

# STUDY OF THE RELATIONSHIP BETWEEN THE TECTONIC STRESS AND THE DEFORMATION OF THE LITHOSPHERE IN THE TERRITORY OF POLAND – A NEW GEODYNAMICS RESEARCH PROJECT

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Sformatowano

## SUMMARY

The main goal of the project is the complex analysis of recent geokinematics and geomechanics of the Earth's crust in the territory of Poland. The analysis will be performed using the archive data as well as the new data acquired during the realisation of the project. Combined analysis of GNSS data obtained from the epoch observations at the stations of PSG (Polish Geodynamic Network) and stress measured in the drilling holes will be conducted. The new thermomechanic 2D geodynamic model will be determined using the finite element method.

## INTRODUCTION

The research foreseen in this project relates to the identification of both the character and the causes of Poland's present-day geodynamics. The fundamental goal of the project is the carrying out of a modern synthesis of research types hitherto conducted separately: geodetic, geophysical, geological and numerical-modelling, as well as their integration into a single coherent system of present-day geodynamics. The achievement of that goal will be possible thanks to the undertaking of broadly-based, interdisciplinary collaboration between the institutions involved in this project: the Institute of Geodesy and Geodetic Astronomy of Warsaw University of Technology, the Institute of Geodesy and Cartography in Warsaw, the Polish Geological Institute, and the Slovak University of Technology in Bratislava. In the development of the model, a fundamental role will be played by high quality measurements undertaken at PSG (Polish Geodynamic Network) points, including GNSS measurements, gravimetric and magnetic measurements. Tectonic-stress directions and regimes will be measured at about 20 drilling holes. The results of those measurements, combined with archive data, will enable the drawing up of a map of horizontal stress trajectories for the area of Poland. On the basis of the geological, neotectonic, gravimetric and thermic data, a mechanical lithospheric model will be created for Poland and adjacent countries. The model will be the basis for the definition of material parameters and lines of tectonic discontinuity, with regard to the thermomechanical stress and deformation model, using the finite element method in 2D. This model will cover the areas of Central and Eastern Europe, and will be focused on the territory of Poland. On the basis of that model, the mutual consistency of the deformation and stress measurements will be checked. Also the distribution and magnitude of the external tectonic forces responsible for lithospheric deformation levels on the territory of Poland will be determined. Research in this field has been carried out in the context of the SAGET (Satellite Geodynamic Traverses), CERGOP and CERGOP 2 (Central European Geodynamic Project) projects, as well as the PSG project (Hefty, 1998; Kłęk, 2005).

## THE POLISH GEODYNAMIC NETWORK

For the purposes of geodynamic research on a national scale using geodetic methods, the Polish Geodynamic Network (Polish acronym: PSG) was set up in the 1990s. Work on the creation of the network was undertaken by the Institute of Geodesy and Cartography, Warsaw in late 1991/early 1992, and ran in consultation with the national geodetic service, which was at that time carrying out a full-scale modernization of the Poland's basic geodetic framework, and also in contact with all of Poland's geodetic groups involved in research in the field of geodynamics. The core of the network being established was made up of points situated in astro-geodetic observatories, other points of the EUREF-POL "0"-order network, and also points of the SAGET geodynamic traverse, included in many international programmes. The positioning of remaining points, selected from the astro-geodetic SAG network, was consulted with representatives of the Polish Geological Institute. The basis for the selection of the location of those points was a map showing the boundaries of principal and subsidiary geological structures, a map of SAG astro-geodetic network points, and also field reconnaissance. The points selected in that manner (Fig. 1) fulfilled the requirements of the geodetic network and, being representative of Poland's basic geological structures, should be an object of interest not only for geodesists but also for geologists and geophysicists (Dobrzycka and Cisak, 2001).

