AD-A102 381 CORNELL UNIV ITHACA N Y DEPT OF GEOLOGICAL SCIENCES F/G 8/5
ON THE COMPENSATION MECHANISM OF THE WALVIS RIDGE.(U)
DEC 79 C L ANGEVINE, D L TURCOTTE N00014-79-C-0569
UNCLASSIFIED NL

1 OF 1
AD A
102381

END
DATE
FILMED
8-81
DTIC

GEOPHYSICAL RESEARCH LETTERS, VOL. 7, NO. 6, PAGES 477-479, JUNE 1980

ON THE COMPENSATION MECHANISM OF THE WALVIS RIDGE

C. L. Angevine [redacted] D. L. Turcotte

Department of Geological Sciences, Cornell University, Ithaca, N.Y. 14853

Abstract. The Walvis Ridge in the south Atlantic Ocean is correlated with the geoid anomalies obtained from the GEOS 3 satellite. It is shown that the correlation is best explained by Pratt compensation with a depth of compensation of twenty to thirty kilometers.

Introduction

The origin of regions of anomalously shallow bathymetry remains a question of considerable uncertainty. Presumably the broad region of shallow bathymetry surrounding Iceland has its origin in processes associated with the ocean ridge. The Walvis Ridge, considered in this paper, and the Ninetyeast Ridge may have had a similar origin. Other areas of shallow topography such as the Hawaiian and Bermuda Swells are likely to have quite a different origin. Since most of these features are compensated the shallow bathymetry implies anomalously low densities at depth in the lithosphere. One possible explanation is the thickening of the oceanic crust. An alternative explanation is a decrease in the density of the mantle beneath the crust.

Two methods have been recently developed which provide information on mechanisms of compensation. The first is cross-spectral correlations of gravity with topography as developed by Dorman and Lewis [1970], Lewis and Dorman [1970], and McKenzie and Bowin [1976]. Using this method Detrick and Watts [1979] concluded that the eastern Walvis Ridge and the Ninetyeast Ridge are compensated by an Airy-type thickening of the oceanic crust, while the western Walvis Ridge is compensated by lithospheric flexure.

A second important source of information on the mechanism of compensation is the correlation of geoid anomalies with topography as developed by Ockendon and Turcotte [1977] and Haxby and Turcotte [1978]. Haxby and Turcotte [1978] showed that the region of anomalously shallow topography surrounding the island of Bermuda was the result of Pratt compensation with a depth of compensation near 100 km. Crough [1978], using the same method showed that the mechanism of compensation for the Hawaiian Swell was nearly identical to that for the Bermuda Swell. It is the purpose of this paper to apply the geoid-bathymetry method to the Walvis Ridge and to compare the results with those obtained by Detrick and Watts [1979].

Methods

Ockendon and Turcotte [1977] used the method of matched asymptotic expansions to express the geoid anomaly as a power series in the slope of the topography. Haxby and Turcotte [1978] applied this expansion to isostatically compensated regions. The density variation with depth was related to topography for Pratt and Airy compensation. For the case of Pratt compensated submarine topography the geoid anomaly becomes:

$$\Delta h = \frac{\pi G}{g} (\rho_o - \rho_w) Ww \qquad [1]$$

where G is the gravitational constant, g the gravitational acceleration, ρ_o the density of a reference column, ρ_w the density of sea water, W the compensation depth and w is the height of the anomalous topography. If the submarine topography is compensated by the Airy method, i.e., by crustal thickening, the geoid anomaly becomes:

$$\Delta h = \frac{\pi G}{g} (\rho_c - \rho_w) \left[2Tw + \left(\frac{\rho_m - \rho_w}{\rho_m - \rho_w}\right) w^2\right] \qquad [2]$$

where ρ_c is the crustal density, T the normal thickness and ρ_m is the mantle density. The relation between geoid anomalies and bathymetry will be analysed in accordance with equations [1] and [2] to determine the compensation mechanism of the Walvis Ridge.

Results

The direct determination of sea surface height by radar altimetry from the GEOS 3 satellite has made possible the construction of a contoured, marine geoid anomaly map [Brace, 1977]. The contoured geoid anomalies correlate well with the broad topographic features associated with the Walvis Ridge but not with narrower [<100 km] features. Narrow features appear to be smoothed out in the contouring process.

