Western Carpathians basement according to results of integrated geophysical investigation with the particular consideration of magnetotelluric data

WOJCIECH KLITYŃSKI and ADAM WÓJCICKI

PBG (Geophysical Exploration Company), Jagiellońska 76, 03-301 Warsaw, PL

Abstract. The recognition of Western Carpathians' basement on the base of integrated geophysical interpretation of selected magnetotelluric (MT) profiles is considered. The results of geophysical-geological interpretation of MT measurements on MT profiles 3 (Przyborów-Zator), 4 (Chyżne-Spytkowice) and 5 (Zakopane-Kraków) are presented.

The MT interpretation allows us to recognize Palaeozoic basement including Cambrian, Devonian and Carboniferous and Mesozoic. This makes it possible to determine elevations and depressions in the basement and flysch Carpathian orogen thickness. Within the crystalline basement determination of fault and depression zones is possible.

The interpretation results point out a twofold resistivity distribution on the studied area. The flysch Carpathians are usually characterized by low resistivities of a wide variety. The rocks of sub-Miocene basement, e.g., Mesozoic, Palaeozoic and Pre-Cambrian are of high resistivity (hundreds and thousands ohmmeters, rarely tens of ohmmeters) and of more uniform distribution. In southern and central parts of the considered sections low resisitivity zones at greater depths are observed – they belong to sub-Miocene basement. On the section of Zakopane-Kraków (5), Pieniny Klippen Belt is distinct of intensive resitivity variation in depth and horizontally.

The interpretation of Bouguer anomaly transformations and modelling results also show a diversification of flysch's basement physical properties. The low resistivity zone in flysch's basement in area of southern part of the profiles refers generally to low density Meso-Palaeozoic and older basement. Such a tendency is not present in residual anomalies, where series of negative and positive anomalies occur. This suggests an obvious connection of negative Bouguer anomaly with deep basement rocks in the area of southern part of profiles.

Key words: flysch Carpathians, Meso-Palaeozoic basement, magnetotelluric, integrated interpretation

Introduction

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Measurements

In 1997-2000 the Geophysical Exploration Company (PBG), Warsaw made deep magnetotelluric soundings, on lines in the western part of the Polish Carpathians. The measurement lines are of several tens of kilometers long with sounding sites distributed about 2-3 km apart. The data acquisition was made with the use of MT-1 magnetotelluric system designed and produced by Electromag-

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netic Instruments Inc. (EMI), Richmond, California, USA. The measurements were made in a frequency range of 300 – 0.0005 Hz. The remote magnetic referencing was applied to eliminate the influence of electromagnetic noise. The field data were processed with the use of MTR15 computer program incorporated in the MT-1 system. The results of data processing were amplitude and phase MT sounding curves, impedance polar diagrams, and skew (Czerwiński, Klityński, Stefaniuk, 2000). They were then subjected to qualitative and quantitative interpretation in connection with other geophysical methods.

Interpretation of MT data

At the first stage of interpretation, an apparent resistivity and phase pseudosections were obtained. The apparent resistivity and phase curves, polar diagrams and skew were analysed in qualitative interpretation. The 1D inversion was made with Bostick, Occam and LSQ methods. Based on Bostick 1D inversion, pseudo 2D resistivity cross-sections were computed with the use of kriging method. The results of 1D LSQ inversion were used to obtain *2D input resistivity section.* The additional data including geological information on the flysch orogen, refraction seismic data, and results of 2D inversion with RRI method were also applied (Czerwiński, Klityński, Stefaniuk, 2000). The results of magnetotelluric data interpretation have provided new elements in recognition of the structure of the flysch orogen and its basement and confirmed earlier interpretation of the roof of the high-resistivity horizon.

As a final result, geoelectric sections are presented (Fig. 1, 2).

In the case of Przyborów – Zator (No. 3) profile and Chyżne – Spytkowice (No. 4) profile a quite strong resistivity contrast between flysch and autochthonous Miocene complex and bedding complex of Palaeozoic and/or Precambrian complex is visible. Exceptionally on northern endings of both sections, low-resistivity rocks of Carboniferous-lying also below low-resistivity autochthonous Miocene-appear. An exception are also high-resistivity Miocene deposits near Sucha Beskidzka on profile No. 4, especially between soundings No. 7 and 8 of profile No. 3 poorly contrasted with high-resistivity Palaeozoic rocks.