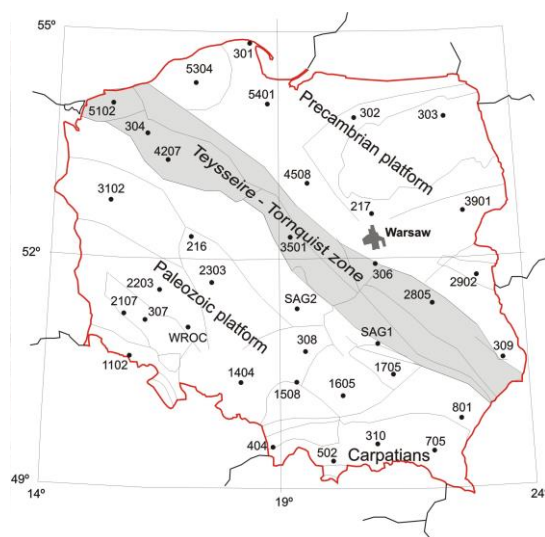


Fig. 1. PSG-network point locations on the background of geological-structure boundaries in Poland

PSG is made up of 36 points, consisting of:

- 11 EUREF-POL "0"-order network points (including 4 permanent GPS stations);
- 22 points, selected from the POLREF network, being a densification of the EUREF-POL network;

- 3 additional stations : WROC (the permanent GPS station of Wrocław University of Environmental and Life Sciences) and two SAGET network points (Belchatów and Święty Krzyż).

Those points were monumented in a manner enabling their fixedness to be maintained for several decades (Fig. 2).

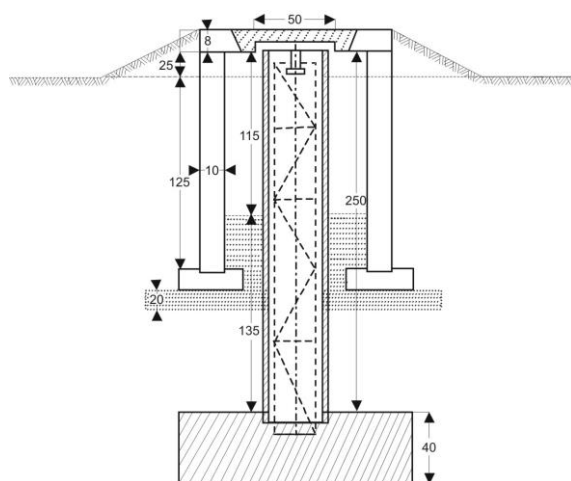
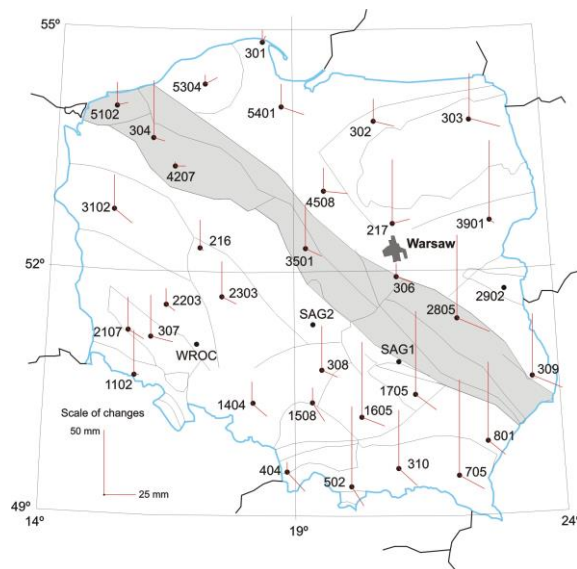


Fig. 2. PSG-point stabilization

GPS measurements at PSG network points, to constitute epoch “0” for the geodynamic research, were carried out in 1997, using Leica SR299 and SR399 receivers, and also in 1997 and 1998, using Ashtech ZXII3 receivers. During 1997-1998, at the PSG network points connected to the national vertical control, was additionally surveyed gravity. In the vicinity of those points, measurements were made of the components of the Earth magnetic-field vector, in the context of research of its spatio-temporal distribution. GPS data acquired at the PSG network points was processed using the Bernese v.4.0 software, according to standards applied in routine processing data in the EUREF permanent network. The final computations were performed in ITRF96, in two groups: separately, for observations made in 1997 and 1998 at their mean epochs. Subsequently, the results were transformed into a common epoch (1998.3), adjusted and converted to the epoch 1989.0. Realization of the ETRF89 in the adjustment of PSG involved the coordinates of 10 stations of the permanent EUREF network (BOGO – Borowa Góra, BOR1 – Borowiec, JOZE – Józefosław, LAMA – Lamkówko, WROC – Wrocław, GOPE – Pecny, GRAZ – Graz, METS – Metsahovi, ONSA – Onsala i WTZR – Wettzell), to which PSG was connected. In order to verify the PSG point coordinates obtained, a comparison was carried out between them and the results obtained in the EUREF-POL (1992) and POLREF (1994-1995) campaigns, constituting the basis of the coordinate catalogue of Poland’s geodetic control (Fig. 3) (Dobrzycka and Cisak, 2001).



