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New gravity map of Carpathians

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Abstract. In the paper the methods and results of a joint gravity map of Carpathians elaboration are presented. The gravity map is located on Czech, Poland and Slovakia territory. The base for the study is a collection of archive data, processed according to an uniform modern approach for constructing the gravity datasets.
The international team has worked out joint data sets for plotting and he transformed of gravity data of Carpathians on the base of agreed approach to data elaboration and data exchange. The worked out gravity data are examples of co-operation of involved countries. They give new information in cross-border areas. New data sets allow us to perform gravity transforms to analyse local and regional anomalies, gravity modelling and other interpretations connected with search for hydrocarbons and geothermal water. They also allow us to present gravity maps of selected areas of Carpathians in 1:25 000 and lesser scales. It should be noted the correctness of the approach to gravity measurements carried out independently in Czech Republic, Poland and Slovakia that has allowed us to integrate results with a quite good accuracy, without additional investigations.

Key words: gravity, terrain corrections, Carpathians, gravity anomalies, gravity map

Introduction

In the paper the methods and results of a joint gravity map of Carpathians elaboration are presented from border Czech, Poland and Slovakia territory. The base of the study is a collection of archive data processed according to an uniform modern approach for constructing the gravity datasets.

The works on a joint gravity map of Carpathian could start after beginning the trans-border co-operation between Czech Republic, Poland and Slovakia and preparing the base for the program CARTA in 1990´s. The existing data from the whole Carpathian area have required an uniform recalculation and standardisation according to principles accepted in the most of EU countries (S. Plaumann 1991). The detailed principles of processing and recalculation procedures considering recent state of archive data have been elaborated, especially for:

- Transformation of co-ordinates of all gravity stations to „42“ system
- Introducing of IGSN 71 system
- New gravity latitude correction formula for WGS 84 ellipsoid.
- Calculating terrain corrections in 166.7 km radius
- Considering the Earth's curvature in corrections.

The Slovak – Czech - Polish international team - on the base of agreed approach to data elaboration and data exchange - has worked out joint data sets for plotting and transforming the gravity data of Carpathians. The worked out gravity data are examples of co-operation of involved countries and give new information in cross-border areas. New data sets allow us to perform gravity transformations to analyse local and regional anomalies, gravity modelling and other interpretations connected with search for hydrocarbons and geothermal water. They also allow us to present gravity maps of selected areas of Carpathians in 1:25 000 and lesser scales. It should be noted the correctness of the approach to gravity measurements carried out independently in Czech Republic, Poland and Slovakia that has allowed us to integrate results with a quite good accuracy, without additional investigations.

Task of the study

The Carpathian area and neighbouring geological units are covered on Czech Republic, Poland and Slovakia territory by half-detailed gravity surveys of similar station density of 4 –5 st./km^2. These works, carried out in individual countries, of various vintages, have been processed in a non-uniform way, in various co-ordinate systems and for various formulae of gravity latitude correction. It was impossible to elaborate a joint gravity map of Carpathians on the basis of original gravity date.

In frame of the CARTA program, considering existing coverage of the studied area by homogeneous gravity surveys, the geophysical investigations have started by creation of a joint gravity anomaly map. An international team of specialists has prepared out uniform principles on calculating anomalies, levelling, and mutual data circulating and exchange. As a result, the data sets of gravity anomalies for Carpathian area processed in each country, were used as a base for geophysical and geological studies.

