480 cm³ value given by Dart (*5*). Specimen STS 19 was redetermined by using a partial endocast method on the cranial base, and using ratios determined on those australopithecines having the same area complete (*6*). The variation was less than 2 percent, and a volume of 436 cm³ was obtained. Specimen STS 71 (Ples. Trans. No. 8) (*7*) was found to be 428 cm³ after reconstruction. This results in a gracile australopithecine average of 442 cm³ for cranial capacity, with a standard deviation of 21.59, and a coefficient of variation of 4.88 (*8*). When the values of the robust specimens, *Australopithecus* ("Zinj") *boisei* and the SX 1585 briefly described by Brain (*9*), both 530 cm³, are taken into consideration, the combined average is 464 cm³, with a standard deviation of 44.71, and a coefficient of variation of 9.63.

Table 2 offers a short statistical analysis, using Student's *t*-test (two-tailed). While these values all indicate that the South African australopithecines differ significantly between robust and gracile, and between either and the Olduvai hominid No. 7 ("pre-Zinj"), it would be premature to accept these tests without extreme caution, since the sample sizes are very small. I have included in Table 2 a test between the giant 752-cm³ gorilla male value (*10*) and those of a large male gorilla sample (*11*), to indicate that it is possible for one specimen to differ significantly from another sample of the same species. Brace (*12*) has suggested that robust and gracile forms are but male and female specimens, that is, that the difference is nothing more than sexual dimorphism. On the basis of the above results, a sexual dimorphism of 16.6 percent would result, given this assumption. This is a most unlikely explanation when it is remembered that the gorilla, a species with extraordinary sexual dimorphism among primates, shows only 16.3 percent dimorphism (*11*).

The conclusions of Wolpoff (*2*), regarding the Olduvai hominid No. 7 as being the same species as the gracile South African form, cannot be supported by these results, as Pilbeam's (*2*) comments show, although these are based on previous incorrect values. While the precise taxonomic differences between robust and gracile forms remain to be determined, these results, plus the considerations of the rest of the morphology of the skull and teeth, and the localities of the finds, all suggest that the difference is most likely specific. It also apears very likely that the Olduvai No. 7 specimen represents a different taxon than either robust or gracile South African australopithecine forms (*13*).

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References and Notes

1. R. Broom and G. W. H. Schepers, *Trans. Mus. Mem. No. 2* (1946); R. Broom, J. T. Robinson, G. W. H. Schepers, *ibid. No. 4* (1950); P. V. Tobias, *S. Afr. J. Sci.* **64**, 81 (1968); R. A. Dart, *Natur. Hist.* **26**, 315 (1926).
2. R. L. Holloway, *Nature* **208**, 205 (1965); **210**, 1108 (1966); M. H. Wolpoff, **223**, 182 (1969); D. R. Pilbeam, **224**, 386 (1969).
3. P. V. Tobias, *Olduvai Gorge* (Cambridge Univ. Press, New York, 1967), vol. 2.
4. A full description of these methods is in preparation for publication elsewhere. In addition to the partial endocast method used on STS 19, other reconstructions were based on four dimensions, and a coefficient was determined from complete endocasts. The validity of this method was first checked on ten chimpanzee and nine gorilla endocasts, and was found to predict cranial capacity within 2 percent.
5. R. A. Dart, *Amer. J. Phys. Anthropol.* **20**, 119 (1962).
6. STS 5, "Zinj," SK 1585, STS 60.
7. R. Broom, J. T. Robinson, G. W. H. Schepers (*1*).
8. These are admittedly lower than expected on the basis of extant pongid samples. This is probably due to both the small sample size of gracile forms, and a bias introduced from using certain gracile forms to estimate the volume of others.
9. C. K. Brain, *S. Afr. J. Sci.* **63**, 378 (1967).
10. A. H. Schultz, *Anthropol. Anz.* **25**, 179 (1962).
11. E. H. Ashton and T. F. Spence, *Proc. Zool. Soc. London* **130**, 169 (1958).
12. C. L. Brace, *Abstracts, Amer. J. Phys. Anthropol.* **31**, 255 (1969).
13. This conclusion is reinforced by certain morphological features of the endocasts which have not been discussed here, but which are currently being studied and will be published in the future.
14. Supported by NSF GS-2300. I am indebted to Professor P. V. Tobias, Mr. Alun Hughes, and Mr. Brian Hume for their support and kindness.

