Analogue study of the Permian fanglomerates based on pseudo-3D GPR data from the Zygmuntówka quarry, Chęciny, South Poland

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Multi-scale 3D geological modelling of the sedimentary cover of the Gorzów Block (north-west Poland) involves reconstructing spatial distribution of lithofacies of Permian and younger deposits overlying the Variscan basement. However their great depth and sparse borehole data motivate us to use analogues of dominant lithostratigraphic units in the South Permian Basin (SPB) to properly delineate these distributions. A significant proportion of the sedimentary cover in the Gorzów Block is formed by alluvial-fan conglomerates which accumulated around volcanic elevations of the north-western part of the Wolsztyn High. The nearest Permian outcrops can be found in the Sudetes and in the Holy Cross Mountains. Although the depositional architecture of the SPB is mainly controlled by local tectonics, quantitative relationships measured in analogue geological situations can aid reconstructions of lithofacies distribution between deep boreholes, particularly when presented as training images for multiple-point statistics (MPS) simulations.

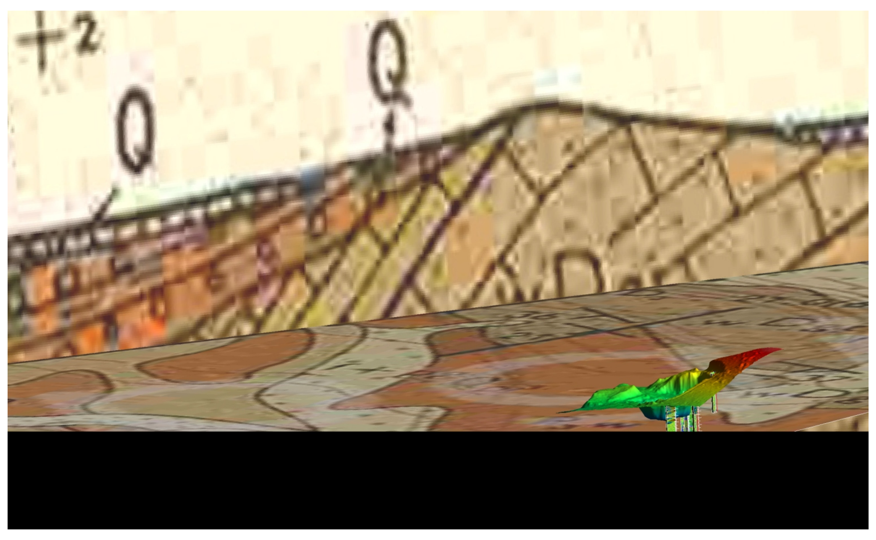


Fig. 1. (left image) Location of the Gorzów Block and the Zygmuntówka quarry in the Holy Cross Mts. Fig. 2. (right image) Geological context of the study area shown by sections from the Detailed geological map of Poland at a scale of 1:50 000 (north to the right). The colour-scale digital elevation model of the Zygmuntówka quarry is apparent in the centre as well as some of the GPR datasets.

We analysed coarse-grained, matrix-supported and clast-supported conglomerates of Late Permian age exposed in the Zygmuntówka quarry near the town of Chęciny (Holy Cross Mountains), South Poland (Fig. 1). The strata is mostly composed of gravel to cobble size clasts of Devonian limestone and dolomite deposited by cohesive, non-cohesive gravity flows and fluvial processes in arid and semi-arid environment (Zbroja et al., 1998). Permian strata have not been significantly deformed and are gently inclined (up to 10) to the southwest; the dominant transport direction was from the northeast (Kostecka, 1962). Permian strata unconformably overlie deformed carbonates of Late Devonian age (Fig. 2).