Gravity IGSN71 system

Previous archive gravity measurements have referred to Potsdam system. In the new elaboration all gravity surveys are referred to IGSN71 system. These both systems differ by value of about 14 mGal. The passage from values in Potsdam system to IGSN71 system has required adding values a value of difference to previous values following from the formula:

$$\ddot{A}_1 = (-14 + \varepsilon) \text{ mGal.}$$

The values of „ε" are estimated on the base of absolute gravity measurements on selected base stations, conducted by national surveying organizations. According to Czech data the value of „ε" changes from 0.15 to 0.25 mGal and thus on Czech and Slovakian territory a constant value of $\varepsilon = 0.2$ mGal has been taken. In Poland the coefficient value has been estimated of $\varepsilon = 0.15$ mGal in Lublin area. The ε coefficient convergence in both cases justifies choosing for Carpathian area a constant value of $\varepsilon = 0.2$ mGal. Hence the value of correction on the gravity system transform is:

$$\ddot{A}_1 = (-14 + 0.2) \text{ mGal}=13.8 \text{ mGal}$$

Gravity latitude correction formula

The formula of calculation of gravity latitude correction is closely connected with the ellipsoid parameters determination that is a mathematical image of the geoid. The progress in the geoid shape investigations implies to work out periodically new formulae of gravity latitude correction. The new formula of gravity latitude correction differs significantly from Helmert formula used in calculations for the archive data. This includes as well extending the formula – three new terms with higher degrees of latitude function as new values of coefficients and introducing new geodetic co-ordinate system (WGS 84). It causes the new gravity latitude correction values are lower than previous ones, by about 4 mGal. (0.1 mGal is the estimated Bouguer anomaly accuracy). Instead of the previous formula of gravity latitude correction used in archive data:

$$\gamma_o = 978\,030\,(1 + 0.005302 \sin^2\varphi - 0.000007 \sin^2\varphi)$$

the new formula of γ_0^{84}, given below, has been applied. Regarding the changes in this formula a new formula of calculation of Bouguer anomaly according to J. Švancara (1996) has been applied in the following form:

$$E_{gB} = g - \gamma_0^{84} - 14 + 0.2 + (0.308\,780 - 0.000\,439 \sin^2\varnothing).H$$
$$(7.265\text{x}10^{-8} - 2.085\text{x}10^{-10}\sin^2\varnothing).H^2 - 2.\pi.G.\sigma.H$$
$$+ T - B$$

where:

g – measured value of gravity

γ_0^{84}=A+B.$\sin^2\varnothing$+C.$\sin^4\varnothing$+D.$\sin^6\varnothing$+E.$\sin^8\varnothing$+F. $\sin^{10}\varnothing$ - value of gravity latitude correction for WGS84 ellipsoid

where:

A =	978 032.677 137	D =	0.123 445
B =	5 163.074 975	E =	0.000 714
C =	22.760 576	F =	0.000 004

∅ – latitude of gravity station in WGS 84 co-ordinate system

- 14 mGal – difference between Potsdam and international IGSN71 system

+0.2 mGal – correction of gravity system

$[(0.308\,780 - 0.000\,439 \sin^2\varnothing).H - (7.265\text{x}10^{-8} - 2.085\text{x}10^{-10}\sin^2\varnothing).H^2]$ – free-air correction

$2.\pi.G.\sigma.H = 0.0419\,251.\sigma.H$ – Bouguer correction

T – terrain correction to 166.7km radius (Hayford O_2 zone)

B – Bullard correction.

For density of 2.67g/cm³ Bullard correction is :

$B = 0.001\,464\,71.H - 3.534{*}10^{-7}H^2$

H – elevation a.s.l. (in metres) in Baltic system

∅ – geocentric latitude (close to latitude in "42" co-ordinate system) of gravity station in degrees

The previous formula for calculation of Bouguer anomaly have had the form:

$$\Delta gB = g - \gamma o + 0.30866 \cdot H - 0.0419 \cdot \sigma \cdot H + T_{22.5}$$

where: $T_{22.5}$ – terrain correction to 22.5 km radius

On the base of the new formula and reduction density of 2.67g/cm³ gravity map for the particular area of Carpathians has been worked out.