**Fig. 3. Differences between catalogue coordinates and PSG epoch-"0" coordinates**

Figure 3 reflects the differences obtained. The average differences were:  $d\phi = -6.2$  mm,  $d\lambda = 13.1$  mm,  $dH = 34.2$  mm. A reason for those differences may have been the successive changing and correcting of ITRF parameters, differing methods of adjustment and selection of reference points, different observation-session duration, the effect of modelling antenna phase centre, and also local seasonal changes in the coordinates of the points.

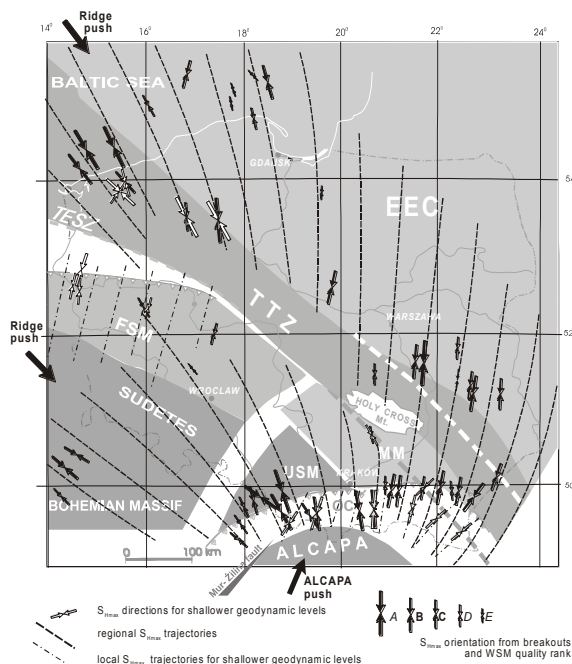
The value and significance of the PSG network for geodynamic research in Poland, the need for carrying out further observing campaigns at the points of that network, and also the main principles concerning observation strategy and the processing of GPS data for geodynamics purposes were all formulated in resolutions of the Polish Academy of Sciences Committee for Geodesy Earth Dynamics Section workshop entitled "Geodynamic research using PSG", which took place in 2002, with the participation of scientific representatives from the geodetic, geological and geophysics communities. The following were declared as necessary:

1. analysing the correctness of the position of the existing PSG network stations,
2. carrying out new GPS campaign at the PSG network, using new, higher-quality measuring equipment, in a manner coordinated with geological measurements, in the integration of PSG with the CERGOP network – in a similar manner to the 1997-1998 operation,
3. carrying out new gravity survey at PSG network points, by means of relative measurements referred to absolute gravity stations, and also linking to gravimetric points situated outside the geological unit; survey of gravimetric profiles and supplementary detail gravity survey,
4. carrying out a detailed analysis of the monumentation of PSG points (annual changes – thermal influence, ground water, changes in atmospheric pressure, indirect impact on deformation of movements inside the Earth's crust),
5. investigating whether in the new CERGOP II project it would not be necessary to take into account of new points (the TT zone is highly differentiated) and to increase the density of points of the geodynamic

