Structural-tectonic conditions of Karviná Subbasin with regard to its position in the apical zone of Variscan accretion wedge

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The contribution deals with the structural-tectonic conditions of the Karviná Subbasin especially in relation to the genesis, spatial distribution and prediction of the continuation of thrust structures on lower structural and stratigraphical levels. Significant thrust zones – the Central and Eastern Thrusts are defined newly. They are part of the apical zone of Variscan accretion wedge the typical representative of which the Upper Silesian Basin as foreland basin is. Discussion is based not only on quite a number of processed special-purpose maps, sections, collected primary documentation, including mine photodocumentation, but also on confrontation with the results from analog and numerical models published by various authors. Moreover, effects of tectonic structures on mining activity in the Karviná Subbasin with emphasis on thrust structures are evaluated as well. With reference to the long-term outlook for production, when under present-day technical and economic conditions, twenty years' coal exploitation is expected, attention is paid to a connection between thrust structures and technologies for present and future coal mining in the case of company OKD.

Key words: *Upper Silesian Basin, thrusts, accretion wedge, Karviná Subbasin, structural-tectonic analysis, coal seam*

Introduction

The Karviná Subbasin, especially its easternmost part including the mining claims of ČSM and Darkov Mines, was traditionally characterised as area with a simple, so-called "taphrogenic" structural-tectonic pattern (Kumpera et al., 1990, Dopita et al., 1997), in which the tectonic style of normal fault character predominated, although in the western part of the Karviná Subbasin, thrust structures were verified and described in seams of the Lower Suchá Member as early as the beginning of the 70's (Hudeček & Sivek, 1977); the vertical amplitudes of displacement of them were usually of the order of several decimetres. Only later, the thrusts the vertical amplitudes of displacement of which were up to several metres were described in a so-called Central Thrust Zone (Grygar et al., 1989; Kumpera et al., 1990). In the easternmost part of the Basin, the first thrusts were verified no sooner than the beginning of the 90's; the uplift on the thrust usually did not exceed the thickness of the seam affected. Nevertheless, in the course of last decade, the thrust structures in the case of which the uplift on the thrust is usually of the order of several ten metres have been verified by mine boreholes and workings in connection with the increasing depth of mining. These thrusts are characterised by small dips and dips decreasing with depth (e.g. Grygar & Waclawik, 2006) with a possibility of transition to interlayer slips. Simultaneously they exhibit a considerable variability in the line of strike.

The tectonic pattern and other phenomena, such as erosion and compressional structures of seams, affect fundamentally space-time relationships among individual face blocks. Structures of tectonic zones of the Central Thrust and the Eastern Thrust defined newly affect substantially the size, geometry and orientation of faces and also the very mining and technical conditions of exploitation of coal seams. For these reasons, faces of irregular shapes have been exploited which is connected with adequate mining operations (face shortening, extension). If in spite of this, reverse faults and compressional deformation zones with more favourable parameters, which are genetically connected with them, are crossed with faces, the far more intensive securing of them is required (cementing of associated rocks, installation of steel supports, boxing, etc.). These operations significantly increase the costs of coal exploitation. The above-mentioned phenomena thus notably affect the exploitability of coal reserves, the amount of mining loss and surface loss.

Results of the study can also contribute to the general knowledge of rules of development of fold-thrust structures of synorogenic collision accretion wedges and extend thus our knowledge of regional-geological conditions of the Moravian-Silesian zone of Bohemian Massif in the context of European Variscides.

Structural geological conditions of Czech part of Upper Silesian Basin

The Upper Silesian Basin is an integral part of the Moravian-Silesian area of Bohemian Massif (Fig. 1). However, of the total area less than one quarter is there in the Czech territory. The continuation of it in the Polish territory is of small significance not only from the point of view of extent but also and above all in relation to the issues of other relationships with the Western European Zone of a system of coal-bearing molasses of the Outer Variscides (e.g. Havlena 1982, Kotas 1985, Grygar & Vavro 1995, etc.). The present-day structural framework of the Basin corresponds merely to a limited erosional remnant of the originally larger

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system of more or less interconnected sedimentary subbasins, developing in the zone of Brunovistulian foreland of European Variscides.

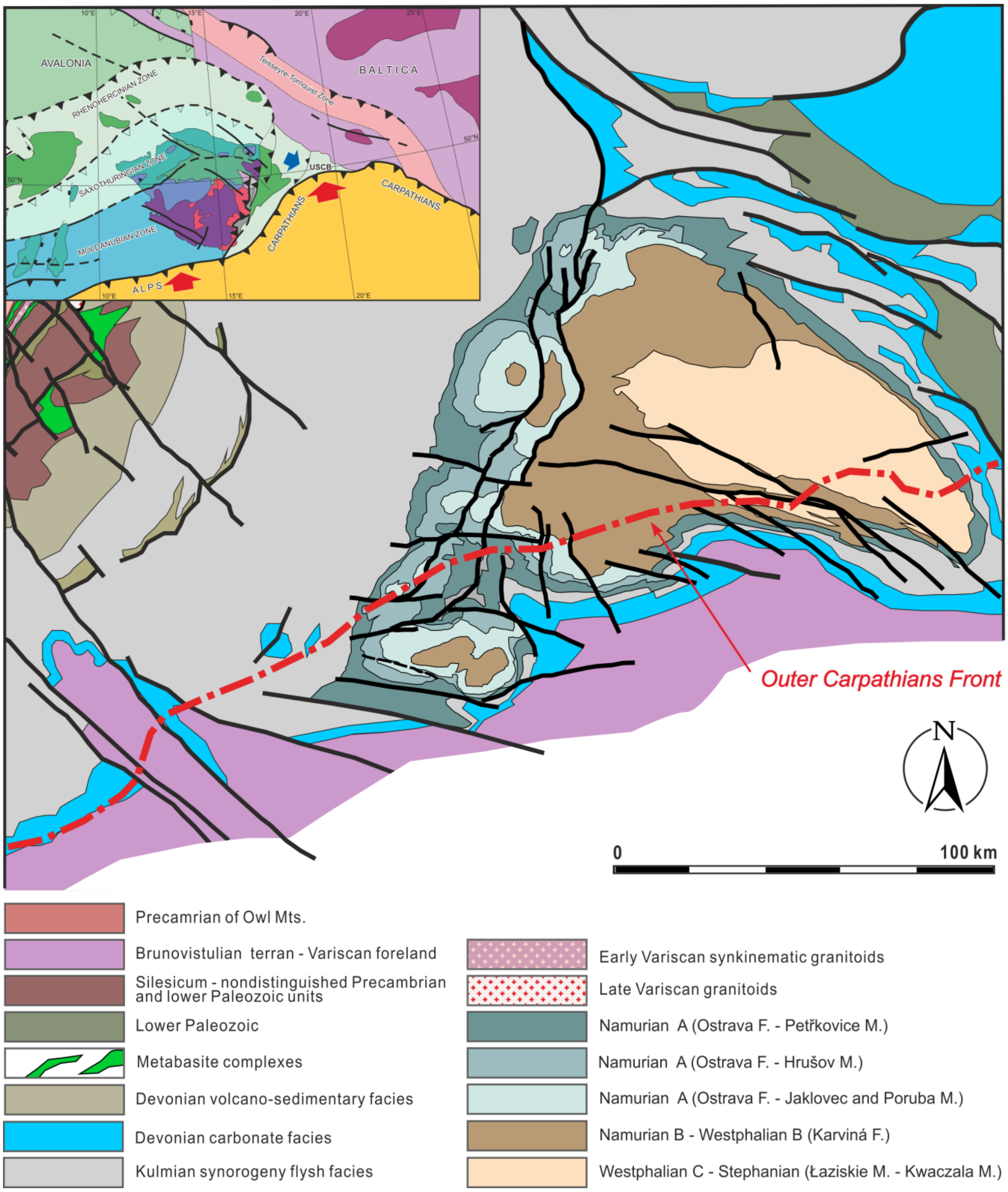

Fig. 1. Rough geological map of Upper Silesian Coal Basin (USCB) in the context of Moravosilesian zone (According to Grygar 1997 and sketch in the upper left corner arr. after T.C.Pharaoh et al. 2000).

As well, the southern boundary of the Upper Silesian Basin is not verified for a fact. In Southern Moravia, in the surroundings of Němčičky, occurrences of Upper Carboniferous containing coal seams have been found by boreholes (Purkyňová, 1978). These occurrences can be considered to be very probably a southern continuation of the original Upper Silesian Basin (Dopita et al., 1997).

The structural-tectonic development and present-day tectonic conditions of the Basin are conditioned by the overall deformation development of Variscan accretion wedge of the Moravian-Silesian area, in the apical zone of which the Upper Silesian Basin is situated (Grygar &Vavro, 1995). However what plays a significant role in the development of structural plan of the Basin, the character of deformation regimes, tectonic styles, kinematics and intensity of deformation, is the forced tectonics of the basement of Brunovistulicum forming the basement of the Basin in the foreland of Variscan orogene.

