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DEFLECTIONS AND GEOIDAL HEIGHTS ACROSS A SEAMOUNT

by Irene FISCHER
Defense Mapping Agency Topographic Center, Washington (*)

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ABSTRACT

Detailed deflection- and geoid charts across the Kwajalein Atoll in the Marshall Islands are presented. They were computed from a density model of the area as deduced from observed astrogeodetic deflection values, bathymetric data, and assumed density variations below the ocean floor. This finely interpolated ground truth information provides a test area for satellite altimetry. In turn, deflections derived from satellite altimetry in oceanic regions may be interpolated similarly by this bathymetric method.

INTRODUCTION

The prospect of detailed and consistent bathymetric surveys in the near future, made possible as well as economic through modern techniques such as side-scanning sonars in multibeam systems (STUBBS *et al.*, 1974), invites investigations of how such an abundant data source may be utilized for geodetic purposes. Although such high quality data was not yet available to us, we studied its usefulness in principle, by substituting available hydrographic charts for the time being. The Kwajalein Atoll in the Marshall Islands (figure 1) provided an ideal test area because there are a number of astrogeodetic deflection stations connected by a first-order triangulation network and there also are several satellite observation stations. The steepness of the atoll walls, indicated in figure 1 by

(*) Opinions expressed in this article are those of the author and do not necessarily reflect a position of the Defense Mapping Agency.

approximate depths lines (in kilometres), explains the large deflections which range from about − 25″ to more than + 25″, and also shows these atolls as distinct topographic features sitting on the 5 km deep ocean floor. The questions were posed :

(a) whether the large deflection values could be duplicated by topographic - isostatic calculations, or what additional information was needed ?

(b) could a detailed deflection chart of the region be constructed to serve possibly as a ground truth check for satellite altimetry ?

(c) what size of geoidal disturbance was caused by such seamounts, to be reflected in satellite altimeter profiles ?

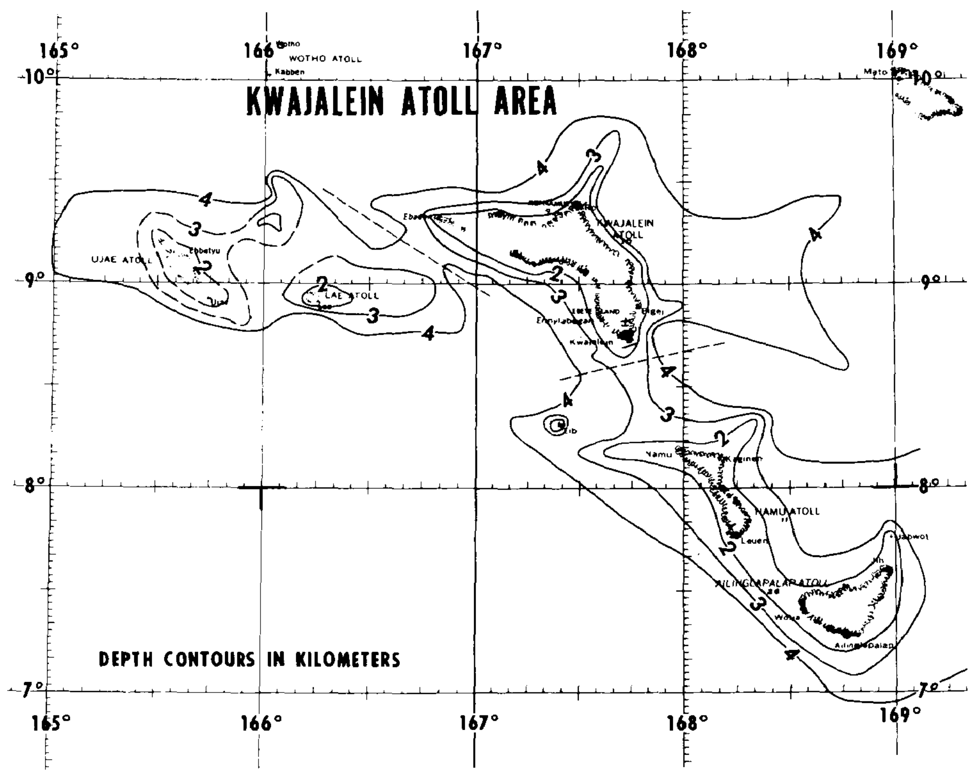

FIG. 1

The first question has been discussed in great detail by I. FISCHER (1973) and by I. FISCHER and P. WYATT III (1974*a*). To summarize the results very briefly : The effect of the "visible" topography, that is bathymetric data out to a distance of at least 1°.5 radius, accounts for the large observed deflections to within less than 3″ root mean square error. To achieve more accuracy, one must take into account also the effect of the masses below the ocean floor, either by isostatic correction or local density variations or both. Several such density models were used to study the effect of variations in the model parameters upon the computed deflections. The feedback from the deflection residuals (*observed* minus *computed* deflections) served as a guide for separating plausible from unlikely models. A geophysical distinction between alternative plausible models which have practically the same computational effect on deflection values would need more specific geophysical information about the area.

