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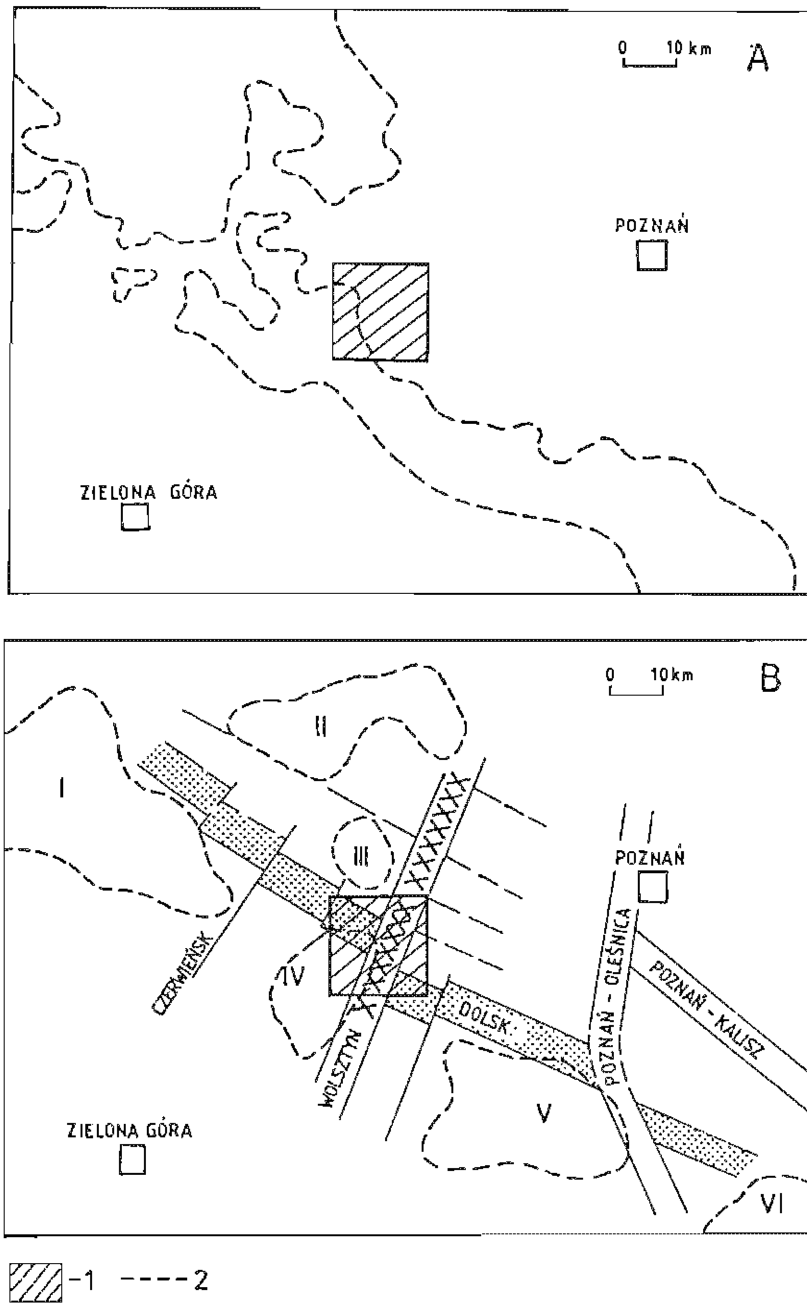
Origin of gas traps in the Rotliegendes sediments of the area Paproć — Cicha Góra (Wielkopolska)

Sedimentological analysis of sediments of the Rotliegendes in the area of natural gas deposit Paproć — Cicha Góra is presented. Research was based on boreholes cores, borehole geophysics, seismics and laboratory analyses from borehole documentation. Maps were prepared and tectonics analyzed basing on computer modelling (SURFER 4.15). Preliminary conclusions on connection of hydrocarbons agglomerations with respective facies and sedimentary environments are drawn. Results can be applied to further optimizing of gas searching in this area.

PALAEOGEOGRAPHY, PALAEOTECTONICS AND LITHOSTRATIGRAPHY OF THE ROTLIEGENDES IN THE AREA PAPROĆ — CICHA GÓRA

The studied region is a fragment of the Wolsztyn Island Upland (WWW), distinguished palaeotectonically as the Wolsztyn Elevation. The latter is in turn an uplifted fragment of Variscan externides. The Wolsztyn Elevation exerts its influence in palaeogeography of the Lower and Upper Rotliegendes. Opinions on its geological structure, palaeogeography and activity during the Rotliegendes deposition are principally different and persistent for a longer time (J. Pokorski, 1988; P. H. Karnkowski, 1980*a*; P. Karnkowski et al., 1991).

According to J. Pokorski (1988) during the Lower Rotliegendes the Wolsztyn Elevation formed generally a vast, shapeless and irregularly northwest-southeast elongated structure, innerly varied into uplifted areas (partly devoid of the Rotliegendes sediments) and rare local depressions (in which often effusive rocks predominated). On the other hand, during the Upper Rotliegendes a palaeogeographical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picture became distinctly different. The Wolsztyn Elevation was composed of many small uplifted „islands", devoid of the Upper Rotliegendes sediments and surrounded with vast covers of clastic sedimentary rocks (Fig. 1A, B). According to J. Pokorski (1988) uplifted areas form two parallel arcs that reflect a Variscan structural pattern. Structures of the outer arc are smaller and they were subjected to weak subsidence at the end of the Rotliegendes. The inner arc (Paproć area with the elevation of Zbąszynek — Nowy Tomyśl inclusive) was active during the whole Upper Rotliegendes, being the alimentary area for the Poznań Graben and the Silesian Trough. Presented model accepts subdivision of the Wolsztyn Ridge into a distinct tectonic zone with deep structural foundations and its segmentation with a system of transversal fractures. This model is also supported by interpretation of palaeotectonics of the western (German) part of the arc with Variscan palaeoelevations (U. Gebhardt et al., 1991).

A model of block tectonics with faults, transversal to the axis of the Wolsztyn Elevation, is mentioned in the paper of P. H. Karnkowski (1980*a*, *b*, 1985) who emphasizes its significance not only during the Rotliegendes but also during development of the whole epi-Variscan cover. The other model (P. Karnkowski et al., 1991) seems to be a static one rather. It assumes existence of a vast elongated elevation, irregularly segmented in the northwest and uniform in the southeast but without distinct tectonic frames (Fig. 1A). Finding sufficient arguments to accept any of these tectonic models is particularly important if delimiting the zones with clastic rocks of the Rotliegendes, the same to define areas to potential search of hydrocarbons at both sides of the Wolsztyn Elevation. It is also important from a point of view accepted by the authors — in a hypothesis on distinct connection of main tectonic fractures with gas occurrence in the Rotliegendes sediments.