Calculation of free-air correction

The free-air correction introduced to Bouguer anomaly calculation expresses vertical changes of gravity. The changes in latitude correction cause changes in calculation of free-air correction. Previously the correction has been calculated as a linear function of gravity station elevation. In the new formula the correction is a function of two parameters: elevation and latitude. However, the relation against elevation is a square function. The new form of free-air correction is shown in previous chapter. The difference of correction values in the new gravity system in relation to the previously used varies

from – 0.02 mGal for elevation of 200 metres

to – 0.15 mGal for elevation of 1000 metres

Considering diverse relief of Carpathians, the new calculated values of free-air gravity will differ significantly from the previous ones.

Calculation of Bouguer correction

Relatively the smallest changes have occurred in calculation of Bouguer correction. This correction is calculated from the term: $-2\pi G\sigma H$, and expresses effect of the horizontal slab in the measurement value. Practically the following term for calculation has been used: $- 0.0419 \cdot \sigma \cdot H$ [mGal]. To increase the accuracy of calculation of other corrections and reductions it is recommended to calculate the Bouguer anomaly by using a new coefficient, increasing the accuracy by introducing the next three decimal digits (C. Królikowski). The new form of the correction is given in the previous chapter and it is:

$$-0.0419251 \cdot \sigma \cdot H \text{ [mGal].}$$

Calculation of terrain corrections

In previous gravity studies it was assumed that considering the terrain relief influence upon gravity meas-

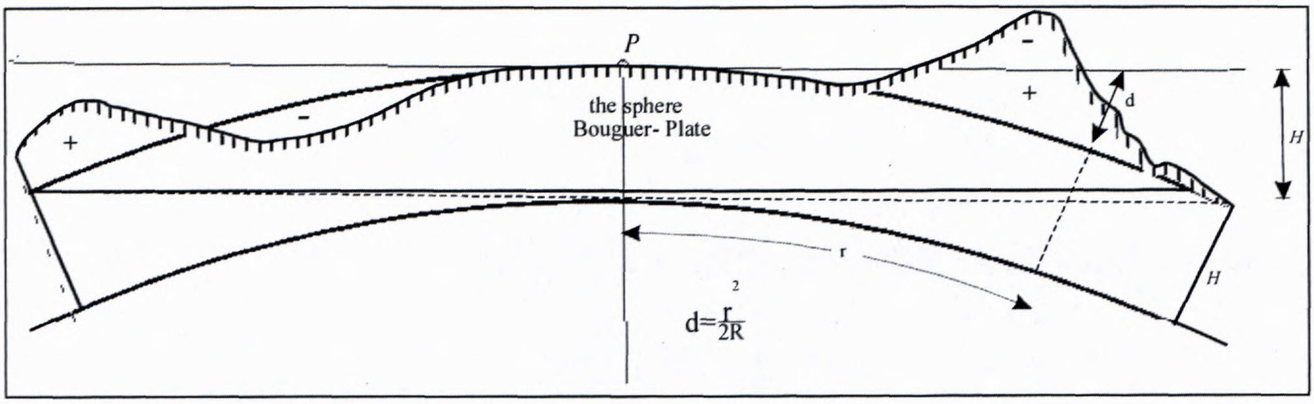

Fig. 1. The scheme indicating the influence of topographical masses to measurement point according to K. Jung
P – measurement point, r – radius of surroundings of measurement point, R – radius of Earth, d – distance of horizon surface from sphere surface, + – sing of gravity effect values of marked areas, H – thickness of Bouguer plate

urements in Poland is sufficient for a radius of 20-30 km. The calculation of terrain corrections for a larger radius (to 166.7 km), conducted in frame of this study and experience of geophysicists from Czech Republic, Germany and Slovakia has pointed out that also the outer zone (over 22.5 km) influences significantly on the correction values. These values reach 2.5 mGal for greater elevations. The calculations of terrain correction in this zone have created new methodical problems. The close neighbourhood of the station as highs over the measurement station plane and lows under spherical surface of measurement station gives negative gravity effects. The g vector - due to these masses in the measurement station - is placed upwards and terrain correction, compensating this effect, has had a positive sign. For greater distances from the measurement station (over 20 km) the third case occurs where we obtain a positive contribution of gravity effect. This refers to masses between the measurement station plane and a spherical surface running through the station, as it is shown in Fig. 1. It is easy to notice that the gravity effect due these masses will be positive (the g vector in the measurement station will be placed downwards as the earth's gravity acceleration). These masses will bring negative effects to total terrain correction values. As it is shown on the plot, the values for the outer zone, over 22.5 km, present a strong relationship with the station elevation. This relationship is similar to a square function.

