

GRAVITY PROSPECTING IN PLATFORM AREAS

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The problem of ambiguity in the interpretation of gravity in platform areas is analysed. A theoretical example is given, presenting ambiguity in the determination of depth and position of faults, even when the form of structures is known. It has been concluded, that the best method of gravity interpretation is the construction of the map and profiles showing the depths of horizon where there is the strongest density contrast. An example is given from the Sultana area in Jordan, where the gravity map is converted into the maps of »quantitative regional« and »true residual«, by means of drilling data. Interpretation of the residual by the method of gravity modelling resulted in the construction of the map of structures and depths of the density contrast horizon, with the positions and throws of the main faults.

Introduction

According to Andreev-Klushin (1965), the platform tectonics takes place in many countries on several continents. Its main characteristics are the absence of folding, nearly horizontal layers and nearly vertical faults. In gravity prospecting one would expect less ambiguity in interpretation than in the areas of intensive folding. Namely, according to the classical paper by Skeels (1947), identical gravity anomalies may be caused either by steep folds in depth or by gentle dipping folds at shallow depths. In the platform areas there are practically no folds, but the same effect can be caused by several small faults. Several faults forming throws at certain depth cause the same gravity anomaly as a single more intensive fault, or as a dipping layer. The Fig. 1 shows a theoretical example. The theoretical anomalies caused by one and two faults were calculated by the published methods, like by Talwani et al. (1959). By the method of successive approximation, the assumed structures were changed until the identical gravity anomaly was obtained for both structural forms (Structures and anomalies »a« and »b« in the Fig. 1). If more faults are possible, there will be more ambiguity in interpretation. There are also other reasons for more ambiguity, like inaccuracies in measurements or corrections as well as the presence of other sources of anomalies, like surface inhomogeneities (loose sand or hard rock), change of density in the basement, etc. The difference of several interpreted structures causing the same anomaly can result in very unpleasant practical consequences and conclusions, since the depth and position of faults are very important in prospecting for water, minerals, oil, etc.

It is obvious that any transformation of gravity anomalies, like residual, derivatives, surface fitting

Ključne riječi: Gravimetrija, Platformske oblasti, Višeznačnost, Interpretacija.

Analiziran je problem višeznačnosti u gravimetrijskoj interpretaciji platformskih područja. Dan je teoretski primjer koji pokazuje da postoji višeznačnost u određivanju dubine i položaja rasjeda i kad je poznat oblik strukture. Zaključeno je da u interpretaciji gravimetrije najbolje rezultate daje konstrukcija karte i profila koji pokazuju dubine horizonta na kojem se javlja najjači kontrast gustoće. Dan je primjer iz područja Sultana u Jordanu, gdje je gravimetrijska karta preračunata u karte »kvantitativnog regionala« i »pravog reziduala«, uz korištenje podataka bušotina. Interpretacijom gravimetrijskog reziduala metodom gravimetrijskog modeliranja konstruirana je karta struktura i dubina horizonta kontrasta gustoće, s položajima i iznosima pomaka glavnih rasjeda.

etc., made without other independent information, cannot help in resolving the ambiguity. Transformed maps derived from the same Bouguer gravity map

