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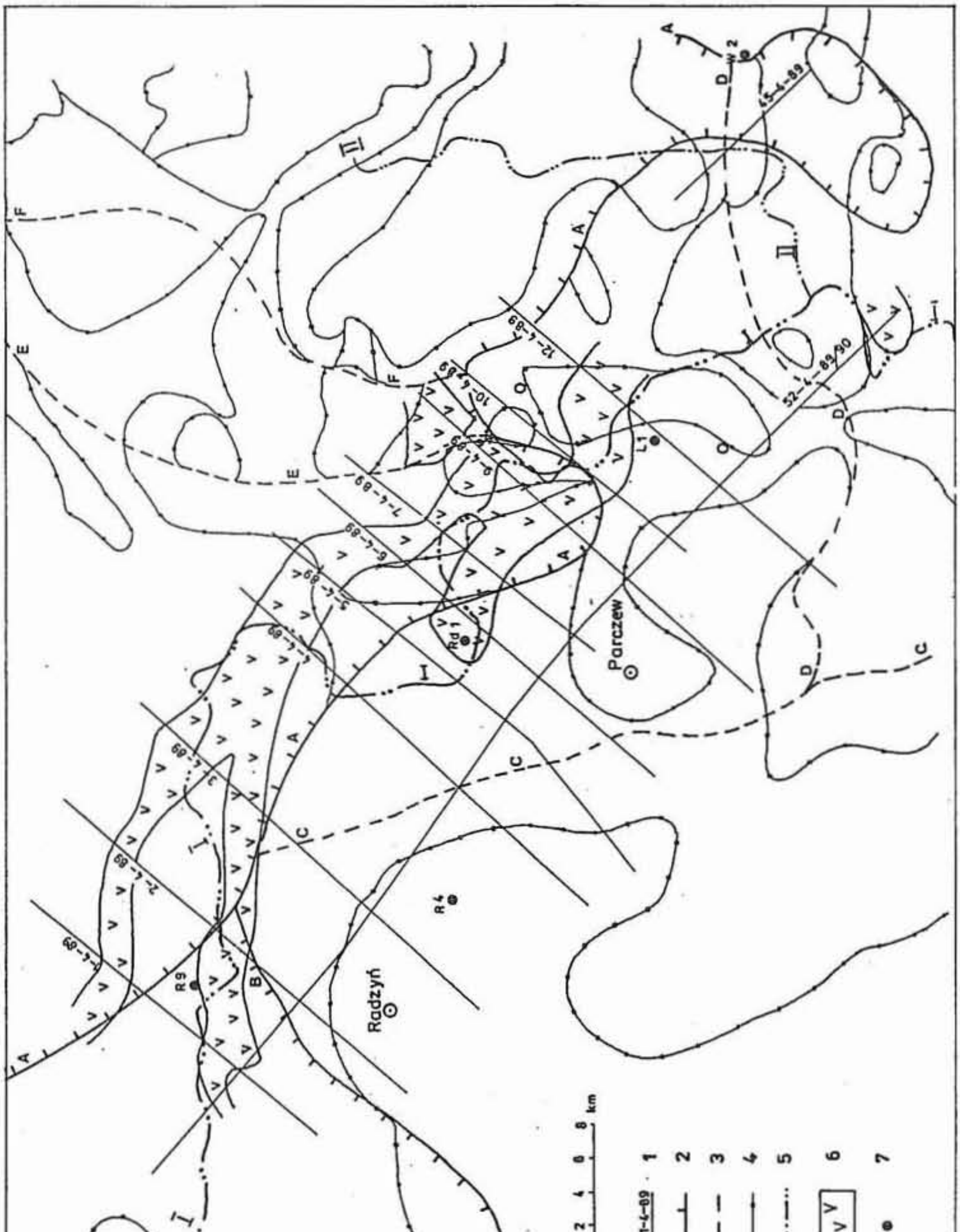
Evidences of influence of tectonics on hydrogeological conditions in the light of results of reflection method

Variations of wave image on seismic profiles are frequently observed at intersections of seismic profiles with boundaries of hydrogeological units or even of surface watersheds. Character of these variations indicates that the occurrence of tectonic disturbance zones or zones of rock looseness is the reason why the said variations appear. Determination of the role of tectonic disturbance zone in formation of hydrogeological conditions depends on the quality and quantity of data acquired. Results of reflection method constitute important sources of information on tectonics; however, their applicability to hydrogeological studies has not yet been assessed in full. Therefore, this paper will be focussed on justification of purposes of application of reflection method to some hydrogeological problems; this attempt will be based on exemplary reflection survey results contained in the report by J. Brauer, W. Kulig (1991).