The studied area occurs at margins of upliftings (Nowy Tomyśl and Lwówek elevations) of the inner arc and of the Rudnik Depression at periphery of the Poznań

Fig. 1. Conception models of palaeoelevation extents (devoid of sedimentary cover) of the Rotliegendes; fragment of the Wolsztyn Island Upland

A. Static model — version preferred by oil mining, based mainly on assumption of occurrence or lack of the Upper Rotliegendes sedimentary cover, with tectonics insignificantly taken into account

B. Dynamic model — version after J. Pokorski (1988), determined by palaeotectonic analysis

1 — investigated area; 2 — extent of Upper Rotliegendes sedimentary cover; palaeoelevations: I — Sulęcin — Międzyrzecz, II — Międzychód — Chrzypsko, III — Lwówek, IV — Zbąszynek — Nowy Tomyśl, V — Kościan, VI — Pogorzel; main fault zones: Poznań — Kalisz, Poznań — Oleśnica, Dolsk (after P.H. Karnkowski, 1980*a*), Wolsztyn, Czerwieńsk (after authors)

Modele konceptualne zasięgu paleowyniesień (pozbawionych pokrywy osadowej) czerwonego spągowca; fragment Wolsztyńskiej Wyżyny Wyspowej

A. Model statyczny — wersja preferowana przez górnictwo naftowe, oparta głównie na przesłankach o występowaniu lub braku pokrywy osadowej górnego czerwonego spągowca, uwzględniająca w nieznacznym stopniu tektonikę

B. Model dynamiczny — wersja według J. Pokorskiego (1988), zdeterminowana przez analizę paleotektoniczną

1 — obszar badań; 2 — zasięg pokrywy osadowej górnego czerwonego spągowca; paleowyniesienia: I — Sulęcina — Międzyrzecza, II — Międzychodu — Chrzypska, III — Lwówka, IV — Zbąszynka — Nowego Tomyśla, V — Kościana, VI — Pogorzeli; główne strefy dyslokacyjne: Poznania — Kalisza, Poznania — Oleśnicy, Dolska (według P. H. Karnkowskiego, 1980*a*), Wolsztyna, Czerwieńska (według autorów)

Graben. These elevations form highly diagenetic clastic rocks of the Lower Carboniferous and partly of the Upper Carboniferous (Westphalian in the boreholes Paproć 2 and 3a) — T. Górecka, Z. Pałka (1986) — and effusive rocks of the Lower Permian. Depressions where varying subsidence occurs, are filled with red clastic sediments and volcanic rocks (effusive rocks and tuffs), underlain on rocks of the Carboniferous or Older Palaeozoic. Proposed interpretation of substrate tectonics of the sub-Permian and Permian sedimentary cover supports the model of J. Pokorski (1988) and P. H. Karnkowski (1985), in which tectonic disintegration of the Wolsztyn Elevation into separate elevations („islands") and depressions is presented. Analysis of thickness and lithofacies of the Rotliegendes sediments in the area Paproć — Cicha Góra underlines existence of two main tectonic directions that cross each other: a younger, approximate NNE-SSW one which reflects transversal fractures of the Wolsztyn Ridge, and the older, close to NW-SE, reflecting zonal structure of the ridge (Fig. 1B). Tectonic direction NNE-SSW (K. Wierzchowska-Kicułowa, 1984) supports existence of a significant fault zone (Wolsztyn Fault) in the Permian substrate, being presumably of the rank of the Poznań — Oleśnica fracture zone. A fracture zone NW-SE (corresponding presumably to the Dolsk Fault) in the studied area, is represented by step block tectonics modified with later rejuvenating movements (P. H. Karnkowski, 1980*a*; T. Wolnowski, 1986), with characteristic and noted at small distances considerable differences in depths of the Carboniferous top surface. Transversal fractures (NNE-SSW), activity of which is to be observed as lenses (salt pillows) even in the Lower Zechstein complex, seem to have been formed above active faults (cf. A. M. Roberts et al., 1990) that considerably modified location of the perpendicular (NW-SE) tectonic zone. The mentioned crossing tectonic zones have determined considerably determined of the Rotliegendes sediments in the area Paproć — Cicha Góra. This deposition occured in phases and was interrupted with erosive episodes (therefore there are therefore numerous erosive hiatuses that indicate absence of many lithological members of the Rotliegendes).

During the first phase sediments of the Lower Carboniferous were mantled with volcanic rocks (effusive and pyroclastic ones), a thickness of which is over 400 m. These rocks were formed during numerous eruptive episodes and are locally separated with sedimentary rocks, several dozen metres thick (e. g. Paproć 19 and 23). Both lithological types represent together a fragment of the Lower Permian volcanogenic Wielkopolska Formation (J. Pokorski, 1981) and/or of the Wyrzeka Volcanite Formation (P. H. Karnkowski, 1987). These sediments have varying thicknesses and are irregularly widespread. They have been locally completely eroded or constitute the only lithological type of the Rotliegendes up to the Zechstein border.