DEFLECTION CHARTS

The second question is answered in the affirmative by the detailed deflection charts presented here in figures 2 through 5. The problems and procedures of constructing them were presented in detail by Fischer and Wyatt (1974*b*). A geophysical distinction between plausible density models is immaterial for interpolating between the observed deflection values, as long as the model is sufficiently refined to produce small residuals; they should be small enough to be graphically interpolated with insignificant

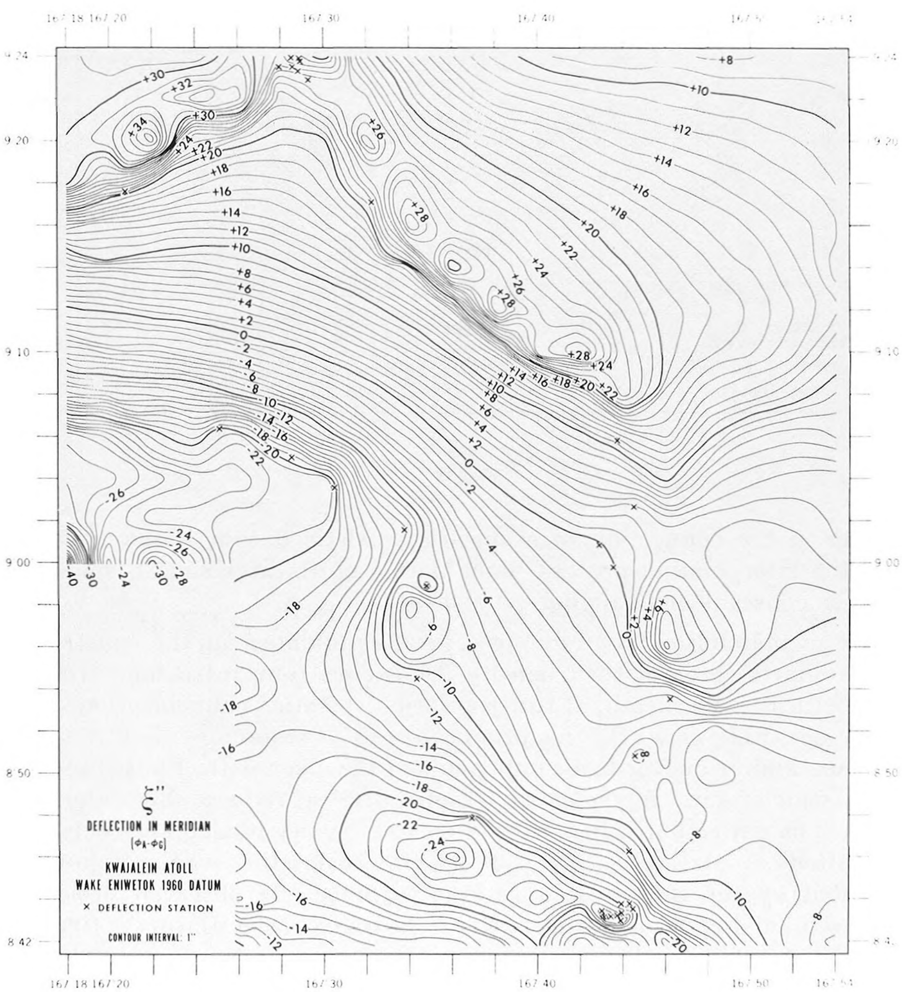

Fig. 2

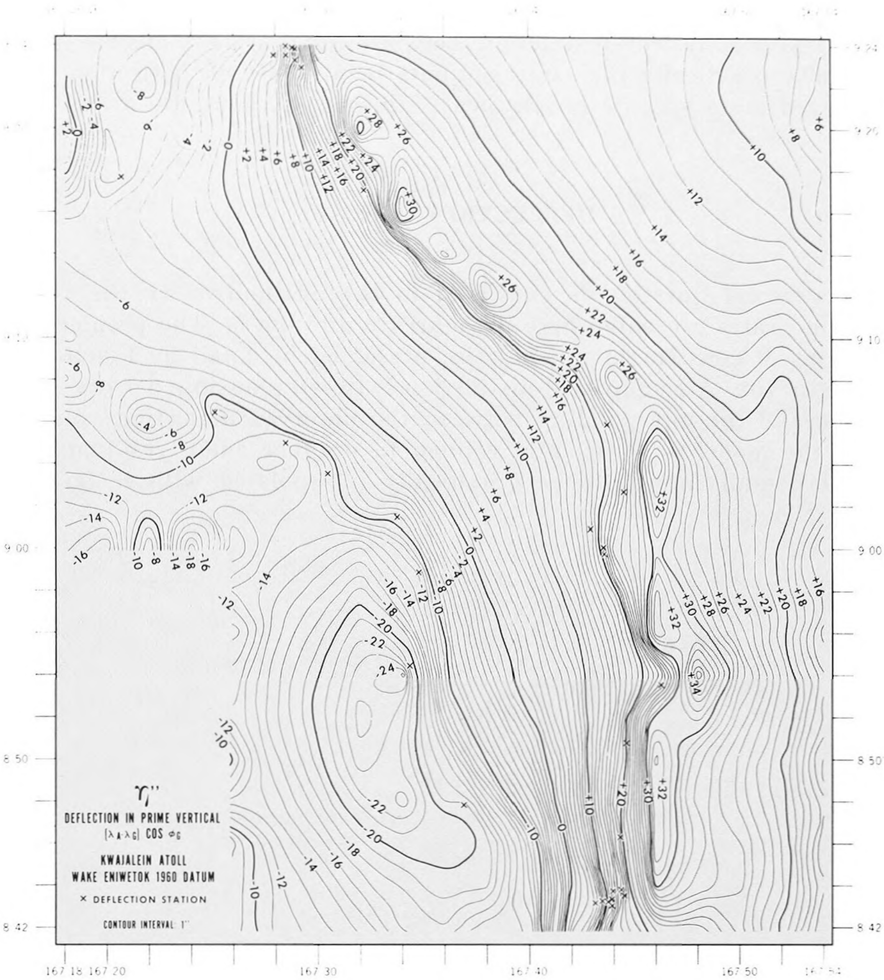

Fig. 3

error. Even the connection to a specific geodetic datum is taken care of within the interpolation process, since datum shifts over such a small area are either constant or changing very slowly.

The model chosen from among several candidates for the construction of these charts (general rock density 2.4 g/cm^3, four intrusions from the basaltic rock underneath, Pratt-Hayford isostatic compensation depth 227 km, see Reference 1974*b*) produced r.m.s. residuals of 1''.1 in the meridional and prime vertical components of the given deflections (Reference 1974*b*), which were interpolated graphically to reduce the error even further. The deflection values caused by the density model were calculated at hypothetical stations at $2' \times 2'$ spacing over the whole region and augmented by the interpolated residuals. Since the observed deflections were given on the local datum (Wake-Eniwetok 1960 Datum), figures 2 and 3 are referred to the same datum. Figures 4 and 5 were derived by datum transformation from the local datum to the World Geodetic System 1972 (WGS-72), established in this region at the satellite stations.