BOUNDARIES OF HYDROGEOLOGICAL UNITS AND THEIR RELATIONSHIP WITH TECTONICS

Hydrogeological units and their boundaries as plotted on the hydrogeological map of Poland on the scale 1:200 000 (C. Kolago, 1981) are shown in Figure 1. To define eventual agreement of the course of their boundaries with the extent of the tectonic disturbance zones it is necessary to assume that these boundaries have been plotted on the basis of adequate data which allows to locate them accurately; any shifting of boundaries for even several hundred metres is groundless. Criteria that have been applied to determine boundaries of hydrogeological units on the said map are not subjected to any analysis in this paper; however, a conclusion can be drawn that tectonic factor has not been considered. This conclusion is supported by the fact that any information on fault zones and their overburden is missing on both the maps and the hydrogeological cross-sections drawn on the respective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map sheets. Although some information was given on the map on hydraulic contacts between Cretaceous and Cenozoic aquifer, no details of these contacts have been explained. It is likely that numerous zones of tectonic disturbances occurring here (J. Brauer, W. Kulig, 1991; T. Krynicki, 1995*a*) act in favour of the appearance of such contacts. On the other hand, the tectonic disturbance zones, if of sealing character, may separate areas of different hydrogeological conditions. Therefore, it is essential to determine eventual relationship between tectonics and boundaries of hydrogeological units or even areas of different groundwater potentials (which are expressed by potential yields of water wells).

If faults can affect hydrogeological conditions or to some extent exert an influence on them, then it should be best observable on the boundaries separating the hydrogeological units.

The boundaries of hydrogeological units as given on the hydrogeological map, are designated with **A** and **B** characters (Fig. 1). The boundaries, and particularly those designated **A**, cuts seismic profiles — which makes it possible to analyse the wave image at places of intersections. A serious difficulties appear from the fact that information is missing on the criteria and accuracy of boundaries of hydrogeological units plotted on the map; it should be considered here that sometimes shifting of boundaries for several hundred metres may locate them within the zone of tectonic disturbances or beyond such zone. A case of seismic profile 1-4-89 is offered here as the example in which the boundary **A** should (according to the hydrogeological map) appear at a station pole 90. However, it is difficult to delimit a tectonic zone here; instead, a small elevation of seismic boundary K, with an amplitude of 10 ms (Fig. 2) appears on the profile. Relatively nearby, e.i. at the station poles 79 and 96, zones with no correlation (marked with N) are observed; they can be considered the tectonic disturbance zones. Thus, translocation of the boundary **A** by 600–1100 m could locate it within one of the delimited tectonic zones (Fig. 2).

Profile 2-4-89 (Fig. 3) is interesting because the boundary **A** and the surface watershed **I** are running near its station pole 148 in addition to the boundary **B** of other hydrogeological units also running very close. Therefore, it can be expected that a distinct change in record appears on seismic profile; in fact, it is proven in full in Figure 3. Weak results were recorded between the station poles 145 and 160 on presented segment of profile 2-4-89; it should be noted that a fault in the Cambrian formations was delimited at the station pole 146 (J. Brauer, W. Kulig, 1991). There is a sound basis allowing to extend this fault up to the Cretaceous. Despite a broad zone where reflected waves have been weakened (which can be identified with the zone of tectonic disturbances), the fault delimited here has not a large throw of its southwestern side. The existence in this area of faults with small amplitudes in the

Fig. 1. Situation sketch of seismic profiles against the background of hydrogeological units

1 — seismic profiles; 2 — boundaries of regional hydrogeological units (**A**, **B**); 3 — boundaries of groundwater regions (**C**, **D**, **E**, **F**); 4 — boundaries of areas with different potential yields of representative water wells (**O**); 5 — surface watersheds (**I**, **II**); 6 — area with velocity of wave propagation in the range of 1700–1720 m/s beneath the aeration zone; 7 — boreholes

Szkic sytuacyjny profili sejsmicznych na tle granic jednostek hydrogeologicznych

1 — profile sejsmiczne; 2 — granice regionalnych jednostek hydrogeologicznych (**A**, **B**); 3 — granice rejonów hydrogeologicznych (**C**, **D**, **E**, **F**); 4 — granice obszarów o różnej potencjalnej wydajności typowego otworu studziennego (**O**); 5 — wododziały powierzchniowe (**I**, **II**); 6 — obszar o prędkości rozchodzenia się fal 1700–1720 m/s poniżej strefy aeracji; 7 — otwory wiertnicze

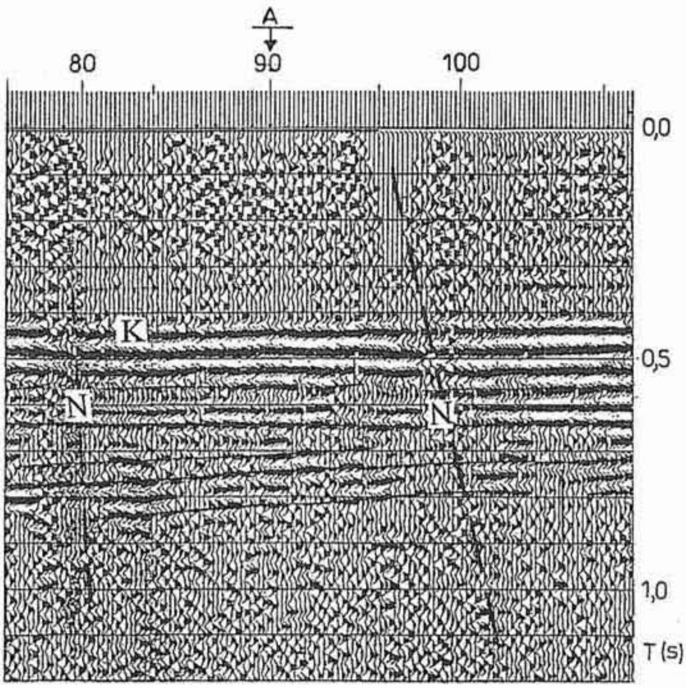

Fig. 2. Fragment of profile 1-4-89, at intersection with the boundary **A** of hydrogeological units