The northern parts of both sections are characterized by a similar structure, where rocks of Carboniferous, Devonian and upper part of crystalline basement lay imperturbably and are well correlated on relatively large sectors. In central part of profile No. 4, the thickness of Palaeozoic probably increases and the high-resistivity horizon corresponds with the roof of crystalline basement dips southward. For the profile No. 3 between soundings No. 7 and 8 a deep trough, filled by rocks of resistivity lower than crystalline basement, occurs. The trough is significantly wider in case of profile No. 4, between soundings No. 23 and 28. For profile No. 3, between soundings No. 4 and 6 Precambrian is situated quite shallowly, directly below Miocene.

In northern part of Zakopane-Kraków (No. 5) profile, between soundings No. 1 and 11 a significant resitivity contrast is observed between the roof of Mesozoic-Palaeozoic basement rocks and overlaying them low-resistivity Miocene deposits and Śląska and Podsląska nappe deposits. Similarly but of a bit smaller resistivity contrast the complex of external part of Magura nappe is characterized. The complexes of southern and central Magura units are characterized by relative high resistivities but location of the roof of basement is not clear. For this section Pieniny Klippen Belt is distinctive of specific lateral and vertical differential. The vertical difference on forefield of PKB for soundings No. 20 and 21 of this profile is also visible as well as on soundings No. 20 and 21 of profile No. 4.

Interpretation of gravity data

The gravity data, used in this study, is the gravity map of Bouguer anomaly of Western Polish Carpathians compiled out in POGC Geological Bureau Warsaw, Poland, according to standards commonly used in EU countries.

The interpretation has started from an analysis of Bouguer anomalies. In south the profiles run through so called central Carpathian gravity deppression – a belt of negative anomalies in Bouguer anomaly image (Fig. 3). This feature runs approximately in W-E direction. The nature and origin of this anomaly are still discussed. However, Bouguer anomaly cannot be used to delineate detailed features appearing on geoelectric sections of magnetotelluric profiles No. 3, 4 and 5 (Fig. 1 and 2) because it is a superposition of effects due to the whole depth range. To connect the features in flysch and its basement in the case of magnetotelluric and gravity data it is necessary to extract and analyse a contribution that refers to these complexes in the gravity anomaly image.

To perform this a residual transformation of gravity anomaly has been chosen that refers to the depth range between 0 and about 10 km below sea level. The anomaly has been calculated using band-pass BTWR method of GRDFFT FUGRO-LCT program. It means that effects of several hundred meters thick subsurface complex and effects of complexes below 10 km have been removed.

Generally the picture of gravity residual anomaly (Fig. 4) is more complicated than the Bouguer anomaly picture (Fig. 3). In southern part of the area belts of roughly W-E negative and positive anomalies appear (Fig. 4). It is interesting that the irregular belt of negative anomalies includes Pieniny Klippen Belt. This structure is visible, as described above, on geoelectric section of profile No. 5. On Fig. 2 gravity profile of residual anomaly is superimposed over the MT section. In central and northern part of the area residual anomalies form irregular spots padded in various directions. In the case of profiles No. 3 and 4 positive anomalies in their central parts may be connected with relatively shallow located Precambrian basement.

The next step was performing the quantitative interpretation of gravity modelling of geological medium. To work out a quantitative gravity model of the geological medium in the studied area, the magnetotelluric interpretation (geoelectric section) along profile 5 has been used along with well-logging density data from neighbouring

