$$\frac{F_{\theta\theta}}{G\sigma r'^2} = - \frac{\cos\phi'}{R^3} rr' \cos\phi \cos\phi' (\cos\theta \cos\theta' + \sin\theta \sin\theta') \quad (11)$$

$$+ \frac{3\cos\phi'}{R^5} (rr')^2 [\cos\phi \cos\phi' (-\cos\theta \sin\theta' + \sin\theta \cos\theta')]^2$$

$$R^2 = r^2 + r'^2 - 2rr' [\sin\phi \sin\phi' + \cos\phi \cos\phi' (\cos\theta \cos\theta' + \sin\theta \sin\theta')] \quad (12)$$

Two separate contributions to U from each degree block are included here: the contribution from topography ($\Delta\rho' = 1.8 \text{ g/cm}^3$ assumed at a datum plane 5 km below sea level) and the contribution from Moho deflection ($\Delta\rho = 0.6 \text{ g/cm}^3$ assumed at a datum plane 12 km below sea level).

In practice the Taylor series truncation in (9) is a good approximation only if $rr' \Delta\phi'^2/R^2 \leq 1$. This limits (9) to elevations above the appropriate datum plane comparable to or greater than the dimensions of the blocks used to specify σ . For the degree-square specification of seafloor depth and free air anomaly in the application considered here, we calculated the potential at 100 km altitude from (9), and we calculated the gravity anomaly from a centered finite difference approximation to the radial derivative of the potential. Sea level gravity was upward continued to 100 km elevation for comparison with the predicted gravity anomaly. An alternative scheme would be to treat the mass contribution (topography or Moho deflection) degree square from each as a three-dimensional prism and calculate the gravitational attraction using the summed line-integral method of Talwani and Ewing (1960).

Fortran programs to calculate the load q and subsidence w from residual depths and to calculate the gravity from the topography and subsidence are available from the author.

APPLICATION

We have applied the bathymetry-gravity algorithm described above to a portion of the central Pacific basin, bounded by 15° and 35° N latitudes and 150° and 165° W longitudes. This region was chosen because (1) gravity, bathymetry, and lithosphere age are all well known; and (2) there are large superposed volcanic loads on the plate of younger ages, notably the Hawaiian island chain. As we shall see, however, the selection of this region in retrospect was far from ideal because of the presence of sea-floor topographic variations of a type different from those assumed in the theory used here.

The gravity from the region is taken from the degree averages of Watts and Leeds (1977). Their values for the area in question are shown in Table 1. The gravity continued upward to 100 km above sea level is shown in Table 2.

The bathymetry is taken from a 1978 NORDA compilation of degree averages provided by AFGL (T.P. Rooney, personal communication, 1978). A few blanks and obvious errors in this data set were filled in by estimating the appropriate degree averages from charts of the Scripps Institution of Oceanography (Chase *et al.*, 1970). The topographic data are shown in Table 3.

The lithosphere ages were taken from the magnetic anomaly maps of Pitman *et al.* (1974). Residual depths were calculated from observed bathymetry using the theoretical depth-age profile of Parsons and Sclater (1977) for the north Pacific. Residual depths are shown in Table 4.

The residual depths were used to calculate the load q on the plate and the resultant subsidence w , following the procedures outlined in the previous section. A plate thickness T of 30 km was assumed for modeling the effect of the Hawaiian ridge (Watts, 1978), and a plate thickness of 5 km was used for modeling the effect of other topography (assumed to have been generated at or near a spreading center) (Cochran, 1979). The resultant distributions of

q and w are given in Tables 5 and 6, respectively.

The gravity at 100 km altitude predicted from the loading and subsidence model of Tables 5 and 6 is shown in Table 7.

It is immediately apparent that the predicted gravity does not match the observations. The predicted gravity is much too large, particularly in the southern half of the area modeled, and provides a much poorer predictor of the rms gravity anomaly than does the a priori assumption of zero anomaly.