For the Carpathian area terrain corrections have been calculated in the radius to 166.7 km. The map of terrain corrections elaborated on the base of calculations, carried out for 22.5 – 166.7 km radius, for the selected area of Poland, is presented in Fig. 2.

Determination of influence of Earth's curvature

By increasing the radius in terrain correction calculations, the difference between Bouguer horizontal slab and the real mass distribution of spherical surfaces of the same thickness increases – Fig. 2. In the measurement station these surfaces agree respectively but on the edge of the area where the correction is calculated (166.7 km from the station), the elevation differences between the surfaces reach 2000 metres. Hence the horizontal slab effect should be replaced with a real effect of masses between spherical surfaces. To obtain this, Bullard correction is introduced.

Gravity data sets and their transformations

All gravity data from the Carpathian area have been used to construct a base gravity anomaly catalogue in "42" co-ordinate system, according to EU standards. On the base of obtained data set, maps of Bouguer anomaly of interesting areas in 1:25 000 or lesser scales can be elaborated. The Bouguer anomaly map from border area of three countries is presented in Fig. 3, using joint data in trans-border area. Because the geological structures run independently from state boundaries, the common gravity map interpretation increases possibility their study across boundaries. Worked out data sets and presented example on cross-border area show the necessity to perform CARTA program and create one, joint catalogue of gravity data for whole Carpathians.

The gravity anomaly map is a superposition of gravity effects due to the whole depth bracket. Thus, its direct interpretation might to be difficult even for an experienced interpreter, especially when regional trend effects are significant in gravity image. For this purpose a number of methods based on frequency analysis, statistics and analytical solutions is applied. For example, to remove a regional trend, polynomial methods are used. Obtained crumbled local structure allow us easily to assign them to geological objects.

The method of trend separation gives a readable picture of local anomalies but no close relationship with depths of anomaly sources. Thus calculation of residual anomalies using Sheppard and BTWR methods is applied, that parameters might be applied to a particular penetration depth bracket. The need of use of two methods for determining residual anomalies follows from the fact that they are based on various theoretical assumptions. Sheppard method is based on weighting anomaly values in calculation station neighbourhood – Fig. 4. BTWR method is based on frequency filtering. The similar result of both methods gives a higher reliability of calculated anomalies. In both anomaly images often of similar elements may be observed as on map obtained from polynomial method.

Fig. 2 Terrain correction map for the whole area in external zone (22.5 166.7km)

To determine anomaly boundaries, especially in the case of tectonics effects, the best method is gradient map calculation. In this case, as in above-mentioned two approaches, filtering of shallow subsurface effects often precedes it. The gradient map confirms and makes more detailed anomaly contours presented on residual maps. Especially it outlines linear tectonic elements.

Remarks and conclusions

The unified data sets, elaborated in Czech Republic, Poland and Slovakia according to EU accepted standards, extend gravity image of Europe. Additionally they form a base for elaboration of a joint gravity map for the whole Carpathian area. The new map will be used for geological