Other specifics of the overall tectonic development of the Upper Silesian Basin follow from its position in the foreland of Alpine tectogene of the Western Carpathians (Fig. 1). The rejuvenation of Variscan structures in the course of Alpine deformation phases in many specific tectonic structures is beyond questions (e.g. Patteisky & Folprecht, 1928; Petránek,1956; Kumpera,1989). Nevertheless, with the detailed study and comprehensive evaluation of mutual interaction between both the tectogenes (Variscan and Alpine) nobody has been concerned yet; the less have been quantified in detail mutual interactions between the Variscan and the Alpine tectogene.

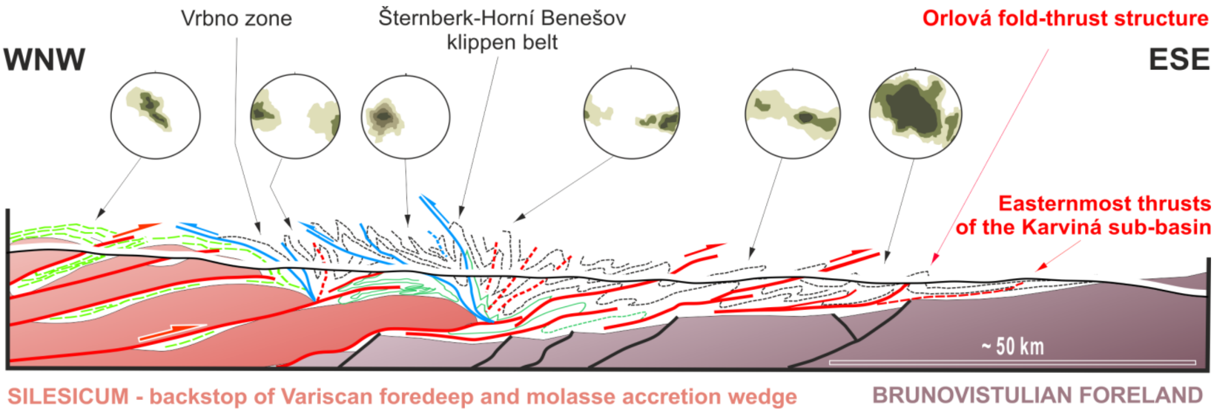

Fig. 2. Schematic structural cross-section across accretion wedge of the Moravosilesian zone. Front thrusts are drawn by hatched red lines whereas back thrusts by hatched blue lines. Contour diagrams correspond to pole to bedding and/or main cleavage systems (according to Grygar 1997 in Grygar & Waclawik 2006).

The flysch foredeep and the coal-bearing molasse (foreland basin) of Moravian-Silesian Zone correspond, from the genetic point of view, to a typical tectonic-sedimentary accretion wedge (Fig. 2). With regard to the known character of sedimentary development (Havlena, 1982; Kumpera,1971, 1983; Kumpera & Martinec, 1995), they have typical features of synorogenic sedimentary accretion prism (in the sense of e.g. Einsele, 1992). A rheologically more competent "tectonic bulldozer" of Silesicum crystalline nappes in the west of Moravian-Silesian area (see e.g. Cháb et al., 2008) conditions a so-called "bulldozer effect" (Grygar & Waclawik, 2006) in the hinterland of Variscan tectogene connected with a passive reverse blocking of the hinterland of sedimentary flysch accretion prism in the course of subduction of the basement of Brunovistulian foreland (Grygar & Vavro, 1995). The Cadomian basement of Brunovistulicum affected markedly by its character and tectonic activity not only the structural geometry of thrusts but also the thickness and character of sedimentary filling of the Flysch Foredeep and the coal-bearing molasse of the Upper Silesian Basin (e.g. Kumpera & Martinec, 1995). The structural morphology of its current buried relief shows that it is not the case of a simple "plate" with a migrating flexure that is subducted towards the west below the advancing thrusts. The structural trend of Brunovistulian foreland is not subparallel to the line of the Variscan thrust front (Grygar & Vavro, 1995; Grygar & Waclawik, 2006). According to the existing structural and sedimentary-paleogeographical analyses, a marked structural direction of Brunovistulicum is the structural ENE-WSW to E-W direction that is older than the NNE-SSW Moravian-Silesian direction (Grygar et al., 1989; Grygar, 1992). Subequatorial structural trends of Brunovistulicum manifest themselves markedly both in the geophysical pattern and in the lithofacies polarity of flysch development of Lower Carboniferous.

The tectonic style of flat thrusts is also conditioned by the fact that the accretion wedge, the part of which the Upper Silesian Basin was, was thrust over the foreland of Brunovistulicum having a relatively flat morphology. From studies of the thickness of filling of coal-bearing molasse (Havlena, 1982; Adamusová et al., 1992; etc.), and also from relatively short seismic profiles (e.g. Čížek & Tomek, 1991) it can be derived that the subduction monocline of basement of Brunovistulicum has generally a very flat dip of the order of several degrees (2°-5°), by no means exceeding, with the exception of relatively limited segments of tectonic ramps, the value of 10°.

The Upper Silesian Basin belongs to the tectonically most complicated Paleozoic molasse basins of European Variscides. The Basin has a polytype and conspicuous zonal tectonic pattern. In its tectonic pattern both complicated thrust-fold deformations and relatively simpler normal fault and transtensional tectonics participate (Dopita et al., 1997). The spatial distribution of both tectonic styles is, to a considerable degree, predisposed by the character of Brunovistulian basement and the regional position in the apical domain of the Variscan accretion wedge. The Basin is markedly asymmetric and shows double polarity in the WNW-

ESE and NNW-SSE directions.

From the point of view of transverse WNW-ESE polarity, it can be divided into two basic structural domains. The crucial role in this division belongs to the Orlová thrust-fold structure (Figs. 1, 2, 3). As for the tectonic style, west of the Orlová structure there is an area of so-called Variscan Foredeep, in which fold-thrusts predominate and east of the Orlová structure there is an area where extensive faults prevail (Karviná Subbasin). Different kinematics and higher intensity of deformations of the Variscan accretion wedge in northern areas (in the Polish part of the Basin) manifest themselves in more complicated tectonic styles on the boundary of nappe structure. Thus the marked structural polarity in the NNW-SSE direction can be observed. Both the stated structural trends have then dominant positions in the overall pattern of Variscan regional stress fields (Grygar et al., 1989, Grygar, 1997). The actual vector addition of them takes place, which shows itself in the overall comprehensive structural-deformation and paleostress polarity and in the structural gradient in the NW-SE direction.