The difficulty lies with the large depth anomalies shown in Table 4. These large positive (shallow depth) anomalies over a substantial area are treated as loads on the lithosphere by the bathymetry-gravity algorithm, whereas the regionally shallow seafloor depth is almost completely compensated by density anomalies most likely below the lithosphere (Watts, 1976). The long-wavelength gravity is correlated to the long-wavelength residual depth anomalies, but the slope of a linear fit between these quantities in the north Pacific is much less (22 mgal/km) than in the algorithm used here based on a plate loading model. Thus the failure of the algorithm for this region of the Pacific is due to the large values for residual depth that arise from a process not included in the algorithm, namely deep compensation of long-wavelength topography.

SUGGESTIONS FOR FURTHER WORK

In spite of the wide disagreement between Tables 7 and 2 (predicted and observed gravity, respectively), the success of the plate flexure model in isolated situations over small areas prompts the belief that this approach toward relating gravity and bathymetry has merit.

For regions similar to the north Pacific area studied here, one of two approaches should be pursued in further work: either (1) a relationship between gravity and bathymetry based on lithospheric loading should be sought only for wavelengths shorter than a few hundred kilometers; or (2) the process that gives rise to long (>500 km) wavelength gravity and depth anomalies should be explicitly modeled as part of the algorithm. If approach (1) is followed, then either small regions can be treated in isolation after 'regional' anomalies have been removed, or the problem should be conducted in the wavenumber domain and a high pass filter applied to both the gravity and depth data. (We avoided the wavenumber domain here to allow for a spatially variable isostatic response function, but perhaps this capability is a frequently unnecessary luxury). Approach (2) involves more free parameters in the algorithm and a much less certain physical basis for modeling; Watts (1976) has demonstrated the approach and the magnitude of the effects for the region studied here.

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Table 1. FREE AIR ANOMALY (MGAL)

LAT/LONG	-165	-164	-163	-162	-161	-160	-159	-158	-157	-156	-155	-154	-153	-152	-151	-150
35	-10	-4	-6	-13	-14	-20	-13	-6	-8	4	-2	0	-12	-14	-11	
34	-15	-4	-3	-11	-10	-7	-8	-10	-15		2	-2	-5	-4	-4	
33	-13	-11	-8	-7	-6	-19	-10	-11	-9		4	2	3	4	0	
32	-24	-5	-11	-4	-5	-14	-12	-16	0		7	4	3	7	4	
31	-7	-3	-9	-10	-16	-11	-14	-1	-1		1	3	19		3	
30	-6	-12	7	3	-7	-22	-18	-9	-3	-15	-15	-10	6	5	0	
29	4	9	3	8	-5	-13	-1	-4	-1	-15	-15	5	5	-2	-8	
28	11	4	13	19	1	-4	13	-2	-1	-15	-15	-10	-6	-6	-10	
27	24	15	12	13	7	-5	20	3	5	-5	-3	2	4	-4	-5	
26	7	9	9	18	6	4	18	17	14	2	0	-3	-3	-3	-2	
25	-15	-16	-12	-1	-3	2	19	31	27	15	12	4	-1	-2	-2	
24		17	26	35	-19	-35	0	15	27	31	27	7	0	-15	-15	
23	16	2	11	21	22	69	-36	-39	-15	-8	15	17	3	-3	-12	
22	0	13	11	-2	41	37	49	114	-2	-80	-27	9	6	-1	-10	
21	12	10	15	7	-2	-14	-21	7	148	89	-37	4	1	-3	-7	
20	0	-1	2	8	13	12	10	-8	-34	331	39	0	0	-6	-8	
19	3	-3	-9	0	9	19	16	-9	-18	-19	-35	0	1	1	-8	
18	4	-3	-11	2	4	17	1	5	9	-2	-8	-3	0	4	-5	
17	-3	-15	-3	3	0	-2	-7	-6	2	11	6	0	-5	-7	-11	
16				5	4	0	-8	-9	-5	-3	-5	-7	-12	-3	-6	

Table 2. FREE AIR ANOMALY AT 100 KM (MGAL X 10)

