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Scientific paper

A Geodetic-Gravimetric Method for Better Modelling of Geological Structures in the Test Area of Croatia

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PROCEEDINGS

Key words: Gravity field modelling, Vertical deflections, Gravity anomalies, 3D seismics, Geophysical prospection, Bjelovar depression, Croatia.

Abstract

A new approach to the modelling of the Earth's crust, especially its upper portion, utilising different kinds of geodetic (vertical deflection components, geoid surface), gravimetric (Bouguer and other gravity anomalies) and geophysical (3D seismic from borehole prospecting) data is presented in this paper. This scientific research formed part of a special contract between the Faculty of Geodesy and INA-Naftaplin, with the aim of establishing the gravity field over a test area in northern Croatia. It should improve the geophysical prospection for minerals, particularly in the field of hydrocarbon exploration.

1. INTRODUCTION

Detailed knowledge of the Earth's crustal structure, especially in the layers closest to its surface, is very important in geodesy, but also in geophysics, e.g. for hydrocarbon exploration in some local areas. In order to increase the quantity and quality of additional information about mass distribution for possible oil-exploration, a broad range of scientific research has been undertaken by the Faculty of Geodesy over the last four years in the area of the Bilogora Hills and Bjelovar depression. All previously existing geophysical and gravimetrical information was combined with carefully planned new geodetic and astronomical measurements. This undertaking required special methodology, based on the existing TC-computer program (FORSBERG, 1984), which has been developed and successfully applied[1].

2. DATA

There are a number of existing data sets for the test-area, some of which were taken from the existing archives: gravimetric measurements, borehole density data, and a part of Rs7 and Pt depths. However, a lot of necessary files required construction; including those for a digital terrain model, digital density model of upper crust masses, digitising of Pt and Rs7 shapes in the larger part, filtering and re-calculation of Bouguer gravity anomalies and complete determination of astro-geodetic deflections of the vertical.

The data files used refer to the following:

a) a digital terrain model with block resolution of 4x5 arcsec (app. 110x120 m) obtained from the digitised Based State Map 1:5,000 (see Fig. 1),

b) a digital model of Tertiary Base (Pt) shape (more than 220,000 discrete points),

c) a digital model of Rs7 shape (more than 210,000 discrete points),

d) a digital surface density model recalculated from the existing 2.5x2.5 arcsec model (Fig. 2),

e) a digital density model of Rs7 and Pt shapes, empirically obtained from the existing borehole density data in the test area (Fig. 2),

f) gravimetrical measurements at more than 30,000 points,

g) astro-geodetic deflections of vertical at more than 50 points.

3. METHODOLOGY

The gravimetric approach in hydrocarbon prospecting has been known for a long time. However, the density contrast between normal and oil-filled strata was usually based only on the gravity anomalies - one (vertical) component of the gravitational vector. In the present research, the idea of using all three vector components (vertical + both, W-E and N-S, components of the vertical deflection - ξ and η) was applied. It is based on its stronger sensibility for small variations in mass-distribution and also smaller loses of accuracy caused by necessary reductions. For this purpose, precise astro-

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[1] ČOLIĆ, K., BAŠIĆ, T., PRIBIČEVIĆ, B. & MEDAK, D. (1995): Applying of the new combined geodetic-gravimetric method in determining of geologic-geophysical structures in chosen test area in Croatia.- Unpublished Final Report for Oil Company INA-Naftaplin, Faculty of Geodesy, University of Zagreb, 38 p.