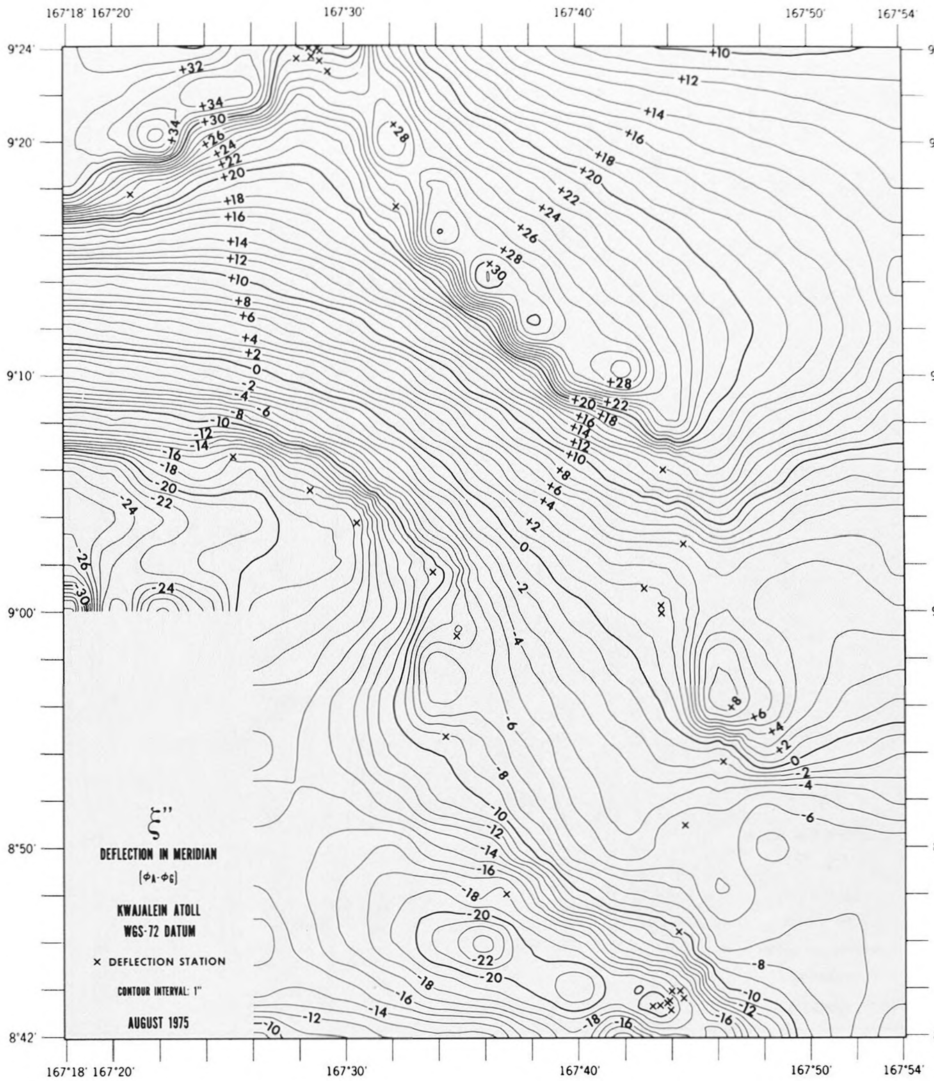

Fig. 4

The great detail contained in these charts is based on the fine subdivisions of the bathymetric area units (0′.5 × 0′.5 and even 10″ × 10″ in the inner areas) and is hardly expected to be seen in satellite altimetry results. By using this atoll as a calibration area in the Pacific, however, one could see the degree of averaging in satellite derived deflections by comparing them with the ground truth data contained in these charts. Such comparison could then be applied to the evaluation of satellite results in other oceanic regions. In turn, when satellite derived deflections will be sufficiently precise or of a known degree of averaging, they may be interpolated for finer detail across their ground path array by this bathymetric method.