Four bathymetric profiles, WAL-1, WAL-3, WAL-8, and WAL-10, were selected from data presented by Detrick and Watts [Figure 5, 1979]. The first two profiles cross the eastern section of the Walvis Ridge while the last two cover the western section. Each profile was digitized after the sediment cover had been removed. The location of each profile was plotted on the geoid anomaly contour map and geoid profiles were constructed by taking data where contour lines intersected the profile traces. As examples, WAL-3 and WAL-10 are shown in Figure 1 with their corresponding geoid profiles. We assumed an equilibrium depth of 5 km for oceanic crust in the area and constructed a plot of geoid anomaly versus anomalous topography for each profile. A least squares line was then fit to each set of data and the geoid anomaly was adjusted so that the value of the intercept was zero.

The results of this study are given in

Paper number 80L0027.
0094-8276/80/0080L-0027$01.00

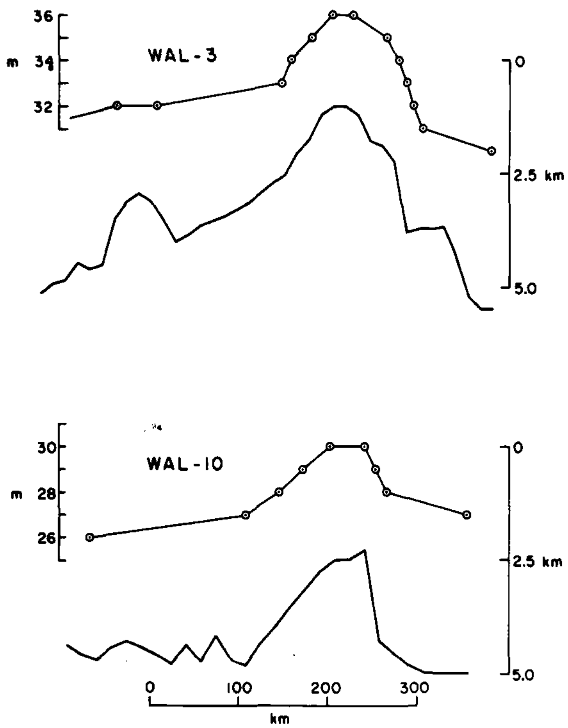

Fig. 1. Projected geoid and bathymetry profiles across the Walvis Ridge. Geoid data is from Brace [1977] and bathymetry profiles are from Detrick and Watts [1979].

Figure 2a for the eastern section of the Walvis Ridge and in Figure 2b for the western section. The dashed line in each plot represents the expected geoid anomaly for Airy-type crustal thickening as given by equation [2] taking $T = 6$ km, $\rho_m = 3.3$ gm/cm^3 and $\rho_c = 2.9$ gm/cm^3. The solid lines in each plot are for Pratt compensated topography as given by equation [1] taking $\rho_o = 3.3$ gm/cm^3 and $W = 20$, 30 and 50 km. The contoured geoid anomalies did not correlate well with either the Ewing seamount on WAL-1 or a seamount on the southwest portion of WAL-8. For this reason no data were taken from these areas.

Discussion

For three kilometers of anomalous topography [$w = 3$ km] it is of interest to compare the results of the two compensation models. For Airy-type crustal thickening the crustal thickness would be 27.8 km. For Pratt compensation of 25 km the Pratt density would be 2.94 gm/cm^3. Therefore the density required for Pratt compensation is nearly equal to the assumed density for the oceanic crust. Therefore the two methods of compensation give rather similar results.

An important assumption in the derivation of equations [1] and [2] is that density variations occur in only one horizontal direction. This may not be a reliable assumption for the western Walvis Ridge which consists mainly of seamounts and guyots.

However, the dependence of the geoid anomaly on topography for the Walvis Ridge, as illustrated in Figures 2a and 2b, favors Pratt compensation. There is no indication that the depth of compensation increases with the amplitude of the topography as is required by Airy-type crustal thickening. The depth of compensation ranges from 30 km [WAL-3] to 20 km [WAL-1] on the eastern section and from 25 km [WAL-8] to 27 km [WAL-10] on the western section.

We conclude that the topography of the Walvis Ridge is compensated by a Pratt-type mechanism with a depth of compensation between 20 and 30 km. This is consistent with results obtained by Chave [1979] for the Walvis Ridge. From Rayleigh wave dispersion, he found the ridge to be underlain by as much as 30 km of anomalous upper mantle rocks. The Ninetyeast Ridge may be compensated in the same manner. Bowin [1973] has modeled that ridge as normal oceanic crust underlain by gabbro and serpentinized peridotite to a depth of 25 km.

