DETERMINATION OF DENSITY FOR REDUCTION OF GRAVIMETER OBSERVATIONS*

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ABSTRACT

This paper outlines a method whereby the density factor used in the Bouguer correction for elevation of a gravity station may be determined. Frequently in the past it has been the practice to assign a density factor based on measurements made upon samples of surface materials in such manner as to give the density in situ, depending upon the judgment of the field man to select samples representative of the near-surface materials. At best, this is a cursory determination which only fortuitously might lead to the correct density for large topographic features. The method outlined here in effect weighs the topography by gravimeter observations taken along a profile crossing the feature. From these data the effective density of the material comprising the topographic feature is determined by a simple graphical method.

Development of gravimeters in the past three years has produced field instruments which make reliable observations of gravity differences to a precision of 0.1 mg. or better. If the final gravity map is to retain all of the precision of the field observations, it is necessary that all reductions be made to a precision somewhat better than that of the original field observations themselves.

The elevation correction includes two factors; that is, (1) a correction for the so called "free air" effect which takes account of the fact that the attraction of the earth on points at different elevations varies appreciably because of the variation in their distance from the center of the earth; the theoretical value of the coefficient for this term is accurately known from the size and mass of the earth, but the actual value varies slightly from this theoretical value,[1] and (2) the "Bouguer"[2] correction which takes account of the attraction on the station of the material between the elevation of the station and that of the base point to which the elevation corrections are made; this term depends upon the density of the surface material.

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[1] Sigmund Hammer, Investigations of the Vertical Gradient of Gravity, Trans. of the Am. Geophys. Union, 19th Annual Meeting (1938), pp. 72–82.

[2] The "Bouguer" correction as used in this paper is the correction for the attraction of the topography as approximated by an infinite horizontal slab of thickness h, where h is the difference between the elevation of the station and that of the base level to which the reductions are made. If this approximation is inaccurate a "terrain correction" must be made, such as is described in the following paper in this journal.

The coefficient for the Bouguer correction is

0.0127σ in mg. per ft., or

0.0418σ in mg. per meter.

where σ is the density of surface material (within the elevation range of the topography). From these coefficients it is evident that if stations differ in elevation by, say, 100 ft., an error in density of 0.1 cgs. units will make an error of about .13 mg. in the reduction of the station. The precision with which the density of the surface material is required depends, of course, upon the range in elevation of the gravity stations. From the example just given it is evident that if the topography is such that the stations may vary by 100 ft. or more in elevation, the density should be known to better than 0.1 cgs. unit if the reductions are to retain a precision greater than 0.1 mg.

Density can be determined by actually making density measurements of samples of the surface material. This, however, is not very satisfactory because the densities of individual samples usually vary over a wide range so that a large number of samples is required for a reliable average value. Also, it is often difficult to get samples which are far enough below the weathered surface to be typical of the rock material within the range of the topography. This is particularly true if there are alternating hard and soft members of the surface formations. The soft members (usually shales) may be covered and the natural outcrops are the hard members, which commonly are typical of only a small fraction of the total section.

The purpose of this report is to describe a method which has been found quite satisfactory for determining density by use of the gravimeter itself. The method seems quite obvious and probably is being used by others but the writer has been unable to find reference to it in geophysical literature.

The density is measured simply by making a special traverse of gravimeter stations across a topographic feature, reducing these stations for several different densities, and finding the density value for which the reduced curve has a minimum correlation with the topography. In this method the sample is an entire topographic unit and the value obtained is the average density of all material within the elevation range of the gravity traverse.

It is essential that the topographic feature selected for a density profile should have at least one reversal; that is, it should be either over a hill or across a valley. A simple slope cannot be used because it is not possible to separate the contribution of density to the slope of the observed gravity profile from a possible regional slope of the properly reduced gravity curve. A hill seems to be somewhat preferable to a valley because the density is more apt to be uniform and typical of the topography as a whole, for valleys frequently contain alluvial material, the density of which is different from that of the general rock section. Rather gentle topographic slopes are preferable because steep features usually will require terrain corrections if the precision of the reduction is to be held to considerably better than 0.1 mg. However, steep features can be used if adequate terrain corrections are made. Obviously, the hill or valley selected must not be associated with geologic structure which might cause a gravity anomaly coextensive with the topographic feature.

In general, the relief of the topographic feature measured should be comparable with the average relief of the topography within the general area for which the density is desired. From an operating standpoint, the ideal feature for a density profile is a gentle hill with a relief of the order of 50 to 150 ft. and a width of $\frac{1}{2}$ mile to one mile preferably, of course, crossed by a road. Relief of this magnitude will require little, if any, terrain correction if the slopes are regular. Gravity stations should be set at such intervals that there are several stations to define the gravity curve across the hill or valley. The gravity differences may be determined with reference to one of the stations of the traverse itself. They should be as accurate as feasible. The relative elevations of the stations, of course, must be determined to a precision of about 1 ft. or better.