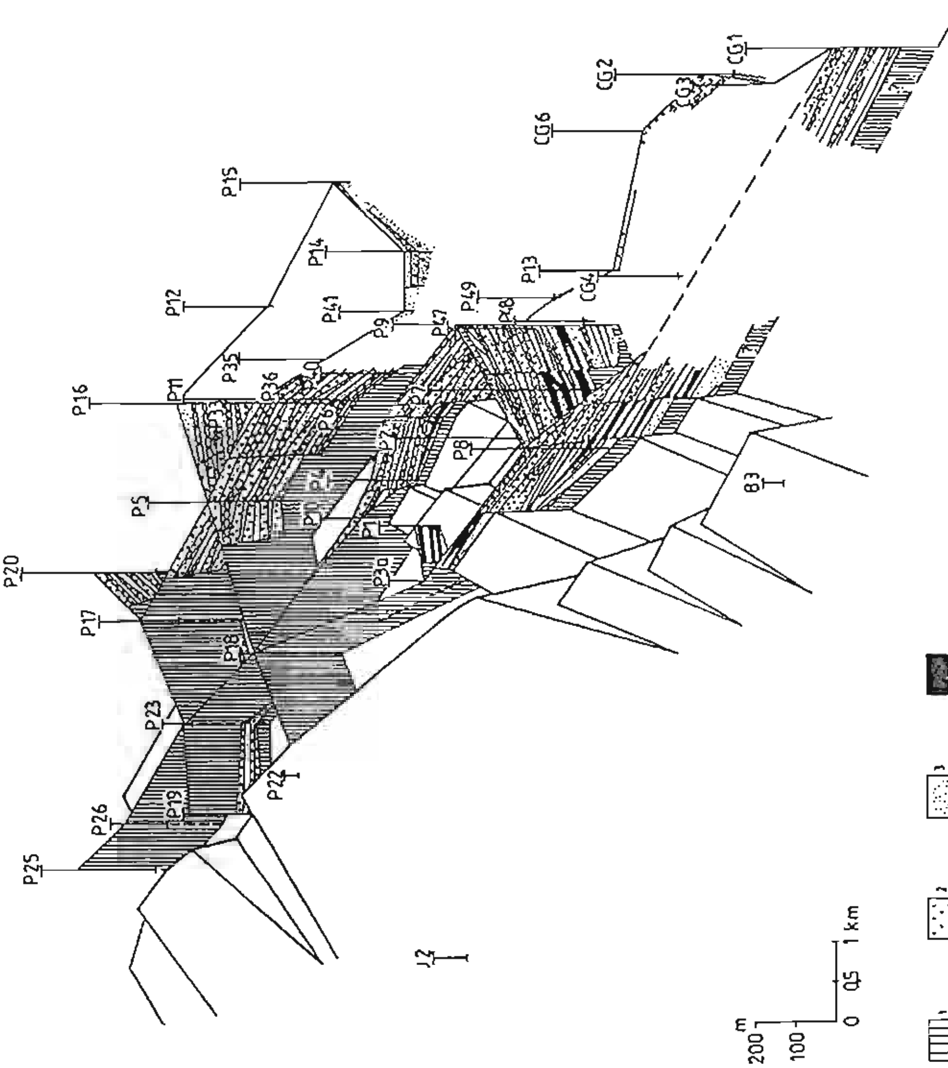
During the second phase red clastic rocks were formed. They are composed mainly of material from the denuded Carboniferous elevations and from strongly eroded volcanic rocks. They form alluvial fans of varying thickness (locally to 400 m), generally increasing to the east and northeast. These sediments belong to the Książ Wielkopolski Conglomerate Formation (P. H. Karnkowski, 1987). In some sections bipartity of a sedimentary sequence is noted, being expressed in many sections by repeated coarse-claste rocks separated with finer sediments. It corresponds in turn to bipartity of the Warta Group (Noteć Formation and Drawa Formation), in agreement with subdivision of J. Pokorski (1981). In marginal sediments that do not represent the whole basin cycle of the Rotliegendes, such bipartity seems to correspond to lower-rank sedimentary episodes. The latter could correspond to local variation in thickness and facies, connected with tectonics of the area.

SEDIMENTOLOGICAL ANALYSIS BASED ON CORE DATA

Data used to detailed sedimentological analysis (description of cores, supplied with interpretation of G. Pieńkowski and P. Kiersnowski (1990) come from 11 boreholes: Paproć 1, 2, 4, 6, 8–10, 14, 16, 19, 35 (Fig. 2). The core from the borehole Cicha Góra 1 was badly preserved and could form the basis for the approximate lithological-facial description only. The analysis was based on all observations from the cores (colour, lithology, largest — most frequent grain sizes, sedimentary and deformation structures) and their interpretation (diastrophic and sedimentary cycles, sedimentary environments). Conglomerates or breccias with sandy-silty or rarely with silty matrix predominate in most sections (the ones in the northeastern part of the studied area and the uppermost top fragments of the Rotliegendes almost in all the sections exclusive). In these conglomerates usually no distinct sedimentary structures are to be recorded, pebbles or angular rock pieces are irregularly arranged, only locally there is grain gradation or very indistinct lamination caused by variability of sizes of rock pieces and quantity of matrix. Occasionally breccias and conglomerates indicate a mud-supported structure — individual rock pieces do not contact with one another or represent considerable degree of packing. More seldom short fragments of the profile contain fine-grained conglomerates with, distinct sedimentary structures — horizontal and trough cross stratifications.

Sandstones, which play secondary role against conglomerates, contain mostly trough cross and horizontal stratifications. Such sandstones predominate mainly to the northeast but also in the upper part of the Rotliegendes in all sections. Well-sorted sandstones that form large inclined sets, are considered to be of aeolian derivation. Presence of quite thick and isolated siltstone patches in the sections Paproć 1 and 2 calls for particular attention. Siltstone sequences in the middle of coarse sediments of the Rotliegendes (Paproć 7–9) are eliminated quite quickly in all directions (or are eroded due to block-like tectonics of a substrate) and are unknown from neighbouring boreholes. They are generally composed of red siltstones, locally with lenticular lamination, dehydratation-compaction and desiccation cracks immersed structures and rare bioturbations. Within siltstone patches there are sandstone interbeds with single beds or thicker sandstone-conglomerate sets that form mostly upward-coarsening cycles.

All the features, being symptoms of predominating coarse-clastic, poorly sorted red conglomerates and breccias, varying content of matrix, frequent absence of sedimentary structures as well as poorly visible or absent sedimentary cycles, absence of faunistic and floristic traces, redeposition phenomena (intraclasts) and very significant lateral facial changes indicate the alluvial fans environment. In this environment subenvironments are connected with debris flows and mudflows (cohesive flows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typical for most proximal sides of fans), covering floods, channels on fan surface and occasionally with sieve deposits (G. Pieńkowski, H. Kiersnowski, 1990).

Such features as predominance of cross-stratified sandstones, presence of single upward-fining sandstones and local traces of plant roots (initial pedogenie horizons) indicate facies of fluvial channels connected with environment of braided rivers but also with distal zones of alluvial fans or (more rarely) of channels in a fan surface. Here subenvironments of channel and floodplain sediments were distinguished.

Large inclined eosets with upwards-increasing dips were distinguished as dune sediments formed in a floodplain (Paproć 9 and 14) during the final Rotliegendes deposition.

Siltstones with lithological features described above are interpreted as sediments of a periodical lake (playa). Coarse-clastie sandstone interbeds (mainly these with reversed grain gradation) within siltstones are considered for sediments of lacustrine fan-deltas or of periodical fluvial predominance.

