



## PRELIMINARY INTERPRETATION OF PSI DATA OF THE NORTHEASTERN PART OF THE UPPER SILESIA BASIN (SOSNOWIEC TEST SITE) – TERRAFIRMA PROJECT

Marek GRANICZNY<sup>1</sup>, Zbigniew KOWALSKI<sup>1</sup>, Janusz JURECZKA<sup>2</sup>,  
Magdalena CZARNOGÓRSKA<sup>1</sup>, Anna PIĄTKOWSKA<sup>1</sup>

**Abstract.** Preliminary interpretation of the Permanent Scatterer Interferometry (PSI) data of the Upper Silesian Basin indicated strong correlation between the recorded PS negative values and structural pattern of the Carboniferous strata. The results indicate that the subsidence is present at the areas of the synclinal structures such as Bytom Basin, northern slopes of the Main Basin and the Little Zaborska Basin (near Zabrze). The clearly visible concentration of the negative values is also noted at hinges and dropped wings of the Będzin and Kłodnica regional faults. Undoubtedly, the two above mentioned faults of the Variscan origin were rejuvenated during the Alpine Orogeny (the Triassic deposits were found in the dropped wings of the faults). The presence of the ground motion along its run, can suggest neotectonic character of these faults. Linear anomalies oriented WNW–ESE formed by changing values of the ground motions are parallel to the boundaries of productive Carboniferous sediments forming the coal basin – Karvina Upper Beds, Ostrava Beds and Karvina Lower Beds. The explanation of these phenomena (genesis and mechanisms) needs further studies.

**Key words:** Permanent Scatterer Interferometry, TerraFirma, Upper Silesian Basin, geological structures.

---

**Abstrakt.** Wstępna interpretacja danych Satelitarnej Interferometrii Radarowej (PSI) wskazała na silną korelację pomiędzy zarejestrowanymi punktami pomiarowymi (PS) o wartościach ujemnych (osiadanie), a przestrzennym rozmieszczeniem struktur geologicznych Górnośląskiego Zagłębia Węglowego. Wstępne wyniki badań wykazały, że osiadanie jest obecne na obszarach struktur synklinalnych, takich jak: basen bytomski, północny skłon niecki głównej oraz małego basenu Zaborska (w pobliżu Zabrze). Wyraźnie widoczne skupienie ujemnych wartości PS jest widoczne wzdłuż zrzucanych skrzydeł uskoku regionalnych: będzińskiego i kłodnickiego. Te uskoki o pochodzeniu waryscyjskim zostały odnowione w trakcie orogenezy alpejskiej (w skrzydłach zrzucanych uskoku znajdują się utwory triasu). Ruchy stwierdzone na powierzchni terenu wzdłuż ich przebiegu mogą świadczyć o neotektonicznym charakterze uskoku. Liniowe anomalie przemieszczeń terenu zarejestrowane wzdłuż kierunków WNW–ESE są z kolei równoległe do granic karbońskich serii produktywnych wyznaczających basen węglowy – górnych warstw karwińskich, warstw ostrawskich i dolnych warstw karwińskich. Wyjaśnienie tych współzależności (genezy i mechanizmu) wymaga dalszych studiów.

**Słowa kluczowe:** Satelitarna Interferometria Radarowa, TerraFirma, Górnośląskie Zagłębie Węglowe, struktury geologiczne.

---

---

<sup>1</sup> Polish Geological Institute, Rakowiecka 4, Warsaw 00-975, Poland

<sup>2</sup> Polish Geological Institute, Królowej Jadwigi 1, Sosnowiec 41-200, Poland

## INTRODUCTION

The City of Sosnowiec is located in the Silesian Voivodeship in the northeastern part of the Upper Silesian Mining District. It covers an area of 91.2 square kilometres. It is the place of residence of about 239 000 inhabitants. Sosnowiec is one of the largest and most important industrial centres in the Voivodeship of Silesia, located at the confluence of Czarna Przemsza and Biała Przemsza rivers in the Silesian Highlands, in the south-east of the Upper Silesian Coal Basin. Sosnowiec was able to develop due to its favourable geographical location and abundant natural resources. The mining of minerals in this area began at the turn of the nineteenth century. It was then that the first hard coal mines were established (Buła *et al.*, 2003).