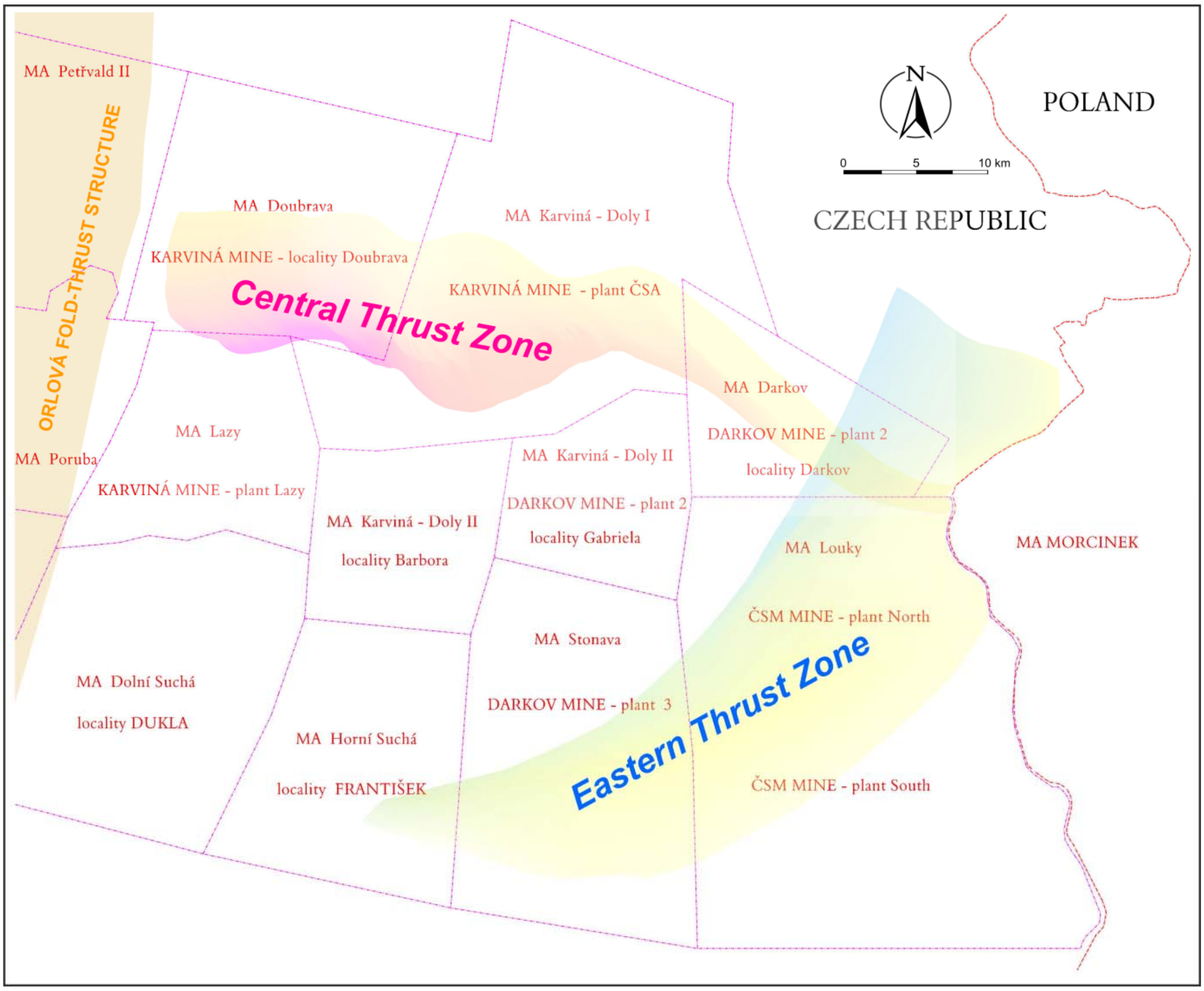

Fig. 3. Schematic map of demarcation of mine fields with representation of extend and intensity of thrust deformations in the area of the Karviná sub-basin. Increase of the transposition on the thrust zones so as their structure deep is schematically expressed by color intensity from pink (deeper and bigger) to yellow (shallower and smaller) for Central Thrust and equivalently from blue to yellow for the Eastern Trust. (compare with Appendixs No. 4.).

A structural boundary between the zones of so-called western and eastern brachystructures (Ostrava and Petřvald Subbasins) is formed by a zone of Michálkovice structure. It is a case of tectonically considerably complicated tectonic zone of NNE-SSW direction and width of up to 800 metres. The Michálkovice structure is of regional importance. The line of it can be observed in the framework of the whole of the Upper Silesian Basin, from north in the Polish part of the Upper Silesian Basin in the Gliwice area, through the Rybnik area, in the Czech part of the Upper Silesian Basin then in the Ostrava area, and further south in the mining claim of Paskov Mine and in the Příbor part of the Basin. It follows from structural-tectonic analyses (e.g. Foldyna & Grmela, 1981) that it is a flat structure with typical listric geometry. In the stratigraphically lower Petřkovice Member, very flat dips of thrusts (15-25°) have been verified; towards the overlying layers, dips increase (Foldyna opus cit.). At the height level of the layers of Ostrava Formation that are denuded already at present, a further increase in dips, an increase in thickness of dislocation zone, transitions into the zones of plastically deformed layers and the splitting of the dislocation into more reverse faults are expected (Foldyna opus cit.). In comparison with the present-day works (e.g. Allmendinger, 1998; Mitra S. & Mount V. S., 1998; Hardy S. & McClay K., 1999; Guohai J. & Groshong R. H. Jr., 2006, etc.), which deal with the thrust-fault structure of accretion wedges, we can designate the Michálkovice structure as typical thrust-fault structure (Fig. 11) formed above a structural ramp in the basement (so-called fault-propagation fold, e.g. Allmendinger, 1998; Cardozo et al., 2003).

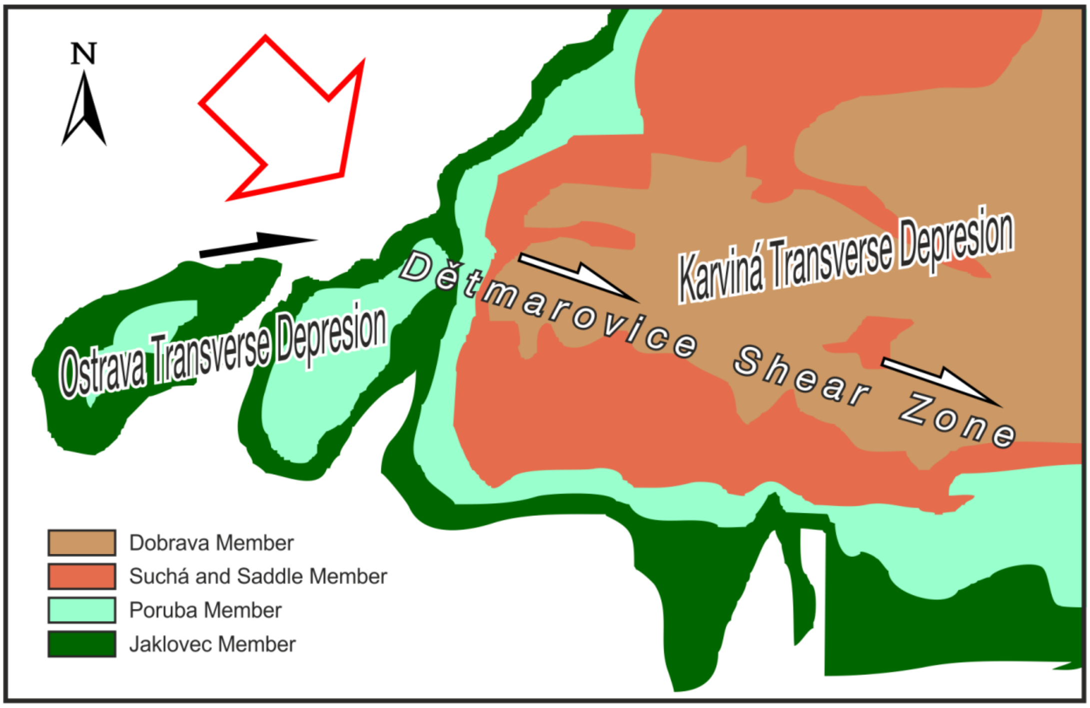

Fig. 4. Schematic map of main transverse structures of Ostrava-Karviná part of the Upper Silesian Coal Basin (according to Grygar & Waclawik, 2006).

The Orlová structure belongs, from the point of view of extent, to the most significant tectonic structures of the Upper Silesian Basin. Many authors (e.g. Dvořák, 1994; Čížek & Tomek,1991; Rajlich, 1993) regard the Orlová, or Orlová-Boguszowice structure (Kotas, 1985) as easternmost fold-thrust structure of the whole of the Moravian-Silesian area, limiting the Variscan nappe structure in the east. However as follows from the paleofacies analysis (Havlena, 1982), and especially from the detailed structural-tectonic research (e.g. Grygar et al., 1989; Kumpera et al., 1990; Grygar, 1996, 1997), the extensive area of thrust tectonics is there also east of the Orlová structure (also Grygar et al., 1998, 2000, 2004, 2005; Grygar & Waclawik, 2006; Ptáček, 1999). Thrust tectonics is represented by minor reverse faults the uplift on which is a few decimetres in size; they occur easternmost as far as the mining claim of closed Morcinek Mine on the easternmost margin of the Karviná Subbasin.

Similarly to the Michálkovice structure, the Orlová structure also represents a complicated fold-thrust structure variable in strike. The vertical amplitude of displacement grows clearly in the north direction, when in the W-E section in the Rybnik area, the horizontal displacement together with that of Michálkovice structure is almost 15 km (Kotas, 1985, Jura, 2001). From the interpretation of cross sections in various positions along the strike it is evident that the Orlová structure represents, likewise the Michálkovice structure, a typical thrust-fold structure developing above the structural ramp in the foreland (fault-propagation folds, or fault-bend fold, e.g. in the sense of Mitra, 1992; Allmendinger, 1998, and others). The genesis of the structural ramp, which is necessary for the initiation of structures of the type of “fault-propagation folds”, can be connected with the development of monoclinal flexure of Brunovistulicum (modified by normal fault tectonics), initiated by sedimentary and subsequently by tectonic loading owing to the gradual thrusting of the Variscan accretion wedge over the foreland (Grygar, 1992; Grygar & Vavro, 1995).

Geology and structural-tectonic characterization of Karviná Subbasin

The Karviná Subbasin represents a partial structure of the Czech part of the Upper Silesian Basin, delimited by the above-mentioned Orlová structure in the west. Tectonically it corresponds to the most subsided area of the Czech part of the Upper Silesian Basin, and thus the youngest coal-bearing sediments of Karviná Member occur in it (Fig. 13). The Karviná Subbasin has the simplest tectonic pattern in the framework of known Czech part of the Upper Silesian Basin. In comparison with the area west of the Orlová structure, differences in thickness of coal-bearing molasse formations (Havlena 1982) and in coal content, lithology, degree of coalification and many other features (see e.g. Dopita & Kumpera 1993, Dopita et al. 1997, Sivek et al. 2003) can be observed. These differences show altogether the lower mobility of Brunovistulian platform foreland in comparison with mobile development west of the Orlová structure (Havlena, 1982; Dopita & Kumpera, 1993, Dopita et al., 1997).

