Acta Geodyn. Geomater., Vol. 3, No. 3 (143), 109-116, 2006

PERIODIC GRAVITY CHANGES IN YOUNG TECTONIC MOVEMENT INVESTIGATION IN ORAWSKA VALLEY AND DUNAJEC FISSURE VALLEY AREA – FIRST RESULTS

Sławomir PORZUCEK*, Janusz MADEJ and Monika ŁÓJ

AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Department of Geophysic, al. Mickiewicza 30, 30-059 Cracow, Poland
**Corresponding author's e-mail:* porzucek@uci.agh.edu.pl

(*Received* February 2006, *accepted* May 2006)

ABSTRACT
Geodynamic processes take place in the Carpathians even nowadays. For tracing them, a research project employing gravity measurements was undertaken. Movements in the crust result in a change of mass distribution, which may be traced with the use of a gravimetric method. Two measurement profiles were designed for tracing geodynamic changes, and in the years 2004-2005 gravimetric measurements were realised. The first results of observed gravity changes are presented in the paper and are followed by preliminary conclusions on the observed changes and the assumed measurement methods.

KEYWORDS: gravity measurements, geodynamic processes, temporal gravity changes

In 2004 a team of researchers from the Department of Geophysics, AGH University of Science and Technology in Cracow started a project no. 5 T12E 031 25, financed by the Ministry of Science and Education, the aim of which were geodynamic investigations in the Outer Western Carpathians.

Young tectonic movements have been known (Zuchiewicz, 1995) to take place in the Carpathians. The so far researches indicate that horizontal movements might prevail there (Hefty, 1998).

A decision was made to run geodynamic investigations, i.e. gravimetric, geodetic, geologic and morphostructural investigations.

Gravimetric measurements made for the needs of geodynamical investigations have been carried out in the Polish part of the Western Carpathians since 1970s. In 1978 gravimetric investigations were used in the first geodynamic area of Czorsztyn (Ząbek et al., 1993). Since the end of the 1970s gravimetric investigations have also been realized by the Institute of Higher Geodesy and Geodetic Astronomy of the Warsaw Technical University. The registered gravity changes were of 0.100 mGal. In the same years the workers of the Institute of Geophysics, AGH (now Department of Geophysics) made experimental gravimetric investigations in a geodynamic area of Olkusz-Wadowice.

Similar investigations have been performed for years in the Sudetes, in the Śnieżnik Massif, where a correlation of vertical movements of rock complexes and gravitational variations was observed (Barlik and Cacoń, 1999).

The authors also investigated changes in the rock mass above a salt dome in Inowrocław, on the basis of which a measurement methodics could be tailored for the needs of geodynamic investigations.

In the framework of the geodynamic investigation project for the Outer Western Carpathians, stations were set in two meridian-oriented profiles: first (profile KO) in Orawa Valley, the other (profile DD) in the Dunajec Valley (Łój et al., 2005). The course of the profiles was so selected as to make them cut the greatest possible number of tectonic units of different neotectonic trends (Żytko et al. 1989, Zuchiewicz 1995, 1998). A special establishment of observation stations was made to enable both gravimetric and GPS geodetic surveys. The stations were fixed for measurements with the use of Autograv of Scintrex and LaCoste&Romberg gravimeters.

One of geophysical methods, i.e. gravimetric method was selected for investigations. Although small in magnitude, the neotectonic movements are expected to affect the mass distribution in the earth's crust. The gravimetric method enables tracing all mass changes in time. For lowering the random and measurement errors, measurements with three gravimeters were planned. There were used two gravimeters the Scintrex (Autograv): CG-3 and CG-3M, and the third one the LaCoste&Romberg (Model-G).

A chain method was selected for measurements, which can be symbolically written A-B-A-B-A, where A and B are stations; gravity difference is determined between these stations. With this method it was possible to lower the error of this difference. A schematic representation of measurements in both profiles is given in Fig. 1.