Far from being inert and stable, the ground beneath Sosnowiec possess numerous risks for inhabitants, infrastructure and cultural heritage. Many of these “geo-hazards” are legacies from the earlier industrial land use. These include a contaminated land, shallow undermining (to a depth of 80 metres), subsidence and polluted underground water, all of which are threats to health and safety and can create huge additional construction and maintenance costs for buildings and the infrastructure. In terms of effects on urban quality of life, the public’s perception of risk associated with these ground-related problems is of equal if not greater importance than the actual physical impact. This perception has major effects on land and property values and discourages new economic development and investment.

The exploitation of the hard coal within the present administrative borders of Sosnowiec was conducted since the end of XVIII century. Almost the whole territory of the city (above 90%) was covered by the mining areas of the hard coal mines. Nowadays, the “Sosnowiec” coal mine was closed in 1997 after 20 years of exploitation. The other coal mines in the vicinity of Sosnowiec were closed, too.

Presently, an exploration runs only in one mine – “Kazimierz–Juliusz” in the eastern part of the city. On the beginning, the hard coal was explored in open cast mines from the Carboniferous outcrops. Later on, several deep mines were constructed. Underground exploration was carried out using “chamber-pillar” system. The “wall” system was used, too.

The exploited area was liquidated by gobbing or roof caving. The maximum depth of exploration works was about 600 metres. The hard coal deposits of the Upper Silesian Mining District are composite beds. Due to its long exploitation thickness of the exploited coal beds get to 35 metres in the Sosnowiec area. In 1999 Polish Geological Institute realized a map in scale 1:10 000 of the total thickness of the hard coal exploitation for the whole territory of the city.

Degraded lands (brownfield sites) in the areas of the closed mines are one of the most important ecological problems of Sosnowiec. This area needs postmining reclamation and can be brought back into new economic uses.

A large part of the city – about 1100 hectares – is an area of the shallow undermining. There is no credible information about its extent and depth.

There are also other mineral deposits within the administrative city borders: Quaternary gobbing sands, Carboniferous clay deposits for construction ceramics and Tertiary limestones and marls for lime industry. Presently, the gobbing sands are explored only in CTL Maczki-Bór sand-pit.

From the hydrogeological point of view, useful aquifers are related with Quaternary and Middle and Lower Tertiary (Kotas, 1972; Pilecka, 2006) In the territory of Sosnowiec, the big regional depression cone was developed within the Carboniferous strata, due to mining activity. Since the coal mines in this part of the basin form system of the communicating vessels, up to now groundwater from the closed hard coal mines have been pumped out to the surface. Relinquish pumping out of the waters is a danger for the working mines since in the future it may cause a water inundation in the large parts of the city.

Modification of the Earth’s is surface or sub-surface undertaken for economic purposes (deep mining surface excavation, deposits of waste materials *etc.*) can have far-reaching consequences for people living in the immediate vicinity, and can present types of geo-hazards that are just as serious as those resulting from natural processes. Such phenomena take place in the City of Sosnowiec and its vicinity.

## SUBSIDENCE

Geohazards are mostly connected with deep mining of coal. Totally in the mining areas of the Upper Silesia already 60,000 ha suffer from the subsidence. The surface becomes pitted with numerous collapse cavities or basins, the depth of which may reach even tens of metres. They may remain dry or may be filled with water (land surface inundation) depending on the local hydrogeological conditions. The subsidence areas can be in danger during floods because they form a kind of interior basins.