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Transcontinental Tidal Gravity Profile across the United States

Abstract. Data obtained from a transcontinental tidal gravity profile across the United States were analyzed. Results for the principal tidal constituents M_2 and O_1 have shed light on the long-standing problem of the indirect influence of ocean tides on the solid-earth tide. The profile consists of nine observational stations distributed almost evenly around latitudes 39 to 41 degrees north across the United States. The observed values of the gravimetric factor and the phase were found to depend on the tidal characteristics of the Atlantic and Pacific oceans. There is no observable correlation between tidal gravity parameters and the regional geology. When the influence of ocean tides is taken into account, it is possible for the first time to bring the gravimetric factors and phases for all the stations of a transcontinental network into a consistent system within the framework of the earth tidal theory.

The solid earth undergoes a periodic tidal deformation, termed "earth tides." This deformation results principally from the attraction of the moon and the sun that manifests itself by a rise and fall of the earth's surface. The magnitude of the elevation change is of the order of 25 cm in the midlatitudes and 50 cm near the equator. The earth tides are greatly influenced by ocean tides, a process that is very complex and often difficult to evaluate because the tidal conditions in open oceans are almost unknown and must be inferred from coastal stations. Extensive efforts were made during the International Geophysical Year (IGY), 1957–58, to carry out long series of earth tidal observations on a worldwide basis. The IGY data clearly indicate the regional differences in the values of the gravimetric factor and the phase (*1*).

A few years ago, the Lamont-Doherty Geological Observatory of Columbia University began a study of spatial variations of tidal gravity directed specifically toward evaluation of the indirect and secondary effects, principally the effects of ocean tides and geological structures, on tidal gravity. The results from a dense network of stations in the New York–New Jersey–Pennsylvania area (*2*) have shown that the amplitude ratio of the M_2 to the O_1 tidal constituents and the phase difference of these two constituents decrease systematically as a function of the station distance from the Atlantic coast.

More recently, a transcontinental tidal gravity profile across the United States was established by Lamont-Doherty; it provided an ideal basis for investigating the influences of the Pacific and Atlantic oceans, and of several major geological provinces, on tidal gravity. The network of the transcontinental profile consists of nine semipermanent observational stations around latitudes 39° to 41°N (Table 1). At least six stations were in simultaneous operation at all times. A long and uninterrupted series of observations of at least 6 months' duration was made at each station to provide data for resolving reliable tidal constituents.

A total of eight nearly identical Geodynamics TRG-1 tidal gravimeters were used. One of the important features of the gravimeter is a system of internal sensitivity calibration by electrostatic deflection of the mass. Relative sensitivity calibrations among the gravimeters, based on simultaneous side-by-side recordings, were found to agree to 1.0 percent or better. In tidal studies, the absolute calibration of a tidal gravimeter to a comparable accuracy is still an extremely difficult problem, which is now under critical evaluation. Fortunately, the study reported here requires only a relative calibration, which can be referred to the absolute calibration value if such accuracy is ever achieved.

Analysis of the data obtained from the stations of the transcontinental profile for the principal tidal constituents M_2 and O_1 has shown that the observed relative values of the gravimetric factor and the phase do indeed follow a definite pattern with respect to distance from the Atlantic and Pacific oceans. Figures 1 and 2 show the relative differences of gravimetric factor $\Delta\delta$ in percent and of phase κ in degrees for M_2 and O_1 (solid dots). These values were determined by analyzing several month-long intervals of data by the method of least squares, and the bars indicate the limits of scattering of the separate analyses. The gravimetric factors for M_2 are high in New York City and low in Point Arena in comparison with those observed in the In-