Solid lines — faults; dashed lines — zones of discontinuities in wave correlation due to tectonic disturbances; K — reflection boundary connected with the lowest section of the Cretaceous sequence; N — zones of discontinuities in wave correlation

Fragment profilu 1-4-89 z miejscem przecięcia z granicą regionalnych jednostek hydrogeologicznych **A**

Linie ciągłe — uskoki; linie przerywane — strefy nieciągłości korelacji fal spowodowane zaburzeniami tektonicznymi; K — granica refleksyjna związana z utworami przyspągowymi kredy; N — strefy nieciągłości korelacji fal

Cretaceous formations, even those of regional importance, has been suggested before (T. Krynicki, 1995*a*).

The boundary **A** situated within clearly visible zones of tectonic disturbances is also seen on other profiles such as: 7-48-89, 12-4-89, 45-4-89, for example. Figure 4 presents a fragment of profile 7-4-89, on which the boundary **A** should be delimited at the station pole 63. A fault delimited here cannot be questionable.

On profile 45-4-89 (Fig. 5), the boundary **A** under discussion is running through the station pole 53. A distinct variation in the wave record is observed in this part of profile; it can be connected with the existence of tectonic disturbance zone.

However, variations of seismic record in places where the boundary **A** occurs can also be less important. For example, based on data on the hydrogeological map, the boundary **A** on profile 4-4-89 should be delimited in the vicinity of the station pole 177 (Fig. 6). A visible change in dip orientation of Palaeozoic and Mesozoic strata is observed here; to some extent, the place can be considered to be a zone of rock looseness. More distinct changes of wave image appear on the profile segments contained between station poles

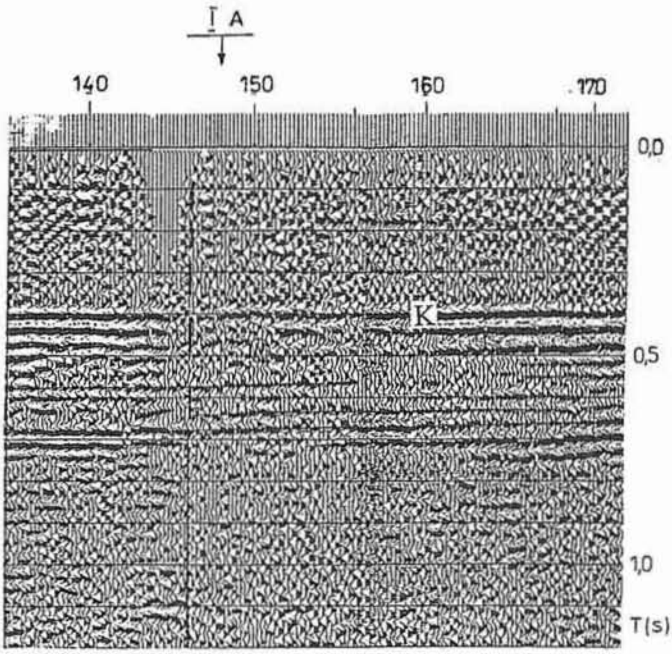

Fig. 3. Variation in seismic record on profile 2-4-89 in the place where the boundary **A** of regional hydrogeological units and the boundary **I** of surface watershed are running

For explanations see Fig. 2

Zmiana zapisu sejsmicznego na profilu 2-4-89 w miejscu przebiegu granicy regionalnych jednostek hydrogeologicznych **A** i wododziału powierzchniowego **I**

Objaśnienia jak na fig. 2

196–230 and 130–165. Results acquired on the latter will be discusses in the following part of this paper dealing with watershed boundaries.

Thus, with respect to what was presented so far, the boundary **A** of regional hydrogeological units is running through those profile segment for which a variable wave images were recorded; in most cases the said variations reflect zones of tectonic disturbances or zones of looseness of rocks. Dissimilarity of wave images on particular profiles can be explained by the fact that the boundary **A** is running through zones of different faults. Too scarce grid of seismic profiles along with complicated tectonics makes it difficult to explain reasons for varied wave image at the occurrences of the boundary **A**, the more so as the accuracy of delimitation of this boundary on the hydrogeological map remains unknown.

Contrary to the boundary **A**, the boundary **B** crosses only two seismic profiles: 2-4-89 and 52-4-89/90 (Fig. 1). Along its considerable length, this boundary's direction is SW–NE. Faults delimited in this part of the area (J. Brauer, W. Kulig, 1991) are of similar orientation as the boundary **B**. In addition, distribution of particular wave velocity zones in deposits beneath unsaturated formations (T. Krynicki, 1995*b*) also corresponds with orientation of the boundary **B**.