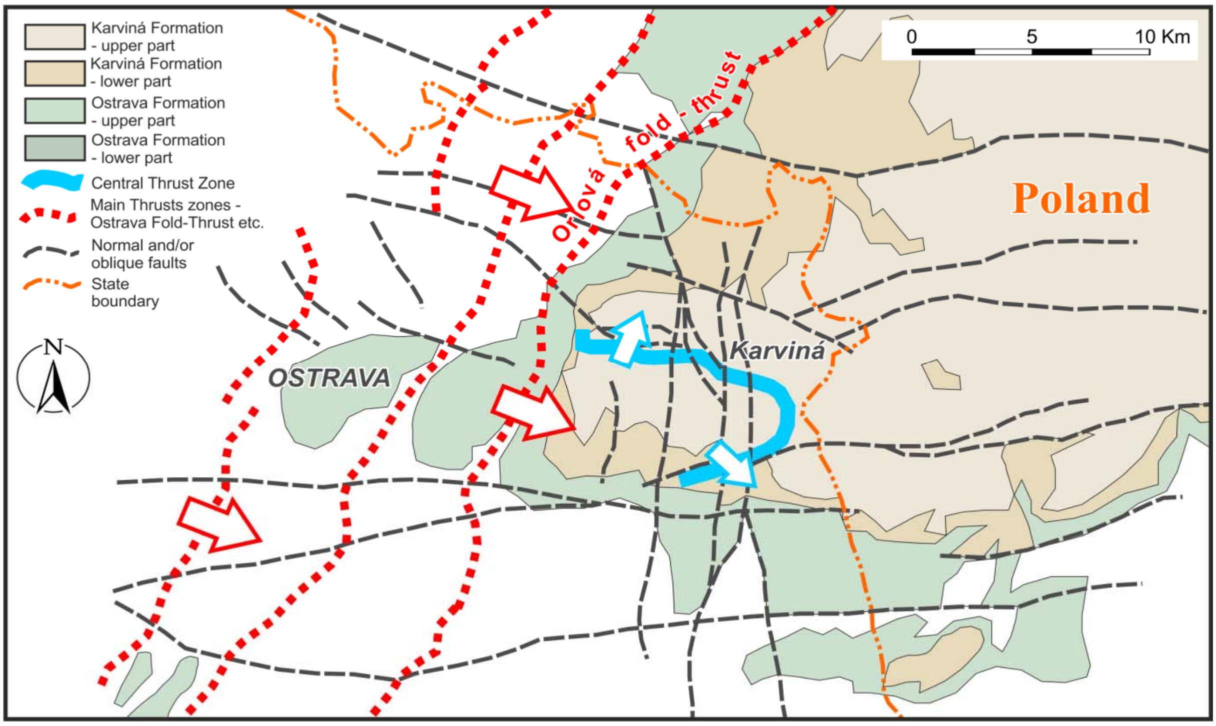

Fig. 5. Schematic structure-geological map of the Ostrava-Karviná part (Ostrava, Petřvald and Karviná sub-basins and adjacent areas) of Upper Silesian Coal Basin with highlighted position of the Central and Eastern thrust zone (blue thick line). Large red arrows indicate top to east thrusting on the main fold and/or fold-thrust structures (e.g. Orlová fault-propagation fold structure). Small blue arrows correspond to measured strike and sense of thrusting, based on slickensides etc., on the individual thrusts in the thrust zone (adjusted according to Grygar et al. 1998 and Ptáček 1999).

In the Karviná Subbasin, coal-bearing sediments developed from underlying non-productive sequences of Hradec and Kyjovice Formation without interruption in sedimentation. We divide them into two basic units – Ostrava Formation and Karviná Formation (Fig. 1). Both the Formations differ markedly from each other in the character of sediments, thickness, area, coal seam development. The upper boundary of the coal-bearing sediments is erosional; in their overlying layers there are sediments of overburden that belong to the Alpine-Carpathian orogene and also to the Alpine autochthonous overburden.

The Ostrava Formation, representing sediments of a paralic coal-bearing molasse, is of Early Namurian age. The development of the Formation passed without interruption from the Kyjovice Member (flysch development), and sedimentation ended with a hiatus above the group of Gaebler faunistic horizons. The Ostrava Formation is divided into four lithostratigraphical units – Petřkovice Member, Hrušov, Jaklovec and Poruba Members. Boundaries of the individual Members are put to significant marine horizons (Dopita et al., 1997).

The Karviná Formation, representing a continental coal-bearing molasse, lies discordantly on the Poruba Member of Ostrava Formation. According to age, we classify it to the Middle to Late Namurian and Westphalian. The Karviná Formation is divided into three stratigraphical units – Saddle Member, Suchá Member (Lower and Upper) and Doubrava s.l. (Doubrava s. s. and Upper Doubrava) Member.

The continental coal-bearing molasse has been preserved merely in several denudation remnants delimited in area. The most extensive and stratigraphically most complete is a denudation remnant of significant positive morphostructure (elevation), so-called Ostrava-Karviná Ridge. Here the Karviná Formation has been explored relatively in detail by mining operations in mine fields of active and also closed mines of Ostrava-Karviná Coalfield. Other, relatively smaller denudation remnants have been verified by boreholes and also shafts in the Frenštát area, and merely by boreholes in the Jablunkov area.

The Karviná Subbasin has objectively the simplest tectonic pattern in the framework of known part of the Upper Silesian Basin. Also for this reason, many authors have considered it as post-deformation, so-called external terrigenous coal-bearing molasse developing only after "Variscan orogeny" (Dvořák, 1994, etc.). For instance Brieda et al. (1975), Kumpera (1980, et al., 1990) and Kumpera & Martinec, (1995) attributed the tectonic style of "craton taphrogenic basin" to it.

As however given below, thrust structures with a relative horizontal displacement of up to the order of several hundred metres are abundant in the area of the Karviná Subbasin. These thrust structures form a complex compressional system designated traditionally as Karviná Central Thrust. With reference to its character and extent, we rank it among significant anomalous structural phenomena of the Karviná Subbasin (Grygar & Waclawik, 2006).

From the tectonic point of view, the Karviná Subbasin can be characterised as apical zone of the Variscan accretion wedge – foreland basin (e.g. DeCelles & Giles, 1996), where especially in the final stages of Variscan tectogenesis, a transtensional paleostress regime predominated. The result is a tectonic style in which dislocations of normal fault character or with a strike-slip component of displacement (combined oblique-slip faults – transtensional faults, etc., Grygar et al., 1989) significantly dominated compressional fold and thrust structures.

The bedding of layers of the Karviná Subbasin is subhorizontal; a dip usually moves in the range of 6°- 15°. Only in the vicinity of regional dislocations of normal fault character, the dip of layers increases up to the values of about 20°-30° and the strike of layers changes. Dips of about 20° have also been recorded in research structural troughs (e.g. Karviná Graben in the mining claim of ČSM Mine). Local changes in dip of layers can be observed in the vicinity of distinct thrusts as well. Axes of longitudinal open folds strike NNE-SSW; thus they are parallel to the Orlová structure. Fold deformation is genetically connected with the development of regional longitudinal faults that conditioned mostly the antithetic rotation of partial blocks of the basement, conditioning the flexure deformation of sedimentary sequences (Grygar et al., 1989). That is why the strike of layers is almost identical here with the strike of major longitudinal dislocations of normal fault character.