Light-grey and very well sorted sandstones with horizontal and inclined bedding noted just under the Zechstein border are interpreted as littoral sediments of the transgressing Zechstein sea. Lithologically they belong to the Rotliegendes but are connected genetiely with the Zechstein. A subenvironment of beaeh sediments was distinguished here, occasionally more coarse-grained, thus indicating transgression of the Zechstein sea (reworking of fluvial sediments in a beaeh zone), fine-grained sandstones of a littoral zone and siltstones that pass into carbonates of an open reservoir (G. Pieńkowski, H. Kiersnowski, 1990).

DEPOSIT TRAPS AND METHODS TO DISTINGUISH THEM

Formation of deposit traps, their filling with gas and survival depend on many opposite faetors. Gas derived from parent rocks, mainly of the Carboniferous and perhaps partly older migrated under tight covering of Zeehstein rocks from the north to the south of the Fore-Sudetic Monocline along the Rotliegendes palaeoslope (J. Oberc, 1978), being collected in local structural or lithologieal traps. Rate of migration and ehance for gas collection depended on regional inclination of strata of reservoir rocks. Along a migration path elevations of the Wolsztyn Island Upland acted as an excellent structural barrier.

In its central part on the northeastern side of the Zbąszynek — Nowy Tomyśl Elevation present inclination of the Rotliegendes palaeorelief results not only from the Permian subsidence of the Poznań Graben but also from its later reconstruction

Fig. 2. Fence sections in the Rotliegendes of the deposit Paproć — Cicha Góra, indicating probable spatial distribution of sediment lithofacies and extents of volcanic rocks

1 — volcanic rocks, 2 — predominance of coarse-clastic sediments, 3 — predominance of fine-clastic sediments, 4 — siltstones; boreholes: P — Paproć, CG — Cicha Góra, B — Boruja, J — Jastrzębsko

Przekroje płotowe przez utwory czerwonego spągowca w rejonie złoża Paproć — Cicha Góra ukazujące prawdopodobny przestrzenny rozkład litofacji osadowych i zasięgi skał wulkanicznych

1 — skały wulkaniczne, 2 — dominacja osadów gruboklastycznych, 3 — dominacja osadów drobnoklastycznych, 4 — mułowce; otwory wiertnicze: P — Paproć, CG — Cicha Góra, B — Boruja, J — Jastrzębsko

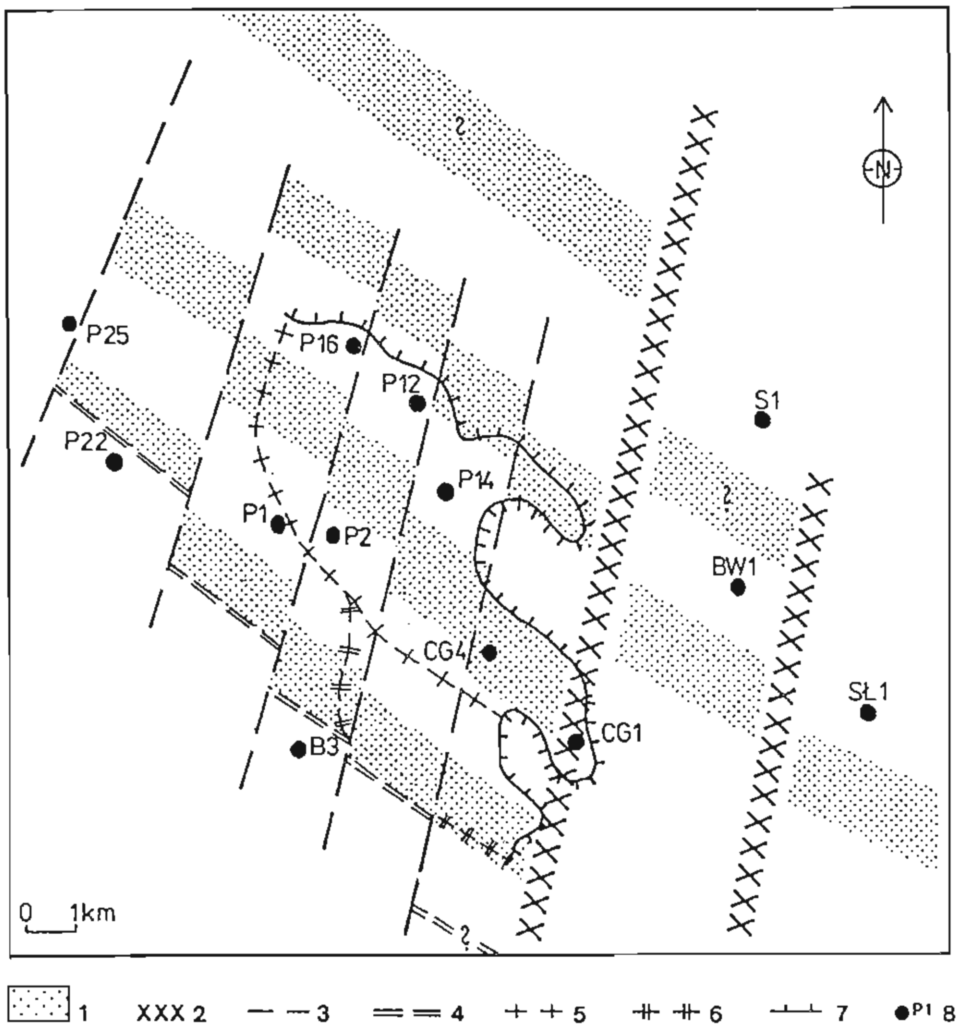


Fig. 3. Sketch of main tectonic directions in the natural gas deposit Paproć — Cicha Góra

1 — older tectonic direction (Dolsk fault zone); 2 — younger tectonic direction (Wolsztyn fracture zone); 3 — faults; 4 — extent of the area devoid of the Rotliegendes sediments; 5 — border at which reservoir conditions in top of the Rotliegendes sedimentary series disappear according to the previous research; 6 — interpreted border of disappearing reservoir properties; 7 — contour of deposit water; 8 — location of selected boreholes