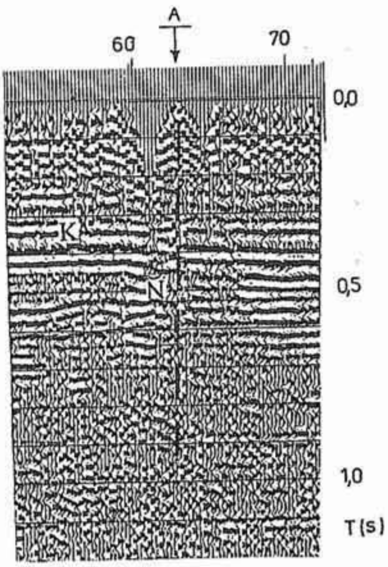

Fig. 4

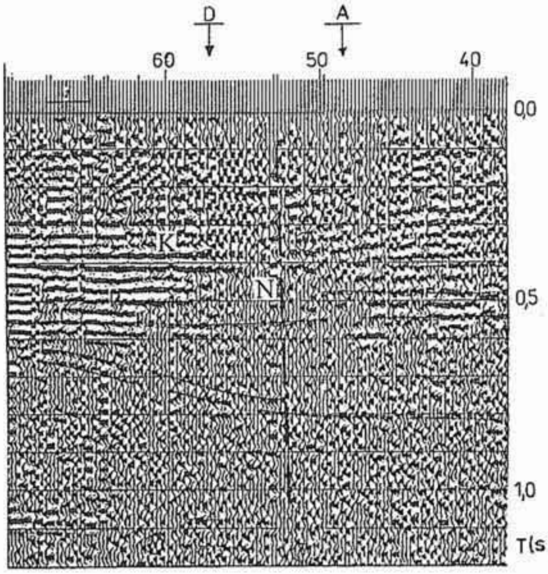

Fig. 5

Fig. 4. Variation in seismic record on profile 7-4-89 in the place where the boundary **A** of regional hydrogeological units is running

For explanations see Fig. 2

Zmiana zapisu sejsmicznego na profilu 7-4-89 w miejscu przebiegu granicy regionalnych jednostek hydrogeologicznych **A**

Objaśnienia jak na fig. 2

Fig. 5. The boundary **A** of regional hydrogeological units and the boundary **D** of groundwater regions in the zone of distinct variation in seismic record on profile 45-4-89

For explanations see Fig. 2

Granica regionalnych jednostek hydrogeologicznych **A** i granica rejonów hydrogeologicznych **D** w strefie wyraźnych zmian zapisu sejsmicznego na profilu 45-4-89

Objaśnienia jak na fig. 2

A configuration of water table contours in the vicinity of profile 2-8-89 also results from tectonic reasons (T. Krynicki, 1995*b*).

In most cases, boundaries of hydrogeological regions delimited on the map (Fig. 1) are in agreement with changes in the wave images. The exemplary case deals with a boundary **D** which crosses three profiles: 12-4-89, 52-4-89/90, and 45-4-89. On profile 12-4-89, the boundary **D** runs through the station pole 22 (Fig. 7). No fault has been delimited here in the report of seismic survey (J. Brauer, W. Kulig, 1991); nevertheless, a gap observed in wave correlation can be interpreted as the tectonic disturbances. Then, the boundary **D** on profile 52-4-89/90 is situated within the zone of Hanna Fault, the importance of which upon formation of hydrogeological conditions was emphasized earlier (T. Krynicki, 1995*b*). On profile 45-4-89, both boundaries **A** and **B** are localized close to each other within the same tectonically disturbed zone (Fig. 5).

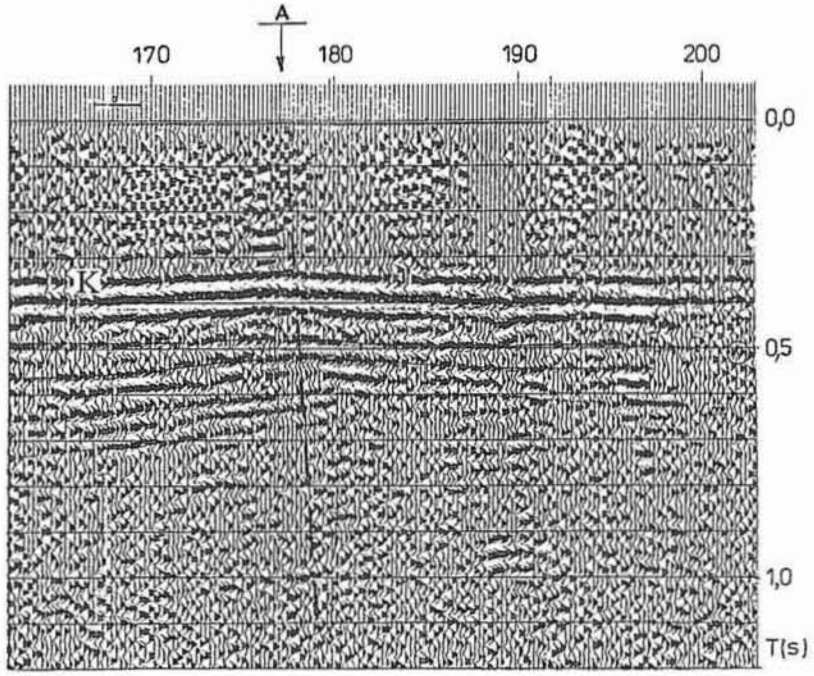

Fig. 6. The boundary **A** of regional hydrogeological units, separating profile 4-4-89 into segments with different dips of strata