LAT/LONG	-165	-164	-163	-162	-161	-160	-159	-158	-157	-156	-155	-154	-153	-152	-151	-150
35	-37	-37	-43	-60	-69	-75	-64	-43	-37	-13	-11	-15	-35	-42	-32	
34	-53	-50	-51	-65	-72	-74	-70	-66	-55	-22	-7	-11	-20	-22	-18	
33	-60	-63	-59	-60	-68	-87	-80	-71	-50	-18	3	5	7	7	1	
32	-64	-56	-57	-54	-64	-85	-85	-75	-38	-13	8	16	22	23	14	
31	-28	-38	-35	-46	-66	-90	-85	-71	-40	-25	-11	9	36	20	12	
30	-16	-20	0	-10	-47	-83	-79	-58	-45	-58	-53	-23	13	14	1	
29	19	27	30	24	-15	-41	-28	-28	-34	-63	-60	-20	-2	-10	-20	
28	49	53	64	64	23	5	27	/	-13	-48	-53	-35	-23	-26	-30	
27	71	74	74	72	47	33	66	48	29	-4	-14	-9	-7	-29	-22	
25	35	45	55	69	51	53	90	100	83	45	22	5	-6	-15	-14	
25	-7	4	27	46	29	38	90	131	131	102	72	34	3	-16	-19	
24	26	66	100	109	34	8	44	84	115	121	105	55	9	-35	-43	
23	54	64	92	119	138	171	50	35	37	25	58	62	23	-16	-38	
22	40	70	81	87	157	176	197	280	147	-15	-11	37	27	-5	-29	
21	44	59	72	70	71	62	80	197	416	373	94	42	18	-9	-24	
20	18	22	33	54	72	77	76	85	231	670	258	59	13	-14	-25	
19	10	-2	-6	25	62	88	75	38	66	138	45	21	9	-5	-22	
18	3	-15	-20	14	40	62	37	31	40	27	1	-2	-2	-5	-21	
17	-11	-30	-12	12	18	13	-4	-3	16	28	13	-7	-23	-31	-34	
15	-4	-7	0	15	15	2	-17	-20	-8	-1	-8	-22	-36	-35	-26	

Table 3. BATHYMETRY (M)

LAT/LONG	-165	-164	-163	-162	-161	-160	-159	-158	-157	-156	-155	-154	-153	-152	-151	-150
35	5760	5800	5860	5820	5790	6020	6030	5750	5700	5630	5630	5640	5630	5630	5630	5630
34	5980	5770	5990	5710	5670	5780	5360	5820	5740	5660	5620	5630	5620	5620	5620	5620
33	5740	5360	5230	5410	5580	5680	5710	5750	5710	5650	5610	5600	5590	5580	5580	5570
32	5580	5340	5120	5400	5630	5640	5590	5730	5710	5640	5600	5560	5520	5480	5440	5440
31	5490	5710	5310	5630	5640	5680	5560	5640	5630	5620	5560	5440	5410	5440	5500	5500
30	5410	5230	5340	5400	5480	5670	5760	5790	5800	5710	5620	5440	5380	5500	5550	5550
29	5220	5240	5040	4910	5140	5390	5350	5600	5740	5690	5620	5600	5550	5520	5460	5460
28	4970	5020	4910	4720	4780	5170	5330	5350	5460	5550	5560	5520	5470	5420	5370	5370
27	4470	4870	4420	5010	5000	5030	5220	5080	5280	5320	5320	5390	5340	5280	5280	5280
26	4210	4870	4830	4780	4890	4710	4790	4720	4780	4890	5240	5410	5380	5330	5360	5360
25	4540	4830	4320	4680	4610	4510	4450	4570	4370	4460	4390	5130	5240	5270	5290	5290
24	3480	4140	3500	3770	4590	4520	4450	4440	4150	4230	4480	4910	5190	5260	5270	5270
23	3970	4330	3740	3680	3890	3230	4050	4320	4490	4560	4630	5000	5100	5340	5470	5470
22	4160	4650	4550	4620	3850	3210	2740	1950	3460	4790	4780	5060	5100	5310	5400	5400
21	4970	4890	4910	4690	4570	4430	3730	2550	1550	2640	4840	5150	5100	5130	5250	5250
20	5240	5170	5210	4980	4720	4650	4400	4060	3320	1260	3780	5170	5180	5250	5450	5450
19	5430	5400	5420	5270	5080	4860	4520	4300	4130	3520	5000	4990	5070	5250	5460	5460
18	5450	5390	5230	5500	5450	5250	5010	4680	4390	4600	4890	4970	5110	5270	5380	5380
17	5400	5320	5110	5400	5630	5530	5390	5150	4780	4810	5090	5170	5230	5260	5250	5250
16	5400	5310	5330	5410	5590	5610	5550	5480	5290	5290	5390	5480	5530	5460	5380	5380