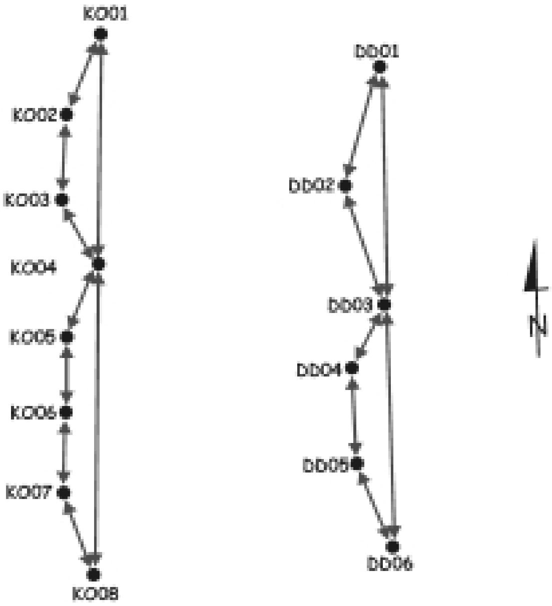

Fig. 1 Scheme of measurement network in profiles KO and DD.

The first, basic gravimetric measurements, were performed in 2004 (Łój et al., 2005), and the successive ones in 2005. In both years the measurements were made in the same period, i.e. in July. In line with the assumed methodics, the gravity differences between stations presented in Fig. 1 could be calculated each year. Each time the gravity value was calculated between stations with each of the three gravimeters. Then the mean from these gravimeters was calculated.

On the basis of the obtained results it was possible to calculate gravity changes between stations between the year 2005 and 2004 (Fig. 2). There is presented a gravity change between stations with two gravimeters: CG-3 and LCR Model-G, and for the average. Unluckily for the authors, it was not possible to calculate changes with the third gravimeter CG-3M. It failed in profile KO in 2004 and in profile DD on 2005.

The analysis of distributions presented in Fig. 2 reveals a visible difference between profiles DD and KO. The values of differences between stations in profile DD are small and in a majority of cases do not exceed 0.01 mGal. The sign of gravity changes for both gravimeters and the mean is nearly the same. Basing on the obtained distributions it is hard to speak about possible trends of changes. The gravity change between stations 6-3 is high as compared to others, regardless the gravimeter used.

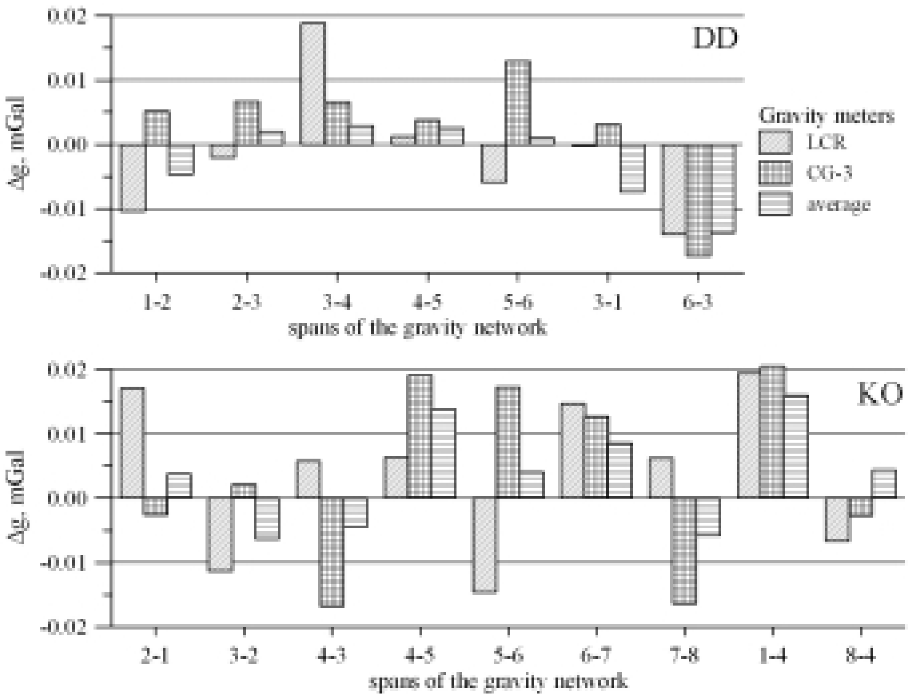

Fig. 2 Gravity changes between stations in profiles DD and KO in 2005 and 2004.