For explanations see Fig. 2

Granica regionalnych jednostek hydrogeologicznych **A** rozdzielająca profil 4-4-89 na odcinki o odmiennych upadach warstw

Objaśnienia jak na fig. 2

The fact that the boundary **D** runs through zones of different faults is the explanation of different wave images recorded on particular profiles in places where this boundary appears. A fault of NW–SE orientation is that one which appears at the intersection of the boundary **D** with profile 12-4-89. The Hanna Fault is the next one that occurs at the intersection of this boundary with profile 52-4-89/90 and further northwestwardly from the boundary of watershed **I** up to profile 45-4-89. The third fault is clearly visible on profile 45-4-89, in the zone where the boundary **A** of the hydrogeological units is also situated (Fig. 5).

The boundary **D** in the vicinity of profile 45-4-89 is also a boundary of areas differentiated on the hydrogeological map, each having different potential yields of representative water wells. This leads to the conclusion that some faults can constitute a boundary between areas of different hydrogeological conditions or that boundaries of such areas are consistent with zones of tectonic disturbances.

Other intersections of boundaries of areas with different groundwater potential with profile 12-4-89 occur in the vicinities of the station poles 150 and 205. The latter is presented in Figure 8. Delimited zones of tectonic disturbances should be connected with boundaries of areas of different water well yields despite the fact that omission of some shot points on

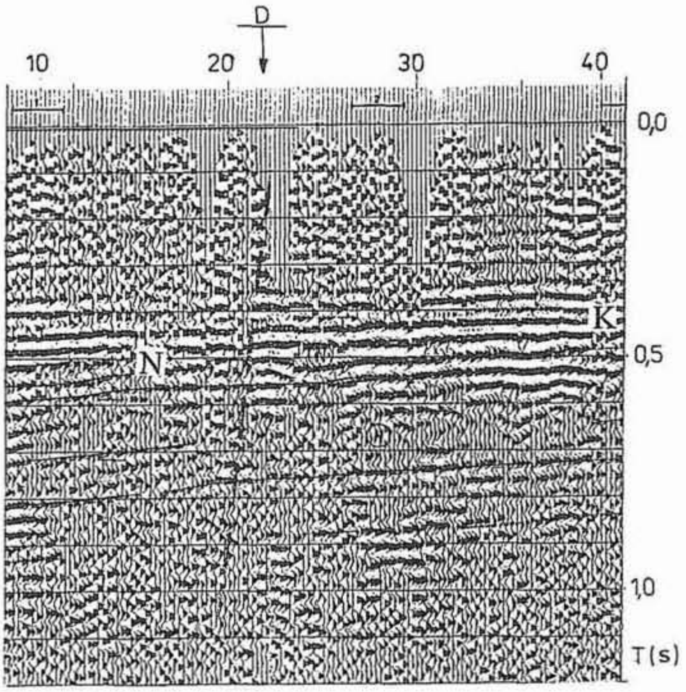

Fig. 7. Fragment of profile 12-4-89 showing seismic record at the intersection of this profile with the boundary **D** of groundwater regions

For explanations see Fig. 2

Fragment profilu 12-4-89 obrazujący zapis sejsmiczny na przecięciu z granicą rejonów hydrogeologicznych **D**

Objaśnienia jak na fig. 2

the segment of profile between the station poles 202–205 could contribute to the decrease of record dynamics. Similar correlation of changes in wave image with places where boundaries are being delimited for areas with different potential water well yields is also observed in cases of other profiles, e.g. 5-4-89 and 6-4-89.

From what is stated above a conclusion can be drawn that the boundaries of hydrogeological regions and sub-regions or even areas of different groundwater potential as plotted on the hydrogeological map occur within zones of variable wave images on seismic profiles; it is further concluded that these variations are most often caused by the presence of faults.

SURFACE WATERSHEDS AND WAVE IMAGE

In the hydrographic atlas of Poland on the scale 1:200 000 (H. Czarnecka, 1980), two boundaries of surface watersheds (**I** and **II**) were distinguished. The watershed **I** is worthy of considering due to its course and numerous intersections with seismic profiles.