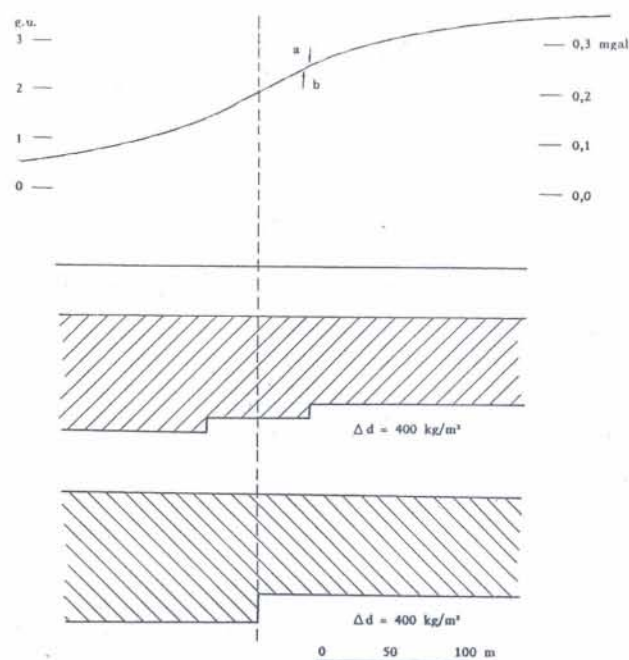


Fig. 1. Ambiguity in gravity interpretation of faults
Sl. 1. Višeznačnost u gravimetrijskoj interpretaciji rasjeda

will deliver the same transformed anomaly, regardless the different cause (structure).

In the following example from Jordan the method of »quantitative regional« and »true residual« was used. The method is developed at the Chair for Applied Geophysics (Faculty of Mining, Geology

and Oil Engineering of the Zagreb University). It is described in detail by Šumanovac (1990).

Gravity prospecting in the Sultana area of Jordan

The area is flat and horizontal. Small elevation differences still existing were determined by levelling, and the elevation corrections computed. No corrections for topographic relief were needed. The position of stations was determined by tape and compass. Gravity was measured by a Scintrex gravimeter.

Most of the surface material are desert sand and gravel, covering the so called upper marl. On some locations limestone is outcropping, covered by marl and sand in larger part of the area.

The main aim of the survey was »on the job training« of local geophysicists in the project of the United Nations Development Programme. The practical aim was the mapping of tectonics in the search for phosphates and ground-water. Exploratory drilling for phosphates was already completed some years ago in the area a few kilometers apart. As the results of the gravity prospecting show, the drilling for phosphates would have been more successful if the gravity survey had been done before drilling.

Anyhow if in the future an exploration for phosphates in this area will take place, the results of the gravity survey would be quite useful.

At the time of gravity surveying wells for water had already been drilled, so it was possible to use their results in the interpretation.

Determination of the density contrast

Information about the contrast is needed for any quantitative interpretation of gravity. Very detailed informations may be obtained by density log, or by classical weighing of cores in air and water. In the case of Sultana area neither the measurements in wells were available, nor the cores. However the petrographic determinations of the drilled rocks were available. So it was decided that the main density contrast is to be expected at the horizon where the limestone is covered by marl. Since there were not enough informations for detailed density determination, the approximation was made, that the marl – limestone contact is the only density contrast and the buried relief of this horizon is to be constructed, causing the measured anomalies. The other unknown density changes will be taken as the regional effect, or will be completely neglected, causing of course certain inaccuracies in the interpretation.

The amount of the density contrast was determined using the depth of the contrast horizon determined by drilling, and the outcrops. It is known that each meter thickness of the material with the density d (in kg/m^3) causes a gravity effect of 0.0419×10^{-3} miligals (or $0,419 \times 10^{-3}$ gravity units, one gravity unit being one micrometer second⁻²). This is valid for infinite horizontal extension and of course for absence of any other cause of gravity anomalies. In such a case it is easy to compute the density contrast from the anomaly difference and the depth difference of the density contrast horizon in two wells. If we have a depth in three wells situated on one straight

line, we can increase the accuracy by eliminating the effect of the linear part of the regional effect. This is done by making the difference in depth ΔH between the middle well and the linearly interpolated value of the depth in two other wells (see Fig. 2).