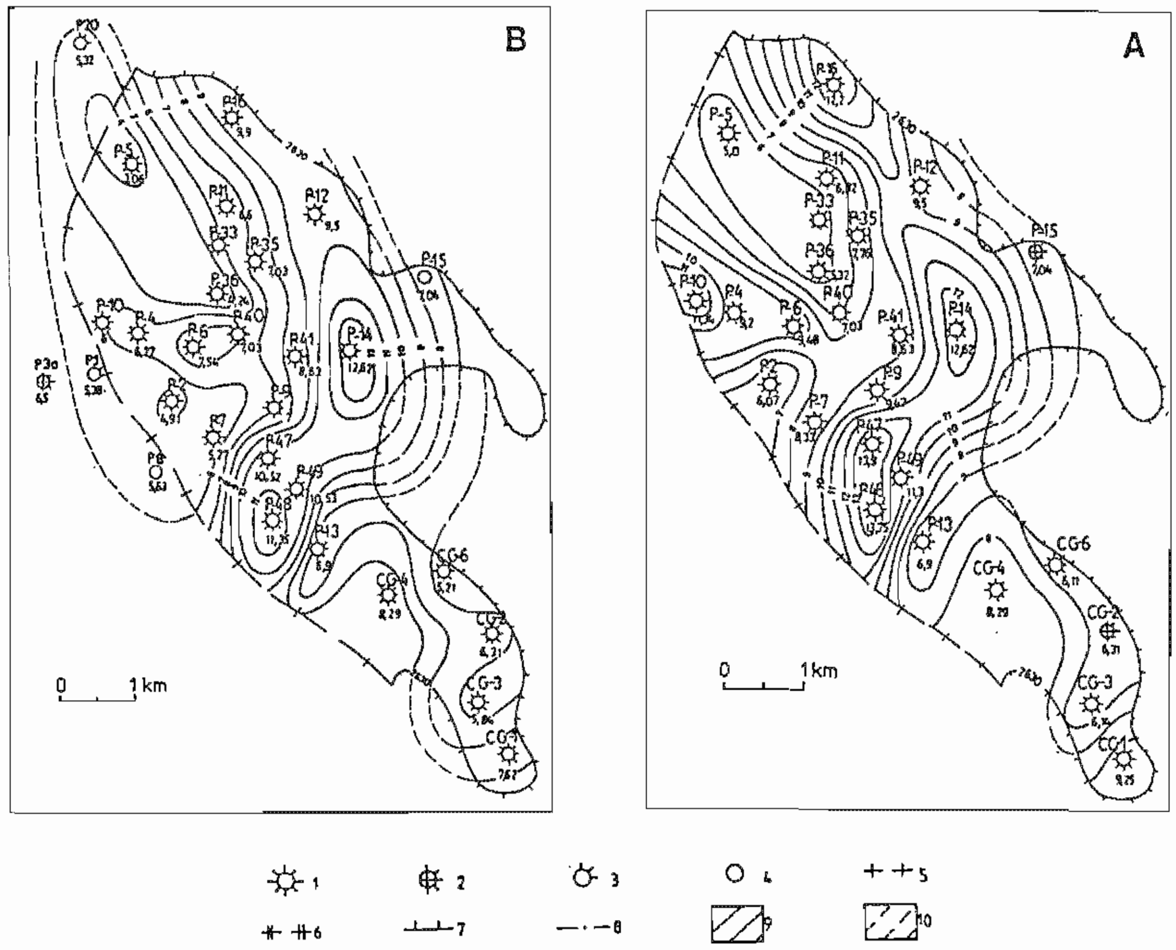
Szkic głównych kierunków tektonicznych w rejonie złoża gazu Paproć — Cicha Góra

1 — starszy kierunek tektoniczny (strefa uskokowa Dolska); 2 — młodszy kierunek tektoniczny (strefa rozłamowa Wolsztyna); 3 — uskoki; 4 — zasięg obszaru pozbawionego utworów czerwonego spągowca; 5 — granica zaniku własności zbiornikowych stropowej części serii osadowej czerwonego spągowca według dotychczasowych ustaleń; 6 — interpretowana granica zaniku własności zbiornikowych; 7 — kontur wody złożowej; 8 — lokalizacja niektórych wierceń

(T. Wolnowski, 1986). This author accentuated that movements of Cimmerian polyphases resulted in reactivation of tectonic zones on the Wolsztyn Ridge and its foreland, thus creating better conditions for vertical gas migration from parent rocks, and could form new structural traps or enlarge the already existing ones at dislocation zones. According to T. Wolnowski (1986) Cimmerian movements as well as the following Laramide reconstruction resulted in further inclination of the whole area to the northeast, intensifying lateral migration of gas inside the Rotliegendes along the impermeable sill of the Zechstein. Such „steepening" could, besides the already mentioned favourable symptoms, have also negative effects in decreased capacity of deposit traps. In a similar way P. H. Karnkowski (1980*a*) interpreted changes (significant for gas migration and collection) in inclination of the Rotliegendes palaeorelief during the Permian and Mesozoic, and gave reasons for differences in development of gas traps in western and eastern Wielkopolska (P. H. Karnkowski, 1985). The western region where the deposit Paproć — Cicha Góra is located indicates a smaller regional inclination (1–1.5°) than the eastern region where greater inclination (2–3°) does not favour a gas collection (traps with larger amplitude between underlying water and tightwater rocks are needed). Top of the Rotliegendes of the deposit Paproć — Cicha Góra is inclined at 1 to 2.7° and due to morphological reasons it is greater than a regional angle. As indicated earlier, the deposit is predominantly composed of sediments of alluvial fans, developed from dislocated (proximal) to distal zones, with inner structure deformed by syn- and postsedimentary block tectonics. In spite of high deposit amplitude (over 150 m), favourable collecting conditions and gas flows are mainly noted in its upper part. Distinct connection of areas with better porosity and permeability and the zones of main tectonic fractures calls for attention (Figs. 3, 5).

But time when potential deposit traps were formed, probable time of their filling is also important. In the deposit Ujazd which contacts with the deposit Paproć — Cicha Góra, generating of gas from Carboniferous sediments was postulated (T. Wolnowski, 1983) to have occured at the beginning of the Triassic whereas its accumulation in the deposit — at the beginning of the Liassic. Many deposits or their fragments could have been destroyed or got empty as, according to P. H. Karnkowski (1985), a process of their main development has been finished during the Tertiary in result of the Late Alpine movements. In a more recent paper on origin of natural gas collected in the deposit Paproć, M. Kotarba et al. (1992) distinguished two phases of hydrocarbon generation in different thermic conditions but they say nothing about age of their migration. Location of the deposit Paproć could result in development of several small tectonic-lithological traps and in filling them with gas in different time. Significance of vertical migration of gas along fault zones (J.-C. Pratsch, 1991) founds the basis for further search in the deposit area (Fig. 5). Significance of such gas migration is supported in the deposit Paproć by gases of mixed composition (coming from two generation phases) and deep abiogenic components of a gas (M. Kotarba et al., 1992)