The subsidence is particularly dangerous causing severe damage to gas and water pipelines, electric cables and a sewage disposal system. In Sosnowiec and its vicinity, it is common to

find houses being strengthened with iron bars anchored in the walls aiming at prevention of the further damage or collapse, but even such reinforced buildings will show cracks and joints in the walls.

There are different methods for evaluating hazards caused by deep mining. These methods should include remote sensing techniques such as: resolution satellite data, aerial photos, thermal imagery, laser scanning, radar interferometry *etc.* The other techniques as geodetic surveying and GPS measurements should be taken under consideration, too. It is necessary to collect systematic information on: inventory of mining works, extent of exploitation and total thickness of exploited coal beds.

## HYDROGEOLOGICAL HAZARDS

Mining exploration caused several risks and hazards related to surface and groundwater:

- a pollution of the surface and the groundwater due to the mining activity (this problem affects mainly the Quaternary useful water-bearing horizon);
- a decrease of surface and groundwater qualities due to the anthropopression;
- a development of the regional depression cone within the productive Carboniferous strata;

- an appearance of negative hydrogeochemic phenomena after the end of exploitation (the inundation of the mine). It is related to higher content of Fe, Cl and SO<sub>4</sub> in waters.

The above mentioned phenomena caused a necessity of acquisition of drinking waters from neighbouring areas, despite large potential of water resources in the City of Sosnowiec region.

## TERRAFIRMA PROJECT

The TerraFirma is one of 10 GMES Service Elements projects being run by the European Space Agency (ESA) under the GMES initiative. The project establishes a “pan-European ground motion hazard information service in support of policies aimed at protecting the citizen” (TerraFirma, 2004). Ground motion hazards include the subsidence in its all forms, landslides and the effects of seismicity, though initially, and to be immediately operational, the focus is on urban subsidence. The project initiator, the Prime and the Co-ordinator is NPA Satellite Mapping of UK. The project started in early 2003 with a core of National Geological Surveys including the UK, France and the Netherlands, but has now expanded comprising of Norway, Poland (Polish Geological Institute – since summer 2003), Israel, Ireland, Greece and Germany. The negotiations are undertaken with other countries. The project remains open to the participation of other major civil engineering organizations, too.

The technology at the base of such a large-scale undertaking uses the data collected by European radar satellites (ERS-1, ERS-2 and ENVISAT) in a process called Synthetic Aperture Radar Interferometry, or InSAR for short. InSAR can cover whole cities and regions. Since there exists an archive of the “repeated” satellite data, measurements can be uniquely provided back in time for the last twelve years.

The InSAR has been available to us for over a decade, providing ground deformation data at centimetre resolution. In the past two years, new ways of processing of satellite radar images have been invented, that allow ground movements to be mapped and monitored to better than 1 mm per year. This pro-

cess is called the Permanent Scatterers Synthetic Aperture Radar Interferometry, or PSInSAR for short (Perissin, 2004). The technique depends on the existence of radar scatterers which consistently reflect signals from successive satellite passes. This means, it works best in urban and arid conditions where vegetation cannot interfere with the coherence. Several tens of images taken during last twelve years (1992 – launching of the ERS-1 satellite) can be processed simultaneously according to the PSInSAR technology. Images are processed by several suppliers, among them, the Italian company TRE – Tele-Rilevamento Europa in Milano.

The TerraFirma project is split into three Stages (0–2, 2–5, 5–10 years). The first stage, which commenced early 2003, was focused on consolidation of the InSAR – based services that already exist, plus an expansion of the user base, principally through national geological surveys, civil engineers and utility operators. The stage 1 also corresponded to seeing the formulation of the overall strategy and an analysis of the various supply, demand and system requirements. With the initial focus on the urban subsidence, 186 European towns representing 26% of the total population have been identified for PSInSAR processing. A few dozens, so far been completed (including Sosnowiec and surrounding area), though Stage 2 of the project (2–5 years) is anticipated as a funding the remaining processing, among them the Tychy scene (southern part of the Upper Silesian Basin up to the Czech border) and mining areas of Ostrava and Karvina. Subsequent stages will see the gradual inclusion of areas suffering risk from landslides, seismicity and flooding due to subsidence.