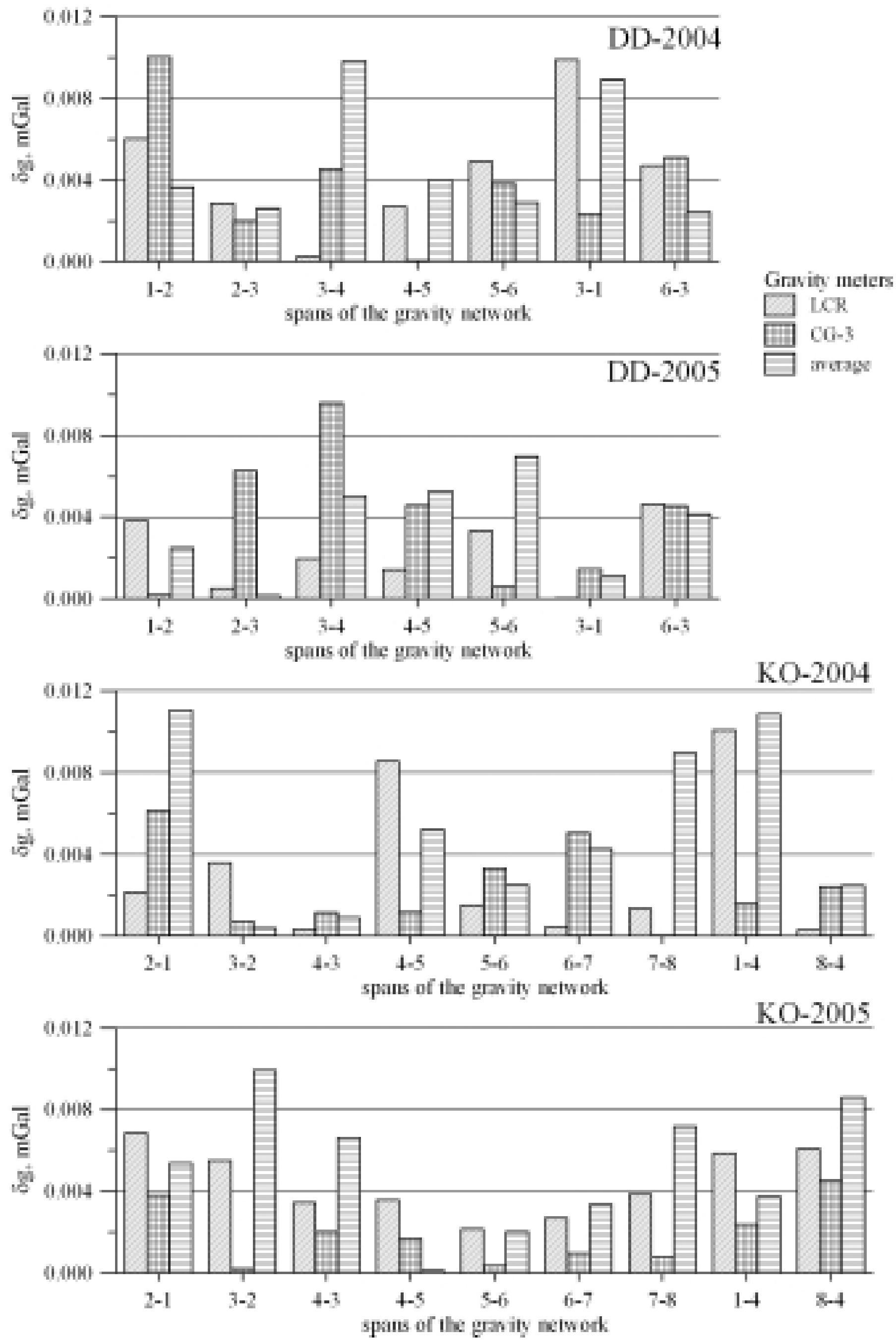

Fig. 3 Error of gravity measurement between stations in profiles DD and KO in 2005 and 2004.

Other relations take place in profile KO. The calculated differences frequently exceed ±0.01 mGal. Additionally, for both gravimeters opposite signs of changes and high values are observed. A detailed analysis of the methodics and the survey itself was made to explain the variability of distribution of gravity changes between stations in profile KO.

During field measurements in 2004 and 2005 an identical surveying method was used so the choice of methods had no influence of the observed changes.

For both series of measurements there were calculated errors with which were burdened the gravity changes between stations in both profiles in the two years, Fig. 3. It turned out that the error distribution in both profiles obtained in 2005 is very similar to that of 2004. Generally, the errors were lower than 0.005 mGal; only in a few cases higher values were observed, but they never exceeded 0.011 mGal. None of the gravimeters can be distinguished on the basis of error distributions and their values.

