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TERRAFIRMA PROJECT — MONITORING OF SUBSIDENCE OF NORTHEASTERN PART OF THE UPPER SILESIAN COAL BASIN

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Abstract. During the last years, new ways of the satellite radar images processing have been invented and developed. It has allowed ground movements to be mapped and monitored with an accuracy better than 1 mm per year. This method is called Permanent Scatterer Synthetic Aperture Radar Interferometry (PSInSAR).The technique depends on the existence of radar scatterers which consistently reflect signals from successive satellite passes.
The Polish Geological Institute obtained PSInSAR processing results for the Sosnowiec area in mid-March 2004. Processing has covered 54 scenes both ERS-1 and ERS-2, registered between 1992 and 2003. Presently, the results of Sosnowiec PSInSAR are the subject of interpretation. Initial results indicated interesting relations between the elongated subsidence anomalies and geological boundaries — Będzin and Kłodnica faults.

Key words: radar, PSinSAR, GIS, interferometry, remote sensing, tectonics, mining.

Abstrakt. Ostatnie lata przyniosły szybki rozwój interferometrii radarowej. Nowa metoda interferometrycznego przetwarzania zobrazowań radarowych (PSinSAR) zastosowana w projekcie pozwala na określenie przemieszczeń z dokładnością do 1 milimetra. Technika PSinSAR polega na analizie przemieszczeń punktów kontrolnych, będących dobrymi reflektorami dla zakresu mikrofalowego. Państwowy Instytut Geologiczny otrzymał przetworzone dane PSinSAR dla rejonu Sosnowca w połowie marca 2004. Proces przetwarzania obejmował 54 zobrazowania radarowe ERS-1 i ERS-2, z lat 1992–2003. Wstępna interpretacja danych wskazała na interesujące związki pomiędzy wydłużonymi anomaliami osiadania a granicami geologicznymi — uskokami będzińskim i kłodnickim. W artykule przedstawiono wstępną interpretację danych.

Słowa kluczowe: radar, PSinSAR, GIS, interferometria, teledetekcja, tektonika, górnictwo.

INTRODUCTION

Subsidence and other mass movements observed within the Upper Silesian Coal Basin are usually connected with the deep coal mining. In the Upper Silesia 60,000 ha of mining areas have already suffered from subsidence. In such cases, the surface becomes pitted with numerous collapse cavities or basins which depth may even reach tens of meters. They may remain dry or be filled with water (land surface inundation) depending on the local hydrogeological conditions. Subsidence areas can be endangered during floods because they form kind of interior basins.

The subsidence is particularly dangerous because of causing severe damage to gas and water pipelines, electric cables, and to sewage disposal systems.

There are different methods of evaluating hazards caused by deep mining. They should include remote sensing techniques such as resolution satellite data, aerial photos, thermal imagery, laser scanning, radar interferometry, etc. (Graniczny, 2004). Other techniques as geodetic surveying and GPS measurements should be taken under consideration, too. It is necessary to collect systematic information and prepare inventory of the mining works, on the extent of exploitation, and on the total thickness of the exploited coal seams.

The City of Sosnowiec is located in the Silesian Voivodship, in the northeastern part of the Upper Silesia Mining District. It covers an area of 91.2 km^2. It is a place of residence for about 239,000 inhabitants. In Sosnowiec and its vicinity, it is

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common to find houses strengthened with iron bars anchored in the walls in order to prevent further damage or collapse, but even such reinforced buildings could show cracks and joints on their walls.

Far from being inert and stable, the ground beneath Sosnowiec poses numerous risks for inhabitants, infrastructure and cultural heritage. Many of these "geo-hazards" are legacies from the earlier industrial land use. They include contaminated land, shallow underground mining (to a depth of 80 m), subsidence and polluted groundwater, all of them threat to the people health and safety, and can create huge additional building and infrastructure repairs and maintenance costs. In terms of effects on the 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, especially on brown field sites.