## GENERAL INFORMATION REGARDING PS DATA SET

The Polish Geological Institute obtained PS processing results of the Sosnowiec area in mid March 2004. Processing has covered 54 scenes of the ERS-1 and ERS-2 registered between 1992 and 2003. Actually, the studied area is extended from Tarnowskie Góry (NW) – Dąbrowa Górnicza (NE) – Jaworzno (SE) to Zabrze (SW). The city of Sosnowiec is located in the NW quart of the studied area. These data could be characterized as follow: the area covered by the PSInSAR image in-

cludes about 1210 km<sup>2</sup>. Nearly the whole area is located in the Silesian Voivodeship. Only, the small part of the image, situated in southeastern corner belongs to the Małopolska Voivodeship.

1. The majority of the investigated area occur within the Upper Silesian Basin (82.6%). 680 km<sup>2</sup> of which is located within the hard coal mine exploitation field. Numerous

- mines were closed during the last 8 years. The active mines occupy about 260 km<sup>2</sup> of the investigated area.
2. The database includes 122 925 points, extending from −39.63 mm to +25.12 mm. After rejecting of 3 extreme records it extends from −28.13 mm to +9.00 mm. 58,115 measurements (47.3%) are stored between −1 mm to +1 mm and 106,759 measurements (86.8%) varies between −5 mm to 1 mm.
  3. 90,537 measurements have got negative values indicating the subsidence. Among them:
    - 32,094 measurements (35.5%) −1 mm – 0
    - 53,168 measurements (58.7%) −2 mm – 0
    - 67,837 measurements (74.9%) −3 mm – 0
  4. The land subsidence bigger than 10 mm (1 cm) has been registered in 1543 measurements, that is an equivalent of the 1.25% of the all measurements or 1.7% of the all negative values. The land subsidence bigger than 20 mm (2 cm) has been registered in 59 measurements that constitute 0.05% of the all measurements or 0.065% of the all negative values.

### INTERPRETATION OF PS DATA IN REFERENCE TO THE ELEMENTS OF THE SURFACE INFRASTRUCTURE

Usually the PS spatial data sets, showing ground motions, are expressed in the colour scale (Fig. 1). The red colour shows subsidence, the orange shows small subsidence, yellow to green colours, values of motions close to “0” and blue shows an uplifting. Such a description was used during the interpretation presented below.

1. The measuring points reflect the surface infrastructure of a “building type”: a dense urban or suburban agglomeration, single buildings of bigger size, industrial objects, big linear objects like conveyers etc. It is worth to mention that at the areas characterized by the blue-green colours a coincidence occurs with on almost geodetic precision. However, at the areas indicated by the red colour, the existing infrastructure in some places is not “reflected”, for example in the Ruda Śląska–Kochłowice area (1A).
2. There are no measuring points at the areas covered by forests, cultivated lands, meadows, parks, wastelands of different type including heaps and water basins.
3. In the northern and northeastern part of the investigated area red coloured areas do not exist (beside the single points). These areas were not affected by the mining exploitation. The blue–green and yellow colours (rarely) occur in this region.
4. The red colour areas occur only at the territories of the past and present hard coal exploitation. They are also present at the areas adjoining to the coal basin. At these areas the yellow colour is also present and rarely green. The zonation of colours is clearly visible green to yellow and red.
5. The areas indicated at the image by different colours do not correspond to: the morphology, geology of the superficial Quaternary deposits and a depth of the top of the Carboniferous strata, as well as the morphology of the top strata.
6. In the northern part of the image (outside the mining activity), the measuring points (blue-green) correlate directly with the superficial building and industrial infrastructure.