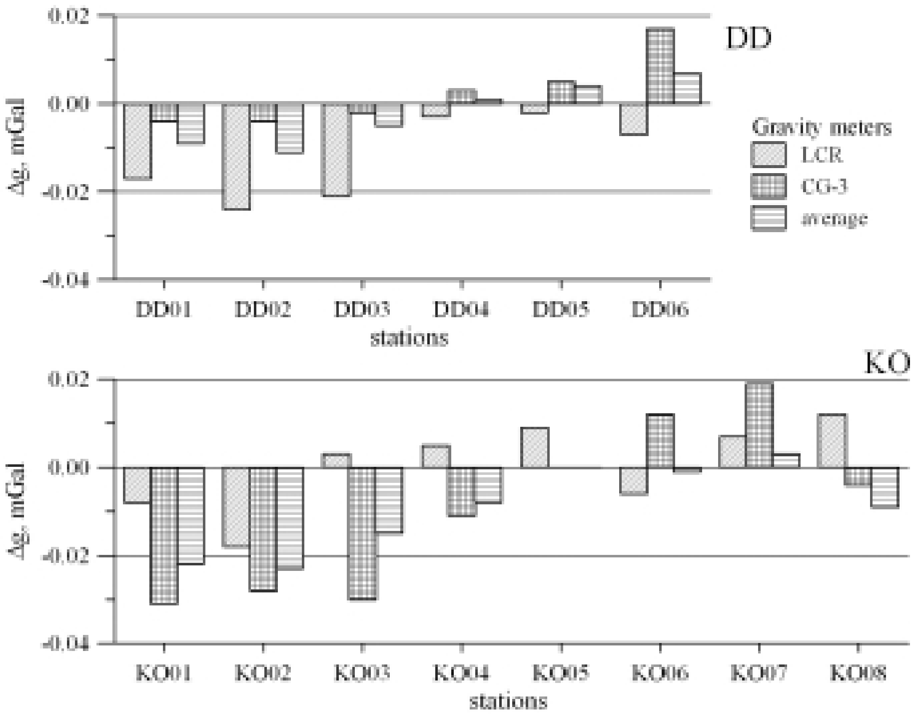

Fig. 4 Gravity change on stations of profiles DD and KO in the years 2005 and 2004.

It was assumed in further analyses that different character of gravity changes distribution in profile KO may be caused by two reasons:

1. seismic tremors observed in the region by the close of 2004 and in the beginning of 2005
2. weather conditions. During the measurement sessions in 2005 heavy rains occurred.

The first cause may be proved true by investigations carried out in 2006. However, this cause does not explain why the gravity changes between stations calculated on both gravimeters were high and had opposite signs.

The second cause seems to be more reliable. Heavy rains might result in high humidity of air, which in turn, had a negative influence on electronic systems in the gravimeters. This fact was observed during stationary, long-term gravimetric observation of earth tides (Dittfeld et al., 2000).

Gravity changes between stations of the analysed profiles are presented in Fig. 4. These changes may also be analysed at the observation stations. As can be seen in Fig. 1 the measurements in profiles were designed in the form of a simple network consisting of two meshes. Owing to this the values at stations could be calculated by adjustment values in the networks. The least squares method, presented in the materials of Joint BGI/ICET Summer School 2002, was used for adjustment the network. Averaged values between stations from the chain method were assumed. However, the time of measurement between specific stations was assumed to be as a weight. The station POGK 99 of the Polish Primary Gravity Network at Nowy Targ was assumed as a fixed point with known value. In the course of these calculations there were obtained gravity changes on stations between 2005 and 2004 – Fig. 4.

The character of changes on stations in the profiles resembles the distribution of changes between stations in the profiles, i.e. changes in profile DD are much smaller than in profile KO.

Gravity changes measured by the gravimeter LCR in profile DD, at points DD1, DD2, DD3 and DD6, considerably vary from the ones measured with the CG-3 gravimeter and their average. As for CG-3 gravimeter, as small changes as > 0.005 mGal are observed (except for station DD06). The average changes in both gravimeters and all stations do not exceed 0.011 mGal. It also follows from the differences presented in Fig. 4 that two groups of stations having a similar character of changes exist in profile DD. The first group with negative change values consists of stations DD1, DD2 and DD3. The other one encompasses the remaining stations, having small positive changes (apart from LCR gravimeter).