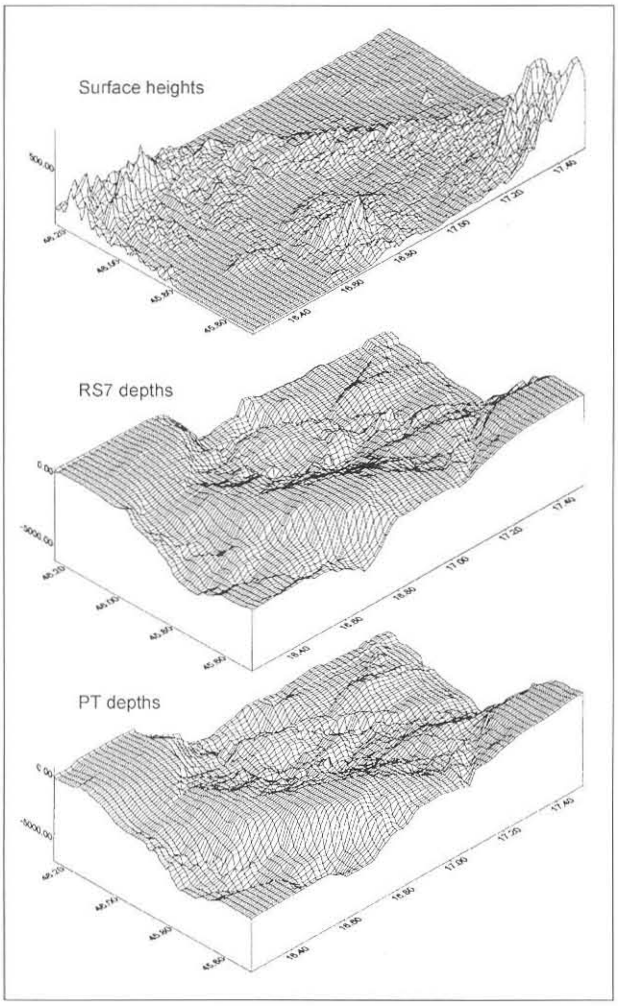

Fig. 1 Digital models of surface heights, Rs7 and Pt depths (in m).

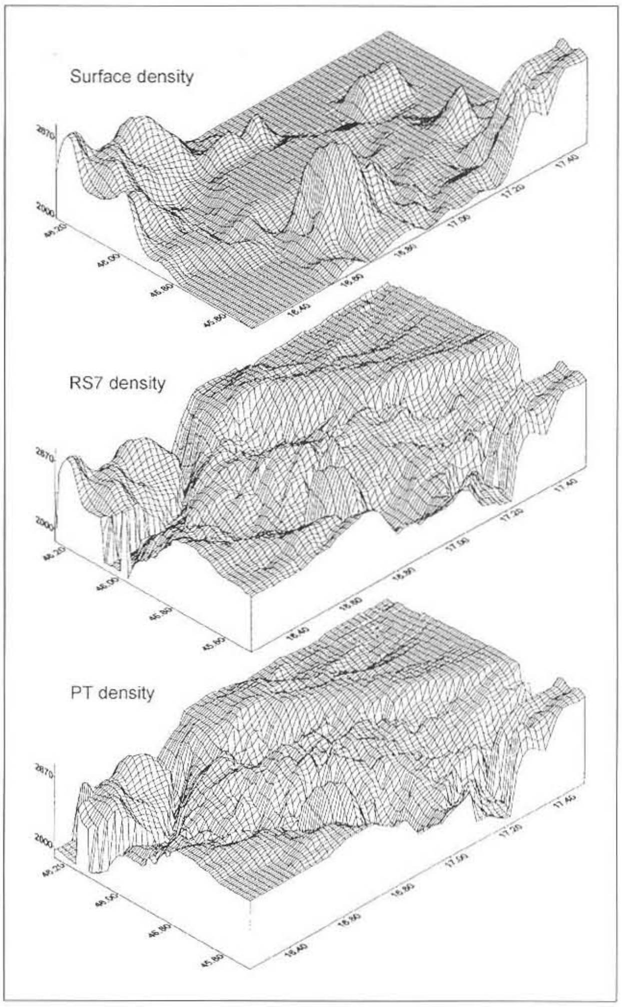

Fig. 2 Digital density models of Earth's surface, Rs7 and Pt shapes (in kg/m^3).

nomical measurements with the Telescope Zenith Camera (TZK2) and partly with the Zeiss Ni2-astrolab apparatus were performed on more than 50 points over our test-area (Fig 3).

After determining deflections of the vertical at the measured points and calculating Bouguer anomalies using GRS80 (MORITZ, 1980) for the data sets mentioned above, we took advantage of the prepared surface density model (ČOLIĆ et al., 1992) as well as empirically obtained density models at Rs7 and Pt depths (JELIĆ, 1984), in calculating terrain influences. The usual method way of mass-modelling assumes a

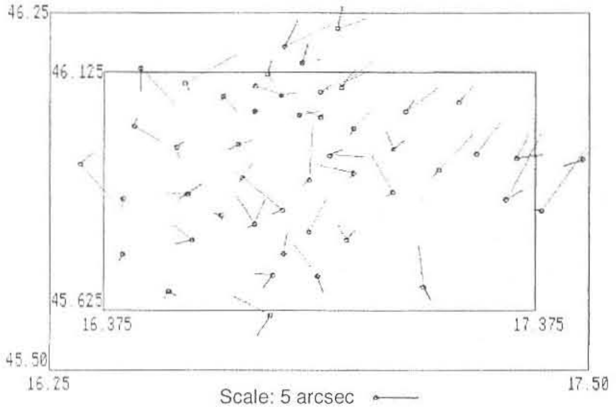

Fig. 3 Measured and calculated vertical deflection points in the test area (in arcsec).