For instance: the agglomeration of Tarnowskie Góry (6A), Ironworks “Katowice” (6B), roads with accompanying villages – Siemienia (6C), Strzyżowice (6D), Psary (6E), linear industrial objects like conveyers in “Katowice” Ironwork (6F), railway station ramps in Dąbrowa Górnicza (6G) or part of the strew around the Kozłowa Góra Basin (6H). The other regularities of the measuring points have not been found.

7. In another southeastern part of the image (within the area of mining activity) the correlation of different elements of building and industrial infrastructure is also visible, for instance a railway tunnel between Mysłowice–Kosztów (7B) or a road with an accompanying building in Jaworzno–Jeleń (7C). However, in some cases, new settlements of the loose building type are “not visible”, for example in Jaworzno (7A).

Generally, it could be stated that there is a distinct difference between the northern (relatively stable) and southern (unstable) areas. That fact is probably related to the mining activity in the Upper Silesia. As mentioned before, the mining activity in the northern area, including the Sosnowiec city practically stopped. In the southern area the coal exploitation is still conducted (Graniczny *et al.*, 2006).

The measuring data show the subsidence of the area limited to few millimetres per year (−1–2 mm). Such small values suggest that the subsidence has no relation to the underground exploitation. Only, about 1% of measurements show values extending from 1 to 2 cm, which could be an indication of the hard coal exploitation. From other sources (geodetic measurements, precise levelling *etc.*) the recorded subsidence reach 10–20 cm per year and even more. Most probably the reason of that is technical limitation of the PS methodology related to wavelength of the SAR systems. Therefore, the data processed from ERS or Envisat satellites show slow and small tendencies of ground movements. The operational capability of ALOS and RADARSAT using L-band, should partly exclude this limitation in the nearest future.