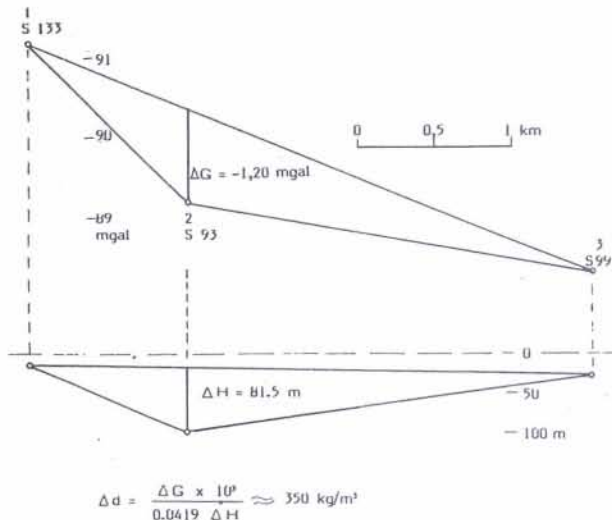


Fig. 2. The Sultana area of Jordan – Computation of the density contrast

Sl. 2. Područje Sultana u Jordanu, računanje kontrasta gustoće

This value is then used instead of the depth difference of only two wells. The same is done for the gravity anomaly difference ΔG . The computation is shown in the Fig. 2. It resulted in the density contrast of 350 kg/m^3 , which is taken as preliminary value. Using this value, the depth contours of the contact marl/limestone were constructed. The method of computation is described in the next chapter. After that, gravity at the three wells was corrected for the local structure, i. e. for the difference of infinite extension and the interpreted structure. The computation of the density contrast was then repeated, and the final value of 352 kg/m^3 was adopted.

Gravity modelling

Gravity modelling in the example presented was the construction of the structure of the marl-limestone contact. It was necessary to separate the anomalies into two parts: one caused by the structure at the horizon of this contact and the other due to all the other sources. The first part we called »true residual«, and the second »quantitative regional«. These names were chosen because the basis for the computation was quantitative, i. e. the data of wells.

The depths of the marl-limestone contact were plotted at the wells and outcrops, and the preliminary depth contours interpolated in the area between the wells, but taking into account the gravity contours.

Further on the wells and outcrops theoretical anomalies and »quantitative regional values« were computed according to Table I: here H is marl thickness in meters determined by drilling, G_m is the gravity effect of the marl (in miligals) taken in first approximation as horizontal plate of infinite extension.

Table 1. Computation of the »quantitative regional«, the Sultana area of Jordan

Tablica 1. Računanje »kvantitativnog regionala«. Područje Sultana u Jordanu

Station	S 66	S 134
H m	0,00	-46,00
G_m mgal	0,00	-0,68
G_s mgal	-0,05	-0,22
G_b mgal	86,95	90,14
Quant. Reg.	87,00	91,04

$$G_m = 0.0419 \times d \times H \times 10^{-3}$$

G_s is the effect of the assumed structure. G_b is the Bouguer anomaly. Density contrast »d« in first approximation was taken 350 kg/m^3 . Quantitative regional is then equal to

$$\text{Quant. reg.} = G_b - G_m - G_s$$

The values were computed for the wells and outcrops shown in Fig. 4, plotted on the map, and contour lines of the »Quantitative regional« interpolated (Fig. 4).

This was done by constructing profiles of gradually changing gravity. The smoothness of the profiles was determined by personal judgement. Computer programs may be used for this purpose also. However, personal judgement cannot be completely eliminated, it will be at least in preparing the parameters for the computation.