Natural gas deposits Cicha Góra and Paproć were delimited on the basis of seismic structural analysis of the Zechstein bottom. Deposit traps, primarily defined as structural ones, were found to be the more complex ones. But the Rotliegendes, gas deposits in the area Paproć — Nowy Tomyśl were also found in top of the Carboniferous, in the Zechstein Limestone and the Main Dolomite. According to T. Kulczyk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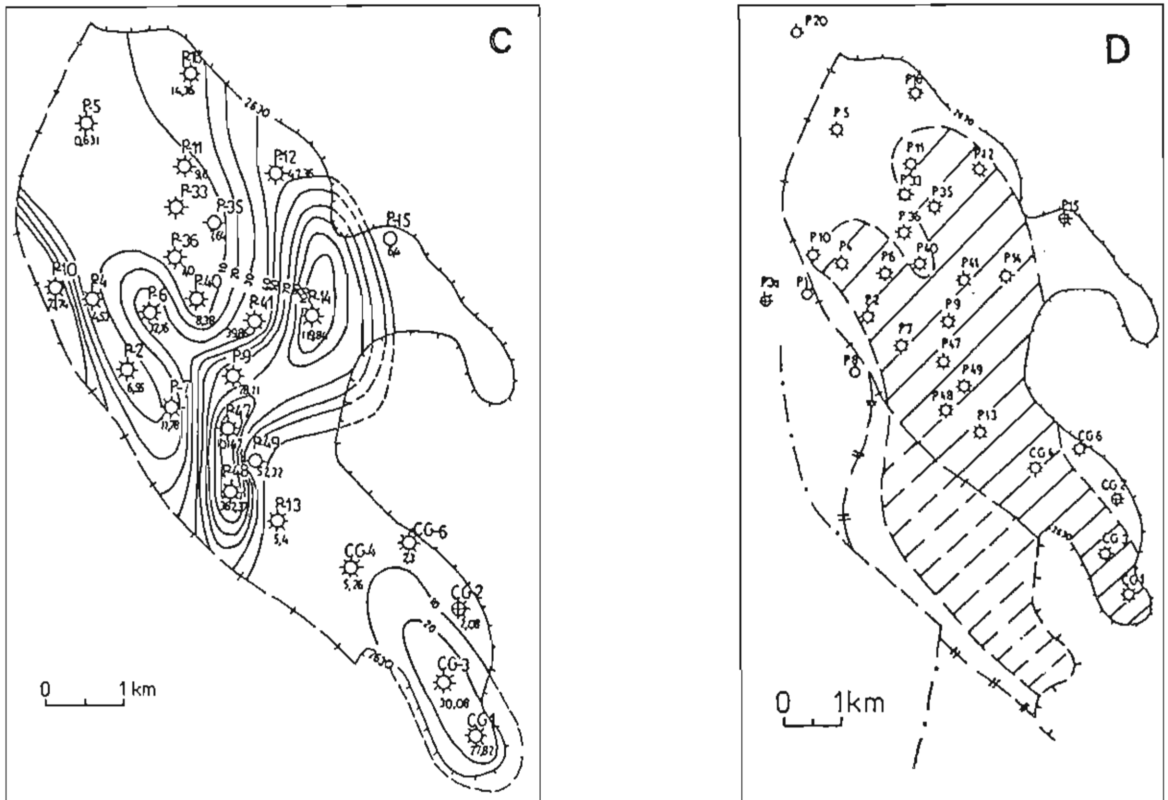

Fig. 4A. Map of effective porosity (in %) in sandstone beds saturated with natural gas (measurements from cored fragments of research and exploitation boreholes)
B. Map of effective porosity (in %) of the whole deposit series (from the top of the Rotliegendes to the deposit water level)
C. Map of effective permability (mD) in gas-saturated sandstone layers
D. Map of known and probable extent of reservoir conditions for gas accumulation

and T. Żołnierczuk (1988), the multilayered natural gas deposit Paproć is located in „...a complex trap of a lithologic-stratigraphic-tectonic type...". Limits of the deposit are formed, besides elimination of beds and changes in collecting properties of the Rotliegendes sandstones, by tectonic borders and its bottom barrier is created by underlying bed of strongly mineralized water (brine) at the depth contour line of 2630 m. With such deposit extent further recognition of its resources can be done in two ways, either by accurate sedimentological and palaeoenvironmental analysis when prospective area of possible lithological and lithological-tectonic traps within the known deposit limits are defined, or by tectonic and seismic analysis when an area of probable structural-lithological traps to the south and southeast from the present deposit is noted. With known problems of seismic examinations (particularly under-Zechstein ones) of small-scale structural features within the Rotliegendes (W. Oleszczuk, R. Pacek, 1988), delimitation of zones in which qualitative changes in a seismic record should be carefully examined.

Graphical specification (Figs. 4A-C) in the deposit Paproć — Cicha Góra of effective porosity in the whole deposit series (from the top of the Rotliegendes to a deposit water level) of effective porosity for sandstone interbeds in a deposit series and of permeability of the latter, accentuate distinct connection of areas with most deposit parameters favourable to a crossed pattern of main directions of tectonic fractures. But on the other hand, shapes of fields with the best deposit parameters can also reflect approximate probable extent of alluvial fans lithofacies, favourable to gas accumulation. Additional numerical analysis of a porosity ratio from cored sections to thickness of the whole deposit series and selectively applied to thicknesses of gas-saturated sandstone beds (charged with error resulting from possibility of occurrence of reservoir rocks of insignificant thickness and good porosity, and opposite — occurrence of reservoir rocks with considerable total thickness and poor porosity), supports existence of the area with maximum favourable (and in the same time compromising) deposit conditions. According to the authors such area can spread also

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1 — borehole with gas output; 2 — borehole with flow of deposit water, intensively gasified; 3 — borehole with weak gas flow; 4 — no flow; 5 — border at which reservoir conditions in top of the Rotliegendes sedimentary series disappear according to the previous research; 6 — interpreted border of disappearing reservoir properties; 7 — contour of deposit water; 8 — extent of sedimentary rocks of the Rotliegendes; 9 — zone with particularly good reservoir properties; 10 — prospective zone with favourable reservoir conditions

A. Mapa porowatości efektywnej (%) w warstwach piaskowców nasyconych gazem (pomiary z odcinków rdzeniowanych z wierceń poszukiwawczych i eksploatacyjnych)