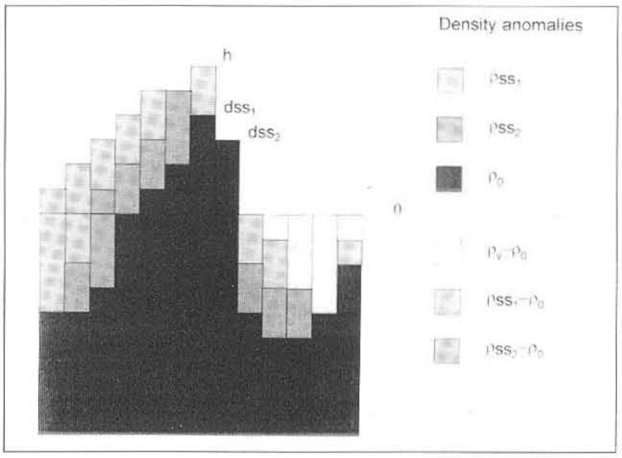

Fig. 4 Modelling of topographic masses.

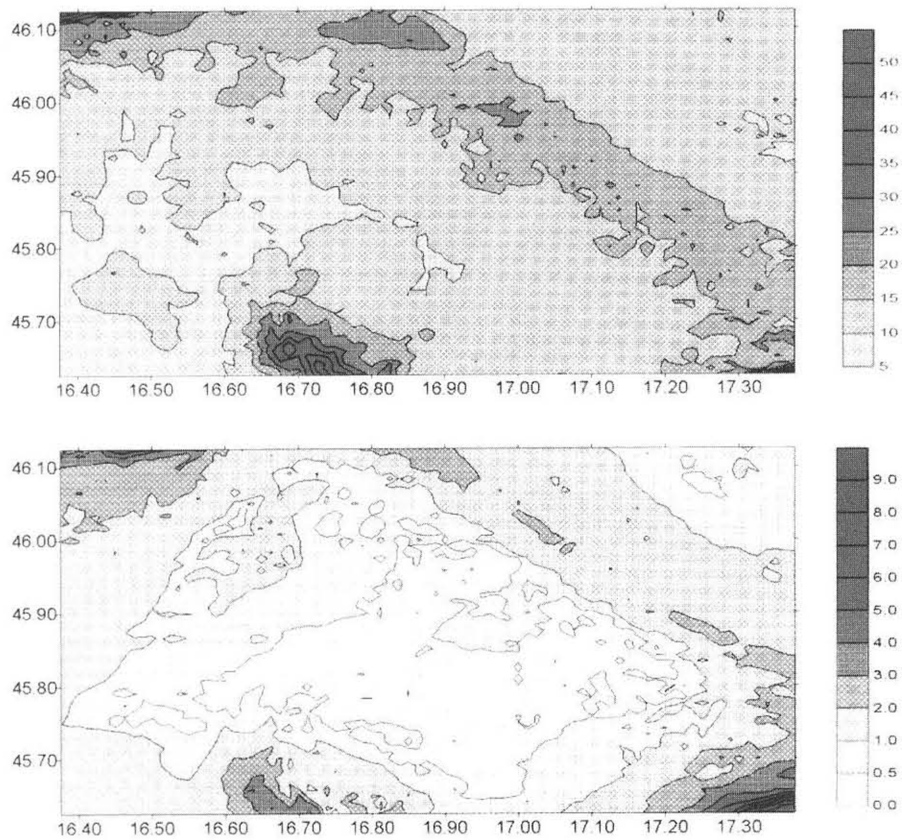

Fig. 5 a) Topographic correction from 3D density model (in 10^{-5} ms^{-2}); b) deflections of vertical from 3D density model (in arcsec).

constant density for approximating polyhedra. The aim of the required method was the use of variable density in all three directions (Fig. 4).

In this case, the Earth's crustal masses, i.e. between the Earth's surface and the Mohorovičić discontinuity, are presented as three layers, characterized by heights h (digital terrain model) and depths dss_1 and dss_2 of the Rs7 and Pt surfaces, followed by the corresponding densities ρss_1 and ρss_2. The third layer of the Earth's crust, between dss_2 and Mohorovičić's discontinuity, was assumed to have the constant density ρss_3 equal to the density of the reference body, i.e. the reference ellipsoid with the reference crust density ρ_0. Therefore, the topographic effect is more complex: besides the elimination of surface topography influences, effects of "covered" topographies (which lead to some compensation) are also eliminated. In this way a topographic reduction was defined in addition to other physical effects which fully utilize information on near-surface (see BRKIĆ, 1994 for details).