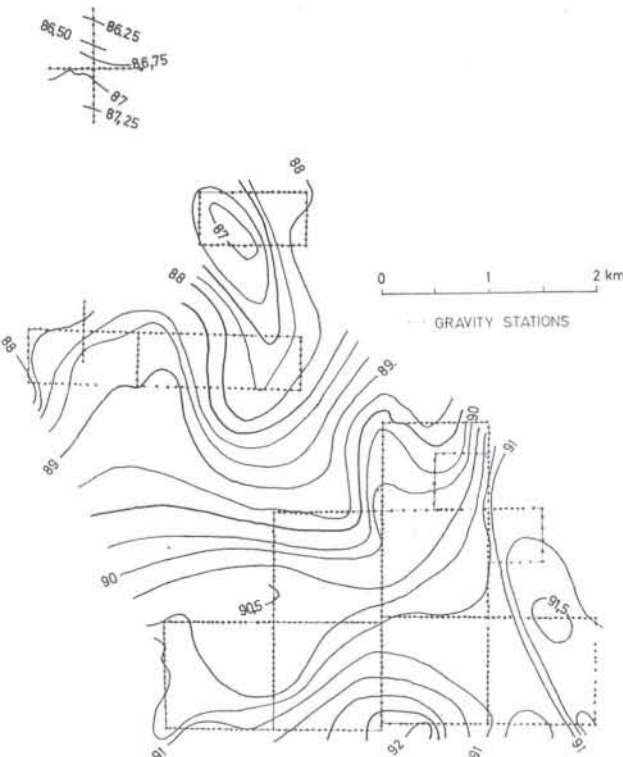


Fig. 3. The Bouguer anomaly map, Sultana area of Jordan. Contours 0,25 mgal (2.5 g. u.)

Sl. 3. Karta Bouguerovih anomalija, područje Sultana u Jordanu. Izolinije na 0,25 miligala (2,5 grav. jedinica)

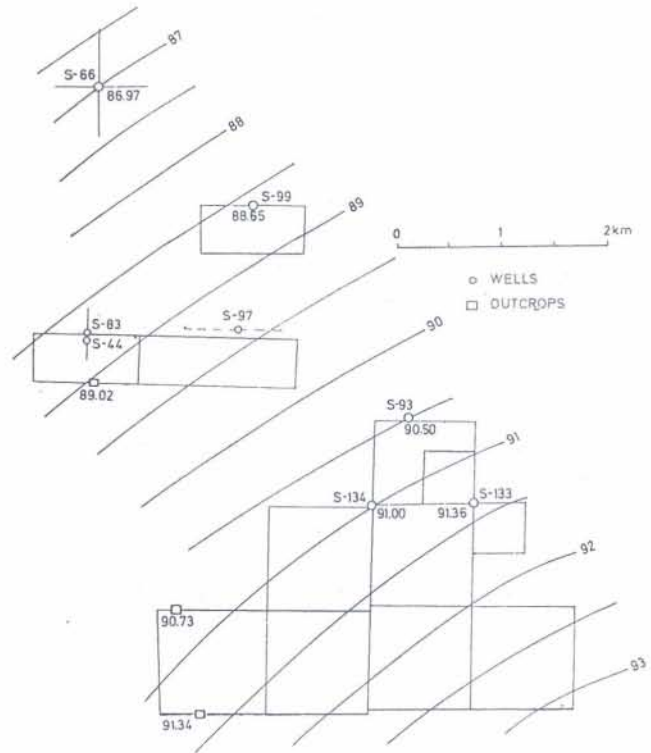


Fig. 4. The Sultana area of Jordan »Quantitative regional«. Contours 0.5 mgals (5 g. u.)

Sl. 4. Područje Sultana u Jordanu. Karta »kvantitativnog regionala«. Izolinije svakih 0.5 mgala (5 grav. jedinica)

The »true residual« (Fig. 5) was constructed by reading the regional correction from Fig. 4, for all the gravity stations, subtracting it from the measured anomalies and drawing the contour lines.

The structures in profiles were constructed by the method of Talwani et al. (1959) using a desk top computer and successive approximations. Each time the computed structure was changed, the effect of the structure on gravity at the wells was also corrected, if necessary, and the new map of quantitative regional constructed and used for the determination of true residual and the structure.

In computer - assisted computation of the gravity effect of two-dimensional bodies, the profile must be a polygon, i. e. composed of straight lines. If the outline of a body consists of curved lines, they have to be replaced by a number of short straight lines. The coordinates of intersections of these lines are then introduced into the computer. In the case of platform structures, this is not needed, since the section already consists of straight lines: vertical faults and horizontal layering. So the computation is less time-consuming and/or more accurate than in the folded areas.