DATABASE

The area covered by a PSinSAR image includes about 1,210 km^2. Almost the whole studied area is located within the Silesian Voivodship. Only a small part of the image, situated in the southeastern corner, belongs to the Little Poland Voivodship. The majority of the investigated area occurs within the Upper Silesian Coal Basin (82.6%). About 680 km^2

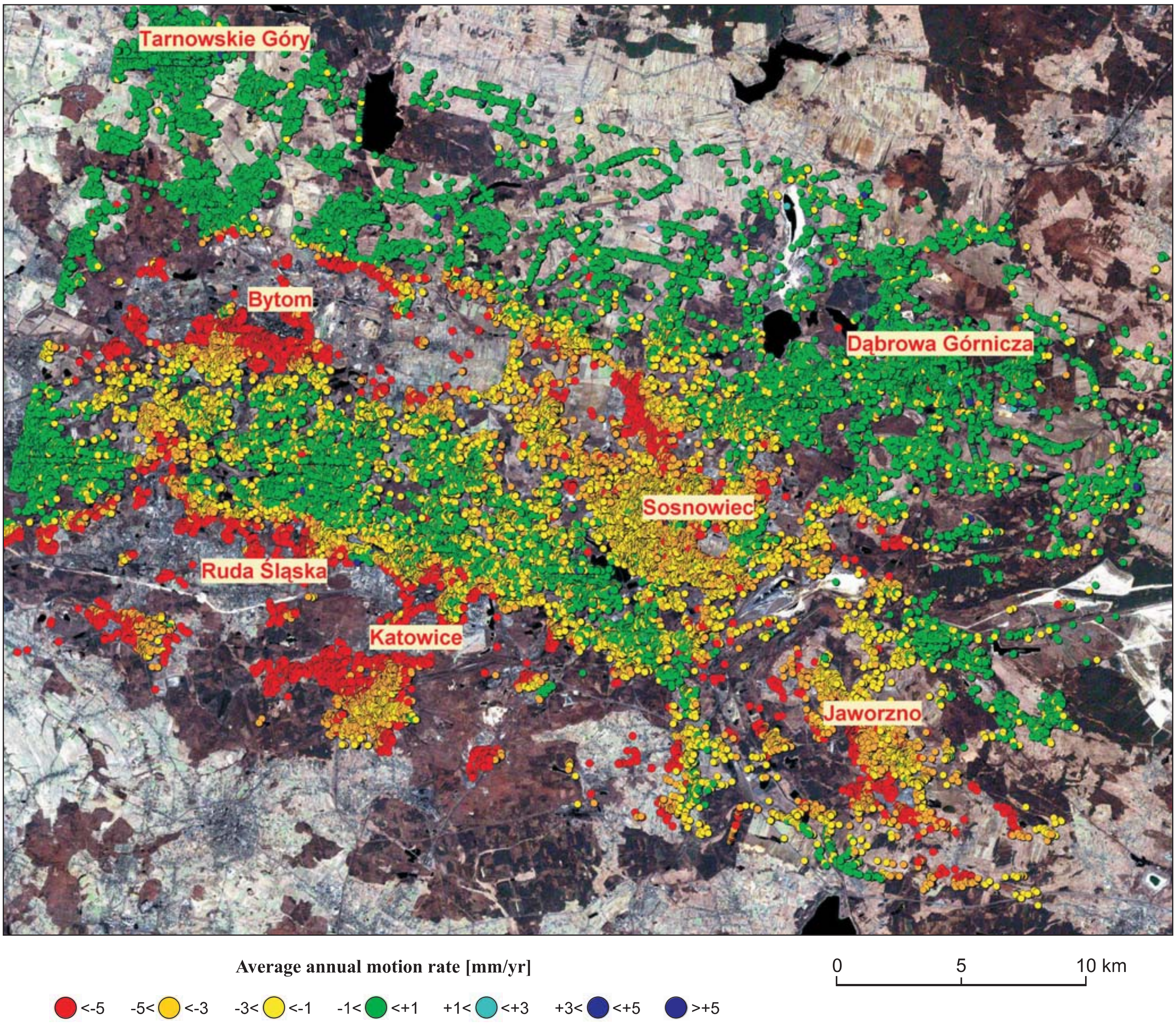

Fig. 1. Overview of PSinSAR measurement points, the Upper Silesian Coal Basin

The different ranges of velocities are shown in the legend of the area is located within the hard coal mine exploitation fields. Numerous mines of that area were closed during the last eight years. The still active mines occupy about 260 km^2 of the area.