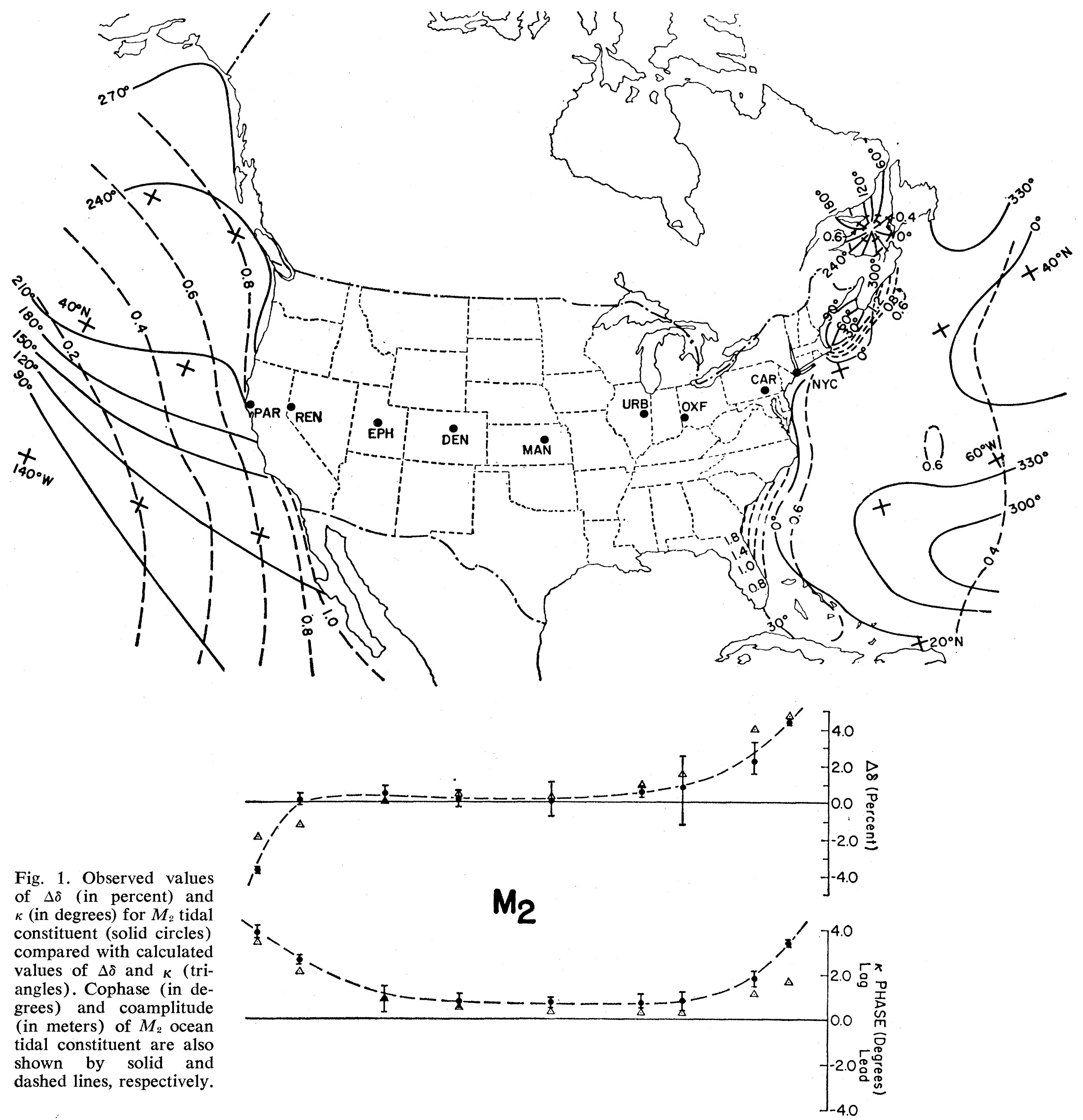