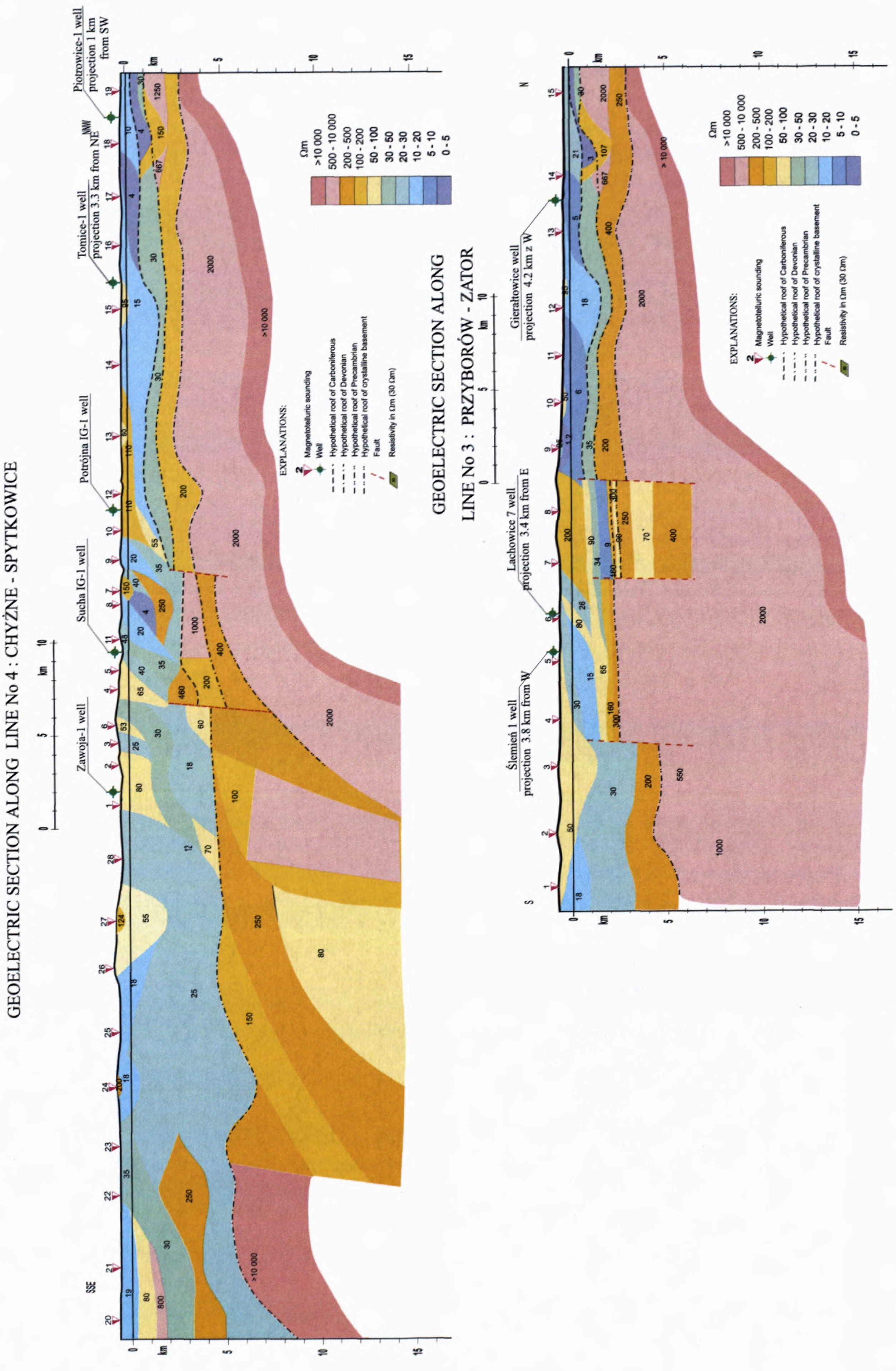

Fig. 1 Geoelectric sections along profiles 3 (Przybrów-Zator), 4 (Chyzne-Spytkowice), according to W. Klityński