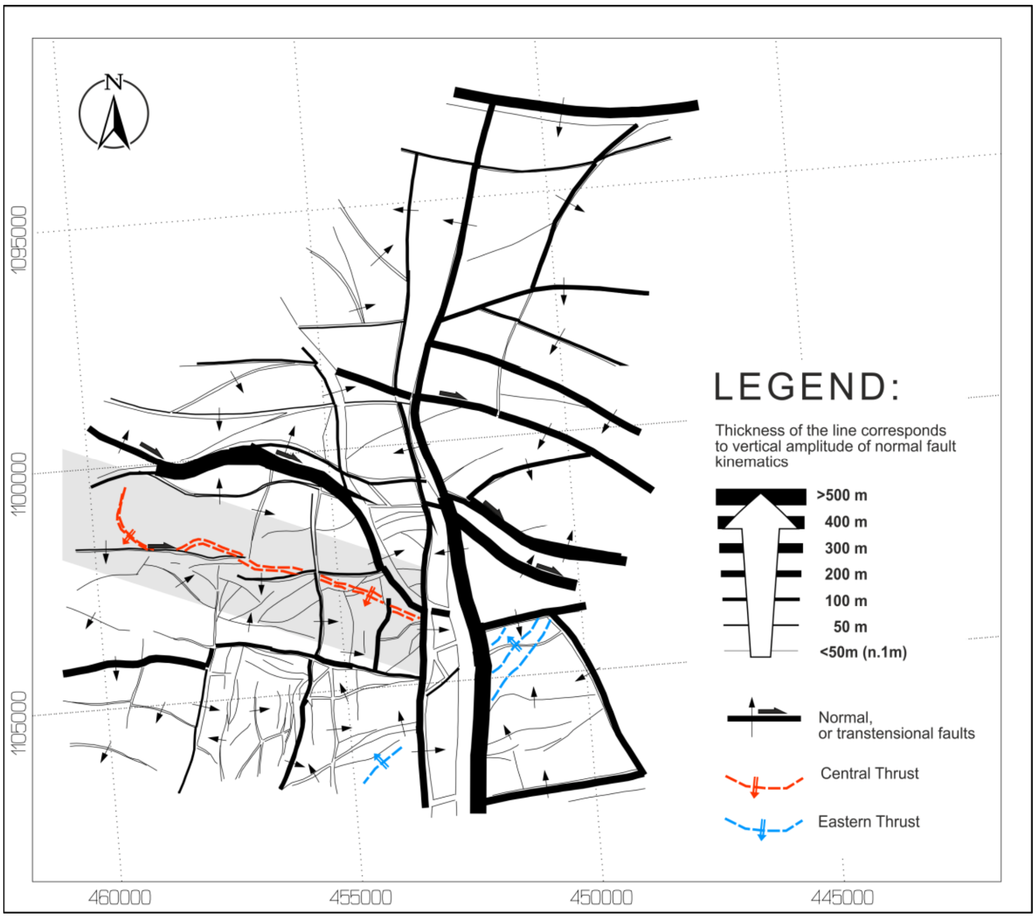

Fig. 6. Synoptic structure map of main faults in the Karviná subbasin area (according to Grygar, 1997 in Grygar & Waclawik, 2006).

The structural plan of fault pattern of the area (Fig. 6) is characterised and conditioned mainly by the major regional dislocations. The basic division into partial tectonic blocks is conditioned by regional longitudinal faults of approximately meridional direction (up to NNE-SSW, exceptionally NNW-SSE) and regional transverse faults of W-E direction (up to WNW-ESE). This basic system of faults can be observed in the framework of the whole of the Basin. It is largely the case of steeply dipping normal faults; the dips ranging from 50° to 70°. In many of them, a horizontal component of displacement was proved as well (Patteisky & Folprecht 1928, Danys – Sivek 1976). They have the character of transcurrent, often en-echelon faults (Grygar et al. 1989, Grygar & Welser 1994). The major structural-genetic function belongs to the submeridional Karviná Graben and the transverse subequatorial Dětmarovice Graben. That is part of a regional structure of higher order – Dětmarovice shear zone defined by Grygar et al. (1989). In the southern flank of this zone, a genetically subordinated Doubrava Horst is there (Brieda et al. 1975).

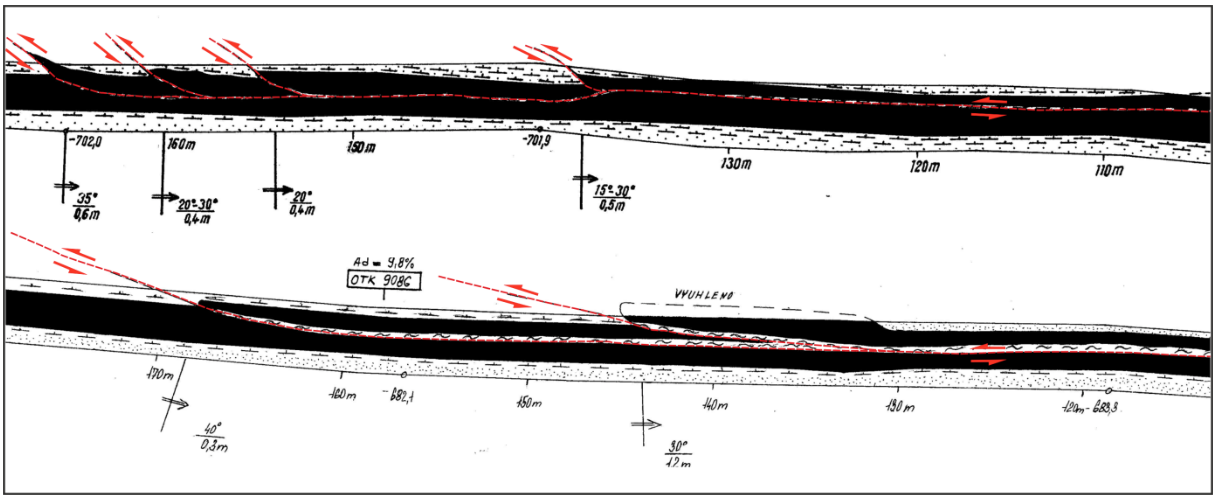

Fig. 7. Examples of the intralayer shear-slip in the seam No. 30 (634). Suchá Member, Karviná sub-basin. Based on primary documentation from the ČSM Mine.

The Dětmarovice shear zone (Fig. 4) of WNW-ESE direction (see Grygar et al. 1989) overlaps the Orlová structure in the west and reaches the Ostrava Subbasin. This significant tectonic domain divides the Basin into its southern – rather stable and northern – rather mobile zones. Part of the rather mobile northern area is also the about 2 km wide Dětmarovice shear zone itself and above all the Dětmarovice transverse depression (Grygar et al., 1989).

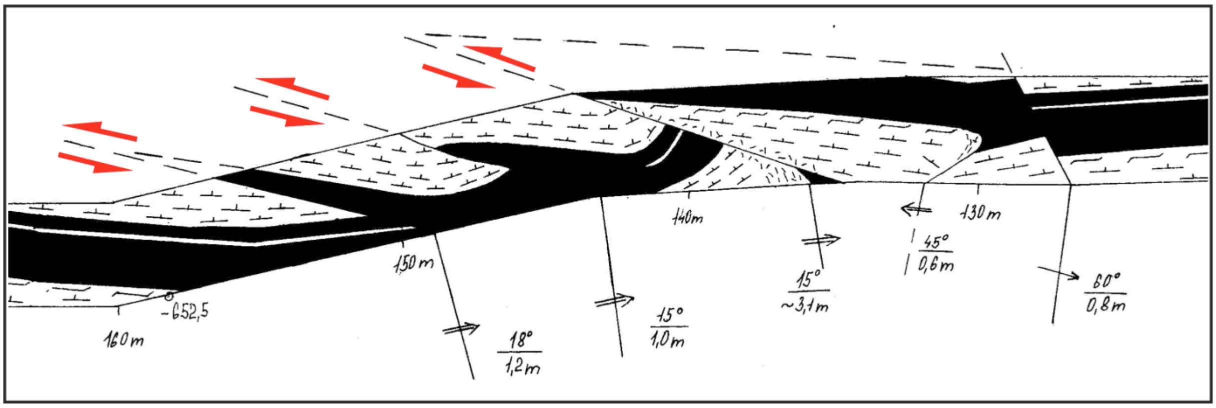

Fig. 8. Example of the thrust deformations in domain of the Central Thrust Zone in the Seam No. 28 (647). Based on primary documentation from the ČSM Mine.

The above-mentioned regional tectonic domains (Dětmarovice shear zone, Karviná Graben) divide the Karviná Subbasin from the structural point of view into four partial blocks with different vertical structural positions and with relatively autonomous inner structural plans. The tectonic zones themselves represent areas of rather mobile structural development. In the case of Dětmarovice shear zone, the strike component of displacement has the dextral character, which corresponds with the already published knowledge of the Žofie fault (Danys – Sivek, 1976), i.e. one of partial faults of this zone. The kinematic development of regional deformation in the Dětmarovice shear zone is connected mainly with an increase in compression along the Orlová thrust-fold structure towards the north (Grygar in Kumpera et al., 1990; Grygar, 1992). That is conditioned by the dextral extrusion of a so-called Vrbice block occurring west of the Orlová structure towards the east (Figs. 9, 10) into the space of the Dětmarovice fault-flexure depression of subequatorial direction

(Grygar, 1997). From the comparison of structural height of blocks south of the Dětmarovice shear zone with the structural level in the axis of depression, the vertical amplitude of displacement of up to 1000 m is evident (Fig. 4 and 6).

Fig. 9. Tectonic ramps and slicken-sides (mirrors) corresponds to thrust zone in the roof of Seam No. 30 (634) – Lower Suchá Member, ČSM Mine. Photo R. Grygar.