Gravity changes observed in profile KO between the year 2005 and 2004 are higher than in profile DD. The changes calculated at stations KO3, KO4, KO6, KO8 from gravimeters CG-3 and LCR have opposite values, i.e. similar as changes between stations. Owing to such a spectrum of changes for both

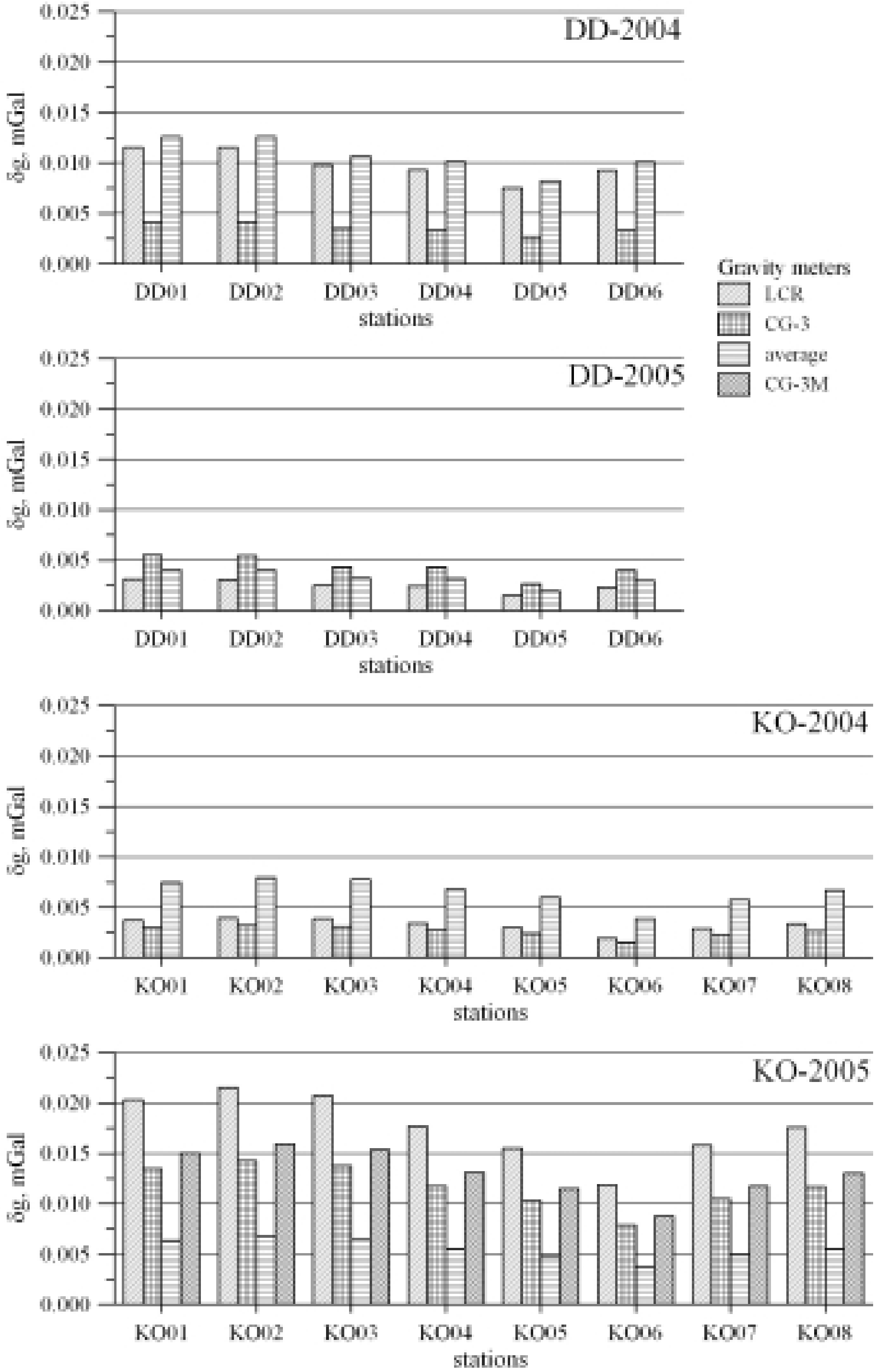

Fig. 5 Gravity value measurement error on stations of profiles DD and KO in 2005 and 2004.

gravimeters and the average, no conclusions can be drawn on the changes of gravity in the profile.

A calculation error for both stations in 2004 and 2005 is presented in Fig. 5. Measurements with a CG-3M gravimeter in profile KO in 2005 are also accounted for. As expected, the biggest errors were obtained on stations in profile KO in 2005. It is interesting that the average value from three gravimeters in the profile was burdened with a considerably small error. The errors are bigger in profile DD in 2004 than in 2005. This seems to also stem out from the measurement conditions. In 2004 the measurements were made during heavy rains, whereas in 2005 the weather was sunny.

