GRAVITY

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1. DESCRIPTION

Gravity surveys measure variations in the gravitational attraction of the earth. These minute changes are caused by local variations in the densities of rocks near the surface (Telford, et al., 1990), as well as a variety of known factors. These factors include the latitude and elevation of the observation point, topography of the surrounding terrain and the tidal effect of the sun and the moon. Corrections can be made for known causes of the variations and the anomalies that remain provide the information about the changes in density that are of interest to explorers (Telford, et al., 1990).

These anomalies in the earth's gravitational field can in some cases be used to define the thickness and extent of the regolith, due to the strong contrast in density between the regolith (including *in situ* weathered bedrock) and fresh bedrock, and in defining regolith features such as palaeochannels. Further contrasts may occur between regolith materials that are developed *in situ* versus those that have been transported, due to the expected increase of porosity in the latter.

Berkman (1995) quotes examples of typical bulk densities for a variety of transported materials including alluvium, gravels (≈ colluvium), loess (≈ parna), sand, mixed sand and clay, and soils; values range from 1.00 to 2.20 t/m^3.

Clays, which represent several types of regolith materials, have a range of 1.63 to 2.60 t/m^3 (Berkman, 1995), which is considerably higher than many other types of transported regolith. Silcrete has a density of 2.45 to 2.60 t/m^3 (Direen, 1999), whereas bauxite is in the range of 2.30 to 2.55 t/m^3. The two main types of ferricretes ("laterites") are pisolitic, and massive-ferruginous (Ollier and Pain, 1996, Butt, 1990). These types correspond to two reported densities for these materials: 1.00 to 2.60 t/m^3 for the poorly consolidated pisolitic ferricrete (Emerson, 1990, Butt, 1990), and densities up to 3.00 t/m^3 for the massive ferruginous variety (Butt, 1990).

No direct bulk density data are available for the other two widespread specific types of duricrusts- Regolith Carbonate Accumulations (RCA) and gypcrete- highlighting a need for further petrophysical research to be undertaken on these materials. The upper limit on densities of these types of regolith is provided by assuming a composition of 100% of the constituent mineral phases, calcite and gypsum, which have grain densities averaging 2.70 t/m^3 and 2.35 t/m^3 respectively. Mann and Horwitz (1979) showed variable compositions for RCA in Western Australia, containing gypsum, dolomite, calcite and quartz in variable abundances. They likened the composition of RCA to limestone, implying densities of 1.74-2.76 t/m^3 (after Berkman, 1995). P-wave velocities of > 5 500 m/s for RCA (quoted by Hawkins & Whitely, 1979) are consistent with densities of 2.65 t/m^3 using empirical conversion methods (eg. Direen, 1999).

A graphical summary of the bulk density data is provided in Figures 1a and 1b. The averaged properties (Figure 1b), taking into account both the dry density minima likely to occur in regolith above the water table, as well as the higher bulk wet values, show a strong difference between transported and residual regolith varieties. The transported varieties have lower average densities of 1.67 to 1.95 t/m^3, whereas average residual regolith densities vary between 2.35 and 2.80 t/m^3.

In Papp, É. (Editor), 2002, *Geophysical and Remote Sensing Methods for Regolith Exploration*, CRCLEME Open File Report 144, pp 100-104.

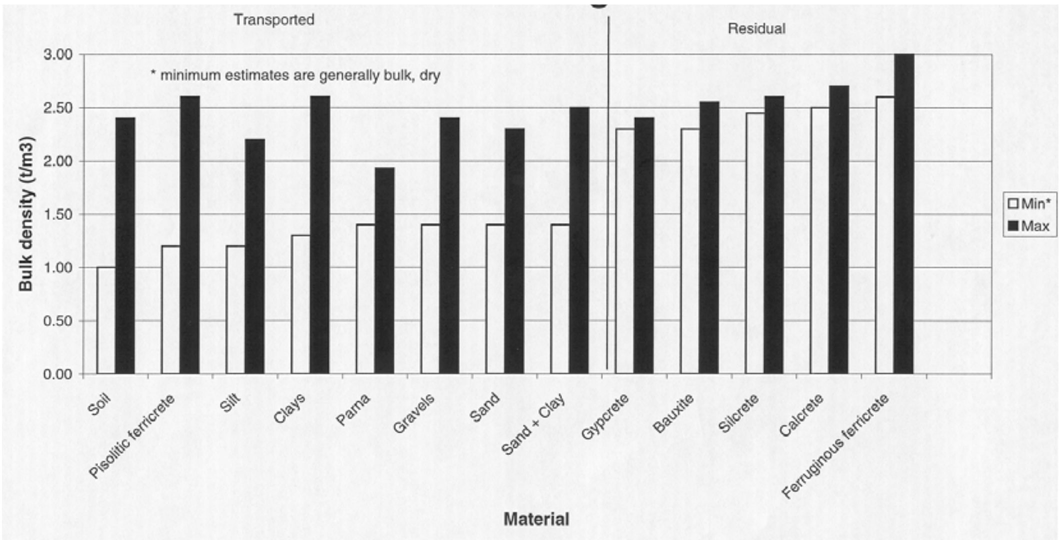

Figure 1a. Bulk density ranges for some common Australian regolith materials.