The analysis of a density traverse consists primarily of plotting profiles of the elevations and of the gravity values with the usual reductions for latitude and free air corrections and with different curves for the Bouguer corrections made with different densities. Under favorable conditions a quite definite selection can be made of the density which comes closest to giving reduced gravity values on a straight line across the topographic feature. Frequently there are some stations which do not fit into a smooth curve for any density, having departures up to a few tenths mg. Our experience indicates that these irregularities are caused by real inhomogeneities in the material as check observations have confirmed the gravity differences. In such cases, it seems best to ignore such points and use, as the density, the value which will give the straight line (if the profile is short, or a smooth curve if long) for which the departures of individual points are a minimum.

If the density profile crosses a geologic contact it is possible that different parts of the curve will indicate a real change in the density of the material sampled. For this reason, it is sometimes preferable to run density profiles along the strike and avoid crossing geologic contacts if suitable topographic features can be found, and to make separate profiles on exposures of beds of different lithology.

The density profile has a theoretical advantage over the sample method of determining densities. In the sample method the reduction depends on using correct values for the free air coefficient and for the calibration of the gravimeter so that all values are in consistent units (milligals). However, the actual free air coefficient (i.e., the vertical gradient of gravity) may depart by a few per cent from the theoretical value because of large regional gravity anomalies. Also, the instrument calibration may be in error. However, the density determined by the density profile method is that which reduces the *apparent* elevation effects. The errors mentioned, if large, will lead to density values which are in error with respect to the true density of the rock material within the topography, but this error will compensate for the instrumental and vertical gradient errors mentioned. This is true only to the extent that vertical gradient, density, and instrument calibration are constant over the entire area for which a given density profile is considered typical.

Figures 1 to 6 show typical density profiles observed in routine field work using the Hoyt[3] gravimeter. This series is selected to demonstrate rather unexpected variations of surface density indicated by such profiles. The six localities are in Caddo and Washita Counties, Oklahoma, all in 9 and 10N, the series running from east to west. The first four are all on the unit shown on the State Geologic Map as the Day Creek-Whitehorse formation, but they show a progressive decrease and then a slight increase of density in going westward as successively younger parts of this formation outcrop. Apparently there is an abrupt change of density between this formation and the overlying Cloud Chief gypsum, indicated by the change from a density of 2.1 (Fig. 4) to 2.7 (Fig. 5). This high density probably is caused by anhydrite and dolomite in the Cloud Chief formation. Farther west the younger Quartermaster formation shows a more "normal" density of 2.4. (This value is called "normal" because it has been shown by density profiles in widely scattered places in southern and southwestern Oklahoma.)

[3] Archer Hoyt, U. S. Patent 2,131,737, October 4, 1938.

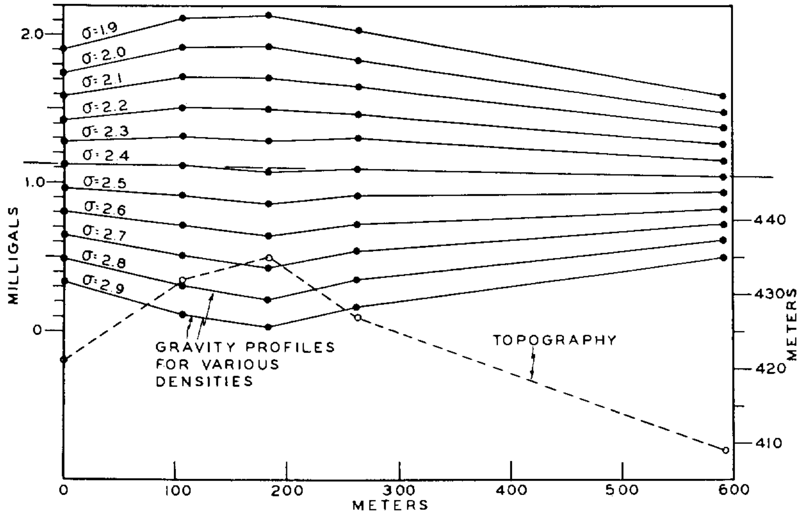

FIG. 1. Density Profile, 10N-10W, Caddo, County, Oklahoma. Whitehorse Sandstone, Indicated Density, 2.4.