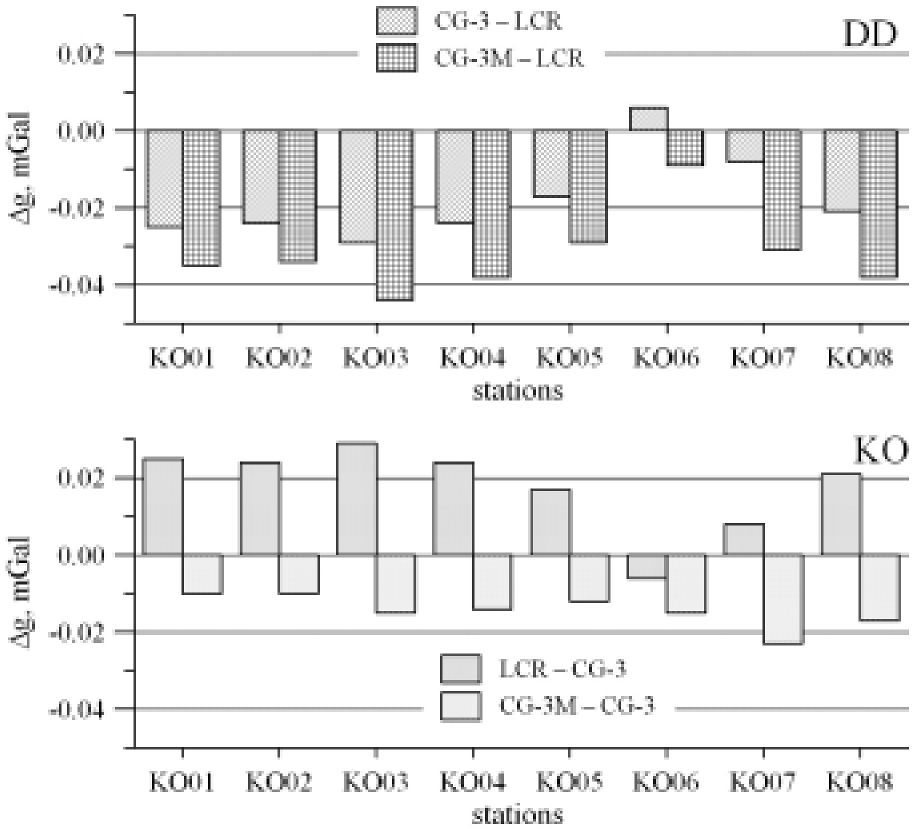

Fig. 6 Comparison of gravity values on stations in profile KO in 2005, calculated for three gravimeters. No averaging values between stations are involved.

It follows from the analysis of Figs. 2 to 5 that during the rainy weather the LCR and CG-3 gravimeters behaved differently. This seems to be confirmed by measurements in profile KO in 2005, performed with all three gravimeters: CG-3, CG-3M and LCR.

Two distributions, being a comparison of gravity values calculated in profile KO, are presented in Fig. 6. In the first distribution an LCR gravimeter was assumed as a reference point for values obtained with the two remaining gravimeters. A CG-3 gravimeter was the reference in the other distribution. The first distribution indicates that values obtained with CG-3 gravimeters had a different character than those obtained with LCR gravimeter, i.e. were smaller. This is confirmed by the second distribution which clearly indicates that values obtained with the LCR gravimeter are bigger and for CG-3 gravimeter are smaller. This does not obviously mean that the CG-3 gravimeters are better than LCR gravimeters; this means that they behave differently during measurements in rainy weather conditions.

An attempt was also made to re-calculate values in observation stations using a different method. This time the directly measured values have been used for the adjustment algorithm of the network, not the values between stations obtained with the chain method. Using such a procedure a double averaging can be avoided – calculation of an average between stations and adjustment the network with the least squares method. Moreover, an error of a value measured in an observation station is obtained and it is not burdened with an error of determining an average between stations.

Calculations were made for the CG-3 gravimeter for both profiles. Initially, in October 2005 measurements for profile KO were made for new data. No chain method was used; measurements were made on stations following the scheme in Fig. 1. Six differences could be measured between stations, i.e. twice as many as in the case of the chain method. Error in gravity difference between stations for 2004 and 2005 and the additional series are presented in Fig. 7. The obtained results are quite astonishing as the error values calculated for 2004 and 2005 are almost identical, and the values themselves are similar in both profiles. However, the error values for October 2005 are much different, i.e. are 3 to 4 times smaller. The double increase in the differences values between stations does not explain that drop in error value. A stable weather without rain seems to have played a crucial role in this case.

