INTERPRETATION OF THE GEOID

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That there were long wavelength non-hydrostatic components in the Earth's gravitational field was first suggested by Jeffreys who fitted 2,000 determinations of g over continents and oceans by spherical harmonics up to, and including, the third degree terms. He found 10-20 mgal anomalies --- negative over the Indian Ocean and the Caribbean and positive over Europe and the West Pacific. It had been taken as an axiom that only short wavelength anomalies existed, so that his discovery was widely discounted because of the poor global distribution of his data. His view was however vindicated by the first satellite observations. On superposing the first satellite geoid determined by Iszak upon Ootilla's geoid which was based, as Jeffreys, on surface gravity determinations (both of which included 4th degree terms), good agreement was observed except over the Pacific area of the globe (Runcorn, 1965). The poor agreement over the Pacific was interpreted as the result of inadequate observations there. Many geoids were determined from satellite observations, including Doppler measurements, and workers in this field followed Jeffreys in their explanations, i.e., that the geoid was the result of density differences in the mantle maintained since the primeval Earth by its finite strength. Various models based on this assumption were developed.

To explain continental drift, I had to find a different explanation for the geoid and proposed (Runcorn, 1963, 1964, 1965, 1966, 1967a) that the geoid is caused by the density anomalies which provide the buoyancy forces driving convection. I showed that the acceleration, inertia and Coriolis terms in the Navier-Stokes equation for mantle flow were negligile compared with the viscous term, assuming the flow velocities are of the order of those for continental drift. The long wavelength gravity anomalies are of the order of 10^{-5} and are consistent with buoyancy forces of the order of 10^{-2} dynes/cc.

I also pointed out that the positive anomalies seemed to be associated with the trenches, a correlation which has become clearer in the more recently-determined geoids, and the negative anomalies were near the extensional features of the crust; this correlation is now known not to be particularly good.

I discussed the possibility of a mathematical connection between the geoid coefficients and the spherical harmonic components of the flow (Runcorn, 1966, 1967 a, b). Clearly the positive and negative anomalies in the geoid are associated with the descending and ascending limbs of the convection current but there has been dispute of the sign to be attached to this association. In the simplest case of constant viscosity, no slip boundary conditions and g proportional to the radius (which is nearly the case for the Moon), I had proved (Runcorn, 1967b), in explaining the Moon's figure, that the negative gravity anomaly was associated with the downgoing stream. I conjectured that in the Earth the more complex situation resulted in the opposite association. In general I argued that the balance between the extra mass associated with the upward surface distortion over the uprising current of hotter and less dense material was one which could yield either sign of the gravity anomaly depending on the conditions. In the case of the Moon the "bulge" towards the Earth is associated with positive gravity.

There is now general agreement that the low harmonics of the geoid are due to mantle convection, but how convection coupled with the plates is obscure. At first it seemed plausible to expect a close association between the ocean ridges and the upwelling mantle convection, but there was serious objection to this in respect of the ridges surrounding Africa. Plate tectonics showed that the phenomena at the ridge would result simply from the moving apart of the plates, hence the convection cells inferred from the geoid do not have a simple one-to-one correlation with the plates. The plates move, on the convection hypothesis, by the net force arising from the complex pattern of viscous drag on the lower lithosphere boundary and this can be calculated. The forces appear to be of the right magnitude and direction to initiate the breaking up of Gondwanaland, if it is supposed that the mantle convection pattern is stationary over the last 100-150 My. In this way convection seems a more profitable geophysical theory than gravity sliding, as it offers the possibility of making important use of the geoid data.

References

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