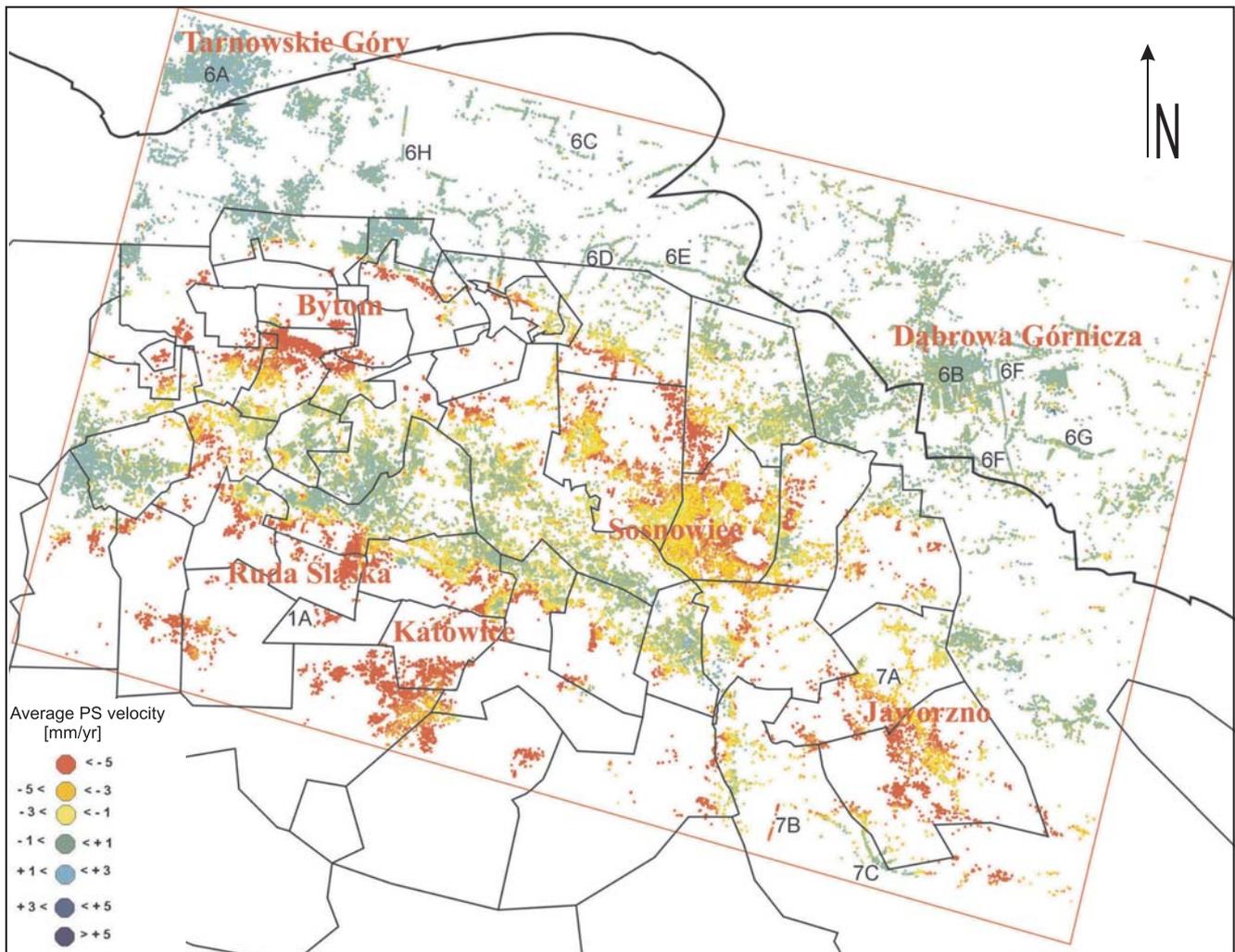


Fig. 1. Distribution of PS versus mining areas

### INTERPRETATION OF PS DATA IN REFERENCE TO THE GEOLOGICAL SETTING

There are some strong analogies between the PS data and the structural setting of the Carboniferous strata:

— Most of the red colours occur at the areas of synclinal structures – the Bytom Basin, northern slopes of the Main Basin, the Little Zaborska Basin (near Zabrze).

— The clearly visible accumulation of the red points is noted at hinges and dropped wings of the Będzin and Kłodnica faults.

— The green colour points occur mainly at the area of the “Main Anticline”, the Zabrze Dome and north of the Bytom Basin.

— The zonal pattern of colour changes from yellow to green, through yellow-orange to red has got a clear parallel character (with a tendency of bending towards south-east) correspond to the strike of the Carboniferous strata. On the other hand, a direction of colour changes from green to red is compatible to the dip of the strata.

— Linear anomalies oriented WNW–ESE formed by changing values of the ground motions are clearly visible. They correspond to structural features (faults, geological boundaries *etc.*) which are parallel to the productive Carboniferous sediments forming the coal basin – the Mudstone Series (Karvina Upper Beds), Paralic Series (Ostrava Beds) and the Upper Silesian Sandstone Series (Karvina Lower Beds). Therefore, the linear anomalies could be interpreted as the surface expression of the active faults and other tectonic features (Fig. 2).

The high-energy seismic activity data (during 1984–2004 period), related to the mining activity, show the evident correlation with linear negative anomalies, mainly in the vicinity of the Kłodnica fault (Nizicki, Teper, 2003).

There are many punctual negative anomalies indicating the subsidence, mainly in the southern part of the scene. They should be a subject of further, detailed studies and correlation.