The results obtained from this study together with results obtained for the Bermuda Swell [Haxby and Turcotte, 1979] and the Hawaiian Swell [Crough, 1979] indicate that a variety of seafloor features may be caused by density anomalies in the upper mantle.

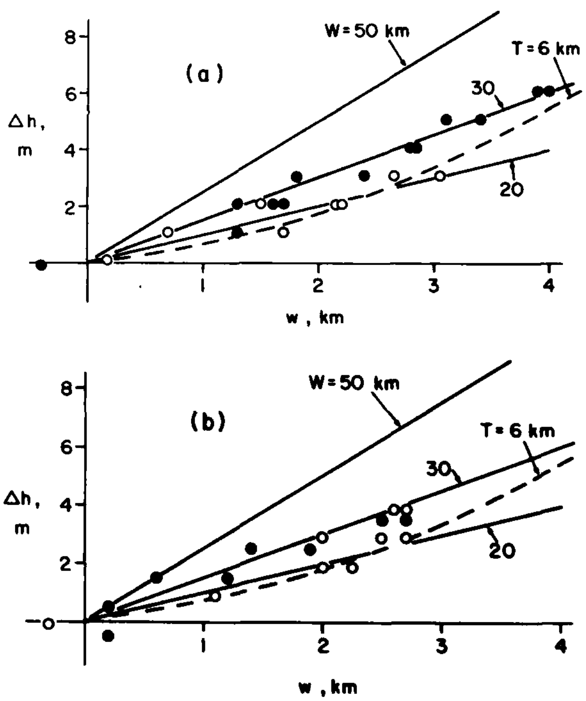

Fig. 2. Dependence of the observed geoid on anomalous topography for the Walvis Ridge. The dashed lines give the dependence predicted by crustal thickening [Airy compensation] while the solid lines represent the dependence predicted by Pratt compensation for several different compensation depths. (a) Data from eastern Walvis Ridge; profiles WAL-1 and WAL-3 denoted by open and filled circles respectively. (b) Data from western Walvis Ridge; profiles WAL-8 and WAL-10 denoted by open and filled circles, respectively.

Acknowledgements. This research has been supported in part by the Office of Naval Research under Contract #N00014-79-C-0569. One of us [C.L.A.] was supported by a Domestic Mining Fellowship from the Department of Health, Education, and Welfare. This is contribution 664 of the Department of Geological Sciences, Cornell University.

References

Bowin, C., Origin of the Ninetyeast Ridge from studies near the equator, J. Geophys. Res., 78, 6029-6043, 1973.

Brace, K.L., Preliminary ocean-area geoid from GEOS-III radar altimetry, Defense Mapping Agency, St. Louis, 1977.

Chave, A.D., Lithospheric structure of the Walvis Ridge from Rayleigh wave dispersion, J. Geophys. Res., 84, 6840-6848, 1979.

Crough, S.T., Thermal origin of mid-plate hotspot swells, Geophys. J. Roy. Astron. Soc., 55, 451-469, 1978.

Detrick, R.S., and A.B. Watts, An analysis of isostasy in the world's oceans 3: Aseismic ridges, J. Geophys. Res., 84, 3637-3652, 1979.

Dorman, L.M., and B.T.R. Lewis, Experimental isostasy, 1, Theory of the determination of the earth's isostatic response to a concentrated load, J. Geophys. Res., 75, 3357-3365, 1970.

Haxby, W.F., and D.L. Turcotte, On isostatic geoid anomalies, J. Geophys. Res., 83, 5473-5478, 1978.

Lewis, B.T.R., and L.M. Dorman, Experimental isostasy, 2, An isostatic model for the USA derived from gravity and topographic data, J. Geophys. Res., 75, 3367-3886, 1970.

McKenzie, D.P., and C. Bowin, The relationship between bathymetry and gravity in the Atlantic Ocean, J. Geophys. Res., 81, 1903-1915, 1976.

Ockendon, J.R., and D.L. Turcotte, On the gravitational potential and field anomalies due to thin mass layers, Geophys. J. Roy. Astron. Soc., 48, 479-492, 1977.

(Received December 10, 1979;
accepted January 8, 1980.)