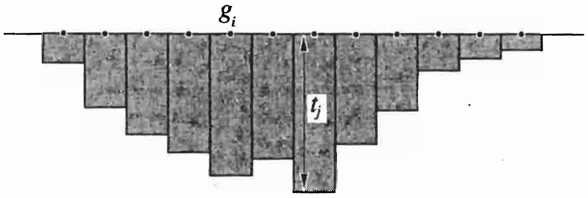

Fig. 10.5. Cross-sectional model of a sedimentary basin, as used in the method described by Bott [35]. Basin is assumed to be infinitely extended perpendicular to profile. Basin is divided into rectangular blocks, one block per field point.

Iterative Methods

As discussed in Chapter 9, forward models are developed by a three-step process. An anomaly is calculated from a model, the calculated anomaly is compared with the observed anomaly, and the model is adjusted in order to improve the comparison. The three-step process is repeated until the modeler is satisfied with the results. A number of computer-based algorithms use the same logical process, but we will consider them inverse methods here because the model is derived automatically with minimal control by the modeler.

An early example was described by Bott [35] to estimate the cross-sectional shape of sedimentary basins. In this method, the basin is assumed to be infinitely extended in one direction and to have uniform density contrast $\Delta\rho$ with respect to surrounding rocks. The basin is divided into N rectangular blocks infinitely extended parallel to the basin and extending to depths t_j, $j = 1, 2, \ldots, N$, as shown in Figure 10.5. Only N field points, g_i, $i = 1, 2, \ldots, N$, along a profile perpendicular to the basin are considered, and each field point is centered above a block. An initial guess is made for the thickness of each block by assuming each block is a slab infinite in all horizontal dimensions. Equation 3.27 provides the thickness of an infinite slab based on a single gravity measurement,

$$t_j^{(1)} = \frac{g_j}{2\pi\gamma\Delta\rho}, \qquad j = 1, 2, \ldots, N\,.$$

The superscript indicates the level of iteration, the first iteration in this case. Then a three-step procedure is conducted to iteratively modify block thickness. The steps are as follows, where k denotes the number of the iteration:

From: Blakely, R.J., 1995, Potential Theory in Gravity & Magnetic Applications, Cambridge U. Press, 441 p. Recommended!

1. The field $g_j^{(k)}$ is calculated at each observation point due to all blocks, assuming thicknesses from the previous iteration. In the original work of Bott [35], this calculation was done in an elaborate way in order to save computer time. With modern computers, algorithms that implement equation 9.2.2 would be appropriate.
1. The residual $g_j - g_j^{(k)}$ is found at each observation point.
2. The infinite-slab approximation is used again to estimate a new set of thicknesses. The correction to each block is calculated under the assumption that the block is an infinite slab of thickness required to accommodate the residual; that is, the new thickness is

$$t_j^{(k+1)} = \frac{(g_j - g_j^{(k)})}{2\pi\gamma\Delta\rho} + t_j^{(k)} .$$

These three steps are repeated until the modeler is satisfied that convergence is met.

Cordell and Henderson [71] improved on this method in a number of ways. They employed data measured on or interpolated to a rectangular grid so that sources could be investigated in three dimensions. Sources are modeled as a bundle of rectangular blocks, one block per gravity value, as shown in Figure 10.6. Block thickness t_j, $j = 1, 2, \ldots, N$, is defined relative to a reference surface, which could represent, for example,

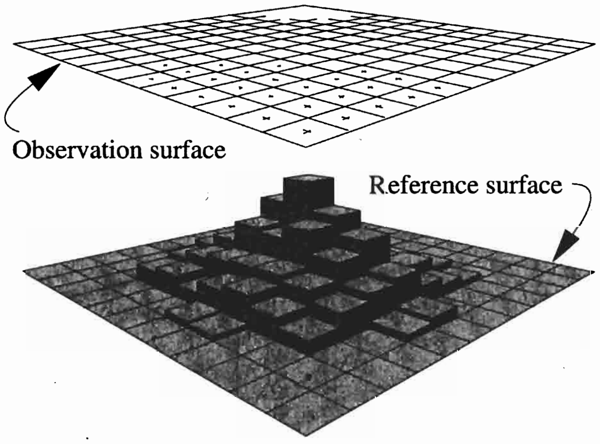

Fig. 10.6. Three-dimensional model for the iterative method of Cordell and Henderson [71]. Block thicknesses are relative to a common reference surface. Observed gravity is measured on a rectangular grid.