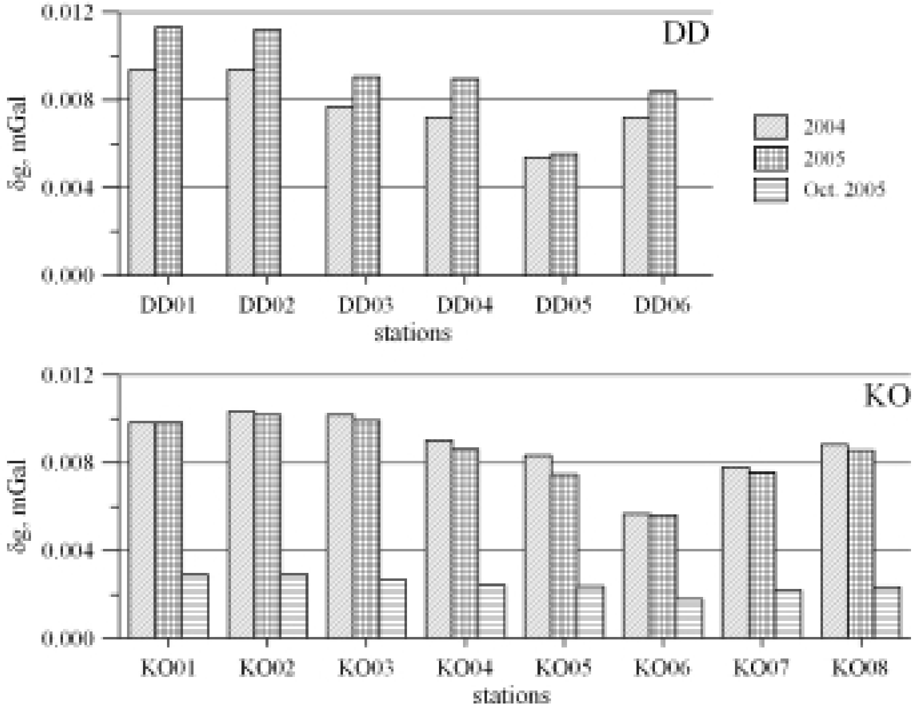

Fig. 7 Error of gravity measurement between stations for CG-3 gravimeter in 2004, 2005 and additional series in October 2005. No averaging of values measured between stations was made.

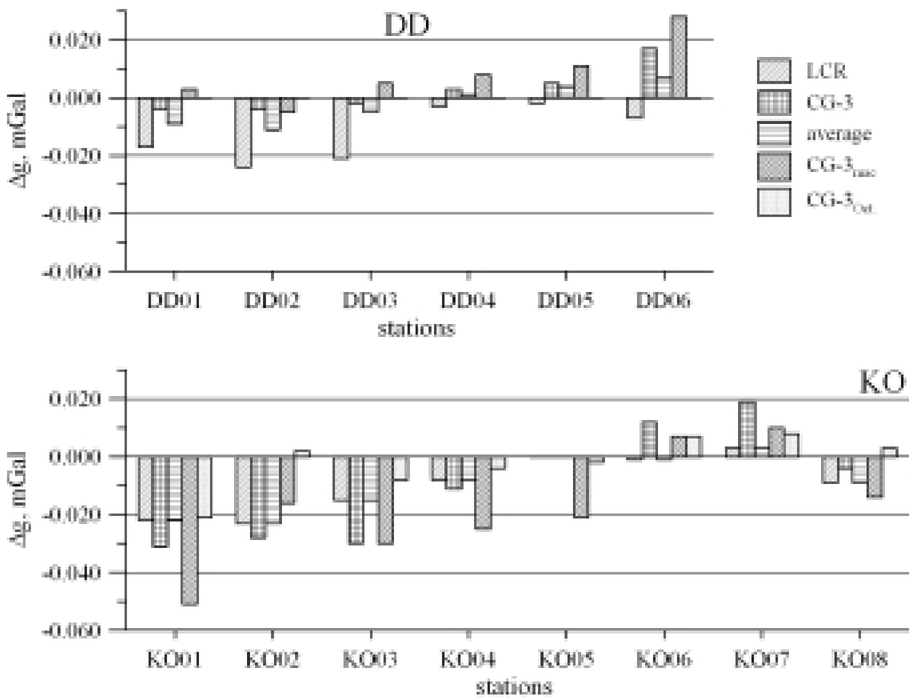

Fig. 8 Gravity changes on stations of profiles DD and KO between 2005 and 2004. LCR, CG-3, average values were calculated by taking averages between stations with the chain method; for CG-3_{mac} and CG-$3_{Oct.2005}$ gravimetric measurements no averaging of values between stations was made.