Fig. 3. Quarry view (facing the northwest)

Fig 4. Lithofacies Z1, bottom level of the quarry, facing the northwest

Zbroja et al. (1998) described five lithofacies within the Zygmuntówka conglomerates. First two are thickly-bedded structureless clast-supported (Z1, Fig. 3 and 4) and matrix-supported (Z2) conglomerates with cobbles and boulders. They constitute about 50% of the lithofacies described in the outcrops and are interpreted as a result of non-cohesive (Z1) and cohesive (Z2) gravity flows (Gani, 2004). The third lithofacies is described as subhorizontally bedded clast-supported conglomerate (Z3), while trough cross-bedded conglomerates correspond with lithofacies Z4 and structureless clast-supported conglomerates arranged in both planar and trough-shaped beds as Z5 (see Figs. 5). Normal grading is often apparent within the last three lithofacies, i.e. Z3, Z4 and Z5. These three are interpreted as deposits of fluvially dominated fans.

Fig. 5. Lithofacies Z5, in the uppermost quarry level, facing the north, channel width about 5-6 m with a depth of 1-2 m

Five pseudo-3D GPR datasets were collected, and GPR grid dimensions ranged from 5 to 25 m. Signal penetration reached on average 10 m. (Fig 6). Closely-spaced parallel GPR profiles were processed and compiled for display and interpretation with SKUA-GOCAD (Fig. 7). Signal velocity was established based on known thickness of strata measured in the quarry. Large amount of cobbles and boulders introduced hiperbola-shaped reflections which obscured the images, and only after the data was migrated (2D Stolt), profiles were interpretable.