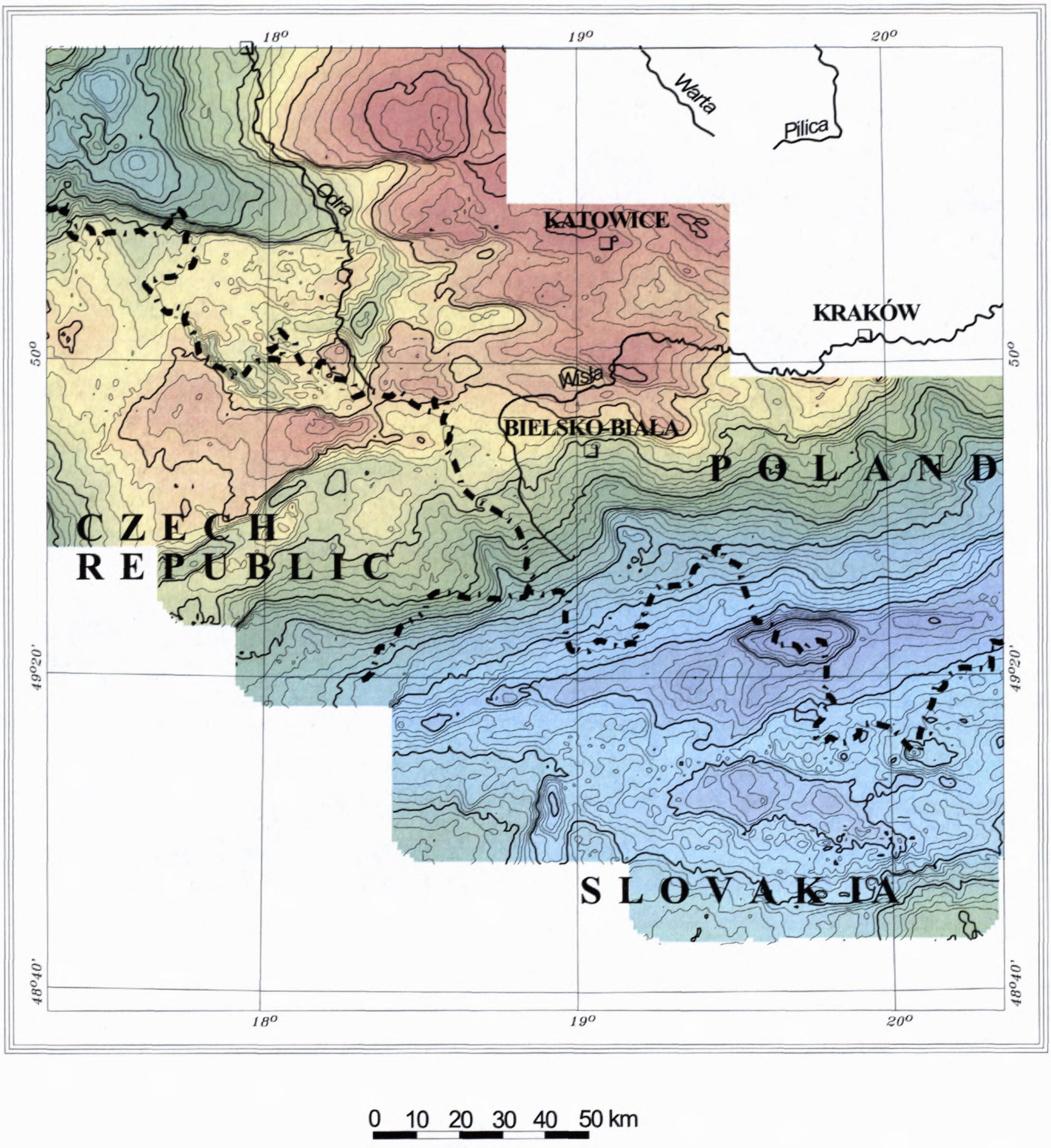

Fig. 3 Map of Bouguer Anomaly on border area of Poland, Czech and Slovakia

analyses, hydrocarbon and geothermal water prospecting and as a base for integrated computer geophysical-geological interpretation.

Because of existing limitations in data access to work out gravity map for the whole Carpathians, a simplified form of output data sets has been elaborated that satisfies law regulations on national data protection. Additionally it is necessary to establish principles on access and the use of the new form of geophysical information. Experi- ence gained when solving this problem may be used in solving other similar topics, including CARTA program.