B. Mapa porowatości efektywnej (%) całej serii złożowej (od stropu czerwonego spągowca do poziomu wody złożowej)

C. Mapa przepuszczalności efektywnej (mD) w warstwach piaskowca nasyconych gazem

D. Mapa aktualnego i przypuszczalnego zasięgu występowania warunków zbiornikowych dla akumulacji gazu

1 — otwór wiertniczy z produkcją gazu; 2 — otwór wiertniczy z przypływem wody złożowej silnie zgazowanej; 3 — otwór wiertniczy ze słabym przypływem gazu; 4 — brak przypływu; 5 — granica zaniku własności zbiornikowych stropowej części serii osadowej czerwonego spągowca według dotychczasowych ustaleń; 6 — interpretowana granica zaniku własności zbiornikowych; 7 — kontur wody złożowej; 8 — granica zasięgu skał osadowych czerwonego spągowca; 9 — strefa o szczególnie dobrych własnościach zbiornikowych; 10 — perspektywiczna strefa o korzystnych własnościach zbiornikowych

southwards, outside the limits at which reservoir properties of the deposit Paproć — Cicha Góra disappear (Fig. 4D). Besides, the interpreted zone of the Wolsztyn tectonic fractures and a model of its influence speak for possible occurrence of the Rotliegendes sedimentary rocks further to the south than expected previously, along the eastern tectonic edge of the Zbąszynek — Nowy Tomyśl Elevation. These sediments can fill minute tectonic depressions and represent similar lithofacial development and reservoir conditions if compared with rocks within the deposit Paproć — Cicha Góra.

INTERDEPENDENCE OF DEPOSIT PARAMETERS AND SEDIMENT LITHOFACIES

Common occurrence of good reservoir rocks devoid of hydrocarbons in potentially positive zones creates a significant problem. The gas field Ujazd in the vicinity and considerably similar to the gas field Paproć — Cicha Góra, is a good example. J. Bojarska et al. (1983) presented interesting results of analysis of lithological and reservoir variation of the Rotliegendes sediments for the area Cicha Góra — Ujazd. On the basis of data from several dozen boreholes (generally of top fragments of sediments) the authors mapped regularities that result in absolute increase in contents of matrix and cement, and in similar way — of clayey and clayey-ferruginous (illite, kaolinite, chlorite and iron compounds) matrix — in such way reservoir conditions got worse towards alimentary areas (i.e. WWW). The deposit Ujazd was proved also (J. Bojarska et al., 1983) to possess no structural end in the southwest but a closing connected with disappearance of favourable reservoir conditions (in top of the Rotliegendes sediments). The authors considered that „...such disappearance is connected with elimination of some sandy inserts that occur within a sandstone-conglomerate complex as well as with changes in type and content of cement". Taking this opinion for granted, a hypothesis however arises that such abrupt linear changes result either from indirect (changes in layer) or direct (dislocations) tectonic conditions. Presence of a dislocation, visible in substrate on refraction sections for the Ujazd area, is underlain by T. Wolnowski (1983). Similarity with mapped (K. Dyjaczyński, T. Żołnierczuk, 1991) linear zone where reservoir conditions of the deposit Paproć — Cicha Góra disappear, is distinct. This zone corresponds in its direction and locality to a western prolongation of the Dolsk fault zone (K. Wierzchowska-Kicułowa, 1984). Block dislocation of the sub-Permian substrate influenced further deposition of the Rotliegendes sediments and their postsedimentary tectonic deformations. This is particularly visible in the area where a sedimentary cover gets thinner i.e. at the northeastern slope of the central part of WWW. Additional evidence for a probable tectonic-structural origin of the gas trap Ujazd is created by the fact that due to block tectonics in a close vicinity of the edge zone, there are rocks with favourable reservoir conditions (e.g. Paproć 1, 2, 4 and 10). Small distance as in the case of the deposit Ujazd from a probable elevation zone (WWW) does not constitute a fixed border of a total absence of lithological deposit traps. Incidentally the very authors (J. Bojarska et al., 1983) suggest in their conclusions a possible occurrence (in spite of deposit conditions getting worse) of natural gas deposit of the Ujazd type to the south of Cicha Góra and Czarna Wieś i.e. in elimination zone for sandstones with good deposit parameters and increased participation of conglomerates. This opinion finds also their support in the area mapped by the authors i.e. the area with probable favourable reservoir conditions to the south of the present extent of the deposit Paproć — Cicha Góra (Fig. 4D).

Preliminary examination of cements in the Rotliegendes sediments of the deposit area (G. Pieńkowski, H. Kiersnowski, 1990) indicated that at first early diagenetic cements (from a point of view of carbonate clasts redeposition), cements in sediments of alluvial fans, braided rivers and playas should be distinguished. These cements are to be connected with calcrete horizons (pedogenic horizons). Carbonate cements have different origin, noted in tops of the Rotliegendes sequence, close to the border with sediments deposited during transgression of the Zechstein sea (they are to be con-

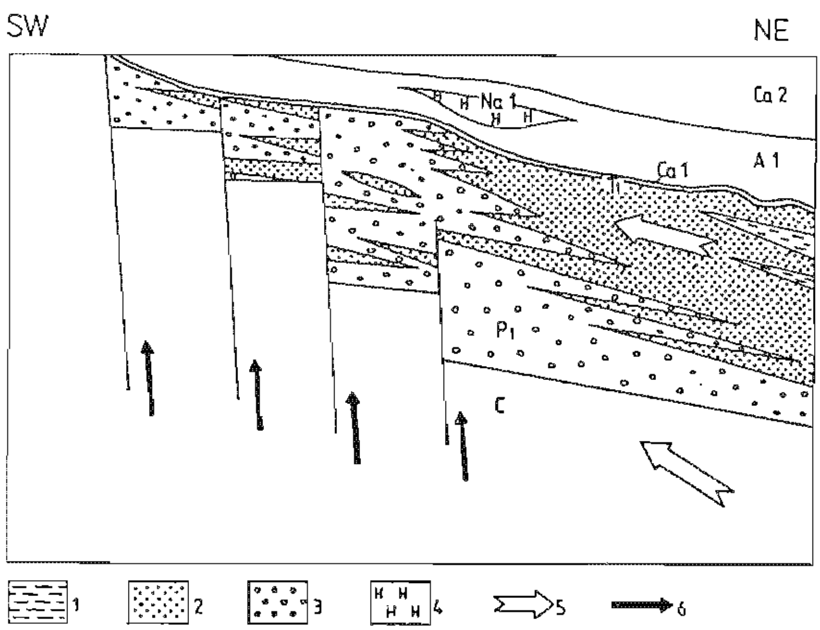

Fig. 5. Schematic section of the gas deposit Paproć — Cicha Góra, expressing probable directions of gas migration and possibilities of its accumulation (structural, lithological and lithological-tectonic traps)