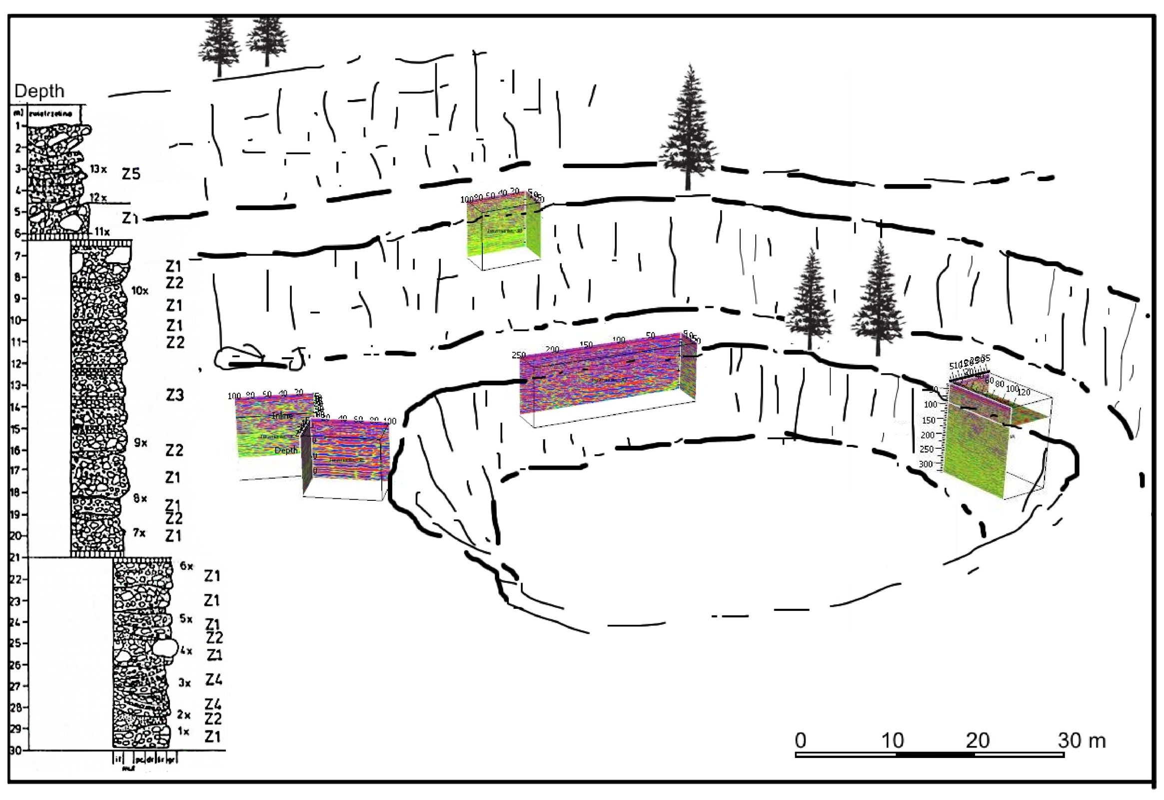


Fig. 6. Sketch of the Zygmuntówka quarry with locations of five pseudo-3D GPR datasets and the vertical profile describing distribution and lithofacies of conglomerates from Zbroja et al. (1998)

Large-scale sedimentary structures (decimetre scale) are, however, apparent on GPR profiles and interfaces between zones of contrasting electromagnetic properties can be traced particularly when horizontal sections are used (time sections, Fig. 7). As in the case of seismic data, the main properties which characterise these interfaces are their shape, dip and azimuth of inclination. The lithofacies described in the quarry outcrops could therefore be distinguished based on these features.

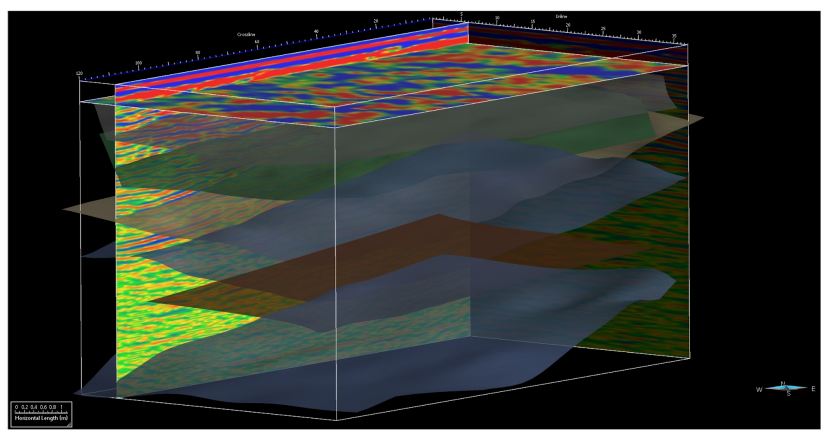


Fig. 7. The image shows one of the GPR datasets A (amplitude) with interpretation mostly planar subhorizontal and inclined stratification. Inclination angle is clearly increasing with depth representing gradual change from gravity flow to fluvial deposition.

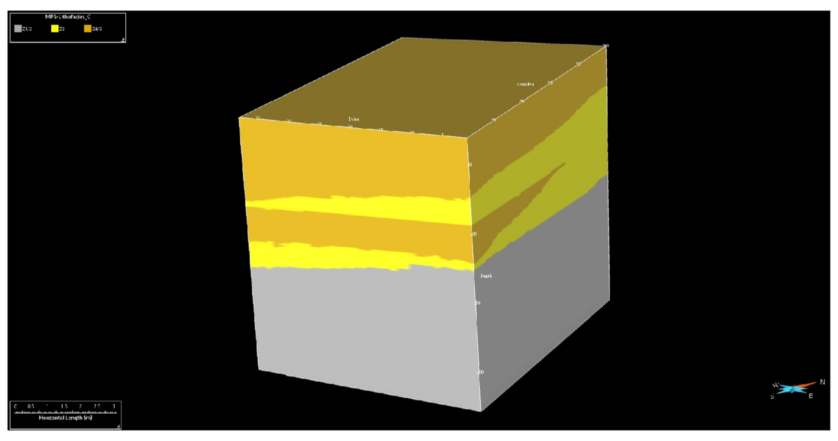


Fig. 8. Interpreted GPR dataset C with distribution of lithofacies. All of the datasets were interpreted this way and dataset C was used as a training image for multiple point simulation.