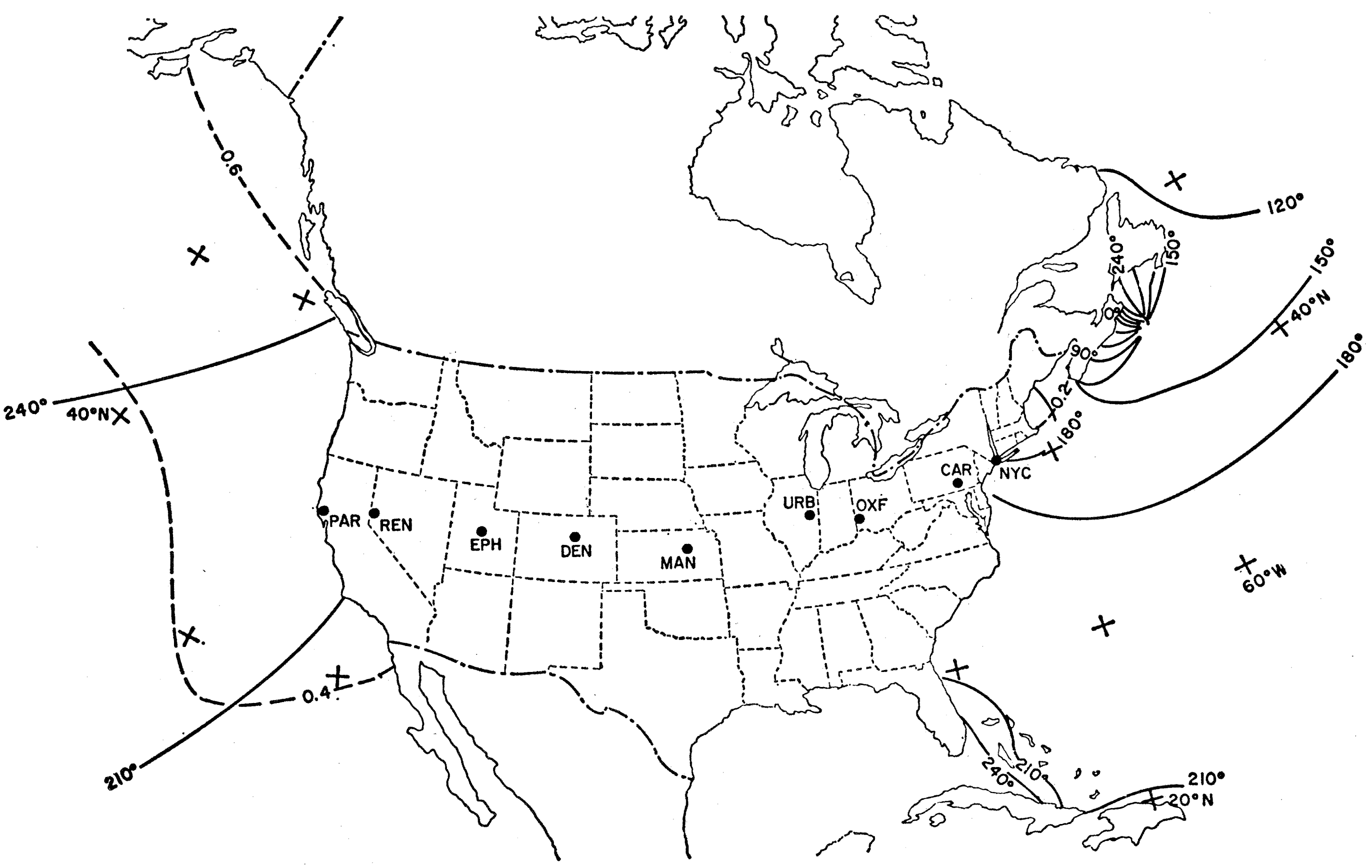