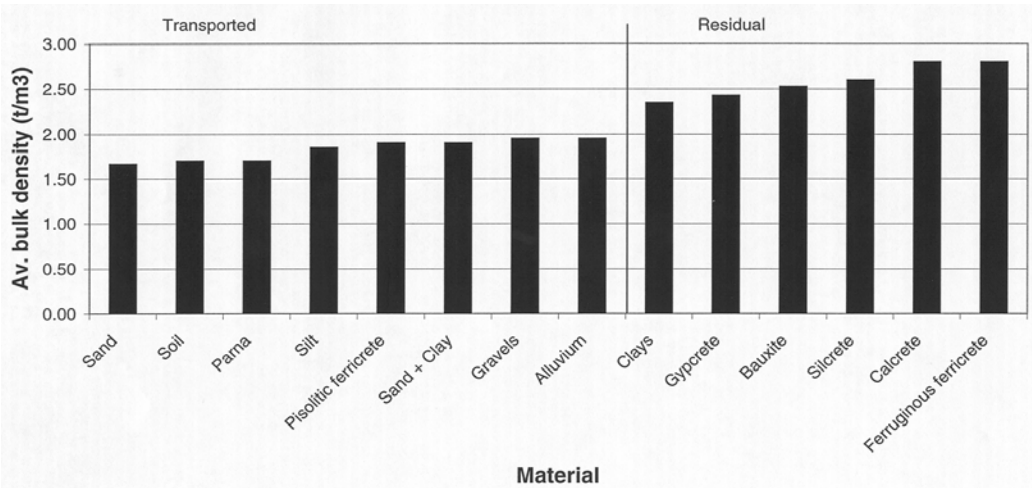

Figure 1b. Average bulk density ranges for some common Australian regolith materials.

2. FIELD PROCEDURES

The major consideration when planning a gravity survey is the location and spacing of the stations. The size, type, depth and density contrast of the feature being defined will determine if the survey is laid out as a grid, a traverse or a series of traverses. These factors will also determine the extent of the grid or traverse and the station spacing. For example, sampling theory dictates that station spacing should be no greater than half the expected width of any bodies being defined. In the case of a 100 m wide palaeochannel, the absolute maximum station spacing which could expect to define the position of the feature is 50 m; obviously, if more detail is required, a closer station spacing would be used.

Another consideration is the horizontal and vertical positional accuracy of the gravity stations. The vertical accuracy of the stations is most important because an error of 0.3μm/s^2 will be caused by each decimeter of error in the height estimate. This scale of error may be greater than the size of the anomaly of interest. To obtain this level of accuracy it is necessary to use optical (spirit level) surveying or precise differential GPS (Global Positioning System) techniques.

General field procedures for gravity surveys involve taking readings in loops where the first station is repeated after a few hours to quantify the drift of the gravimeter and allow for correction of this in post processing. These techniques are described in most geophysics texts such as Telford, et al. (1990).

3. DATA PROCESSING

The acceleration due to gravity depends on latitude, elevation, topography of the surrounding terrain, tides, and density variations in the subsurface (Telford, et al., 1990). Corrections are made during processing to remove the effects of latitude, changes in elevation and topographic effects. The effect of tides can be mathematically modelled and removed during processing, or they can be assumed to occur as a linear drift over a few hours and removed along with the instrumental drift as mentioned previously in the field procedures. The anomalies in the earth's measured gravity acceleration remaining after these corrections have been applied are due to density variations in the earth's crust and can provide information about the regolith. Further descriptions of the standard corrections and how they are applied can be obtained from texts such as Blakely (1996), Telford, et al. (1990).

4. DATA INTERPRETATION

Gravity anomalies remaining after appropriate corrections have been applied represent the superimposed effect of density changes at various depths. The smoothness or apparent wavelength of the anomaly is generally an indication of the depth of the source of the anomaly: the smoother the anomaly, the deeper the source. In regolith studies it is necessary to separate these longer wavelength anomalies from the sharper, shorter wavelength anomalies that are due to near surface sources. Telford, et al. (1990) describes methods to remove the longer wavelength deeper anomalies, known as the regional, leaving the shorter wavelength residual anomalies.

For a given gravity anomaly, an infinite number of density distributions can be found to produce the same anomaly. Hence some knowledge of the geology of the area is necessary for a good interpretation of the data.

5. APPLICATIONS

The gravity method can be applied to many problems in regolith studies such as determining depth to bedrock or depth of weathering, defining palaeochannels and mapping sinkholes and collapse structures. Smyth and Barrett (1994) described how gravity can be used to define palaeochannels in the search for gold and uranium in the Yilgarn Block of Western Australia. They concluded that gravity, followed by EM soundings and drilling, proved to be a cost-effective exploration approach.

Qureshi (1979) used a detailed gravity survey of the Woy Woy district in NSW to determine the thickness of young unconsolidated sediments overlying bedrock. This study showed the applicability of the gravity method in a built-up area where many other geophysical methods cannot be applied.