Table 4. RESIDUAL DEPTH ANOMALY (M)

LAT/LONG	-165	-164	-163	-162	-161	-160	-159	-158	-157	-156	-155	-154	-153	-152	-151	-150
35		-18	-69	-134	-105	-86	-322	-343	-74	-35	24	7	4	-9	-22	-35
34		-232	-33	-154	11	40	-82	-167	-138	-69	0	27	11	8	-6	-19
33		14	383	502	311	130	24	-17	-63	-39	15	44	41	38	35	38
32		174	403	512	326	85	64	9	-43	-34	26	54	81	114	141	168
31		269	38	427	96	31	30	39	48	47	45	100	207	224	181	115
30		355	524	403	332	246	45	-56	-97	-118	-39	40	214	261	128	6
29		545	514	703	822	586	325	91	28	-119	-82	-19	-12	32	49	96
28		723	668	772	951	880	484	317	284	161	65	42	69	112	149	193
27		1229	818	862	661	666	624	427	554	341	295	282	199	242	296	283
26		1189	823	852	897	781	950	957	914	848	725	368	185	202	245	203
25		1159	863	862	997	1061	1150	1204	1071	1258	1161	718	465	349	312	279
24		2224	1559	2038	1912	1081	1146	1204	1207	1484	1391	1135	692	399	322	299
23		1740	1369	1753	2008	1787	2441	1510	1327	1144	1068	785	602	495	242	99
22		1550	1049	1043	1068	1627	2461	2320	3704	2181	838	641	548	571	344	241
21		745	814	939	999	1107	1241	1730	3104	4165	3064	853	532	571	530	397
20		475	540	505	757	1045	1104	1343	1672	2401	4450	1919	518	491	410	197
19		400	410	375	510	685	894	1223	1432	1591	2190	699	698	507	416	194
18		390	430	270	280	315	504	733	1057	1336	1115	814	723	572	401	290
17		440	505	300	390	140	229	358	587	946	905	614	523	452	411	410
16		450	520	430	380	180	149	198	257	436	425	314	219	158	222	291

Table 5. PREDICTED LOAD (BAR)

LAT/LONG	-165	-164	-163	-162	-161	-160	-159	-158	-157	-156	-155	-154	-153	-152	-151	-150
35	-5	-28	-54	-43	-34	-131	-139	-28	-14	10	3	2	-4	-9	-14	
34	-46	-14	-57	9	17	-31	-55	-55	-27	0	11	4	3	-3	-7	
33	4	153	200	124	51	9	-8	-26	-15	6	17	15	14	13	14	
32	97	153	242	127	31	25	3	-18	-14	13	21	31	44	55	64	
31	107	3	163	31	30	11	15	20	20	19	39	41	87	71	45	
30	136	207	151	125	44	14	-24	-40	-47	-15	15	85	104	49	6	
29	213	194	271	320	225	125	33	10	-49	-33	-8	-7	10	17	39	
28	277	254	294	360	342	183	121	109	62	24	14	26	42	55	74	
27	432	305	330	245	252	238	157	213	126	110	109	75	93	115	111	
26	454	298	312	337	291	364	325	350	324	277	136	65	75	93	77	
25	556	414	322	356	391	429	456	401	400	445	270	175	133	119	107	
24	576	447	327	431	400	404	455	430	558	528	435	264	149	122	117	
23	478	444	511	472	671	1107	741	495	397	384	367	223	189	89	34	
22	701	503	508	577	451	647	744	1005	1015	315	219	195	217	129	97	
21	299	290	319	390	509	730	566	817	979	1549	337	183	212	203	155	
20	177	195	173	271	379	420	516	822	1326	1012	956	173	176	154	77	
19	153	154	140	189	249	321	438	515	713	544	390	257	224	157	77	
18	149	163	99	103	116	186	255	332	519	503	324	255	213	150	107	
17	169	192	109	151	48	.05	132	214	353	339	223	193	170	155	167	
16	176	201	156	147	68	50	75	95	163	153	116	81	57	83	114	