Data from the Sosnowiec area were processed within the TerraFirma Project in mid-March, 2004. Processing has covered 54 scenes of both ERS-1 and ERS-2, registered between 1992 and 2003 (Fig. 1) (TerraFirma Atlas, 2004). The database includes 122,925 points, extending from –39.63 to +25.12 mm. After rejecting of 3 extreme records, it extends from –28.13 to +9.00 mm.

Some 58,115 measurements (47.3%) are stored between –1 to +1 mm, and 106,759 measurements (86.8%) vary between –5 to 1 mm. The 90,537 measurements have got negative values indicating subsidence. Among them:

— 32,094 measurements (35.5%) — 1–0 mm,
— 53,168 measurements (58.7%) — 2–0 mm,
— 67,837 measurements (74.9%) — 3–0 mm.

Land subsidence bigger than 10 mm (1 cm) has been registered in 1,543 measurements, what is an equivalent of 1.25% of all the measurements or 1.7% of all their negative values. Land subsidence bigger than 20 mm (2 cm) has been registered in 59 measurements what constitutes 0.05% of all the measurements or 0.065% of all the negative values.

PRELIMINARY INTERPRETATION OF PSinSAR DATA

The measuring points reflect the surface infrastructure of "building type": dense urban or suburban agglomeration, single buildings of the larger size, industrial objects, large linear objects, like conveyers, etc. It is worth to mention that within the areas characterised by blue and green colours, the coincidence occurs with nearly geodetic precision. However, within the areas indicated by red colour, in some places the existing infrastructure is not "reflected". For example, in the Ruda Śląska–Kochłowice area (1A) (Fig. 2).

There are no measurement points within the areas covered by forests, cultivated lands, meadows, parks, wastelands of different types, including heaps and water basins. In the northern