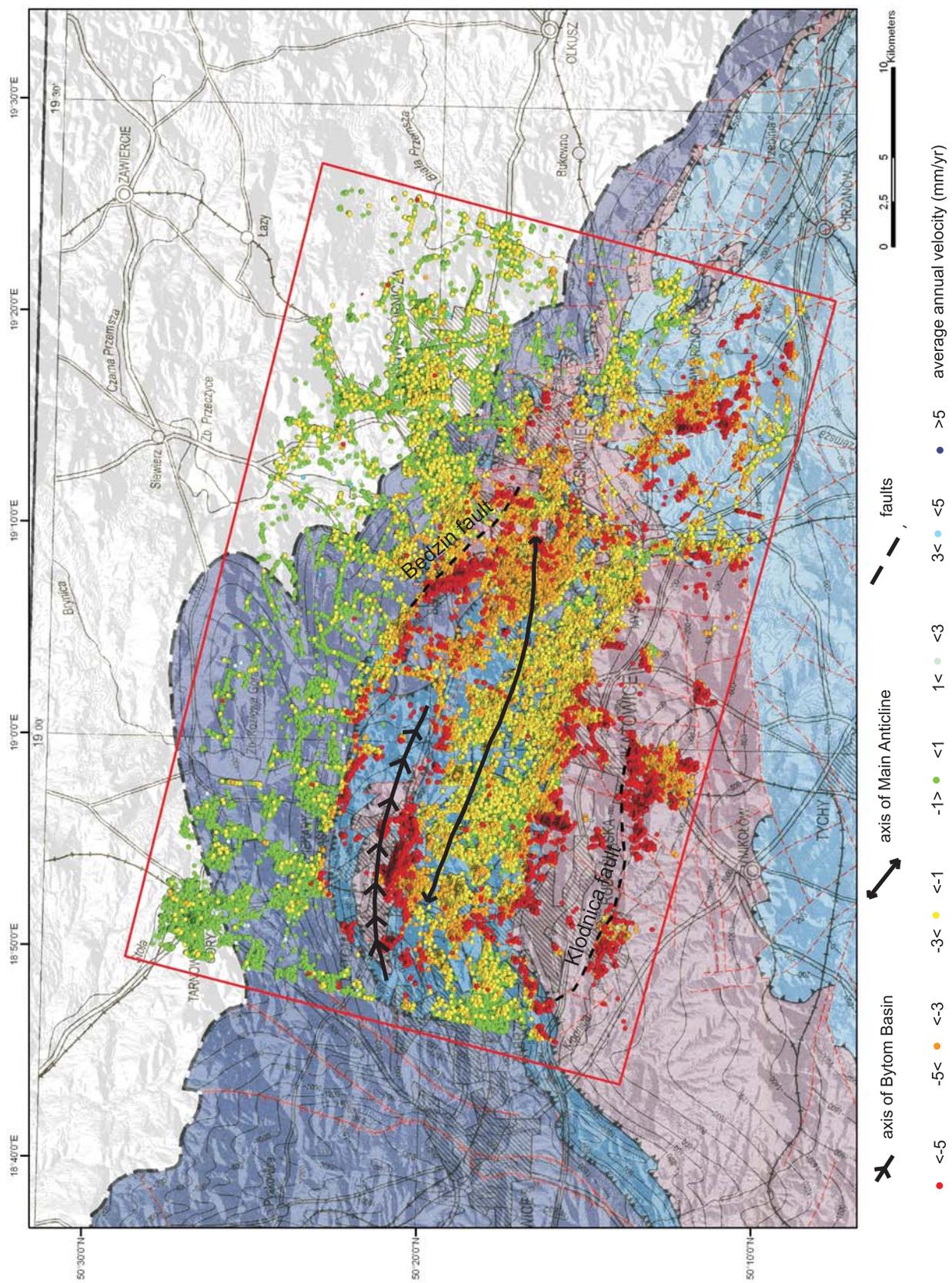


Fig. 2. Distribution of PS versus superimposed on geological map (according to Jureczka *et al.*, 2005)

There is an observed uplift in the area of Tarnowskie Góry agglomeration, which is situated outside the productive Car-

boniferous sediments. The explanation of this phenomena is not clear and needs further studies.