Predominant lithological types: 1 — siltstones; 2 — sandstones; 3 — conglomerates; 4 — salt pillows; 5 — main direction of lateral migration of gas; 6 — direction of vertical migration of gas; C — Carboniferous; P_1 — Rotliegendes; T_1 — Kupferschiefer; Ca1 — Zechstein Limestone; A1 — anhydrite; Na1 — oldest halite; Ca2 — Main Dolomite

Schematyczny przekrój przez obszar złoża gazu Paproć — Cicha Góra, obrazujący prawdopodobne kierunki migracji gazu i możliwości jego akumulacji (pułapki strukturalne, litologiczne i litologiczno-tektoniczne)

Dominujące typy litologiczne: 1 — mułowce; 2 — piaskowce; 3 — zlepieńce; 4 — poduszki solne; 5 — główny kierunek lateralnej migracji gazu; 6 — kierunek wertykalnej migracji gazu; C — karbon; P_1 — czerwony spągowiec; T_1 — łupek miedzionośny; Ca1 — wapień cechsztyński; A1 — anhydryt; Na1 — najstarsza sól kamienna; Ca2 — dolomit główny nected with mixing of sea and meteoric waters in a littoral zone). This phenomenon can influence unfavourably the reservoir conditions in top fragments of the Rotliegendes sedimentary rocks, in areas with primarily favourable conditions.

These observations are closely conformable to the research results derived from Paproć 1, 2, 4, 6, 7 boreholes (Z. Gregosiewicz et al., 1985) and similar to the results from gas deposit Ujazd (J. Bojarska et al., 1983). It is noticed in topmost sandstone-conglomerate sequences, sulphate and illite-chlorite cement content increase.

SEDIMENTARY CONDITIONS AND OPTIMIZATION OF FURTHER SEARCH FOR NATURAL GAS DEPOSITS

Gas deposits, recognized up to the present in the area Paproć — Cicha Góra, focus in top of the Rotliegendes and secondarily, in top of the Carboniferous. They are mainly small structural traps, connected with the previously described mosaic fault pattern, isolated in the top by the Zechstein sediments. A gas concentrates in top sandstone layers, with predominantly good reservoir conditions but of varying origin (Fig. 5). These sandstones come from a littoral zone of the Zechstein sea but there are also fluvial sandstones and secondarily — aeolian and channel alluvial cones sandstones. With such varying origin, collecting properties of sandstones depend mainly on grain gradation and sorting, as well as diagenetic processes (primary and secondary cements).

There are however regularities with possible practical influence. Sandstones (of fluvial as well as littoral derivation) are concentrated mostly in uppermost parts of the Rotliegendes what is connected with phenomena of the Zechstein sea transgression (raising of the erosion base), as well as with progressing palaeorelief smoothing. Sandstones start also to predominate in the whole section towards the northeast. Good reservoir conditions connected with facial origin occur therefore in the upper part of the Rotliegendes and/or regionally towards the northeast. Such search works would be the most prospective from facial reasons but in the same direction an amplitude of potential reservoir sediments gets also decreasing. In such situation the most prospective should be the „compromising" zones where already significant sandy interbeddings of fluvial and secondarily also of aeolian origin are noted, and there is still a short distance to the tectonicly active edge zone of the Wolsztyn Ridge. The area to the south of the boreholes Paproć 7, 13, 48 and Cicha Góra 4 are promising if thickness of reservoir sediments is taken into account. Further recognition boreholes in this zone along tectonic edges of the Wolsztyn Ridge could give good results.

Search of reservoir rocks (lithological traps) in lower members of the Rotliegendes close to the Wolsztyn Ridge is more risky and uncertain. Conglomerates of proximal facies of alluvial fans that predominate here, do not possess any reservoir properties. Sandy channel deposits with good collecting properties are noted as of secondary significance (except the area of Cicha Góra where their greater agglomeration resulted in deposit effects). Some prospects on presence of small lithological traps and gas influx also in lower members of the Rotliegendes could be connected with playa margins (boreholes Paproć 1 and 2) where there are fluvial sediments of local fan-deltas. Taking the deposit Paproć — Cicha Góra as example, search for lithological traps of gas deposits should be preceded by detailed tectonic analysis of the Rotliegendes sediments and also, if possible, of the sub-Permian substrate. Analysis of tectonic situation of the deposit Paproć — Cicha Góra allows to refer it to other deposits or to define the prospective areas.

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GENEZA PUŁAPEK ZŁOŻOWYCH GAZU ZIEMNEGO W CZERWONYM SPĄGOWCU REJONU PAPROCI — CICHEJ GÓRY (WIELKOPOLSKA)

Streszczenie

Paleogeograficzny obszar dolnopermskiej Wolsztyńskiej Wyżyny Wyspowej stanowi niecałkowicie dotychczas rozpoznany region o dużym potencjale gazonośnym. Odkryte w ostatnich latach, największe do tej pory, wielowarstwowe złoże (karbon, czerwony spągowiec, cechsztyn) gazu ziemnego Paproć — Cicha Góra uzasadnia potrzebę dalszych poszukiwań w tym rejonie.

Przedstawiono wyniki analizy sedymentologicznej i tektonicznej opartej na materiale rdzeniowym z czerwonego spągowca z wierceń rozpoznawczych i eksploatacyjnych w złożu gazu ziemnego Paproć — Cicha Góra. Jako główne wyróżniono środowiska sedymentacji stożków aluwialnych oraz strumieni roztokowych tworzących się w tektonicznej strefie krawędziowej wyniesienia Zbąszynka — Nowego Tomyśla. Jako

podrzędne opisano środowiska sedymentacji okresowych jezior (playi) i wydmowe oraz w stropie sekwencji osadowej niewielkiej miąższości klastyczne osady przybrzeżne transgredującego morza cechsztyńskiego. Osady te powstawały w aktywnej strefie tektonicznej, zdeterminowanej przez dwa główne krzyżujące się kierunki strefy tektonicznej Dolska i strefy tektonicznej Wolsztyna. Strefy te wielokrotnie reaktywowane wpływały na typ i tempo sedymentacji osadów czerwonego spągowca, ułatwiały pionową migrację gazu oraz spowodowały powstanie strukturalnych i tektoniczno-litologicznych pułapek gazu. Przedstawiono hipotezę związku obszarów o najkorzystniejszych parametrach złożowych (porowatość, przepuszczalność, litofacje) z przebiegiem krzyżujących się głównych kierunków tektonicznych. Porównanie warunków złożowych i sytuacji geologicznej złóż gazu Paproć — Cicha Góra i Ujazd uzasadnia przesłanki za dodatkowymi poszukiwaniami niewielkich pułapek litologiczno-tektonicznych wzdłuż strefy uskokowej Wolsztyna.