Gravity changes on stations in the years 2005 and 2004, calculated employing the above-mentioned methods are presented in Fig. 8. The changes calculated with the second method in both profiles with CG-3 gravimeter usually are bigghher than the ones from the first method. Nonetheless, the changes values rapidly drop in the additional measurement, to obtain values smaller than in the remaining cases.

CONCLUSIONS

The results of gravimetric measurements performed in 2004 and 2005 for two profiles in the Polish part of the Outer Carpathians are presented in the paper. Very small differences taking place in the earth's crust were observed. The expected gravitational results of these changes were small, staying within the measurement error. Measurements were made with three different gravimeters, to reduce the influence of the gravimeter quality on the measured parameters. Unfortunately, for objective reasons, each year the measurements were made with only one gravimeter in only one (but different) profile. This made it impossible to calculate gravity changes for both profiles as measured with this gravimeter.

It follows from the results that weather conditions (especially high humidity) have a significant influence on the measurement. Each gravimeter has electronic elements which are sensitive to this factor. Ideally, measurements should be made during sunny and windless weather, which is hardly ever possible.

It seems that by increasing the number of different gravimeters should eliminate this obstacle. However, logistic and financial difficulties appear in this case. Thus, other options should be considered. The time-consuming chain method should be abandoned and most of the measurements should be done between stations; gravity values on stations should be calculated directly from the obtained differences. Such measurements would not have to be done during one session, thanks to which the weather factor could be eliminated. Having obtained about 10 differences between stations it would be possible to accurately calculate changes on stations and eliminate accidental errors.

REFERENCES

Barlik, M. and Cacoń, S.: 1999, Gravity changes observed in the Polish part of Eastern Sudety Mountains and Fore-Sudetic Block, Exploration Geophysics, Remote Sensing and Environment, 6, No. 2, 8-10.

Dittfeld, H.-J., El Wahabi, A. and Simon, Z.: 2000, Meteorological influence on tidal gravimeter drift, Proceedings of the Workshop 'High Precision Gravity Measurements with Application to Geodynamics, and Second GGP Workshop', Edited by B. Ducarme and J. Barth□lemy, 17, 217-228, Luxembourg, 2000.

Hefty, J.: 1998, Estimation of site velocities from CEGRN GPS campaigns referred to CERGOP reference frame, Publs. Warsaw Univ. Technol., Inst. Geod. & Geod. Astron., Report on Geodesy No. 9 (39), 67-79.

Łój, M., Madej, J. and Porzucek, S.: 2005, Methodology of periodic gravimetric investigations in monitoring geodynamic processes: selected examples, Acta Geodynamica et Geomaterialia, 2, No. 3, 103–112.

Network adjustment, in materials of Joint BGI/ICET Summer School 2002 on Terrestrial gravity data acquisition techniques: 2002, Louvain-la-Neuve, Belgium, Sept. 4 – 11.

Ząbek, R., Barlik, M., Knap, T., Margański, S. and Pachuta, A.: 1993, Continuation of geodynamic investigations in the Pieniny Klippen belt, Poland from 1985-1990, Acta Geophysica Polonica, XLI, No 2, 131-150.

Zuchiewicz, W.: 1995, Selected aspects of neotectonics of the Polish Carpathians, Folia Quaternaria, No. 66, 145-204.

Zuchiewicz, W.: 1998, Quaternary tectonics of the outer West Carpathians, Poland, Tectonophysics No. 297, 121-132.

Żytko, K., Gucik, S., Ryłko, W., Oszczypko, N., Zając, R., Garlicka, I., Nemcok, J., Elias, M., Mencik, E., Dvorak, J., Stranik, Z., Rakus, M. and Matejovska, O.: 1989, Geological map of the Western Outer Carpathians and their foreland without Quaternary formations. In: D. Poprawa & J. Nemcok (Eds.), Geological Atlas of the Western Outer Carpathians and their foreland, 1: 500 000, Państwowy Instytut Geologiczny, Warszawa.