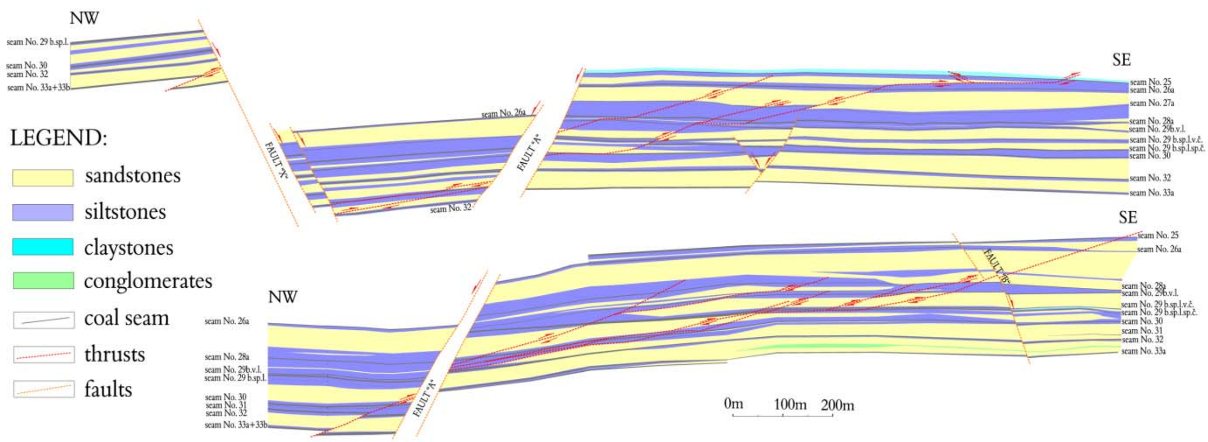

Fig. 10. Lithological cross-sections represent tectonic style in the zone of the Eastern Thrust Zone (red hatched lines and arrows). Lower Suchá Member, ČSM Mine.

As already mentioned above, one of anomalous structural phenomena of the Karviná Subbasin is the system of compressional deformations designated traditionally as Karviná Central Thrust (Grygar et al. 1989, Dopita et al. 1997, Ptáček 1999, etc.). To the genesis, spatial distribution and prediction of thrust structures the essential part of this work is devoted.

Methodology

In the framework of the study, available mine documentation was collected from those mines where any manifestations of thrust structures and accompanying deformations had been recorded. Basic mine maps and also derived maps were converted into a uniform CAD format of Microstation program. In this way seam maps from the Karviná Mine (localities of Doubrava and ČSA), Darkov and ČSM Mines were processed. Thus, in specific layers of the CAD system, data on thrusts and normal faults are there separately; individual seam levels are differentiated as well. To illustrate better the behaviour of thrust structures, the expected lines of thrusts are also digitized in separate layers.

To acquire the thorough knowledge of deformation processes connected with the thrust structures, primary documentation (e.g. Figs. 7, 8) capturing these structures in situ was studied and collected. The selection of extensive primary documentation was made so that it could express the character of thrust structures of various disturbance intensities, from various stratigraphical levels in the Karviná Subbasin.

With reference to strict safety measures in gassy mines of OKD company, photodocumentation on thrust structures were carried out in a limited degree as well (e.g. Fig. 9).

Moreover, important data were acquired from geological exploratory boreholes. On the basis of data from geological exploratory boreholes and mine workings, lithological conditions were analysed in relation to the genesis and spatial distribution of thrust structures and intraseam faults. The data from exploratory boreholes were a single source of information in places with the expected occurrence of thrust structures, where mining operations had not been performed yet.

Confrontation with the results from analog and numerical modelling (Suppe & Medwedeff, 1990; Calassou et al., 1993; Allmendinger, 1998; Mitra S. & Mount V. S., 1998; Hardy S. & McClay K., 1999; Johnson & Johnson, 2002; Savage & Cooke, 2003; Shaw et al., 2004; Guohai J. & Groshong R.H.Jr., 2006; Lallemand et al., 1992; Tavani et al., 2006, etc.) as well as comparison with structural-tectonic conditions of similar sedimentary foreland basins and thrust accretion wedges enabled the developing and making of the original model of genesis and development of the Central Thrust more accurate.

When creating a uniform digital archive of structural-tectonic elements, attention was naturally paid to faults in seams. Normal faults and thrusts were separated in the Microstation program by assigning to various data layers. In the program environment ESRI ArcGIS 9.3, the statistical analysis of strikes of thrust and normal fault structures in the framework of individual tectonic blocks or selected areas was done. Made rose diagrams and tectonograms (*Appendix No. 1*) represent the statistical assessment of seam fault variability in strike and enable the analysis of their relations to the major regional structures.

Evaluation of geological and structural-tectonic conditions in relation to thrust structures

Deformation processes depend, among other matters, to a considerable extent on lithological conditions. For this reason it was necessary to supplement the results of structural-tectonic analysis by results of the analysis of lithological conditions (Fig. 10). Special attention was then paid to interrelationships between lithological conditions and thrust tectonics in the eastern part of the Karviná Subbasin. From works published earlier (e.g. Grygar et al., 1998; Ptáček, 1999), from documentation studied and also from our own measurements and observations in situ in the ČSM Mine (Fig. 7) follow spatial and genetic relations of thrusts to the lines of seam splitting, lithological boundaries between competent and noncompetent rocks, the number of layer boundaries, etc. In the framework of study of these relations, detailed lithological sections in places providing the latest and most comprehensive data on thrust structures, i.e. in the mining claim of ČSM Mine were constructed.

Inside the tectonic blocks that are delimited by faults of regional importance, the rock mass is disturbed by a system of small and so-called seam faults. Only agreed differentiation between them is made. The uplift on seam faults is not mostly greater than several decimetres; it is 1 m as a maximum. Quantitative parameters of seam and also small faults depend on each other. Intraseam faults often run across the whole tectonic block and are also interpretable in vertical sections from overlying to underlying seams. That is why we consider these faults to be significant discontinuities affecting the internal structure of coal seams and the distribution of shear joints in coal seams.

On the basis of statistical assessment it can be stated that generally it is faults striking W-E up to WSW-ENE and NNW-SSE, i.e. those that are parallel to the regional transverse and longitudinal fault structures that predominate.

In the southern part of area of the Karviná Subbasin and its surroundings, strikes parallel to those of the regional transverse fault structures predominate. In the northern part, in the vicinity of Dětmarovice shear zone represented here by the Doubrava fault, the systems which are oblique to the strikes of major tectonic structures play a significant role. These systems correspond to pinnate so-called Riedl R- and R´-shears.

It is the systems of R´ shears oriented in the NNW-SSE direction and occurring in the mining claim of Doubrava Mine that are the most distinct. These systems represent here the most frequent system of small seam faults.

As already indicated in Introduction, one of anomalous structural phenomena of the Karviná Subbasin is the system of thrust (compressional) structures that was traditionally designated as Karviná Central Thrust (e.g. Grygar et al., 1989; Grygar, 1996; Dopita et al., 1997; Ptáček, 1999; and others). Above all in the western part of the Basin, partial thrust structures of various amplitudes have been documented (e.g. Hudeček & Sivek, 1977; Kumpera et al., 1990). Thrust structures were recorded here near in the uppermost part of the Lower Suchá Member as early as the beginning of the 70's. Whereas on higher stratigraphical levels, uplifts on thrusts usually did not exceed the thickness of the affected seam, near the base of Karviná Formation, uplifts of the order of several ten metres were verified (Grygar & Waclawik, 2006). In the eastern part of the Basin, the thrusts on which uplifts did not exceed the thickness of the dislocated seam were verified subsequently at the end of the 90's (Fig. 4 and 6). In connection with mining activities performed at increasing depths, many thrusts of regional importance have been verified also in the eastern part of the Basin in the last decade (*Appendices No. 2* and *No. 3*).

The hitherto experience of stratigraphically higher seams shows (Grygar et al., 1989, 1997; Ptáček, 1999; and others) that the Central Thrust is not any simple thrust plane having a constant spatial geometry. Especially the dip of this structure is very variable. Extensive interlayer dislocations – flat thrusts and also marked tectonic ramps (Fig. 9) are typical. On these ramps, at the accumulation of shear stresses "a shearing failure" along the steeper thrust plane mostly occurs in the roof of the seam (Grygar & Waclawik, 2006). Subsequently, thrusts continue in interlayer slips. Interlayer slips in the seam itself, or in the immediate vicinity of the seam, cause anomalous deformations of the seam similar to boudinage and other accompanying phenomena. These deformations have typical features of an early, synlithification plastic stage deformation.

According to the existing knowledge it can be stated that thrusts in the Karviná Subbasin have very small dips (5° - 35°). What is characteristic is also a change in dip with depth with a possibility of transition to interlayer slips. So far verified thrust structures exhibit simultaneously a considerable variability in strike (lines in individual seams – see *Appendices No .2* and *No .3*).