Parallel steeply inclined tabular arrangement of radar reflections indicated lithofacies Z1 or Z2 described by Zbroja et al. (1998) as debris flow sediments. Subhorizontal parallel stratification suggested lithofacies Z3 deposited by fluvially dominated laminar flood flow. Trough-shaped concord stratification, often filled with cross strata indicated lithofacies Z4 or Z5 associated with channel deposits. Radar facies correlated with the lithofacies of Zbroja et al. (1998) are summarised in Table 1.

Table1

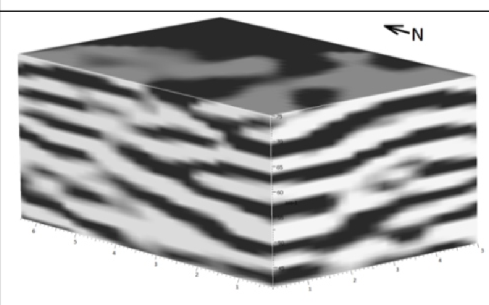
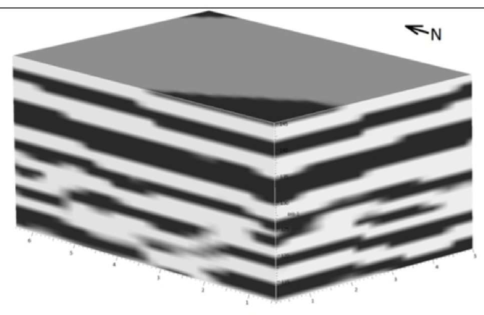
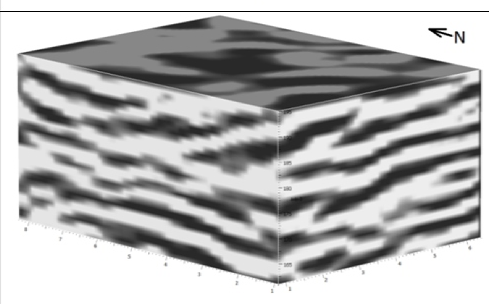
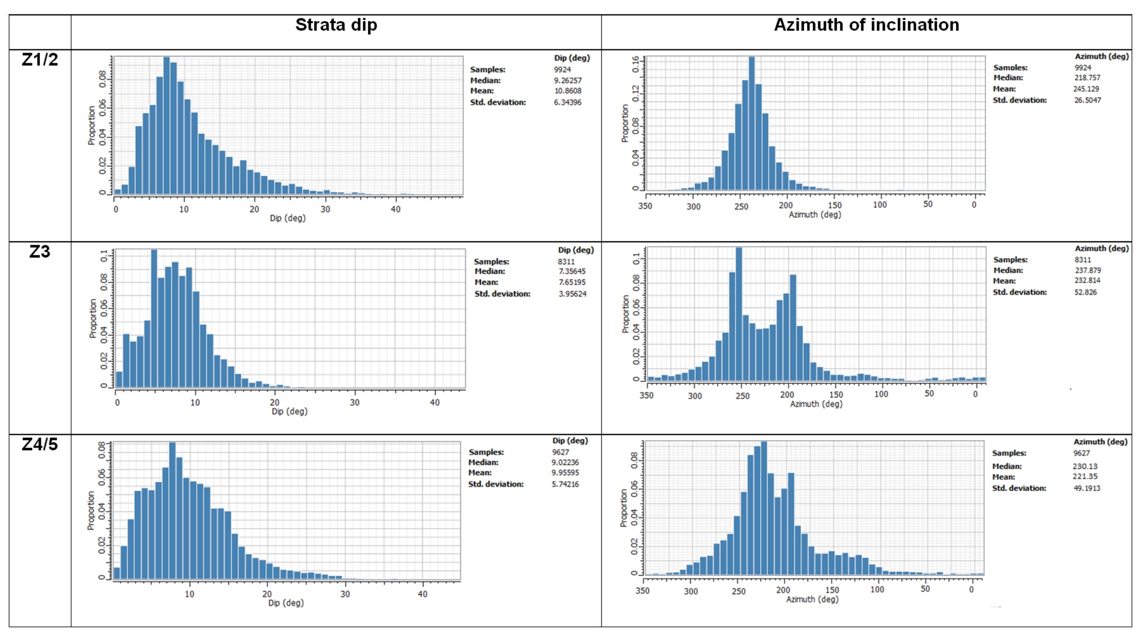
	Description	3D image	Sedimentary interpretation
Radar facies Z1/Z2	Parallel steeply inclined (above 8-9°) to SW continuous reflections		Cohesive and noncohesive debris flow, corresponds to lithofacies Z1 and Z2 of Zbroja et al. (1998)
Radar facies Z3	Parallel subhorizontal (mostly inclined at an below 8-9° to SW) continuous reflections		Deposition by laminar surface water flow, corresponds to lithofacies Z3 of Zbroja et al. (1998)
Radar facies Z4/Z5	Trough-shaped semicontinuous semiconcordant reflections		Deposition by fluvial processes within braided, or meandering channels, corresponds lithofacies Z4 and Z5 of Zbroja et al. (1998), see Fig. 4.