the top or bottom of all blocks. Similar to the method of Bott [35], initial block thickness is estimated by assuming each block to be an infinite slab. However, the ratio

$$\frac{t_j^{(k+1)}}{t_j^{(k)}} = \frac{g_j}{g_j^{(k)}}$$

is used to revise block thickness rather than an infinite-slab approximation. As before, the three-step procedure of calculation, comparison, and adjustment is carried out automatically at each iteration. This algorithm has been implemented in a Fortran program described by Cordell [65], and a similar version is available in a form compatible with microcomputers (Cordell, Phillips, and Godson [73]).

A somewhat different approach was described by Jachens and Moring [137]. Like the two previous methods, their method estimates the shapes of basins filled with low-density deposits, but their method takes into account the possibility that underlying basement rocks may have variable density. Their method proceeds by separating gravity measurements into two components: the component caused by the basins themselves and the component due to variations in density of underlying basement. Let g represent observed gravity after regional fields are removed (isostatic residual gravity (Chapter 7) would be an appropriate starting point) and let $g = g_\mathrm{b} + g_\mathrm{d}$, where g_b is the anomaly caused by underlying basement and g_d is the anomaly caused by low-density deposits. Then the following steps are conducted:

1. The first iteration assumes that g_b is defined by just those stations located on basement outcrops and calculates a smooth surface through just these data, as shown by the dashed line in Figure 10.7. This constitutes the first approximation $g_\mathrm{b}^{(1)}$ to the basement field g_b; it is only a crude approximation because stations will still include the effects of nearby basins. These effects are to be removed in subsequent iterations.
2. The first approximation to g_d is found by subtracting $g_\mathrm{b}^{(1)}$ from observed gravity g. This new residual $g_\mathrm{d}^{(1)}$ is used to find a first approximation to basement depth using the infinite slab approximation, similar to the method of Bott [35].
3. The gravitational effect of the basins can then be calculated by a variety of methods. Jachens and Moring [137] used the method of Parker [204], to be discussed in Chapter 11. This result is subtracted

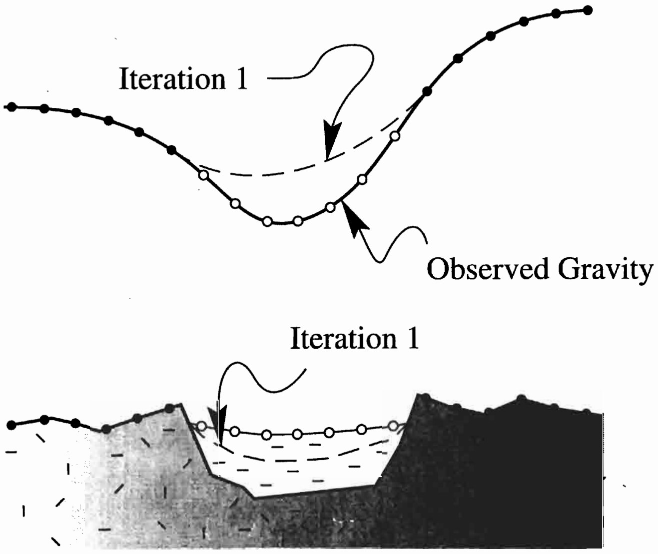

Fig. 10.7. Separation of residual gravity into two components, the component caused by density variations within basement and the component caused by basin fill. Closed dots signify measurements made on basement outcrops, open circles on sedimentary or volcanic cover.

from basement gravity stations to produce the next approximation for basement gravity $g_b^{(2)}$.

These three steps are repeated until the solution converges to the satisfaction of the modeler. Two products result: the shape of low-density basins and the gravitational attraction of basement without the effects of the basins. The method was applied to the entire state of Nevada by Jachens and Moring [137] in order to analyze the shape and distribution of basins in this part of the Basin and Range (Blakely and Jachens [31]), and a similar method was used by Saltus [250] to estimate the thickness of concealed sedimentary deposits beneath the Columbia River Basalt Group in Washington State.

Linearizing the Nonlinear

Although potential fields depend nonlinearly on certain source parameters, this dependence is nearly linear with respect to sufficiently small changes in those parameters. For example, the potential field of a polygonal prism is related to the coordinates of the corners of the polygon