The input-data was data files forming coarse and fine grids of the following data: relief heights, Rs7 and Pt depths with corresponding density values. All coarse grids cover the area 45.00°-46.75° (latitude) with 15.0°-18.5° (longitude) with a 60x90 arcsec raster. The fine grids are given in a 4x5 arcsec raster covering the area 45.50°-46.25° (latitude) and 16.25°-17.50° (longitude). The computational area is defined by 45.625°-46.125° (latitude) and 16.375°-17.375° (longitude).

A special software package in Fortran77 was developed to provide the numerical solution for this methodology. It uses even coarser grids of the above mentioned data, resulting in a larger area of computation. This program facilitates the calculation of the all important topographic effects: topo-isostatic, relief correction and the so called residual correction (RTM).

Filename	Mean	St. dev.	Min	Max	Description
FDTMS	160.80	79.56	91.00	863.00	Digital terrain model
FDBSRS7	-1613.61	1382.81	-6097.00	479.00	Rs7-depths model
FDBSPT	-1981.81	1569.40	-6848.00	722.00	Pt-depths model
FDDMS	2121.16	168.64	1970.00	2800.00	Density model - surface
FDDMSRS7	2250.65	141.27	1970.00	2800.00	Density model - surface/Rs7
FDDMRSPT	2403.12	214.41	1970.00	2800.00	Density model - Rs7/Pt

Table 1 The final input data files (heights and depths in metres, densities in kgm^{-3}).

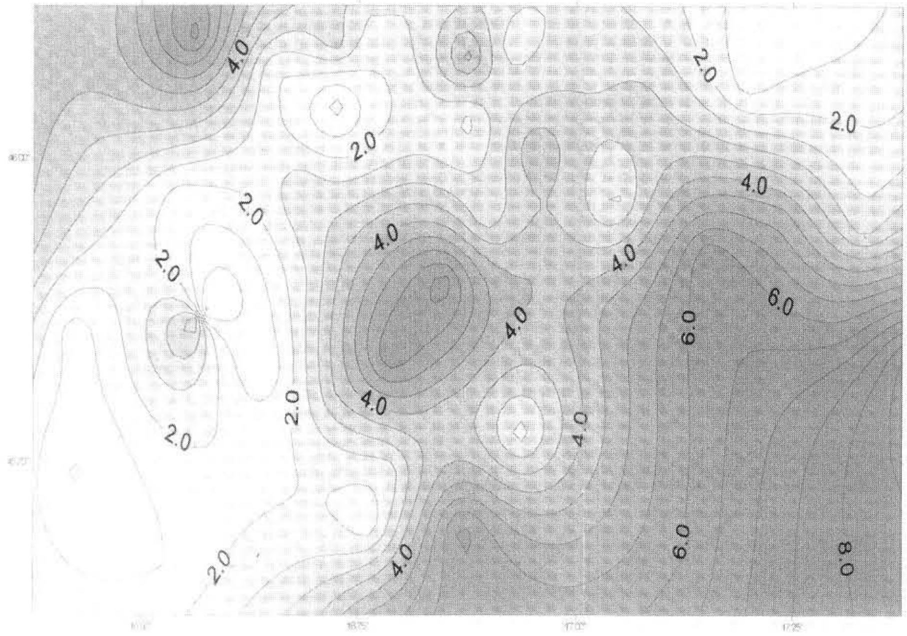

Fig. 6 Differences between measured and calculated vertical deflections (in arcsec).

4. RESULTS

The final input data files are not the most important result but deserve to be mentioned with their statistics (Table 1).

We have computed output grids of topographic corrections (complete Bouguer anomaly) and total deflections of the vertical (Fig. 5), as well as geoid undulations. The Bouguer anomaly map is the result of the interpolation of more than 24,000 filtered gravimetric measurements involved with a 3D geological model. The mean value is 21.40 x 10^{-5} ms^{-2}, standard deviation ±9.80 x $10^{-5}ms^{-2}$, maximal value 60.89 x $10^{-5}ms^{-2}$ and minimal value -9.81 x $10^{-5}ms^{-2}$. A digital model of Bouguer anomalies was also calculated for the constant densities of 2120 kgm^{-3} and 2670 kgm^{-3}.

The calculated geoid surface using a 3D-geological model shows that the undulations vary approximately 40 cm over the entire area. The most important result is a digital model of vertical deflections based on 53 measured points (see Fig. 6). The maximal difference between the measured and topographic deflections is 8.92 arcsec, minimal 0.39 arcsec, with standard deviation ±1.81 arcsec.