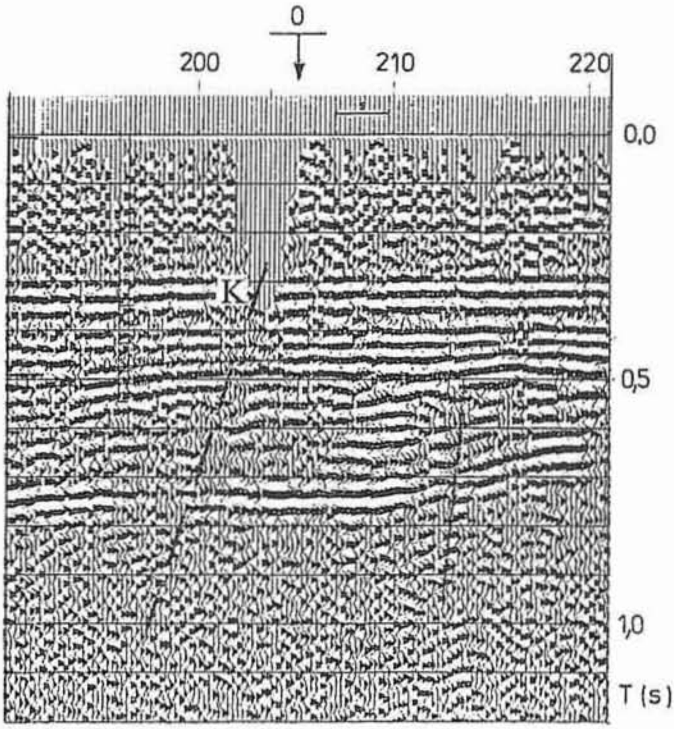

Fig. 8. Variation in seismic record on profile 12-4-89 at the boundary with different potential yields (**O**)
For explanations see Fig. 2

Zmiana zapisu sejsmicznego na profilu 12-4-89 na granicy obszarów o różnej wodonośności (**O**)
Objaśnienia jak na fig. 2

Based on general orientation and the couse of the watershed **I**, three regions can be distinguished:

— western — extending up to profile 3-4-89, with dominant W–E orientation;

— central, between profiles 4-4-89 and 7-4-89; a variable direction of its course is its characteristic feature;

— eastern — extending eastwards of profile 7-4-89; the NE–SE orientation is dominant here except a small fragment near profile 52-4-89/90 where the course of the watershed **I** is close to that of the regional Hanna Fault.

A number of faults distinguished on the basis of directions of boundaries of wave velocities in formations beneath the aeration zone is similar to that when a depth to water table was used to delimit the faults (T. Krynicki, 1995*b*); however, it should be noted here that full accordance of the regions distinguished by both methods have not been reached. It is characteristic that the course of the zone of wave velocity of 1700–1720 m/s is, in general, close to the course of the watershed **I** (Fig. 1). Omitting a question of criteria applied to differentiation of the surface watersheds as it was omitted in the case of boundaries

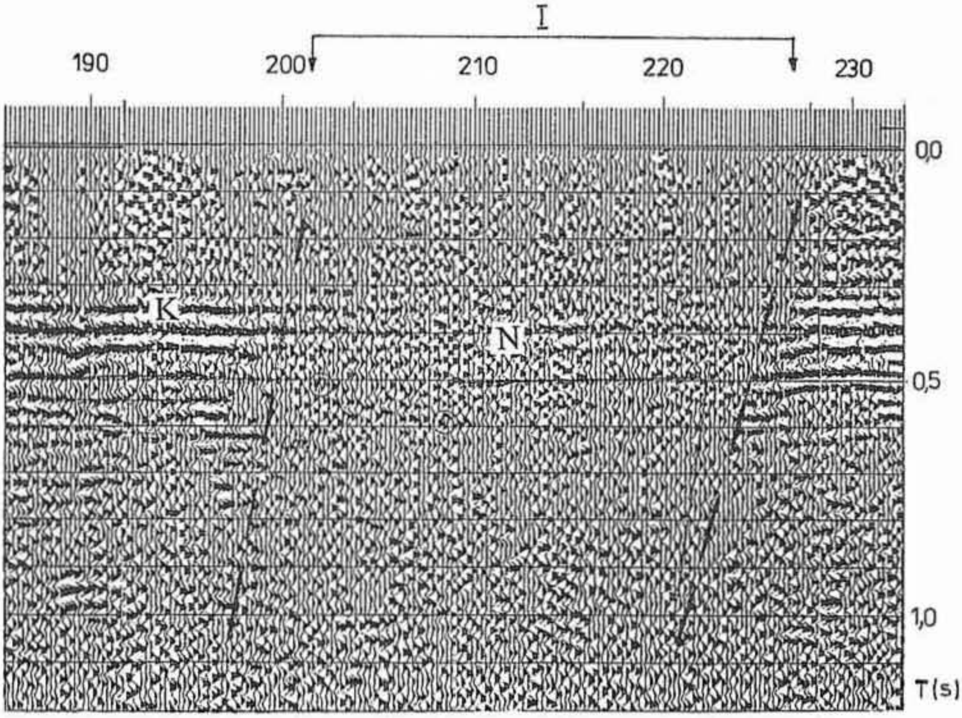

Fig. 9. Fragment of profile 4-4-89 along which the surface watershed **I** is running
For explanations see Fig. 2
Fragment profilu 4-4-89, wzdłuż którego przebiega wododział powierzchniowy **I**
Objaśnienia jak na fig. 2

between the hydrogeological units, an important task still remains open aimed at defining eventual correlation of variation in wave image in places where the watershed **I** intersects seismic profiles.