Thrusts have been recorded in the interval from the seam 23 to the seam 40, i.e. from the base of Upper Suchá Member to the base of Saddle Member. In the stratigraphically higher seams, thrusts do not occur. In the south-western part of the Karviná Subbasin, i.e. in the localities of Dukla and Lazy, thrusts have not been recorded in the stratigraphic interval of the exploited Karviná Formation either.

On the basis of comprehensive analysis of structural data, map data and primary documentation, Grygar & Waclawik (2006) modified the relatively simplified idea of the only regional thrust structure of Central Thrust. The originally defined zone of western and also northern thrusts in the Karviná Subbasin (localities of Doubrava and ČSA), i.e. the originally delimited Central Thrust Zone (Grygar et al., 1989) does not form any continuous zone with eastern occurrences of thrusts in the mining claims of ČSM and Darkov Mines. For this reason, two spatially independent, but genetically and temporally related and mutually conditioned structures were delimited. It is a case of a newly defined Eastern Thrust Zone and the Central Thrust according to the original conception (Grygar & Waclawik, 2006; Fig. 5, *Appendix No. 4*).

The Eastern Thrust Zone was defined newly (Grygar & Waclawik, 2006). To the delimitation of this structure, the mining claim of Darkov Mine – locality of Darkov (*Appendix No. 3*) is crucial. In the Saddle Member, a system of NE-SW to NNE-SSW thrusts dipping towards NW to WNW was verified; in the stratigraphically higher Suchá Member, a system of NW-SE thrusts generally dipping towards SW is evident. This situation is one of key factors leading to the definition of two geometrically independent thrust structures – the Central and Eastern Thrusts.

Generally, the trace of the Eastern Thrust Zone runs in the NE-SW direction (see also the statistical analysis of strikes of intraseam faults – *Appendix No. 1*). In the framework of Eastern Thrust Zone, towards SW the linesof partial seam thrusts bend to WSW-ENE. On the contrary, towards NE, the traces of seam thrusts bend up to the NNE-SSW direction. Thus they are parallel with the strikes of major regional thrust-fold structures of the Upper Silesian Basin (Orlová-Boguszowice structure, Michálkovice structure, etc.).

The stratigraphically lowermost thrust structures of the Eastern Thrust Zone were verified in the seam No. 40 (Prokop). At the base of the Upper Suchá Member, in the seam No. 23, thrusts were found in the stratigraphically highest position.

Genetically the formation of the eastern thrusts can be connected with the development of major thrust structures of the Upper Silesian Basin, especially with the kinematics and the mechanism of formation of Orlová structure. This is proved above all by the strike identical with that of major thrust structures and by the identical trend in increase in intensity of deformation towards NNE. On the basis of development of thrust structures primarily in the mining claim of ČSM Mine, where the zone was verified to the greatest extent, a possibility of occurrence of other thrust deformations of similar genesis and extent further east is not expected (Grygar & Waclawik 2006).

As for position, the Central Thrust Zone generally strikes WNW-ESE. In the Doubrava mining claim it however bends sharply to NNE-SSW, i.e. the strike of Orlová structure. From structural maps, multiple continuous changes in strike of individual thrusts are evident (*Appendix No. 2*).

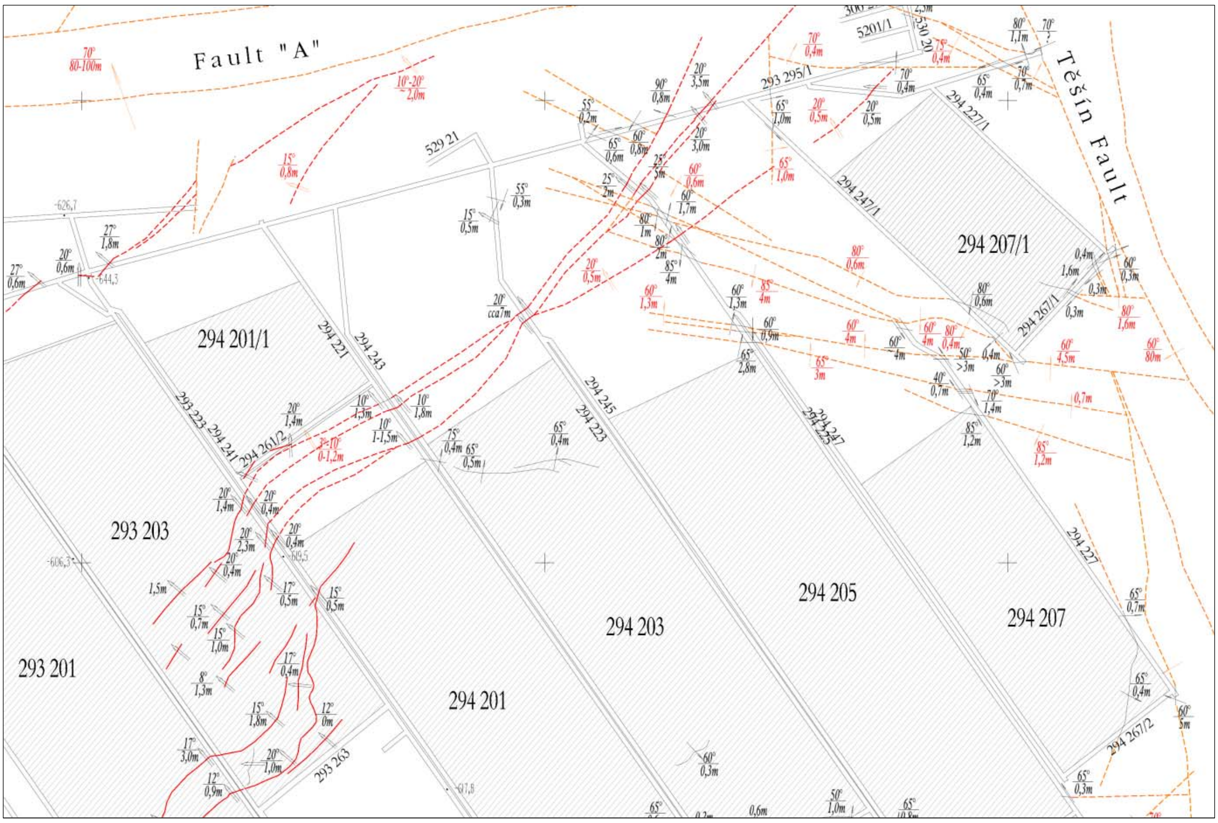

Fig. 11. Cut-out from the geological-structure map of the Seam No. 29b. (648+649). Lower Suchá Member, ČSM Mine. Red lines represent thrusts and orange line corresponds to normal faults.

The stratigraphically lowermost thrust structures were verified in the uppermost part of Poruba Member in the southern part of Doubrava mining claim. However, the vertical amplitude has here, in comparison with the Eastern Thrust, substantially higher values. The maximum known uplift on the thrust of 53 m occurs in the uppermost part of Poruba Member, i.e. in the immediate floor of lowermost seam of the Karviná Formation, i.e. the seam Prokop. With reference to the assumption of rather deep rooting of the Central Thrust Zone in the Ostrava Formation, the occurrence of thrusts can be expected also further south. This conception is supported by the results of geological exploratory boreholes drilled lately in the Lazy mining claim. Further east, in the mining claim of Karviná Mine, ČSA plant, the stratigraphically lowermost thrusts were verified also on the level of seam No. 40 (504). However, uplifts on the thrusts here have far smaller values. The maximum value is merely 8 m. This fact proves that the Central Thrust Zone disappears east-south-eastwards.

From the point of view of acquiring the knowledge of interrelationships between the Central Thrust Zone and the Eastern Thrust Zone, the area of Darkov Mine – locality of Darkov is crucial (Grygar & Waclawik, 2006). The Central Thrust Zone disappears here; on the contrary, in the Eastern Thrust Zone the vertical amplitude of displacement on individual thrusts have the highest values (about 20 m in the seam No. 39a – *Appendices No. 2* and *No.3*).

Similarly to the Eastern Thrust, the Central Thrust is the case of a relatively wide zone of partial thrusts and thrust deformations. In the western part, in the vicinity of Orlová structure, deformations of Central Thrust have maximum values. In the horizontal projection, the Central Thrust Zone has the width of up to 2.5 km. The total strike length of the Zone in the framework of Karviná Subbasin is almost 10 km.

In contrast to the genesis of the Eastern Thrust, which is genetically connected with the development of major thrust structures of the Upper Silesian Basin, especially with the kinematics and mechanism of formation of the Orlová structure, the clarification of formation of the Central Thrust is substantially more comprehensive and complicated. What is atypical is above all the transverse position of the Central Thrust in relation to the strike of the Orlová structure in the framework of not only the Upper Silesian Basin but also the whole of the Moravian-Silesian zone (Grygar & Waclawik, 2006).