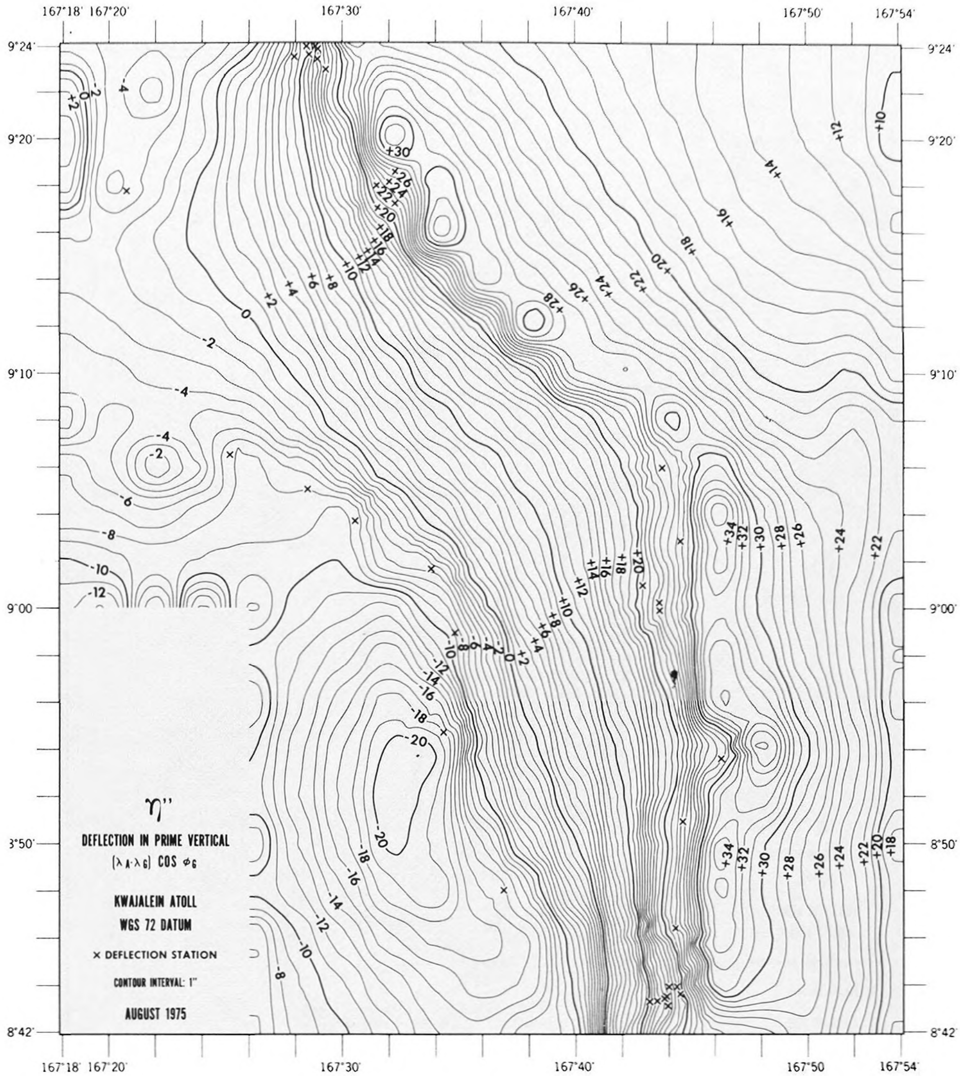

Fig. 5

GEOID CHARTS

To answer the third question, geoid charts were computed from the deflection charts. For the geoid chart on local datum (figure 6), a conventional zero meter value was adopted at a centrally located starting point. The conventionally computed height increments between adjacent grid points of the $2' \times 2'$ array were adjusted for zero loop closures (381 unknowns determined from 1106 observation equations). The geoid heights were contoured at 10 cm intervals. Since a 1″ uncertainty in the deflection causes a 1.8 cm uncertainty in the height increment between grid points at 2′ spacing, the uncertainty of the chart from the fixed center to the edge,