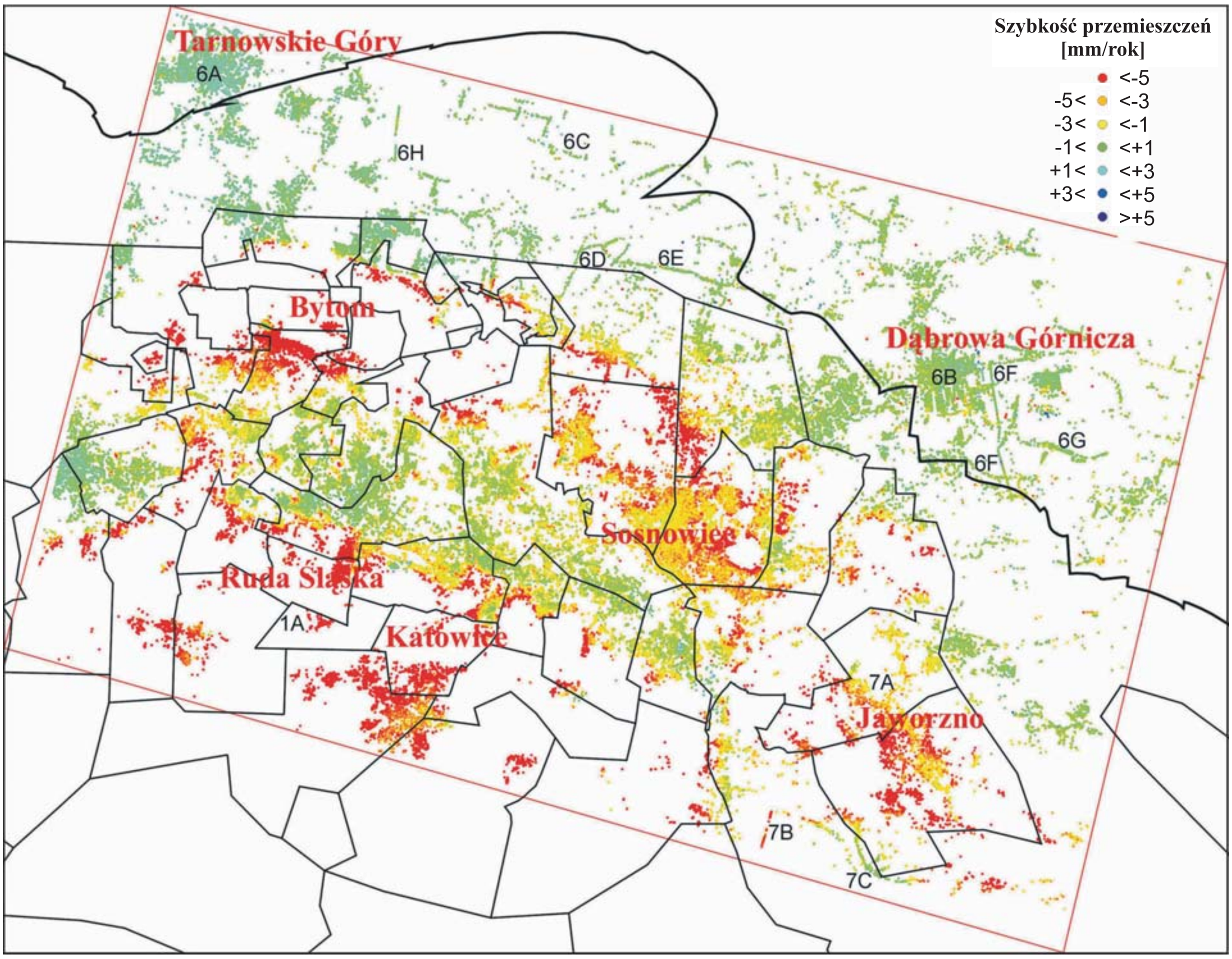

Fig. 2. PSinSAR data versus mining areas

and northeastern parts of the investigated area, there are no red coloured areas (except for the single points). These areas were not affected by the mining exploitation. The blue, green and yellow colours rarely occur in this region. The red colour areas occur on the past and present hard coal exploitation territories, only. They are also present in the areas adjoining the coal basin. In these areas, the yellow colour is also present, but green is rarely there. The colours zonation from green to yellow and red is clearly visible.

The areas indicated on the image by different colours do not correspond to morphology, geology of the superficial Quaternary deposits, to the depth of the Carboniferous strata surface, neither to morphology of the upper strata.

In the northern and the northeastern part of the image (outside the mining activity), the measuring points (blue and green) correlate directly with the surface buildings areas and the industrial infrastructure. For instance, with the Tarnowskie Góry agglomeration, "Katowice" Ironwork (6B), with roads accompanying by Siemienia (6C), Strzyżowice (6D), and Psary (6E) villages, with linear industrial objects such as conveyers in "Katowice" Ironwork (6F), railway station ramps in Dąbrowa Górnicza (6G) or as a strew part around the Kozłowa Góra Basin (6H). Other correlations with the measuring points have not been found.

On another part of the image (within the area of mining activity), there are also noticeable correlations with different elements of housing and industrial infrastructure; for instance, with the railway tunnel between Mysłowice and Kosztów (7B) or with road with accompanying buildings in Jaworzno–Jeleń area (7C). However, in some cases, new settlements of the loose building type are "not visible", for example in Jaworzno (7A). Finally, there is no direct correlation between the operating and closed mines and the PSinSAR image.

However, there are some analogies with the structural setting of the Carboniferous strata (Fig. 3). Most of the red colours occur on the areas of the synclinal structures: Bytom Basin, northern slopes of the Main Basin and Little Zaborska Basin (near Zabrze). Clearly visible accumulation of the red points is noted on hinges and dropped wings of the Będzin and Kłodnica faults. The green colour points occur mainly on the area of the "Main Anticline", the Zabrze Dome, and north of Bytom Basin.