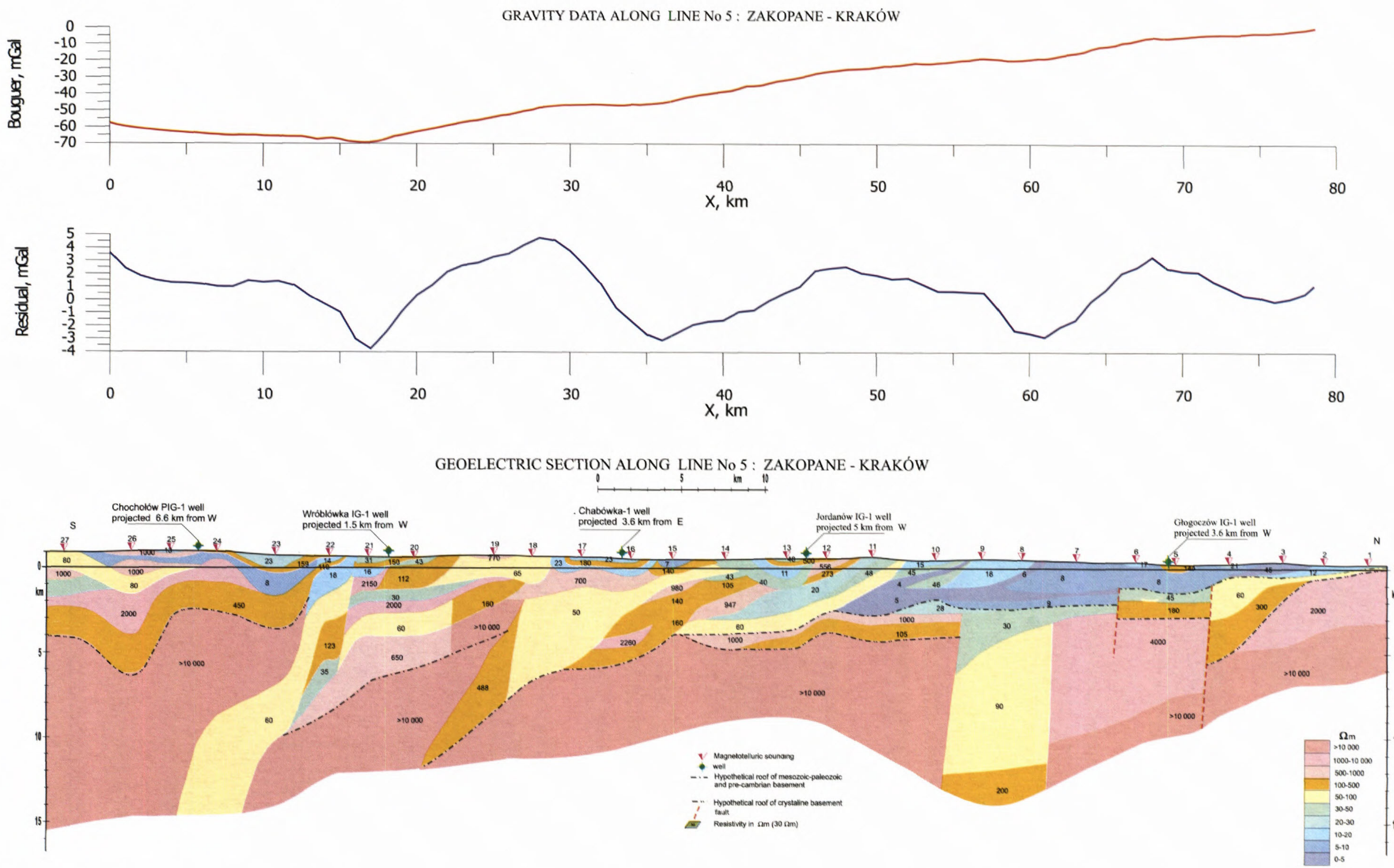

Fig. 2 Geoelectric section along profile 5 (Zakopane-Kraków) compiled with a graph of gravity/Bouguer and residual anomaly (penetration bracket about 0-10 km below sea level), according W. Klityński and A. Wójcicki.