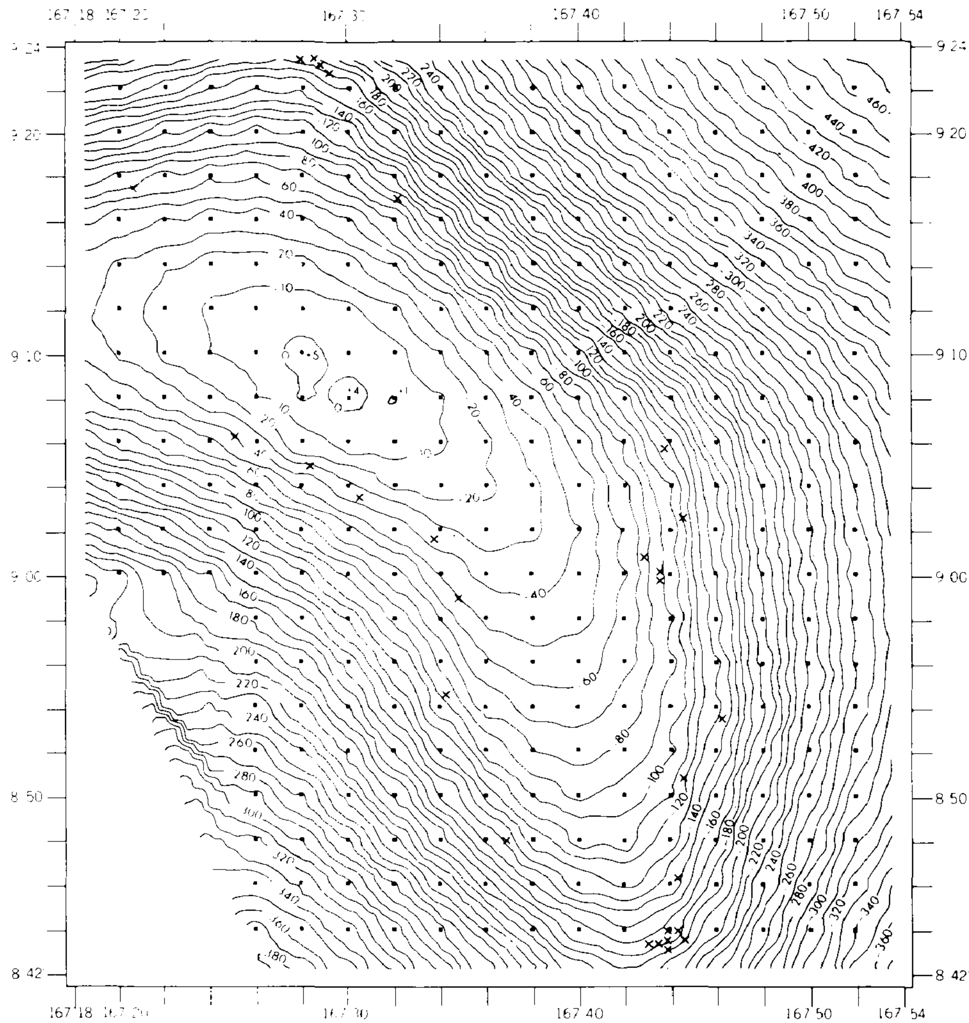

FIG. 6. — Kwajalein Atoll. Geoid undulations, Wake-Eniwetok 1960 Datum. Contour interval : 10 cm. × : Deflection station.

including an about 10 cm uncertainty in the adjustment, is estimated as about 12 cm.

The geoid chart referred to WGS-72 (figure 7) was computed by datum transformation using geoid height values derived at the satellite stations. The overall uncertainty must include the uncertainty of the transformation and is estimated at about 40 cm.

The difference between the high and low points on the two charts is 4 m and 5 m; but the geoidal disturbance must be more than that, since it obviously extends beyond the chart limits. To trace the disturbance further, geoid computations were made for an enlarged (1° × 1°) area by direct calculation via the disturbing potential :

$$\Delta N = \frac{k}{g} \cdot \frac{m}{s}$$

where k = gravitational constant
g = mean value of gravity
s = distance of the mass m from the station A
ΔN = geoidal contribution of the mass m at the station A.