In the northwestern part of profile 52-4-89/90, the watershed **I** is situated at the station pole 50. A fault being a vertical plane disturbing the Carboniferous formations was delimited in this place (J. Brauer, W. Kulig, 1991); on the other hand, more shallow boundaries, including those in the Zechstein, are continuous, in principle. However, other slope of the fault mentioned here so as if its plane dips towards NW, creates a contribution justifying the extension of zone of looseness in the rock medium into the Cretaceous beds. When considering profile 1-4-89, the watershed runs through the station pole 50. The wave image acquired at this point justifies the plot of the tectonically disturbed zone within the entire depth intervals shown in Figure 7 (T. Krynicki, 1995*a*).

Both the watershed **I** and the boundary **A** of regional hydrogeological units cross profile 2-4-89 almost in the same place (Fig. 1), and results acquired are presented in Figure 3. Variation in seismic record is expressed in a clearly visible way; it may results from tectonic disturbances.

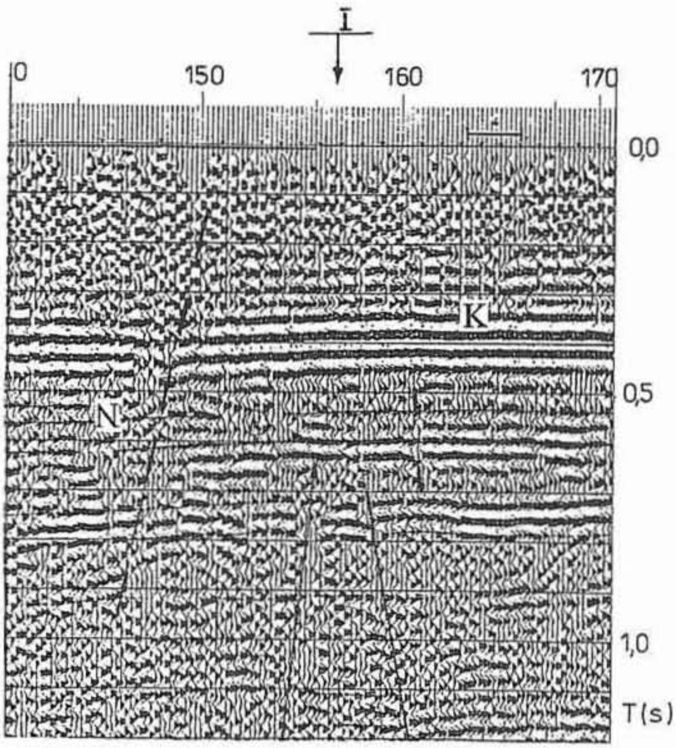

Fig. 10. The surface watershed I appearing in that place on profile 5-4-89 where faults have been delimited in the Palaeozoic formations and where the Mesozoic formations become slightly less shallow
For explanations see Fig. 2

Wododział powierzchniowy I, występujący na profilu 5-4-89 w miejscu wyznaczenia uskoków w utworach paleozoicznych i zaznaczającego się nieznacznego spłycenia utworów mezozoicznych
Objaśnienia jak na fig. 2

On profile 3-4-89, the watershed **I** did not reflect itself in a more distinct way in the record of reflection boundaries in a complex of formations belonging to the Carboniferous, Jurassic, and the lower section of Cretaceous. On the other hand, record of both deeper and shallower formations than those mentioned here contains some elements of variations in the wave image, namely a decrease of dynamics of boundaries and correlative discontinuity.

Interesting is a 3 km long segment of profile 4-4-89 contained between the station poles 195 and 228, along which the watershed **I** is running. A distinct variation in record is observed here (Fig. 9). A fault disturbing the Palaeozoic formations is strongly evidenced in the vicinity of the station pole 220 (J. Brauer, W. Kulig, 1991), but it is likely that the fault continues in the Mesozoic. Of striking character is a width of zone of decreased velocity between the station poles 200 and 225. In principle, it is accepted and approved in practice that a width of fault zone is dependent on the throw amplitude, but the amplitude of the fault under discussion is not large. Therefore, it should be accepted that the width of this zone is connected here with the direction of the fault course which is almost parallel to

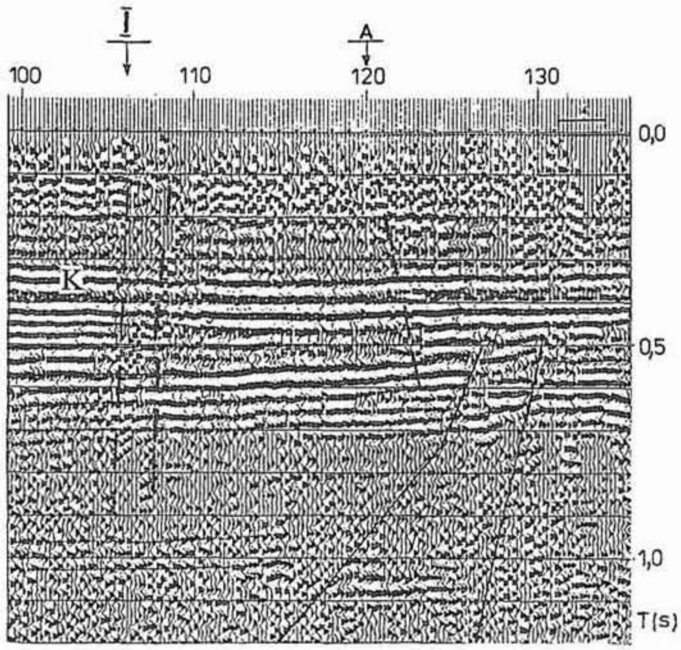

Fig. 11. Variations in seismic record on profile 6-4-89, indicating the occurrence of tectonically disturbed zones in the vicinity of intersection with the boundary **A** and with the watershed **I**