Fig. 1. Observed values of $\Delta\delta$ (in percent) and κ (in degrees) for M_2 tidal constituent (solid circles) compared with calculated values of $\Delta\delta$ and κ (triangles). Cophase (in degrees) and coamplitude (in meters) of M_2 ocean tidal constituent are also shown by solid and dashed lines, respectively.

terior Plains and Rocky Mountains. The maximum difference amounts to approximately 8 percent. The observed values of $\Delta\delta$ (M_2) increase and decrease logarithmically as a function of the effective distances from the stations to the nearest ocean. There is a lag of about 4° for the phases of M_2 in both New York City and Point Arena; these phases also decay logarithmically toward the midcontinent, where the phase lag is less than 1°. The gravimetric factors and phases for O_1 are considerably different from those for M_2. The gravimetric factors for O_1 are nearly equal for all stations east of Kansas, and the value of $\Delta\delta$ increases at a rate of about 0.14 percent per 100 km toward the west coast. The phases for O_1 are equal, with a constant lag of about 1° across the continental United States. They gradually begin to lead west of Ephraim, and the lead increases very rapidly to a lead of 5° in Point Arena.

Tidal observations off the Atlantic and the Pacific coasts (*3*) are considered to be the best known, although there is a lack of satisfactory information on the corange values of the ocean tidal constituents in open oceans. The M_2 and O_1 constituents off the entire Atlantic coast from Narragansett Bay, Sandy Hook, and Atlantic City to Daytona Beach, Florida, indicate that the ocean tide is nearly simultaneous along this stretch. The Greenwich epoch for M_2 varies from 355° to 370°; for O_1 it varies from 180° to 220°. Even in Bermuda, the Greenwich epoch for M_2 varies from 365° to 360°; for O_1, from 195° to 200°. The cotidal lines



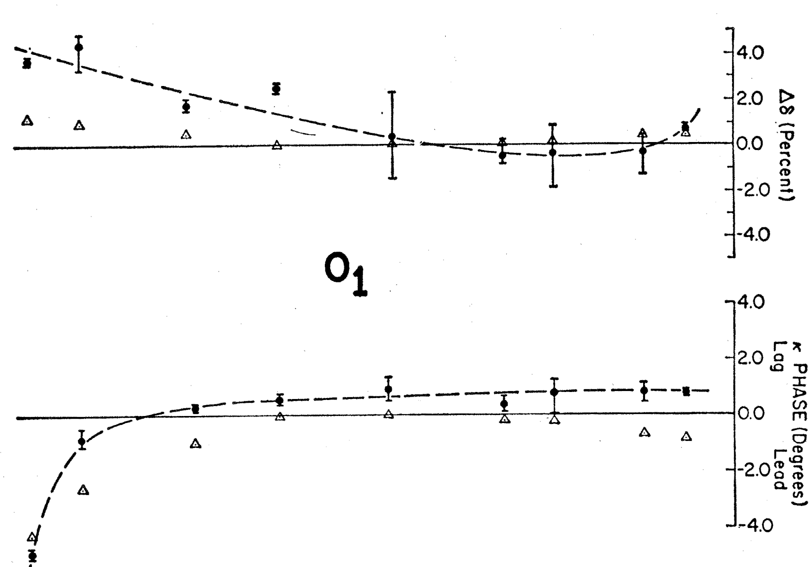


Fig. 2. Observed values of $\Delta\delta$ (in percent) and κ (in degrees) for O_1 tidal constituent (solid circles) compared with calculated values of $\Delta\delta$ and κ (triangles). Cophase (in degrees) and coamplitude (in meters) of O_1 ocean tidal constituent are also shown by solid and dashed lines, respectively.

for the M_2 constituent, on the other hand, are nearly perpendicular to the Pacific coast. The Greenwich epochs for M_2 vary from 150° in San Diego and Santa Monica to about 215° in San Francisco (Golden Gate), from 250° to 260° in the Oregon coast, and from 260° to 270° in Seattle, Washington. As yet, the O_1 constituent is nearly constant with a Greenwich epoch of 200° to 250° from the lower California coast to Seattle. (Detailed tidal information is shown in Figs. 1 and 2.)

Table 1. Summary of solid-earth tidal observations with Geodynamics TRG-1 gravimeters.

Station and host institution	Code	Location		Height (m)
		Latitude (N)	Longitude (W)	
New York City (Columbia University)	NYC	40°49.0′	73°58.0′	31
Carlisle, Pennsylvania (Dickinson College)	CAR	40°12.3′	77°11.6′	143
Oxford, Ohio (Miami University)	OXF	39°30.9′	84°44.9′	256
Urbana, Illinois (University of Illinois)	URB	40°06.7′	88°13.7′	221
Manhattan, Kansas (Kansas State University)	MAN	39°11.8′	96°34.9′	326
Denver, Colorado (Metropolitan State College)	DEN	39°44.4′	104°59.5′	1592
Ephraim, Utah (Snow College)	EPH	39°21.7′	111°36.1′	1830
Reno, Nevada (University of Nevada)	REN	39°32.4′	119°48.8′	1355
Point Arena, California (Columbia University)	PAR	38°54.3′	123°42.4′	12