The assumption is made here that the 5 km deep ocean with a flat bottom is the normal state, so that the disturbance is caused by the additional masses with their density difference from the water, and their isostatic compensation, if any.

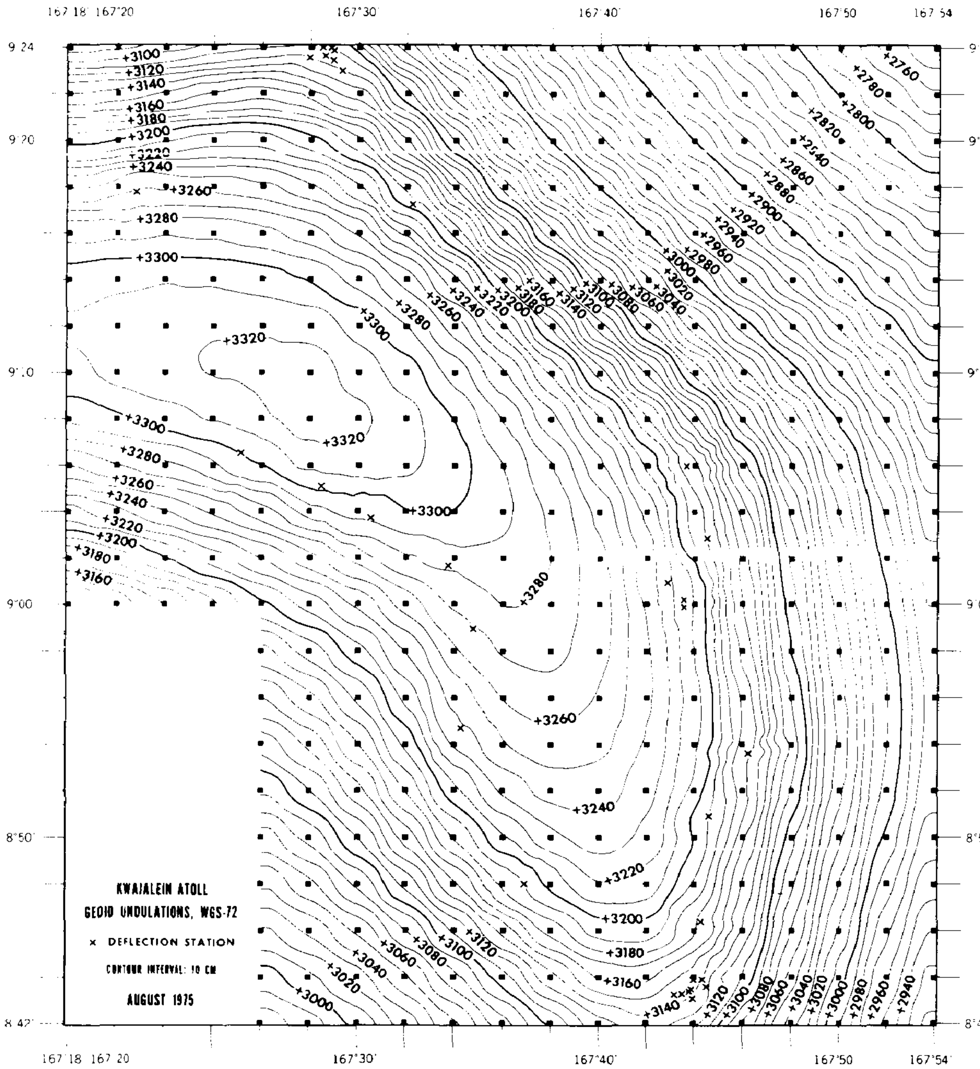

FIG. 7

The same data set (5° in latitude and 4° in longitude) and density model that produced figures 6 and 7 were used to produce the enlarged chart. Also, the atoll group within the 4 km depth line was divided into three sections (see dashed dividing lines in figure 1), namely the Kwajalein

TABLE I

A Geoid Profile Across Kwajalein Atoll.
Contributions From Specific Sections of the Data Set