Table 6. PREDICTED SUBSIDENCE (M)

LAT/LONG	-165	-164	-163	-162	-161	-160	-159	-158	-157	-156	-155	-154	-153	-152	-151	-150
35	-11	-90	-174	-140	-108	-433	-460	-84	-44	35	8	5	-12	-29	-47	
34	-324	-47	-233	10	56	-96	-208	-178	-88	-1	35	12	10	-9	-26	
33	8	497	552	393	163	30	-14	-84	-47	21	55	50	44	40	44	
32	212	510	777	407	92	83	10	-58	-47	33	64	94	137	174	221	
31	348	-24	541	80	92	32	53	70	69	58	124	260	276	224	144	
30	429	669	465	388	293	37	-81	-131	-154	-49	44	274	335	155	-8	
29	679	595	556	1017	703	394	97	32	-164	-108	-25	-31	25	49	121	
28	880	789	315	1165	1088	566	378	341	196	70	39	79	131	175	241	
27	1543	935	1331	746	777	739	474	669	380	338	346	237	295	364	357	
26	1420	883	938	1035	887	1141	1310	1097	1009	867	413	195	228	289	239	
25	2061	1532	982	1040	1185	1311	1412	1230	1500	1395	832	543	412	369	343	
24	1053	973	3862	2877	1206	1163	1285	1303	1719	1639	1365	822	454	379	376	
23	974	1152	341	658	3245	3947	2558	1507	1120	1132	1120	675	590	268	96	
22	2506	1859	1895	2274	724	1199	1292	6749	3674	950	611	570	675	391	287	
21	796	847	931	1174	1819	3003	1276	1521	1373	5901	1068	515	642	635	493	
20	543	594	511	797	1124	1302	2213	3074	5275	1273	3610	463	519	474	217	
19	481	471	425	576	745	945	1287	1516	2632	887	1553	774	577	483	219	
18	465	504	297	307	347	565	787	1130	1643	1787	1047	795	647	460	329	
17	528	599	324	475	133	255	397	641	1079	1032	663	584	526	482	507	
16	561	633	521	464	210	171	231	285	500	479	354	245	169	257	363	

Table 7. PREDICTED GRAVITY (MGAL)

LAT/LONG	-165	-164	-163	-162	-161	-160	-159	-158	-157	-156	-155	-154	-153	-152	-151	-150
35	5	4	3	3	-1	-11	-13	-6	2	7	9	9	9	8	7	6
34	10	17	20	20	14	2	-5	-3	3	3	9	13	13	13	11	9
33	31	51	60	51	35	20	10	6	9	14	18	20	20	20	20	17
32	48	70	81	67	46	32	22	15	16	20	25	30	32	32	31	26
31	60	76	85	73	56	42	31	25	23	25	32	40	43	43	38	28
30	80	101	109	102	85	62	43	31	24	25	33	42	44	44	37	27
29	103	131	145	148	130	99	72	54	40	35	36	39	40	40	38	32
28	131	160	175	180	167	139	113	95	78	64	57	52	51	49	42	42
27	162	189	196	195	189	175	160	143	130	111	92	77	70	65	52	52
26	184	213	221	224	223	223	218	211	197	171	134	103	86	74	57	57
25	206	251	273	277	272	273	272	266	259	233	186	140	108	86	64	64
24	209	277	334	347	335	335	329	317	305	275	226	171	126	94	67	67
23	209	270	313	341	383	416	414	405	360	297	238	191	137	99	66	66
22	210	259	286	316	348	393	445	515	467	365	260	188	146	103	74	74
21	159	201	230	266	312	365	408	475	501	464	324	207	153	118	61	61
20	116	149	173	207	253	303	362	435	487	443	345	220	152	114	76	76
19	95	119	134	157	190	231	283	342	381	342	280	203	149	113	72	72
18	85	104	109	116	135	163	202	248	279	264	218	172	135	104	72	72
17	79	97	97	97	96	109	134	165	192	184	159	130	108	93	68	68
16	64	79	79	76	70	72	84	100	115	114	99	83	70	62	51	51

LIST OF CONTRIBUTING SCIENTISTS
(1 November 1976 - 30 September 1979)

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