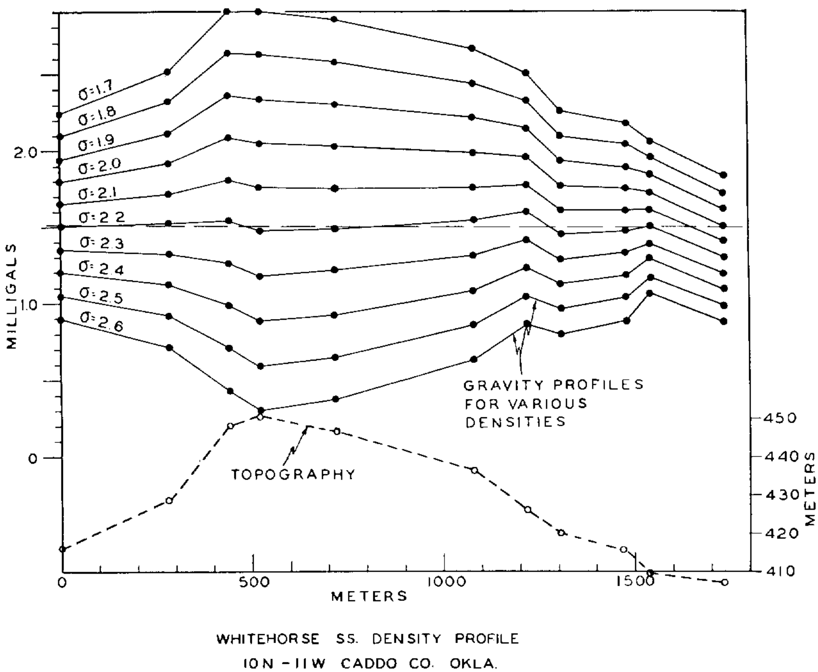

FIG 2 Density Profile, 10N-11W, Caddo County, Oklahoma. Whitehorse Sandstone, Indicated Density, 2.2.

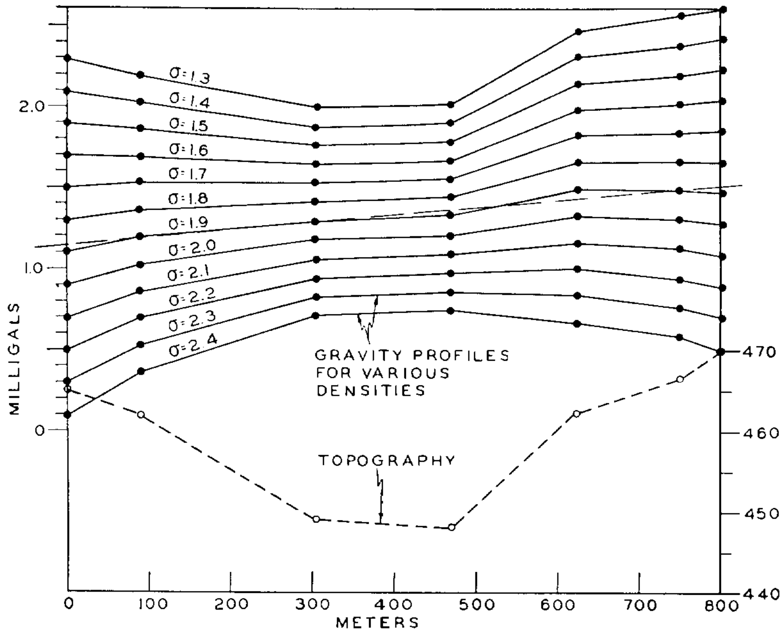

FIG. 3. Density Profile, 10N-12W, Caddo County, Oklahoma. Whitehorse Sandstone, Indicated Density, 1.9.

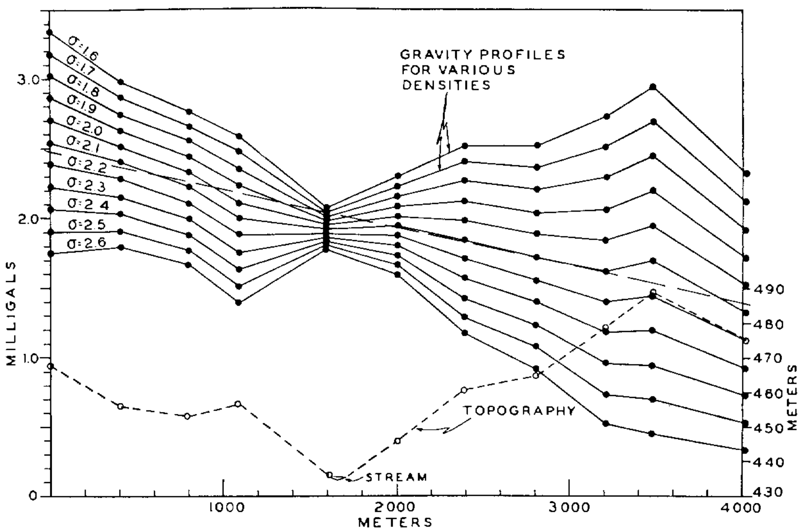

FIG. 4. Density Profile, 10N-13W, Caddo County, Oklahoma. Whitehorse Sandstone, Indicated Density, 2.1.