Latitude North	Longitude East	Full Data Set	Kwaj.	W	SE	Remainder	Fig. 7-8 − 21 m
		m	m	m	m	m	m
8°30′	167°00′	4.3	1.5	0.7	0.8	1.3	
32′	02′	4.6	1.6	0.7	0.9	1.4	
34′	04′	4.8	1.8	0.7	0.9	1.4	
36′	06′	5.1	2.0	0.7	0.9	1.5	
38′	08′	5.4	2.3	0.7	0.9	1.5	
40′	10′	5.6	2.5	0.6	0.9	1.6	
42′	12′	6.0	2.9	0.6	0.9	1.6	
44′	14′	6.3	3.2	0.6	0.9	1.6	
46′	16′	6.7	3.6	0.5	0.9	1.7	
48′	18′	7.1	4.3	0.5	0.9	1.4	
50′	20′	7.6	4.8	0.5	0.9	1.4	
52′	22′	8.2	5.5	0.5	0.9	1.3	
54′	24′	8.7	6.1	0.4	0.8	1.4	
56′	26′	9.1	6.8	0.4	0.8	1.1	+ 1.3
58′	28′	9.7	7.4	0.4	0.8	1.1	+ 1.1
9°00′	30′	10.3	8.0	0.4	0.8	1.1	+ 1.0
02′	32′	10.9	8.7	0.3	0.7	1.2	+ 0.9
04′	34′	11.4	9.1	0.3	0.7	1.3	+ 0.6
06′	36′	11.4	9.2	0.3	0.7	1.2	+ 0.5
08′	38′	11.2	8.9	0.3	0.6	1.4	+ 0.3
10′	40′	10.8	8.4	0.2	0.6	1.6	+ 0.1
12′	42′	9.9	7.5	0.2	0.6	1.6	0.0
14′	44′	9.1	6.7	0.2	0.5	1.7	− 0.1
16′	46′	8.4	6.0	0.2	0.5	1.7	− 0.1
18′	48′	7.9	5.4	0.2	0.5	1.8	− 0.2
20′	50′	7.3	4.9	0.2	0.5	1.7	− 0.1
22′	52′	6.9	4.4	0.2	0.4	1.9	− 0.1
24′	54′	6.7	3.9	0.2	0.4	2.2	− 0.3
26′	56′	6.5	3.5	0.1	0.4	2.5	
28′	58′	6.2	3.1	0.1	0.4	2.6	
30′	168°00′	6.0	2.7	0.1	0.4	2.8	
32′	02′	5.8	2.3	0.1	0.3	3.1	
34′	04′	5.6	2.0	0.1	0.3	3.2	
36′	06′	5.4	1.8	0.1	0.3	3.2	
38′	08′	5.2	1.6	0.1	0.3	3.2	
40′	10′	5.0	1.4	0.1	0.3	3.2	
42′	12′	4.9	1.3	0.1	0.3	3.2	
44′	14′	4.8	1.2	0.1	0.2	3.3	
46′	16′	4.6	1.1	0.1	0.2	3.2	
48′	18′	4.6	1.0	0.1	0.2	3.3	
50′	20′	4.5	0.8	0.1	0.2	3.4	
52′	22′	4.4	0.8	0.1	0.2	3.3	
54′	24′	4.4	0.7	0.1	0.2	3.4	
56′	26′	4.4	0.7	0.1	0.2	3.4	
58′	28′	4.4	0.6	0.1	0.2	3.5	
10°00′	168°30′	4.3	0.6	0.1	0.2	3.4	

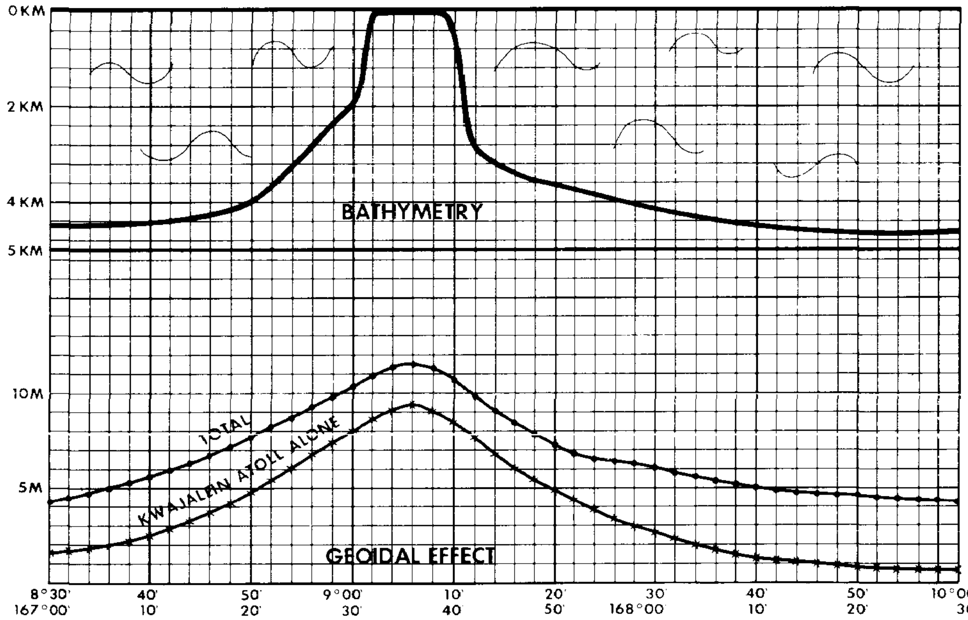

FIG. 8. — Profile across Kwajalein Atoll. 8°30′ N, 167°E to 10°N, 168°30′ E.