The results obtained for the two-dimensional case is shown in the Fig. 6. the test carried out on one profile by threedimensional method (Talwani et al. 1960) has proved no important differences. In the Fig. 6 the map of profile positions is presented. The depths to the limestone are plotted on profiles and the marl cross-hatched.

The crystalline basement was not reached by drilling in any part of the area, so it is expected to be

so deep that the effect of density changes in the basement can be treated as a part of the regional. Its change is expected to be smooth enough to be determined by computations on wells. In the case of relatively shallow basement, the density changes in basement are not so smooth, and often cannot be separated from the gravity effect of the structure in sediments or at the basement top. Such a case was on the Kharga oasis in Egypt.

Conclusion

The amount of the density contrast was determined by the combination of gravity and depths from three boreholes. Using this density contrast, gravity modelling was performed from the Bouguer gravity and the results of wells. So the gravity anomaly map was converted into the map of tectonics and depths of the horizon of density change. The main structural relations are determined including the positions and displacements of main faults, deep grabens etc. The phosphate deposits are situated close to the horizon of the density contrast, so the obtained tectonic map indicate the parts of the area favorable for further exploration and exploitation of phosphates, as well as the areas where the phosphates are expected to be deep for economical mining. On the other hand the water wells situated near the main faults yielded more water than the wells far from the faults, particularly in deep grabens. So the constructed tectonic map is expected to serve as a guide for more successful water prospecting.

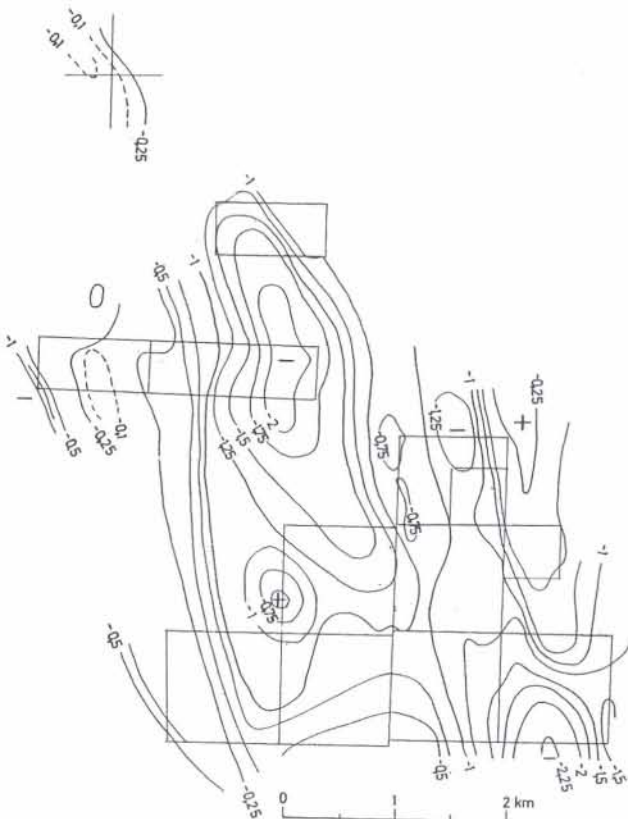


Fig. 5. The Sultana area of Jordan. »True residual«. Contours 0.25 mgals (2.5 g. u.)

Sl. 5. Područje Sultana u Jordanu. »Pravi rezidual«. Izolinije svakih 0.25 miligala (2.5 grav. jedinica)