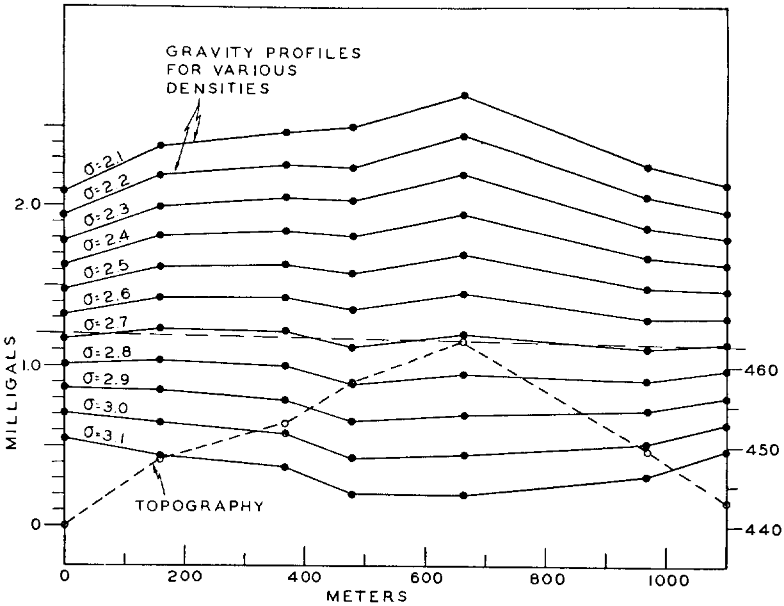

FIG. 5. Density Profile, 9N-15W, Washita County, Oklahoma. Cloud Chief Gypsum, Indicated Density, 2.7.

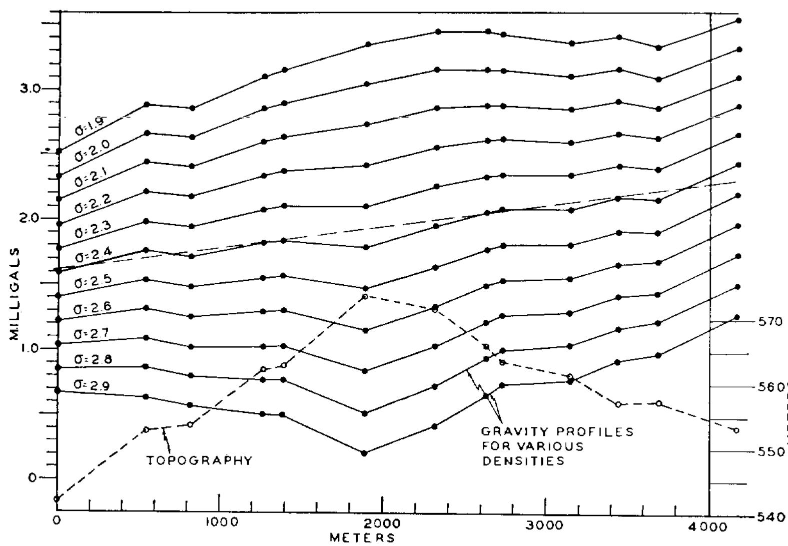

FIG. 6. Density Profile, 10N-19W, Washita County, Oklahoma. Quatermaster Formation, Indicated Density, 2.4.

In cases where a material of one density overlaps material of a different density, it may be necessary to make more complex reductions of the gravity values. A good example of this is the overlap of the Trinity sandstone over the Permian in southern Carter County, Oklahoma. The Trinity sandstone has a density of about 2.1 and the underlying Permian a density of about 2.4. An estimate was made of the general configuration and elevation of the contact at the base of the Trinity. Then the Bouguer correction was calculated with a density of 2.1 for the estimated thickness of Trinity under the station location and a density of 2.4 for the thickness of the Permian between the bottom of the Trinity and the base elevation to which all the stations were referred.

Another case of complex densities occurs at the Llano Estacado escarpment in eastern New Mexico. The surface density above the escarpment is about 2.0 and that below the escarpment is about 2.4. In this case the relief of the escarpment is around 200 ft. When stations are reduced with a single density there is a distinct discontinuity in the reduced gravity map at the escarpment. This situation was handled by estimating from gravity profiles across the escarpment the proportions of the topographic relief to which the densities measured above and below the escarpment should be assigned in order that the reduced gravity would be smooth across the topographic feature. When complex reductions were made for the thicknesses with the two densities thus indicated, a satisfactory reduced gravity picture could be made across this rather rugged topographic feature.

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