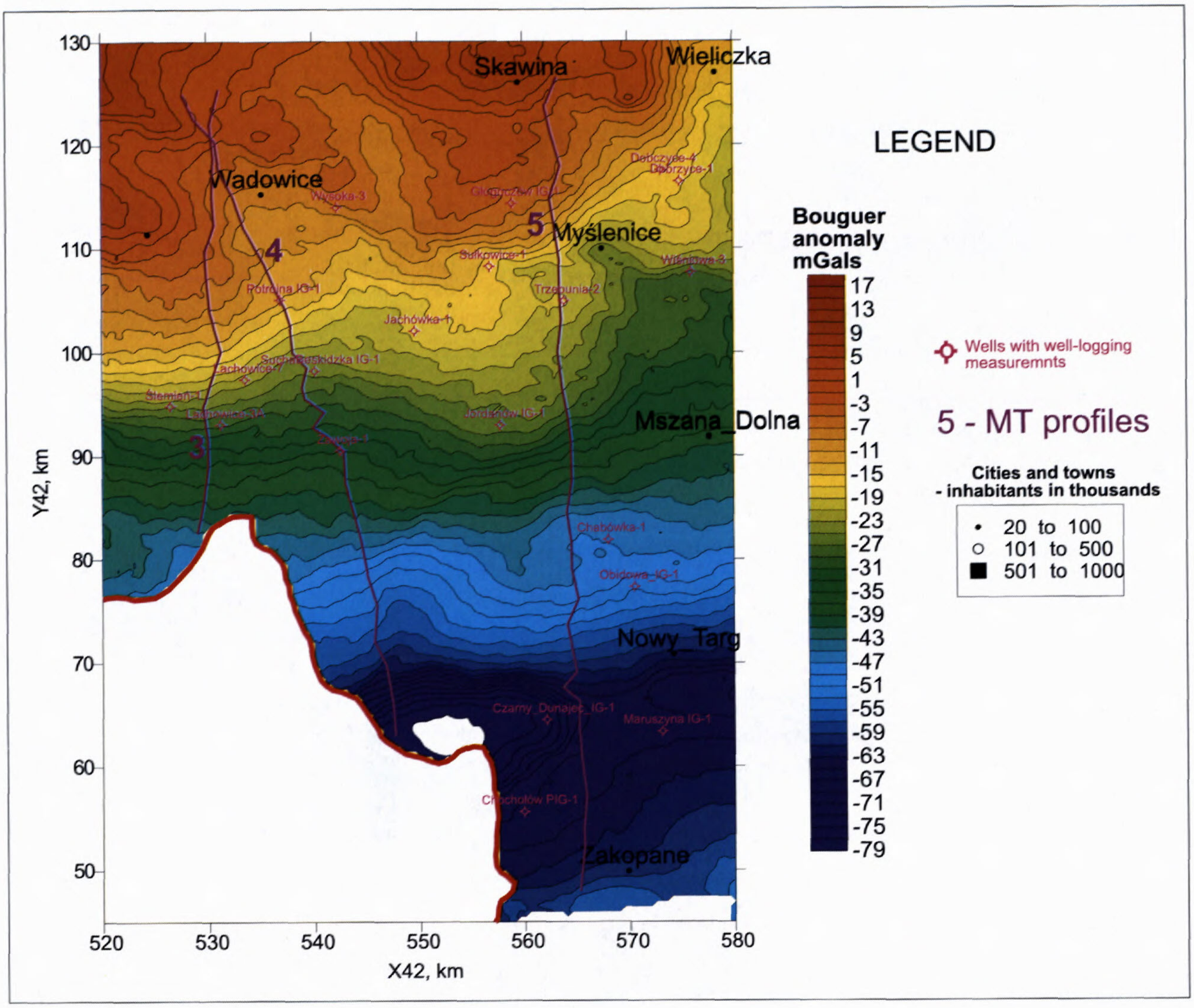

Fig. 3 Bouguer gravity anomaly of the studied area, according to A. Wójcicki

7 wells (shown in Fig. 3 and Fig. 4). Generally the model encloses the following complexes: Precambrian, Meso-Palaeozoic (as proposed on geoelectric section – Fig. 2) and flysch-Miocene complex, divided according to well data and geoelectric section (Fig. 5). In the modelling process, gravity effect of the model has been adjusted to Bouguer anomaly. The results show similar two-fold differentiation of geological medium that MT results – low density flysch and Miocene deposits and Meso-Palaeozoic-Precambrian basement of higher density. In both complexes densities vary significantly. An interesting fact is the basement in southern part of the profile, south of Pieniny Klippen Belt, which is lower than in the rest of the section.

Discussion on rock physical parameters

In 19 wells, drilled in the studied area, distributions of physical parameters have been worked out. In this case an approach to density, velocity and resistivity determination, elaborated in PBG (Pepel, Umiński; 1995), where a complete set of well logging information, empirical relationships between physical parameters and drill core samples measurement results are used.

Regarding to geophysical interpretation of profiles there are two difficulties. The first is the fact the stratigraphic units are interpreted in individual wells by geologists in various styles (for example – in one well we have Śląska and Podśląska nappes together, in other separately). The second problem is that the wells are usually not located on profile lines, but at distance of several kilometres from the lines. Because of a complex geological structure of Carpathians and their basement the estimation of physical parameters from these wells on considered profiles may be inaccurate. Thus, the parameters obtained during the modelling may differ from parameters measured in projected wells.