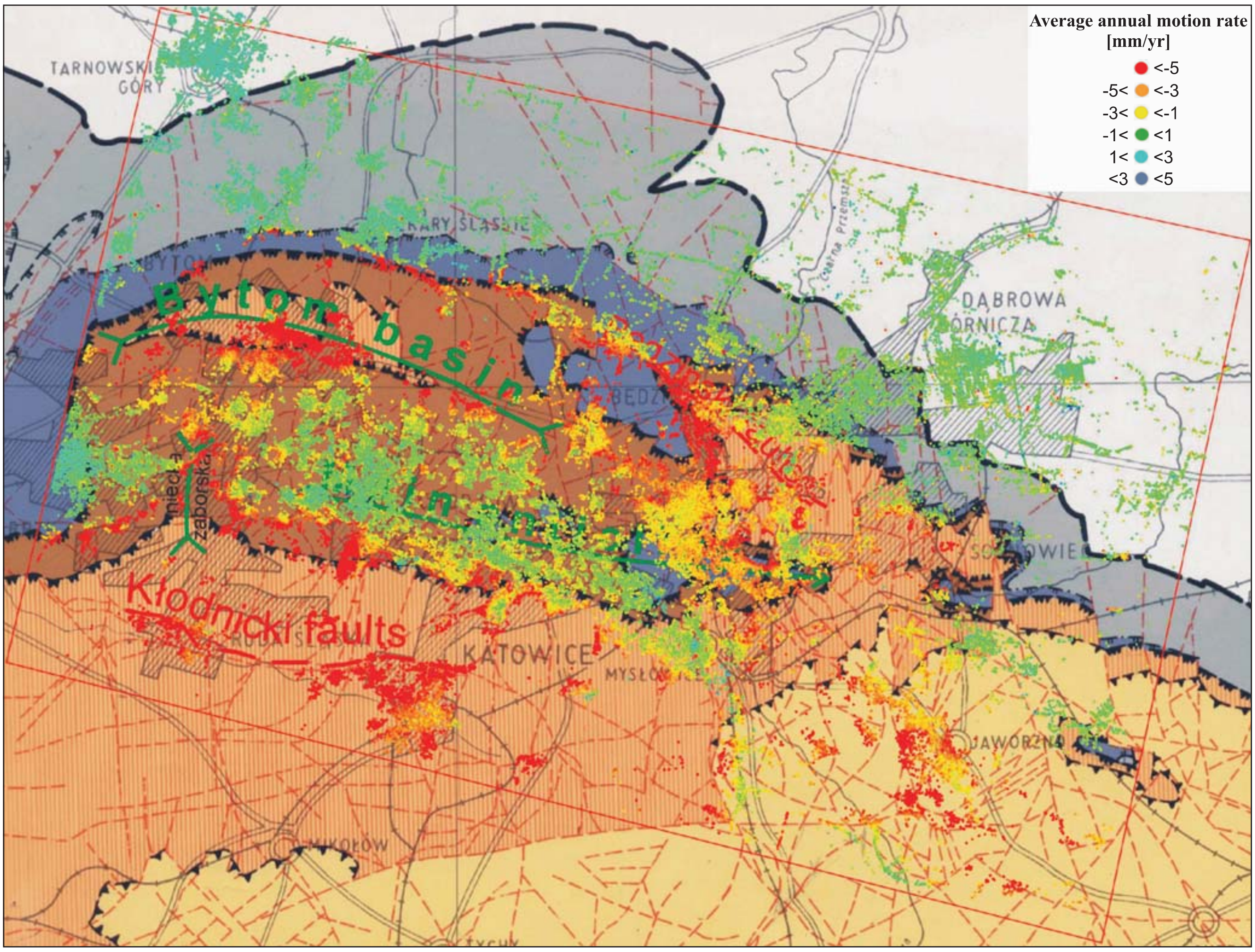

Fig. 3. PSinSAR data versus geology of Upper Silesian Coal Basin

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

CONCLUSIONS

The measurement data show subsidence of the area limited to few mm per year: 1–2 mm. Such small values suggest that these subsidences have no relation to the underground exploitation. About 1% of measurements, only, show higher values of 1 to 2 cm, which could be an indication of the hard coal exploitation. The subsidence recorded by other techniques (geodetic measurements, precise levelling etc.) reached 10–20 cm per year, and even more.

A strong correlation between the recorded negative values and structural pattern of Carboniferous strata is out of question. It is difficult to determine the character of this correlation and of its genesis, at this moment. The measurement's results indicate that the subsidence is present within the areas of synclinal structures and of the dropped wings of the two large regional faults (Będzin and Kłodnica). Undoubtedly, the two above mentioned faults of the Variscan origin were rejuvenated during the Alpine Orogeny, as the Triassic deposits were found in the dropped faults wings (Buła *et al*., 2003). It could be the indication of the active tectonic movements, too. However, further studies are needed to prove this hypothesis.

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