According to Grygar et al. (1989), deformations in the Central Thrust Zone are genetically connected with the mobility of the Dětmarovice shear zone and simultaneously exhibit a genetic relationship to the major thrusts of the Orlová structure. On the basis of confrontation with the results from analog and numerical models (Suppe & Medwedeff, 1990; Calassou et al., 1993; Allmendinger, 1998; Mitra & Mount, 1998; Hardy S. & McClay 1999; Johnson & Johnson, 2002; Savage & Cooke, 2003; Shaw et al., 2004; Nemčok et al., 2005; Guohai & Groshong, 2006; Tavani et al., 2006, etc.) and also on the basis of comparison with the structural-tectonic conditions of equivalent sedimentary basins and thrust accretion wedges, the original model of genesis and development of the Central Thrust Zone can be made more accurate and can be supplemented.

The anomalous position of the Central Thrust is in relation with the Dětmarovice dextral shear zone. This shear zone separates the area of structurally higher blocks of the Karviná Subbasin from the structurally subsided Dětmarovice transverse depression. In addition to the dextral strike component, the Dětmarovice zone has thus simultaneously the character of normal fault flexure, disturbed by a system of transcurrent normal faults (Dětmarovice fault, Eleonora fault, Žofie and Jindřiška faults - Grygar & Waclawik 2006). In this way, a vector addition of the transpressional component of stress (e.g. Schreurs & Colleta, 2002) derived from the dextral strike displacement takes place, and thus an anomalous increase in the state of stress in the internal (stratigraphically lower) zone of flexure occurs.

The Dětmarovice shear zone could, in the course of early stage of Late Variscan thrust deformations, act as so-called accommodation zone above the structural ramp in the foreland basement (e.g. Calassou et al., 1993, Wilkerson et al., 2002) that compensated marked kinematic and deformation differences between the northern more mobile segment and the southern more stable segment of the Karviná Subbasin. Its accommodation function was connected with substantially greater compression and east-vergent thrust of the northern segment of Czech part of the Upper Silesian Basin west of the Orlová structure, i.e. the structural elevation of Vrbice block to the subsiding Karviná transverse depression. Among other matters, a deformation phenomenon of tectonic extrusion into a space of greater tectonic subsidence manifests itself here (e.g. Ratschbacher et al., 1991).

From the mine-geological documentation, the spatial dependence of the lines of thrust planes on the position of line of connection of seams of mainly Saddle Member is evident. These significant lithological anomalies create predisposition for the formation of structural ramps and for the blocking of advance of the thrust front of accretion wedge towards east. In the Suchá Member, the majority of thrusts in the Eastern Thrust Zone have been documented. This statistically supported fact is connected undoubtedly with the intensity of mining operations growing with depth, when seams of the Suchá and also Doubrava Members were gradually mined, and also and mainly with the anomalous lithological development of the Suchá Member. The markedly higher number of stratal boundaries in the Suchá Member in comparison with the underlying Saddle Member is crucial to the formation of flat thrusts with an extensive interlayer slip.

Conclusion

The aim of the submitted work was the clarification of extent, geometry and genesis of thrust deformations of Variscan accretion wedge in the Karviná Subbasin in relation with the overall structural-tectonic conditions of the Basin. In the program environment CAD (Microstation) a uniform digital archive of structural-tectonic documentation of active mines of OKD in the Karviná Subbasin was created. By the analysis of data of the created digital archive, in cooperation with the study of primary mine documentation, photodocumentation, data from geological exploratory boreholes, and last but not least, on the basis of our measurements and observations in situ, ***the Eastern Thrust Zone*** and ***the Central Thrust Zone*** were defined newly.

Genetically the formation of thrusts in the ***Eastern Thrust Zone*** can be connected with the development of major thrust structures of the Upper Silesian Basin, especially with the kinematics and mechanism of development of the Variscan thrust wedge, especially then the Orlová fold-thrust structure. The genetic connection between the easternmost thrusts and the overall comprehensive structural development of accretion wedge is proved especially by the identical strike of the Eastern Thrust Zone and the fault line of Orlová structure and the identical trend in increase in the intensity of deformations towards NNE. The maximum intensity of thrust deformations was verified in the 5^{th} block of Darkov Mine – Darkov locality in the seam No. 39a (512); here the vertical amplitude of displacement fluctuates around the value of 20 m. The so far verified total strike length of the Eastern Thrust Zone is almost 6 km. The width of the Zone in horizontal projection is up to 3 km and the width of the Zone in the framework of one seam level is up to 700 m. The general dip of the Zone fluctuate in the range of 10°-15°; individual partial thrusts (thrusts on ramps) then usually have greater dips ranging from 20° to 45°. Of thrust deformations in the Eastern Thrust Zone, the maximum utilization of stratal anisotropy of the sequence of strata of Karviná Formation is typical. Above all, interlayer and intraseam slips, which often cause anomalous deformations of seam resembling boudinage, play a significant role. These deformations have typical features of early, synlithification plastic stage deformation.

In accordance with Grygar et al. (1998), we connect genetically the deformations in the ***Central Thrust Zone*** with the mobility of the Dětmarovice dextral shear zone and with the development of the Orlová fold-thrust structure of "fault-propagation fold" type (e.g. Mitra, 1992). The anomalous (transverse WNW-ESE) position of the Central Thrust Zone in relation to the major longitudinal thrusts and fold systems of the Upper Silesian Basin can be explained by genetic connection with the Dětmarovice shear zone. This zone separates the area of structurally higher blocks of the Karviná Subbasin from the structurally subsided Karviná transverse depression. In addition to the dextral strike component, the Dětmarovice zone thus has simultaneously the character of normal fault flexure, disturbed by a system of transcurrent normal faults. A vector addition of the transpressional component of stress (e.g. Schreurs & Colleta, 2002) derived from the dextral strike displacement takes place, and thus an anomalous increase in the state of stress in the internal (structurally and stratigraphically lower) zone of flexure occurs. The carried out structural-tectonic analysis, synthesis of other pieces of structural data and primary documentation, and also confrontation with the results from analog and numerical models (Suppe & Medwedeff, 1990; Calassou et al., 1993; Allmendinger, 1998; Mitra & Mount, 1998; Hardy & McClay, 1999; Johnson & Johnson, 2002; Savage & Cooke, 2003; Shaw et al., 2004; Nemčok et al., 2005; Guohai & Groshong, 2006; Tavani et al., 2006, etc.) confirm these connections. In comparison with the Eastern Thrust Zone, in the Central Thrust Zone the intensity of thrust deformations increases in the WNW direction. The maximum intensity of thrust deformations was thus verified in the Doubrava mining claim, in the uppermost part of the Poruba Member; there the vertical amplitude of displacement is up to 53 m. In the horizontal projection, the Central Thrust Zone has the width of up to 2.5 km. The total strike length of the zone in the framework of the Karviná Subbasin is almost 10 km. Similarly to the case of the Eastern Thrust, thrusts in the Central Thrust Zone also maximally utilize stratal anisotropy and interlayer and intraseam slips.

One of objectives of the work was the study of a genetic and spatial relationship between thrust structures and overall geological conditions of the rock mass. From special-purpose maps, detailed lithological sections, primary documentation and our own observations in situ, the following facts follow:

- the character of thrusts corresponds to the "flat thrust-ramp" type ("ramp and flat", Pluijm & Marshak 1997),
- what is typical is the flat geometry of thrusts – interlayer slips above all in the complexes of seams and also noncompetent rocks (siltstones, claystones),
- thrusts have higher dips in competent rocks (sandstones, conglomerates),
- reverse thrusts are not frequent in the rather high parts of a thrust zone,
- vertical amplitudes of displacement (uplift on a thrust) increases towards the underlying layers,
- the gradual widening of a thrust zone towards the stratigraphically higher parts of sequences of strata takes place,
- thrust lines are often parallel to the traces of marked, lithologically contrast boundaries (siltstones versus sandstone, etc.),
- an increase in proportion of sandstones in the SE direction in the framework of the Suchá Member, and a decrease in number of stratal boundaries connected with it; the formation of structural ramps is evoked (see above),
- the lines of compressional thrusts are dislocated by significant normal faults – the thrusts are older than the normal faults. However, it is necessary to take into account that movements along significant thrusts were rejuvenated, e.g. by loading by nappes of the Carpathian System.

The thrust structures of the ***Eastern Thrust Zone*** and the ***Central Thrust Zone*** have affected, owing to their extents and characters, markedly the utilization of coal reserves and also the economics of mining of seams of the Karviná Formation in the framework of the Karviná Subbasin. Another objective was thus to contribute to the acquiring of knowledge of the role of tectonic structures (with emphasis on thrust deformations) that is of importance to the present and the future mining activity of OKD. New knowledge and results of work can be thus useful in the design of geological exploration and new mining capacities.

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