Conclusions

The results of integrated geophysical interpretation show a distinction between two geological complexes –

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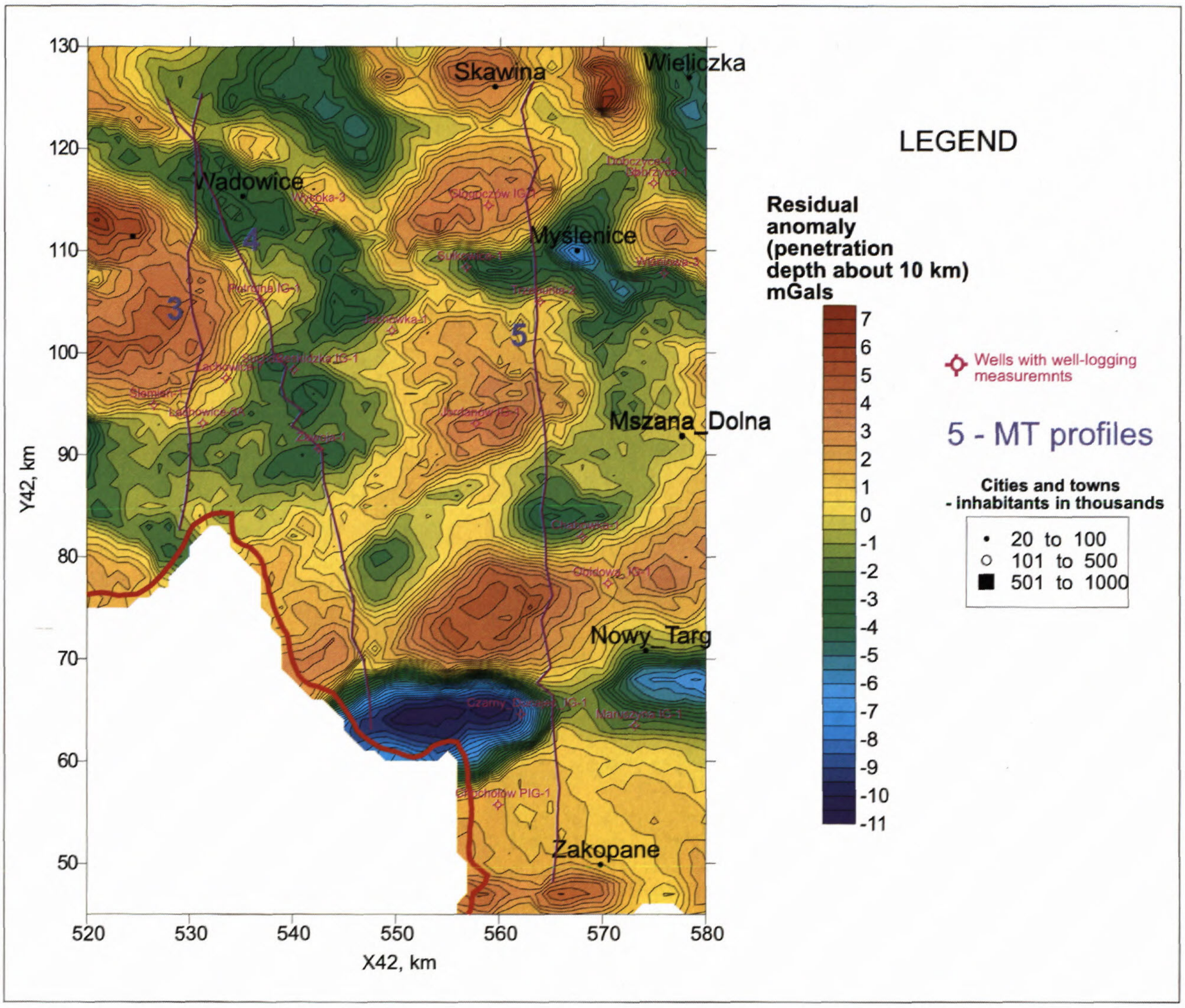

Fig. 4 Residual gravity anomaly using BTWR method, penetration bracket about 0-10 km below sea level, according to A. Wójcicki

lysch and Miocene complex and Carpathian basement complex. Both complexes are differentiated – the shallower flysch and Miocene complex is generally more diverse than the basement apart from the southern part of the studied area. In northern and central part of interpreted profiles Paleozoic sediments are traced. In southern part of the studied area (on profile 5), Pieniny Klippen Belt zone can be observed.