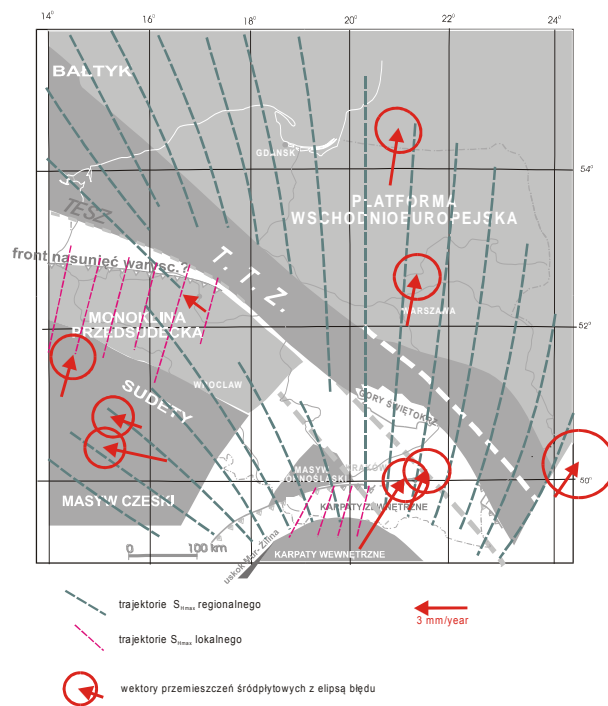
- network. Such points could be taken from two geodynamic profiles: South-East and North-West, established as part of the EUROPROBE project,
6. analysing the standards of permanent GPS stations with regard to their usefulness for geodynamic purposes, especially from the point of view of the precision of the data determined,
  7. increasing the number of permanent GPS stations in Poland (for monitoring horizontal movements, checking on deformations, e.g. on both sides of the Pieniny strip, determining the main directions of deformations within Poland, functions other than geodynamic),
  8. a uniform processing of data from the GPS campaigns and gravimetric survey at PSG network points (1997-1998 observations, and also new measurements) and also carrying out of a detailed analysis of the results,
  9. carrying out a joint geological and geodetic interpretation of the results of geodetic measurements.

## PREVIOUS STUDIES REGARDING THE DEFORMATIONS OF THE EARTH'S CRUST OVER THE AREA OF POLAND

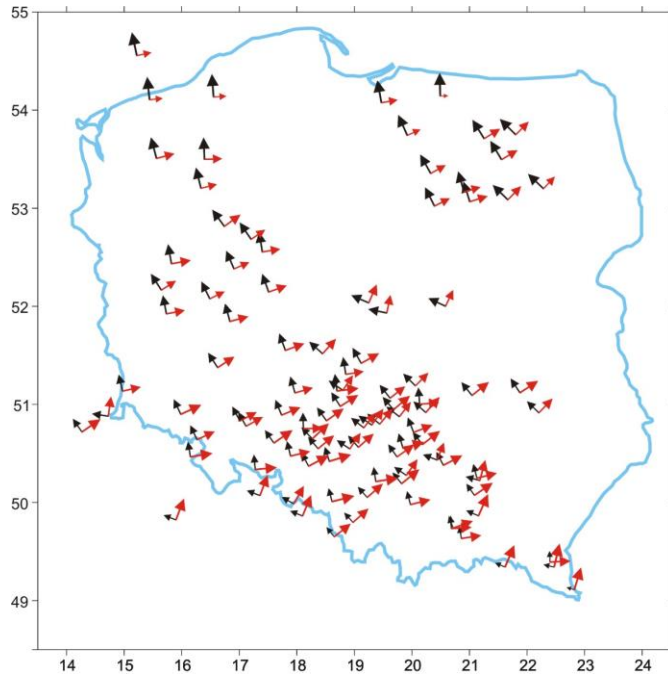
The model of the stresses in the Earth's crust over the area of Poland as developed, shows regularities in the distribution of tectonic-compression directions (Jarosiński, 2006) (Fig. 4). The results of those stresses agree with the directions of deformation, calculated using observations made as part of the CERGOP campaign (Hefty, 1998) (Fig. 5), as well as with the directions of the principal axes of deformation ellipses (Klęk, 2005) (Fig. 6).



**Fig. 4. A sketch map of the  $S_{Hmax}$  orientation from breakouts and hypothetical trajectories of  $S_{Hmax}$  for Poland**



**Fig. 5. Accordance of present-day tectonic-stress trajectory directions and interplate movement vectors (Hefty, 1998)**



**Fig. 6. Main deformation-direction axes, from the CERGOP campaign**

In 2005, two consecutive GPS campaigns on 6 selected points of the PSG network were planned, in order to obtain supplementary observations from the geodynamic operation carried out as part of the CERGOP project and the Polish section of the EPN network (Fig. 7). At those points, a 5-day observation campaign was carried out in spring 2006, and is to be repeated in 2007. The results of observations in the network composed of the points set out in Fig.7 will serve to specify interplate velocities and their interpretation.

