Gravity Interpretation—Ten Points

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Introduction

Gravity interpretation has shown a capacity for growth over the years but has it achieved much progress? With gravity there can be no exact answers to geological problems but is it somewhat similar to gardening, football and horseracing where anyone can assert his own theories with breezy panache, if not confidence, fairly certain that he will not be contradicted? At least with gardening *et al.* a result does eventuate; but gravity, in common with much of geophysics, often leaves hypotheses untested.

In gravity modelling in crustal studies we try to elicit geological information at depth from our gravity readings which in the two-dimensional case are often taken over crustal features of great importance. Modelling means the forward problem where anomaly causing density inhomogeneities are postulated and their gravity effects computed often with the Talwani *et al.* (1959) procedure or some other algorithm. Cordell and Taylor (1971) have pointed out that geophysical modelling entails the concept of abstract, bulk physical properties representing physical quantities which are demonstrably variable, accordingly it behooves us not to try to force too much into an interpretation of gravity data.

Thinking about gravity interpretation problems led me to group my ideas on the subject under ten headings covering problems and pitfalls to concern the interpreter. These ten points are discussed briefly hereunder:

1. Principles

The fundamentals of gravity modelling are covered in many places in the literature; a good paper is Al-Chalabi's (1971) study of nonuniqueness. The problem of ambiguity is a major one in gravity work; it has as contributing factors: inherent non-uniqueness following from potential theory, incomplete data, observational errors and inadequate models. An adequate model is one which gives a summary of the essentials of the postulated feature. A model can only be a simulacrum as the number of density boundaries is never known and may be very large. Such boundaries are assumed to be straight and to separate homogeneous regions, these assumptions may be gross simplifications of the true subsurface. The assumption of two dimensionality may contribute to the ambiguity as conditions along the y axis may not be sufficiently uniform.

2. Procedure

The usual procedure in modelling is to assume density contrasts and one or more depth variables and to vary the other parameters until the model and observed data "agree" according to some criteria. Following Hjelt (1971) we can regard the observed anomaly as the sum of two terms: the theoretical (computed) anomaly of the assumed model bodies and an error term; it is the aim of interpretation to minimise the error term. The theoretical anomaly is a function of an interpretation parameter whose components are the position, geometry and density of the anomalous bodies. Interpretation errors can arise from the choice of an inappropriate model and also from noise in the form of deterministic or random disturbing fields. The number of papers in the literature attests to the considerable effort that has been devoted to estimating, removing or filtering out these unwanted fields. Profiles of gravity values are much used in the interpretation procedure; often these profiles have many interpolated, not measured, gravity values on them. The profiles may contain sparse data and may be incomplete, noisy and not quite representative of two dimensional features. These factors can greatly vitiate our interpretations.

3. Plausibility

We should beware of forcing our geological thinking onto the Procrustean bed of false models. Whilst novel and startling models are to be encouraged they need to be plausible geologically. All gravity interpreters have gone through the sad experience of emoting over the recumbent bodies of pet models on which much time was lavished; they had to be discarded because by successive modification they eventually become unreasonable in gross geological terms. Despite this it should be stated clearly that modelling is a protean procedure; its very versatility is it strength.

4. Philosophy

If we look at the philosophical side of things we realise that modelling interpretations need to be criticized and to be testable in some way i.e. we need to be able to verify or falsify our theoretical model. Followers of the eminent philosopher of science Sir Karl Popper (1968) would point out that ultimate verification is not possible but conclusive falsification is. Gravity workers should ask themselves "Under what circumstances would I admit that my model is untenable?" or "What corroboration (in the form of auxiliary geological, geophysical or drilling data) does my model require?" On the one hand, little is learned from the falsification of a bold model (just another crazy idea shown to be wrong) or from the confirmation of a cautious conjecture (a "me too" very marginal contribution to well established theory). On the other hand confirmation of novel models resulting from bold predictions and/or the falsification of cautious conjecture on an apparently free-from-risk theory are truly informative. Such achievements have a profound effect on the web of theory in which we work. I reckon that although gravity may be *regarded* as an important tool in crustal studies there are difficulties in assessing its real contribution. At the moment it only seems clear that we do enlarge background theory and set up hypotheses for consideration. While gravity modelling has produced useful results, especially in sedimentary basin studies, it certainly does not seem to have produced any great impact on major earth science theory.

5. Petrophysics

In gravity modelling knowledge of the physical properties of rocks is of vital importance. There is a great amount of work to be done on the measurement not only of densities but also of magnetic susceptibilities, thermal conductivities and velocities under various P-T conditions. We rely heavily on other geophysical methods to provide constraints in setting up and testing models. It is worthy of note, as Zietz and Bhattacharyya (1975) have pointed out, that practically nothing is known of the physical characteristics of the rocks that produce a magnetic anomaly although one would never infer this from the plethora of papers on magnetic interpretation methodology in the geophysical literature. The value of seismic velocity data in constraining gravity models can be overplayed but its importance is indisputable when properly used.

6. Petrology

Auxiliary geological control is vital for successful gravity interpretations. Petrological investigations of deep drill core and artificial laboratory melts together with theoretical studies provide important information for model construction. Unfortunately many geophysicists ignore or disdain petrology; this is regrettable, after all, we are dealing with rocks.

7. Perception

There is more to seeing than meets the eyeball; we are familiar with optical illusions causing us problems in perception. Natural scientists know that the Almighty did not make it easy to perceive natural things; this contrasts with man made objects, they are invariably easy to perceive. We know the difficulty of perceiving a gravity anomaly in a complex noisy background. The problem of perception is more than this. Perception cannot proceed without expectations built into the mind; these expectations derive from familiar experiences. What happens if our concepts and ideas, derived from experience, are faulty? There may be a tendency to see in gravity data what one expects rather than what is there — we may tenaciously cling to misguided models in our gravity work. Even without perception problems observations are theory dependent and thus fallible e.g. *vide* Chalmers (1976). "This gravity anomaly will be useful to model" is a statement common to all interpreters yet it presupposes a large body of physical, mathematical and geological theory all of which may not be correct. Critical attitude to and comprehension of subsumed theory change from interpreter to interpreter. It is this very variety of talents that slowly leads to advances in our knowledge.

8. Parsimony

The Principle of Parsimony, Occam's Razor, has greatly influenced scientific thinking for six centuries. "Entities are not to be multiplied without necessity" is a dictum which forbids unnecessary embellishments i.e. the assumption of superfluous facts. However it is not implied that natural laws or systems are simple. The Principle of Parsimony should be kept in mind by gravity interpreters; it has obvious applicability.

9. Petitio Principii

We should be wary of begging the question in gravity modelling. Founding an interpretation on a basis that requires just as much proving as the conclusion itself is not an uncommon situation e.g. in contentious assumptions of regional fields and isostatic mechanisms or in inversion problem definition and parameterization.

10. Perfection

I consider that perfection in modelling is probably unattainable. Although paragons may not exist we should be proud of the advances in the interpreter's art brought about by sophisticated computer modelling that has facilitated insight into regional structure and geology where previously there was little or nothing. However it would be naive to think that our current theories, based on geophysical modelling, will survive intact. It is necessary to remember that the history of science is the history of superseded theories.

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