Table2



The most distinct reflections were manually traced and transformed into surfaces (Fig. 7). There surfaces were quantitatively characterised by their inclination and azimuth. They were grouped according to radar facies they represented and described by histograms and statistical values shown in Table 1. Surfaces associated with debris flow deposits clearly are much more uniform and steeply inclined than those related to sheet flood deposition. The average azimuth values are similar for each of the radar facies (Table 2), although in the case of lithofacies Z4 (sheet flood deposits) the mean azimuth of inclination (232.8) is the most similar to the azimuth of inclination of the Devonian subcrop (234.2, Fig. 7). For this facies standard deviation is the highest (52.8) and the distribution is clearly bimodal which may reflect slightly convex shape of alluvial fan topography. Summary done with SKUA-GOCAD showed that facies Z1 and Z2 represent around around 50% of lithofacies in all GPR datasets, which confirms observations in quarry outcrops done by Zbroja et al. (1998).

Based on this classification, sedimentary facies were interpreted (painted) on each of the pseudo-3D GPR voxets. A series of MPS simulations utilising different parameter was carried out, and dataset C (Fig. 8) showing the most reliably relationships between all radar facies was used as a training image. Based on probability cariterion, the results of simulation were used to carry out estimation of the most probable result. Simple, ordinary and Bayesian kiriging was also attempted to reconstruct distribution of dip and azimuth values from surfaces. These simulations, however, did not give reliable results.