Figure 2 shows how a gravity profile measured along a seismic line in the Broken Hill region of NSW has been modelled to estimate the thickness of the weathered zone. The broken line joining the square symbols in the top half of Figure 2 is the observed gravity profile. The solid line is the profile calculated from the model in the bottom half of Figure 2. The model can be derived from whatever information may be available such as surface mapping, drill hole data, seismic data or other geophysical information. In this example seismic refraction and drilling data were used to constrain the model. The observed gravity low is interpreted to be due to a zone of weathered material that has a lesser density than that of the fresh bedrock.

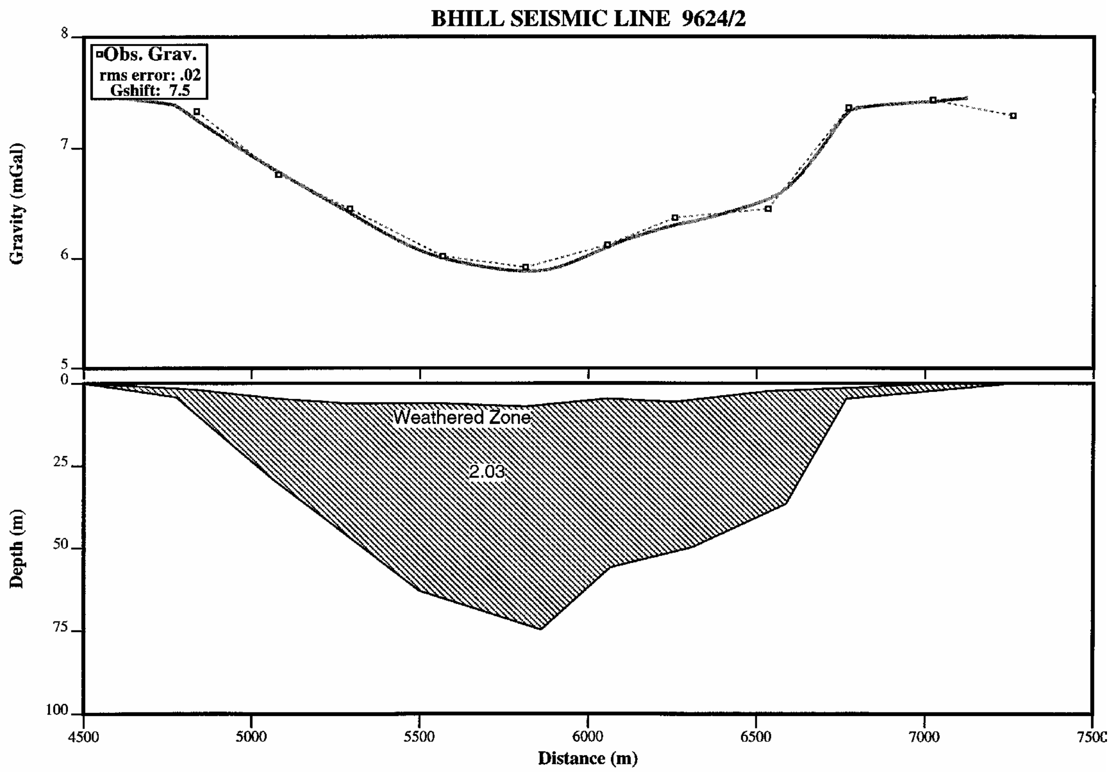

Figure 2. Gravity profile and 2D model of a palaeochannel filled with alluvium of density 2.03 t/m^3 showing the depth to fresh bedrock of density 2.67 t/m^3. This example is from GA seismic line 9624/2 south of Broken Hill, described by Gibson, et al. (1997) and Foster and Shirtliff (1998).

6. PROBLEMS, LIMITATIONS

Many geological conditions can complicate the gravity response (Smyth and Barrett, 1994). These can include insufficient density contrast between bedrock and the regolith, local variations in bedrock density and high regional gravity gradients. In addition, poor field technique and data reduction methods can introduce errors that may obscure many geological features of interest.

7. SURVEY ORGANISATIONS

Many geophysical contracting companies provide gravity surveying services. With the advent of GPS surveying, a number of geodetic survey companies have also specialised in gravity surveying.

Geoscience Australia (GA) maintains the reference standards for gravimetry in Australia through the Australian Fundamental Gravity Network. This is a network of about 800 gravity observations at about 250 locations throughout Australia. These observations are the reference values used as control for exploration surveys and engineering standards. GA also maintains the Australian National Gravity Database of gravity surveys carried out in and around Australia. Information on gravimetry in Australia can be obtained from GA's website at http://www.ga.gov.au.

8. COSTS

Prior to the introduction of GPS technology, it was necessary to use optical surveying techniques to obtain the height accuracy necessary for detailed gravity surveys. This was costly and time consuming. GPS surveying has greatly reduced the cost of detailed gravity surveys in many cases by allowing one observer to obtain a gravity measurement and an accurate position and height at the same time.

Current costs (as of April 2002) for gravity surveys range from \$10/station for surveys with station spacing in the order of tens of metres to \$100/station for surveys with station spacing in the order of a number of kilometres and where helicopter transport is involved.

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