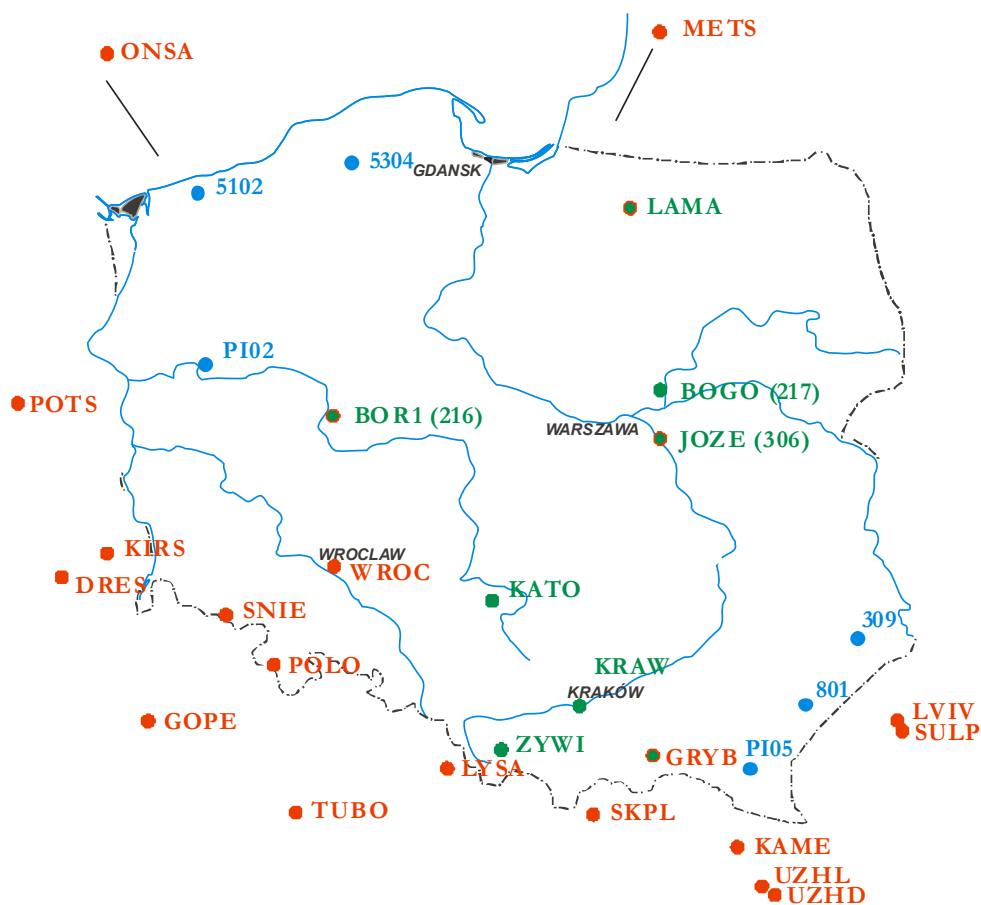


Fig. 7. The CERGOP network, EPN and selected PSG points

## SUMMARY

The results of the research presented have enabled to develop the foundations of the project, the implementation of which is expected during 2008,. The project will cover the developing of a mechanical lithospheric model for Poland, on the basis of geological, neotectonic, geodetic, gravimetric and thermic data. The model will form the basis for defining material parameters and lines of tectonic discontinuity relating to the thermomechanical stress and distortion model, using the finite element method in 2D. The model created will cover the area of Central and Eastern Europe and will be focussed on the territory of Poland. On the basis of that model, the mutual consistency of the deformation and stress measurements will be tested. The distribution and

magnitude of internal tectonic forces, responsible for horizontal deformations of the lithosphere over the area of Poland will also be determined. A material output of the study will be a database for Poland, collecting all information regarding:

1. changes in coordinates and in gravity at PSG network points,
2. directions of interplate movements,
3. deformations,
4. directions of present-day horizontal stresses,
5. tectonic regimes,
6. fault-line coordinates, indicating Quaternary and present-day activity.

The data obtained during the implementation of the planned project will form the basis for the development of a present-day geodynamic digital map of Poland. A thermomechanical 2D model of the Central and Eastern Europe continental plate will be encoded, enabling the modelling of dependences between external tectonic forces, horizontal lithospheric deformation and stresses, employing the ANSYS software. It will be possible to make future use of the structure of this model also for other types of modelling. The results of the research regarding links between gravimetric and magnetic anomalies, and the boundaries of geological structures, will also be set out, with the goal of determining more precisely the locations of those boundaries.

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