5. CONCLUSIONS

The main aim of this research was to acquire new information for potential hydrocarbon exploration. After careful examination it was discovered that the residual map (differences between measured and calculated deflections of vertical) shows a very significant anomaly of 6 arcsec near Bjelovar. This cannot be interpreted as a relief disturbance (because the area is flat), and more detailed measurements and further investigations are required.

It is very interesting that the same narrow area is highlighted on the map of differences between Bouguer anomalies with a 3D density model and Bouguer anomalies with a constant density model (2120 kgm^{-3}), see Fig. 7. The two different approaches tend to have the same results over the same local area, thus justifying both the invesment and effort involved in this multidisciplinary project.

Acknowledgment

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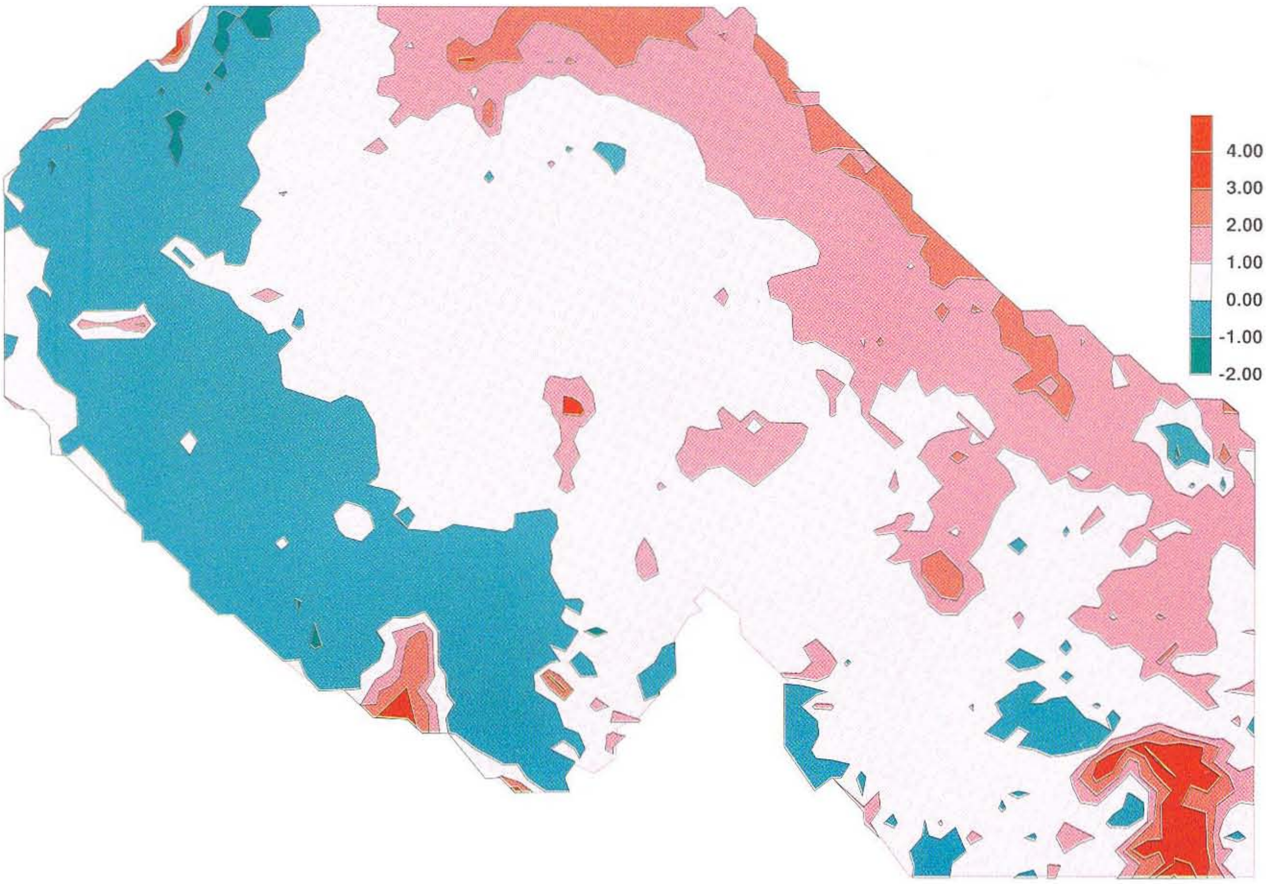

Fig. 7 Differences of Bouguer anomalies: dg_{3D}-dg_{2120} (in $10^{-5}ms^{-2}$).

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