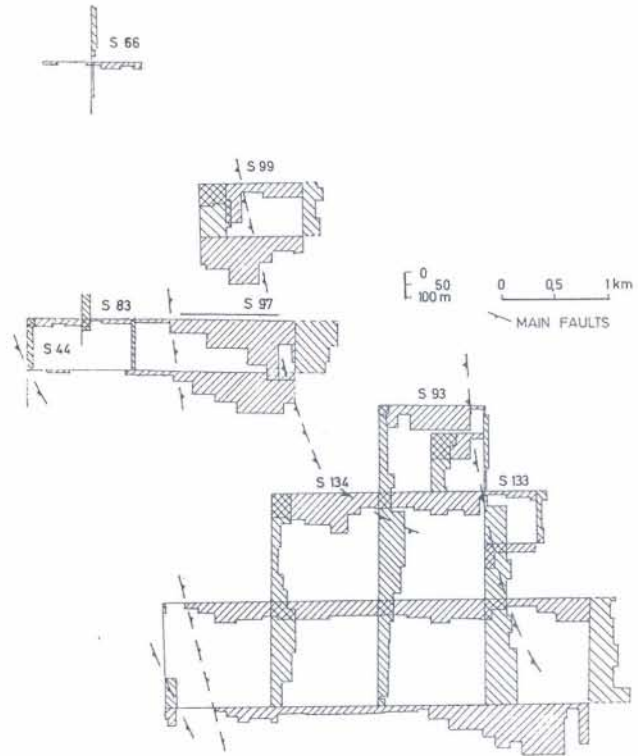


Fig. 6. The Sultana area of Jordan. Map with interpreted profiles giving positions of the main faults with their throws, and the depths of the contact marl-limestone

Sl. 6. Područje Sultana u Jordanu. Karta s interpretiranim profilima koji pokazuju položaje i pomake glavnih rasjeda i dubine kontakta lapor-vapnenac

Obviously the method presented could be successful in constructing the tectonic maps in many other platform areas. The conditions to be fulfilled are: the availability of a good gravity map and of boreholes – or other independent informations of the depth of the density contrast horizon. After the additional wells are drilled, the computation can be repeated and the results corrected.

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Gravimetrijska istraživanja u platformnim oblastima

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Platformne oblasti zahvaćaju velike površine na više kontinenta, a odlikuju se skoro horizontalnom uslojenošću i vertikalnim rasjedima. Prema tome, kod interpretacije se javlja jedna nepoznanica manje, naime oblik struktura. Uprkos toga, postoji višeznačnost kod interpretiranja dubine horizonta promjene gustoće i kod određivanja položaja rasjeda. Višeznačnost se može razriješiti do izvjesnih granica gravimetrijskim modeliranjem tj. računanjem oblika struktura i dubina horizonta promjene gustoće, iz gravimetrijskih anomalija, a uz korištenje rezultata bušotina ili drugih neovisnih podataka.

Na području Sultana u Jordanu najprije je iz petrografskih podataka bušotina zaključeno da je glavni kontrast gustoće na granici lapora i vapnenca. Zatim je korištenjem podataka dubina tog horizonta iz bušotina i gravimetrijskih anomalija izračunan iznos kontrasta gustoće (350 kg/m^3). Kod toga je pretpostavljena

linearnost gravimetrijske anomalije na kratkoj dužini profila. Zatim su po metodi, koju je opisao Šumanovac (1990), na tačkama bušotina izračunane teoretske gravimetrijske anomalije. One su odbijene od mjerenih vrijednosti, čime su dobivene vrijednosti »kvantitativnih regionala« na tačkama bušotina. Interpolacijom je konstruirana karta izolinja regionala, sa koje su očitane vrijednosti za sve mjerene tačke. Oduzimanjem tih vrijednosti od mjerenih anomalija dobiven je tzv. »pravi rezidual«. Iz njega su gravimetrijskim modeliranjem, pretežno dvodimenzionalnim, dobivene dubine horizonta promjene gustoće (kontakt lapor – vapnenac) i glavni tektonski odnosi. Korištenjem tih podataka izvršen je popravak teoretskih gravimetrijskih anomalija na bušotinama, i prethodno opisani postupak je ponovljen. Kao konačni rezultat dobivena je karta profila s dubinama granice lapor-vapnenac i položaji, te iznosi pomaka glavnih rasjeda.