Atoll, its west and its southeast neighbors, in order to see the amount of their specific contributions to the chart. Figure 8 shows a typical profile across the Kwajalein Atoll (from 8°30′ N, 167° E to 10° N, 168°30′ E), the steep feature of the atoll, and the corresponding geoidal curve with very long tails on either side. The dashed geoidal curve represents the contribution of the Kwajalein section alone. As expected, it constitutes the major part, is of almost the same shape, but its tails decrease somewhat faster. The effects of the other two more distant sections are relatively small, and so is the effect of the remainder of the data area. Table I gives the numerical details along this particular profile.

This Table also gives a comparison with the geoidal heights on WGS-72 in figure 7. There is a slight tilt apart from a 21 m bias which may be interpreted as a datum difference. A datum transformation can be derived and applied to the 1° × 1° geoid area to refer it to WGS-72 (figure 9).

The amount of geoidal disturbance caused by the atoll, a 5 km seamount, appears to be of the order of 10 m. The "visible" topography of the Kwajalein Atoll, that is the bathymetric data of this section without the model refinement, would produce a similar curve as in figure 8, but about 2.5 m higher.

SUMMARY

Deflection- and geoid charts across the Kwajalein Atoll are presented here as ground truth information for evaluating satellite altimeter results in this Pacific area. They were computed from very detailed bathymetric data and a density model deduced from the feedback of some astrogeodetic

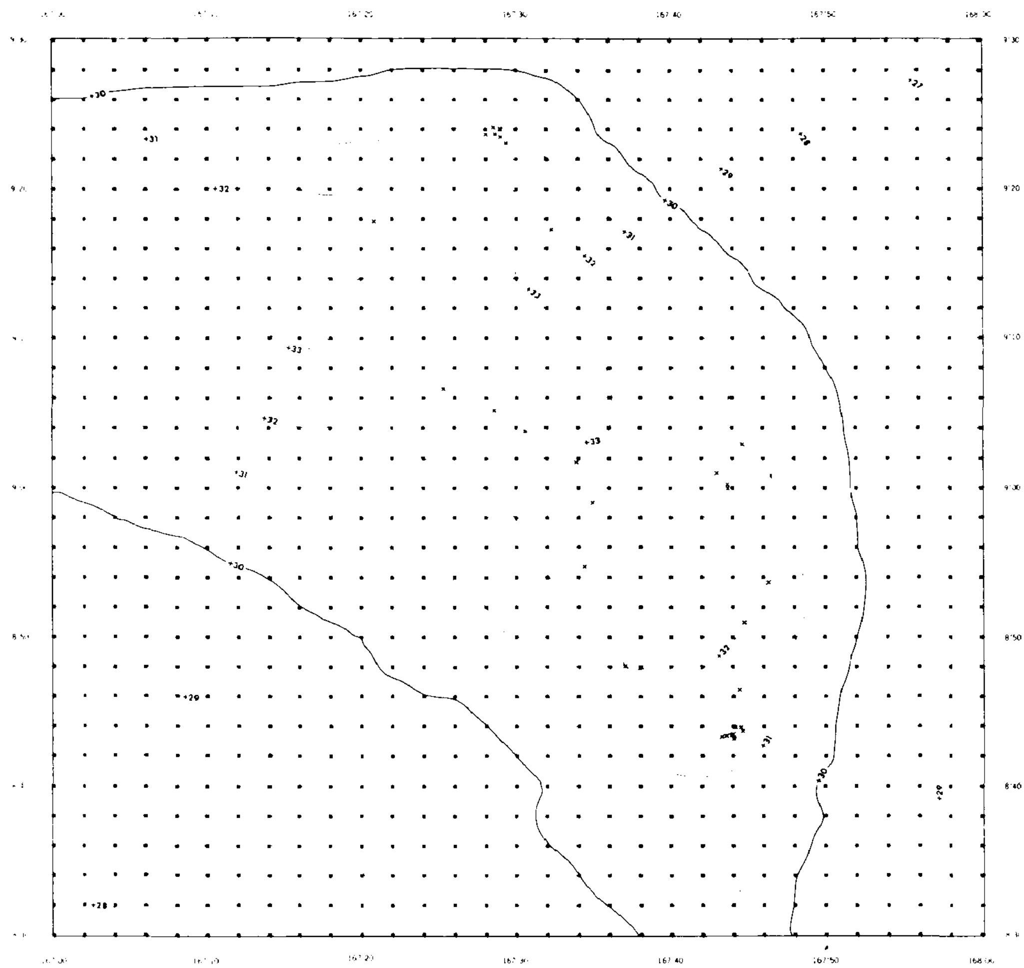

FIG. 9. — Geoid undulations in the Kwajalein Area, WGS-72, contour interval 1 m (computed directly without intermediate deflections). × : Deflection station. August 1975.

deflections observed on the islands. The accuracy of the charts is estimated at about 1″ of arc and half a metre respectively. The geoidal disturbance caused by the atoll is of the order of 10 metres.

The computations for the charts were programmed and carried out by Mr. Philip WYATT III.

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