The effects of ocean tides on tidal gravity are (i) a variation in the height of the point of observation, (ii) distortion of the tidal potential, and (iii) an addition to the variation of the vertical component of acceleration of gravity due to the water mass of the ocean tide. With cotidal and corange information for the M_2 and O_1 ocean tidal constituents (*3*), quantitative calculations were made for each station by taking these effects into account. The calculation for the effects of (i) and (ii) was carried out to a radial distance of 1500 km centered at the station; the effect of (i) was obtained by integrating the Boussinesq solution for the distortion of a half-space and Kuo's solution for the distortion of a multilayered medium (*4*) under a concentrated point load of the water mass, whereas the effect of (ii) was assumed to be proportional to the variation in height of the observation point. The proportionality constant was determined on the basis of the gravity effect of displaced medium with an average density of the crust and upper mantle to a depth equivalent to one wavelength of the surface load. Refinements for calculating the effects of (i) and (ii) on a spherical-shell earth model are now in progress. The effect of (iii), which is comparatively smaller than effects of (i) and (ii) except for a station very close to the coast, was calculated by integrating the total attraction of the worldwide distribution of the water mass. The results from the total effects (i), (ii), and (iii) on the M_2 and O_1 earth tidal constituents for the stations of the transcontinental profile are plotted as triangles in Figs. 1 and 2.

The observed values $\Delta\delta$ and κ agree remarkably well with those calculated for the M_2 constituent. For the O_1 constituent the agreement is not so good, but the general trend of the O_1 constituent for these values of $\Delta\delta$ and κ indicates that even though the cotidal and corange information for the O_1 ocean tidal constituent is inferior to that for the M_2 ocean tidal constituent, the O_1 ocean constituent is obviously a primary influence on the O_1 earth tidal constitutent. Nevertheless, there is a considerable degree of uncertainty about the ocean tides on open oceans. Currently, the agreement between the observed deviations of the gravimetric factors and the phases and the calculated deviations due to the influence of ocean tides does substantiate the primary importance of the influence of ocean tides on tidal gravity. The small residual deviations of both the gravimetric factors and the phases, after subtracting the effects of ocean tides on tidal gravity, do not correlate with the major different geological provinces, such as the Interior Plains and the Rocky Mountains. These deviations may well result from the imperfect knowledge of the tidal characteristics on open oceans. Although the question of the influence of geological structure on tidal gravity has drawn much attention in the past, the theoretically calculated gravimetric factors for several earth models involving drastic differences in the crustal and upper mantle structures are nearly constant (*1*). The results reported here confirm such a theoretical consideration.

Theoretically, the most probable values of gravimetric factor for the earth as a whole, according to the earth models of Jeffreys and Bullen and of Gutenberg and Bullen, are nearly constant in the range 1.155 to 1.165 (*5*). The theoretical phase is zero for a rigid earth; although still subject to question, the theoretical phase is of the order of 1° when account is taken of the tidal dissipation of the earth (*6*). These earth models deduced from seismic body waves have long been regarded as a close approximation to the actual earth and have been further supported by excellent agreement between the theoretical and experimental values of the periods of the free oscillations of the earth (refinements, particularly with damping taken into account, are still needed). It is safe to conclude, however, that we have far better knowledge about the earth's interior from which the characteristic numbers are derived than about the tides on the open oceans. It is now evident that it is fruitless to try to verify the theory of earth tides by using the inferred or theoretically calculated cotidal and corange charts to make corrections for the indirect effects of ocean tides on tidal gravity or tidal tilt, as has been done in the past. If measurements can be made to an accuracy of 1 percent or better, we may more appropriately consider the possibility of mapping ocean tides on the open oceans by means of extended earth tidal gravity measurements on adjacent lands. A study to determine the feasibility of this method is under way.

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References and Notes

1. J. T. Kuo and M. Ewing, in *The Earth beneath the Continents*, J. Steinhart and T. J. Smith, Eds. (American Geophysical Union, Washington, D.C., 1966), pp. 595–610.
2. J. T. Kuo, K. Hunkins, M. Ewing, *Trans. Amer. Geophys. Union* **46**, 47 (1965).
3. G. Dietrich, *Veroeff. Inst. Meeresforsch. Univ. Berlin* **41**, 1 (1944).
4. J. T. Kuo, *J. Geophys. Res.* **74**, 3195 (1969).
5. L. E. Alsop and J. T. Kuo, *Ann. Geophys.* **20**, 286 (1964).
6. L. B. Slichter, *J. Geophys. Res.* **68**, 4281 (1963).
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