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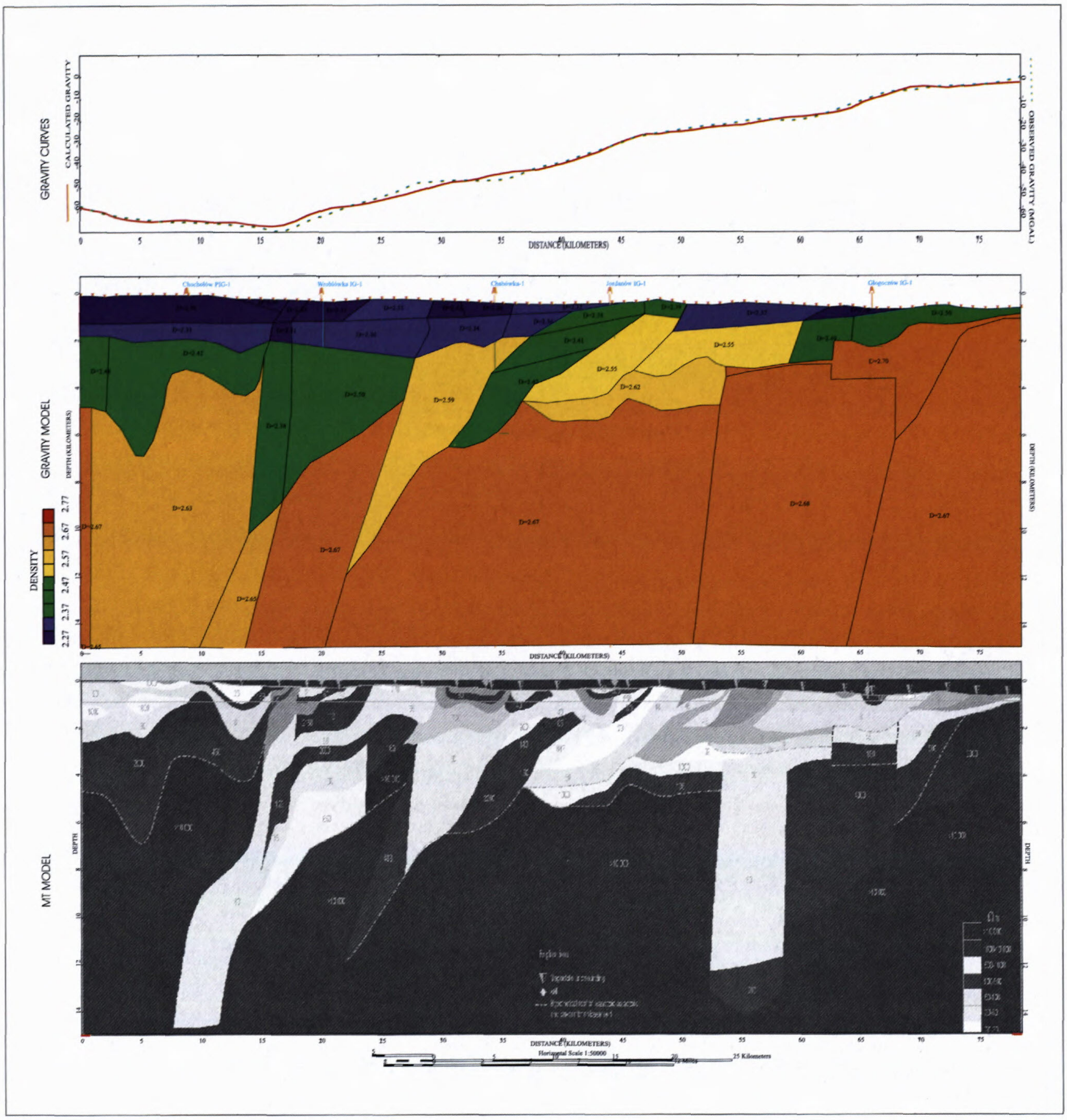

Fig. 5 Results of gravity modeling along profile 5 (Zakopane-Kraków), according to A. Wójcicki