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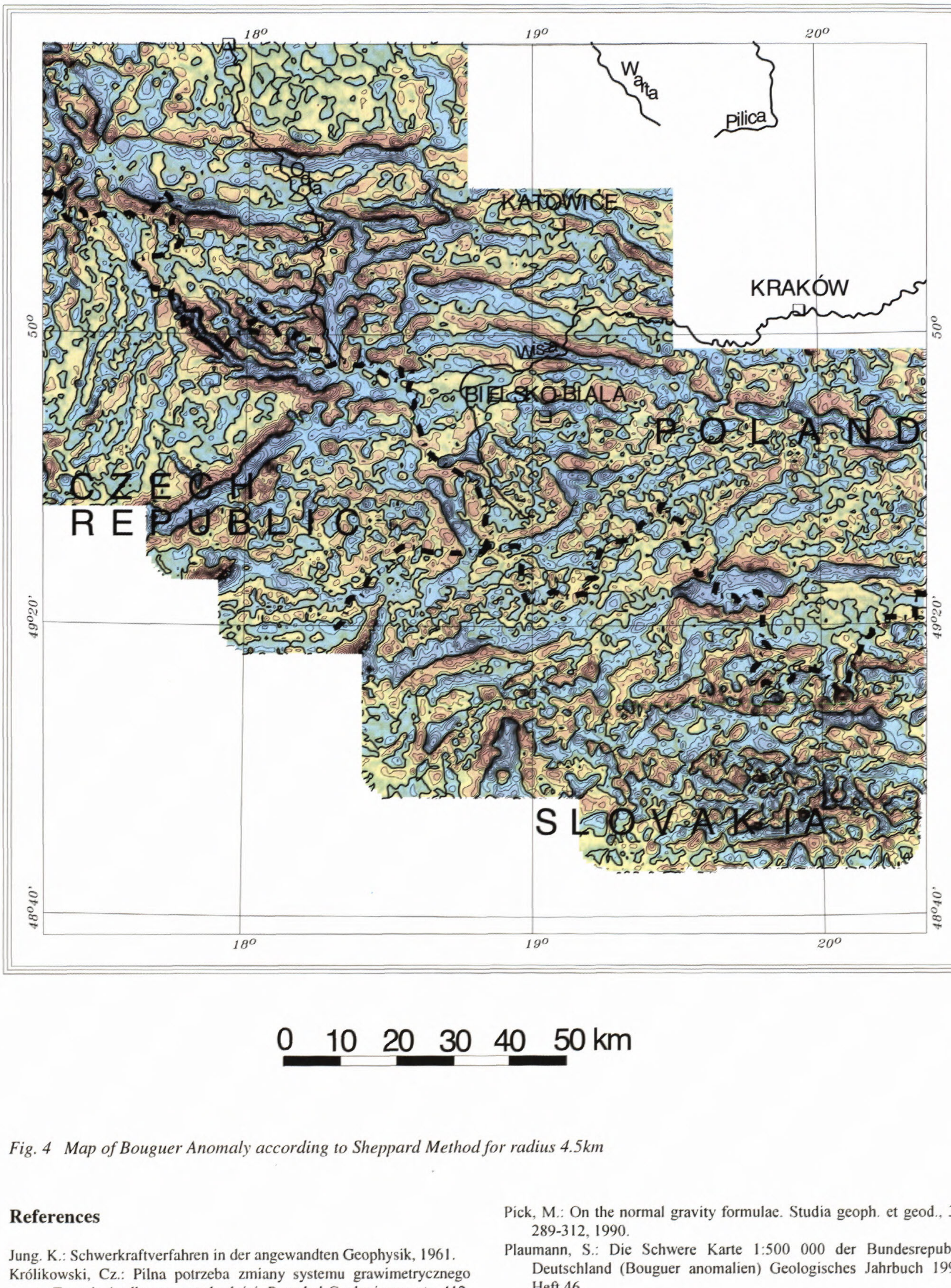

Fig. 4 Map of Bouguer Anomaly according to Sheppard Method for radius 4.5km

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