## CONCLUSIONS AND RECOMMENDATIONS

The strong correlation between the recorded negative values and structural pattern of the Carboniferous strata is out of question. It is difficult to determine a character of this correlation and its genesis, at present. The measurement results indicate that the subsidence is present at those of synclinal structures and the areas of dropped wings of the two big regional faults (Będzin and Kłodnica). Undoubtedly, the two above mentioned faults of the Variscan origin were rejuvenated during the Alpine Orogeny (the Triassic deposits were found in the dropped wings of the faults). It could be the indication of the active tectonic movements, too. Further studies are needed to prove that hypothesis.

The Sosnowiec case study and examples from other European cities have indicated, that the geological application of PSInSAR is evident for monitoring the subsidence in relation to the mining and tunnelling, climate change-driven shrink-swell ground conditions, landslides, volcanic and tectonic motions, and for assessing localized flood risk.

The PSI data could be most usefully applied together with GPS measurements. Both technologies have overlapping fea-

tures but they are complementary and, when used together, they become powerful tool in the accurate monitoring land displacement.

A synergistic approach to monitoring ground movements offers great possibilities that need to be explored further. For example:

- PS data can identify the optimal location for permanent GPS stations by detecting and eliminating areas that lack the necessary stability.
- GPS data from permanent stations can be used as the reference control points in computing PS deformation values.
- A vertical movement of PS can be more accurately determined by removing the horizontal component of motion derived from GPS measurements.
- The precision assessment and error bar computation is enhanced when cross-checked with GPS data.

## REFERENCES

- BUŁA Z., HABRYN R., PIĄTKOWSKA A., KOWALSKI Z., DOKTÓR S., 2003 — Model budowy strukturalnej Górnego Śląska i zachodniej Małopolski w świetle kompleksowej analizy danych teledetekcyjnych i geologiczno-geofizycznych. Archives of PIG, Warszawa.
- GRANICZNY M., KOWALSKI Z., CZARNOGÓRSKA M., JURECZKA J., PIĄTKOWSKA A., 2006 — Potential of SAR Interferometry for identification of ground motions., in Abstracts – Living Morphotectonic of the European Lowland. 28–30 August 2006, Cedynia, Poland.
- GRANICZNY M., KOWALSKI Z., JURECZKA J., CZARNOGÓRSKA M., TERRAFIRMA PROJECT — Monitoring of subsidence of northeastern part of Upper Silesian Coal Basin. *Pol. Geol. Inst. Sp. Papers*, **20**: 59–63.
- JURECZKA J., DOPITA M., GAŁKA M., KRIEGER W., KWARCIAŃSKI J., MARTINEM P. 2005 — Geological atlas of deposits of the Polish and Czech parts of the Upper Silesian Coal Basin 1:200 000. Państw. Inst.Geol., Warszawa.
- KOTAS A., 1972 — Ważniejsze cechy budowy geologicznej Górnośląskiego Zagłębia Węglowego na tle pozycji tektonicznej i budowy głębokiego podłoża utworów produktywnych. *W: Problemy geodynamiki i tąpnięć*. Komit. Górn. PAN, **1**: 5–55.
- NIZICKI R., TEPER L., 2003 — Uskok kłodnicki – uwagi na temat przebiegu, dystrybucji przestrzennej uskoków towarzyszących oraz wieku deformacji. *Mat. XXVI Symp. pt Geologia formacji węglonośnych Polski*. Wyd. AGH, Kraków, 115–120.
- PERISSIN D., PRATI C., ROCCA F. - ERS-ENVISAT Permanent Scatterers International Geoscience and Remote Sensing Symposium (IGARSS 2004), Anchorage (Alaska), 20–24 September 2004. Pages 1–4.
- PILECKA E. (ed.), 2006 — Związek lineamentów z sejsmicznością indukowaną na terenach górniczych Górnośląskiego Zagłębia Węglowego. Wyd. IGSMiE PAN. Kraków.
- TERRAFIRMA, 2004 — A ground motion information service for Europe. TerraFirma Atlas: 22–23. [www.terrafirma.eu.com](http://www.terrafirma.eu.com).