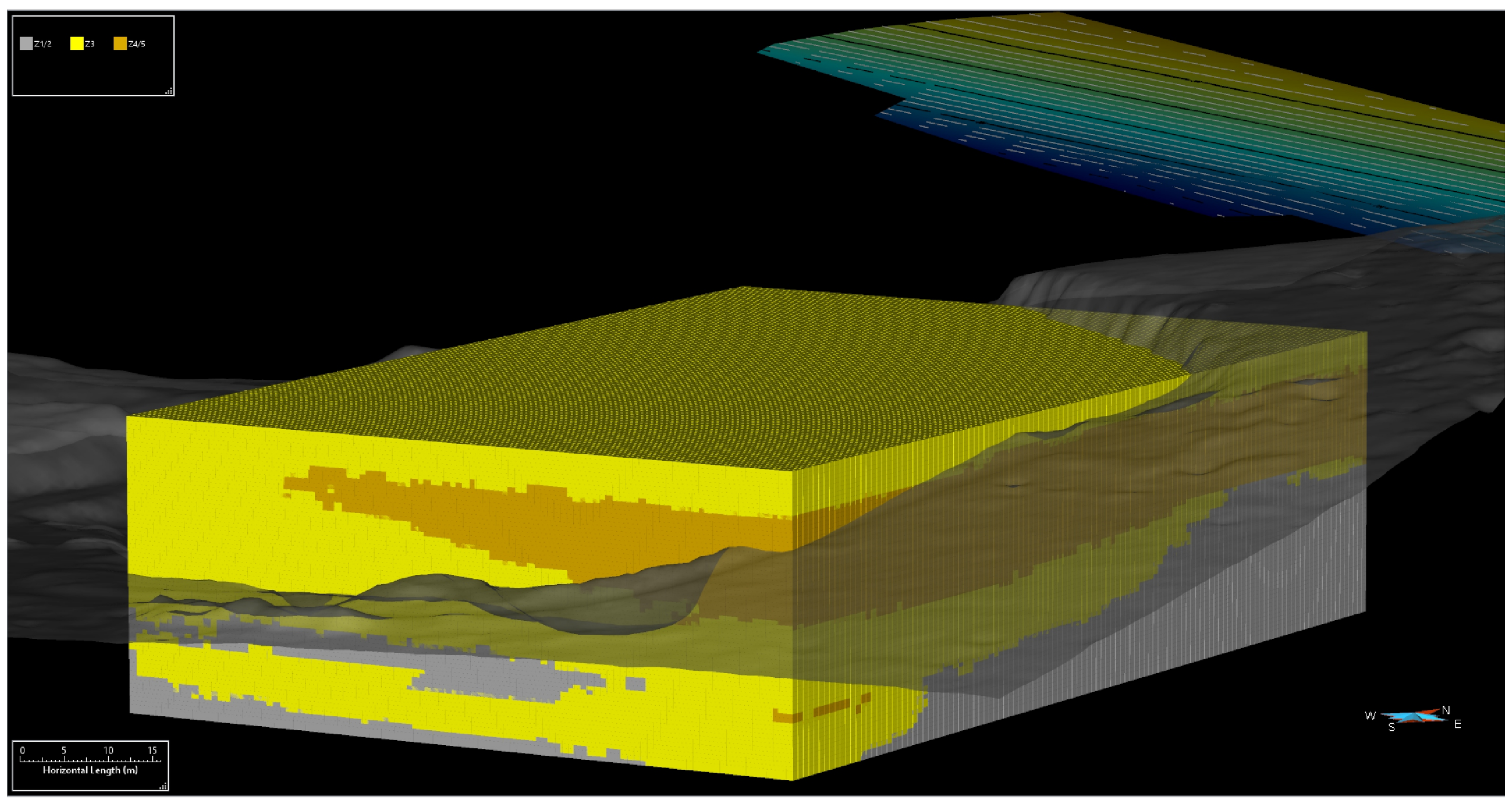


Fig. 9. Result of MPS simulation of lithofacies distribution across the Zygmuntówka quarry with the Devonian subcrop surface in the background. Grey zones represent lithofacies 1 and 2, i.e. structureless gravel with boulders deposited by cohesive flows; yellow colour represents lithofacies 3; while orange represent channel deposits. Grey surface represents the topography of the Zygmuntówka quarry.

The MPS model will be validated with new field observations, particularly the distribution of lithofacies in the quarry cliffs which will be precisely mapped. Any discrepancies will be corrected, and new simulations can be carried out. The final geostatistical model will be referred to the local paleogeography (Fig. 9) and can be used as a training image to reconstruct distribution of the main lithofacies from borehole for the 3D multi-scale geological model of the Gorzów Block.

Literature

Gani, M.R. (2004) From Turbid to Lucid: A Straightforward approach to sediment gravity flows and their deposits. The Sedimentary Record 2, 4-8

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