For explanations see Fig 2

Zmiany zapisu sejsmicznego na profilu 6-4-89, wskazujace na występowanie stref zaburzonych tektonicznie w sąsiedztwie przecięcia z granicą **A** i wododziałem **I**

Objaśnienia jak na fig. 2

this profile; with respect to what is discussed here the watershed **I** can be considered running within the fault zone. The decrease of wave dynamics on the discussed segment of profile 4-4-89 seems to be connected with the occurrence of the zone of wave velocity in the range of 1700–1720 m/s. Similar width of the zone also appears on profile 5-4-89; however, a distinct change in the wave image is recorded here. This fact indicates that a tectonic factor affects the result acquired. Circumstances for delimiting the tectonically disturbed zone appear in the place where the watershed **I** intersects profile 4-4-89 on the south-west from the boundary **A** of hydrogeological units (Fig. 1); such a situation exists despite the fact that the wave image is less changed here than on the segment of profile 4-4-90 discussed above.

According to the map, the watershed **I** on profile 5-4-89 should be situated in the vicinity of the station pole 157 (Fig. 10). A fault zone was delimited here, which disturbes the lower Palaeozoic formations (J. Brauer, W. Kulig, *1991*); a width of the zone is defined by two faults. Extension of both faults upward situates them in the vicinity of the station pole 157. However, just simple extension is insufficiently justified, since waves occurring in the time interval of 0.3–0.4 s keep correlative continuity. A small change appears in the dip of strata in the vicinity of the station pole 160. The wave image acquired in the area of station poles 146–148 is characterized by the decrease of amplitudes and a gap in wave correlation; both usually appear in fault zones although the omission of several shot points would also affect the dynamics of the record. Missing correlation of changes in the wave image with profile 5-4-89 (Fig. 10) can be explained by not very accurate delimitation of the watershed on the map. However, should the watershed I be shifted around 500 m towards the station pole 500, then it would be located within the fault zone.

To some extent, a 2 km long segment of profile 6-4-89, restricted by the station poles 100–125, remains in similar situation with respect to the watershed I as the part of profile 4-4-89 discussed so far. Intensive reflected waves have been recorded here, except a small fragment between the station poles 106 and 109. The watershed I intersects profile 6-4-89 in the vicinity of the station pole 106, i.e. in the area where a distinct variation appears in the seismic record. This variation should be connected with a zone of tectonic disturbances. Variation in the record of wave image can also be observed in places of intersections of the watershed I with following profiles: 7-4-89, 9-4-89, and 52-4-89/90; variation of the wave image on other profile (10-4-89) is less visible.

CONCLUSIONS

A majority of boundaries of both hydrogeological units and areas of similar potential yields of representative water wells — as plotted on the hydrogeological map of Poland on the scale 1:200 000 — correlate well with zones of variations in seismic wave images. Character of variations in record of reflected waves may attest that they result from the presence of faults. The fact is that boundaries of hydrogeological units exhibit relationship with the tectonics; however, particular boundaries not necessarily run along their entire length through the same fault zones that disturb both the Palaeozoic and Cretaceous formations. The occurrence of faults in the overburden of the Cretaceous formation is likely, but a full analysis not limited to seismic data only is required to document this idea. It should be considered that the delimited faults exert an influence on the hydrogeological conditions. This inclines to the acceptance that making use of results of reflection method is useful in hydrogeological studies.

When delimiting the surface watersheds, it is well motivated to refer to those seismic data the course of which seems to show relationship with variations of the wave image, also with the area of the occurrence of some velocities of wave propagation in the substratum of the aeration zone.

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PRZEJAWY WPŁYWU TEKTONIKI NA WARUNKI HYDROGEOLOGICZNE W ŚWIETLE WYNIKÓW METODY REFLEKSYJNEJ

Streszczenie

W artykule przedstawiono przykłady zmian obrazu falowego na wybranych przekrojach sejsmicznych, zlokalizowanych w części podniesionej prewendyjskiej platformy wschodnioeuropejskiej. Zmiany zapisu fal odbitych, wiązanych z utworami mezozoicznymi, występują w miejscach przecięcia się większości przekrojów z granicami jednostek hydrogeologicznych, wyznaczonych na mapie hydrogeologicznej w skali 1:200 000, a także z wododziałami powierzchniowymi. Charakter zmian obrazu falowego wskazuje, że są one spowodowane zaburzeniami tektonicznymi. Poszczególne granice jednostek nie przebiegają jednak na całej swej długości w strefach tych samych uskoków. Wyniki analizy zapisu sejsmicznego przemawiają za celowością korzystania z danych metody refleksyjnej w kartografii hydrogeologicznej.