

SIMPLIFIED CLASSIFICATION OF PLATFORM FOLDS

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Syndepositional character of tectonic deformations is a common feature of the platform covers. It is caused both by the differential vertical movements of basement blocks and by the horizontal displacements of rocks salts, frequently occurring in the epicontinental environments of platforms. These syndepositional processes result in local changes of thickness which may be either gradual or – across the growth faults – more abrupt. These changes in turn cause the shapes of many platform folds to be variable in various planes of their vertical and horizontal sections.

Zechstein-Mesozoic structural complex in the Polish Lowlands offers many examples of different types of platform folds. This complex rests either upon the Lower Permian Rotliegendes strata or upon the pre-Permian basement (partly heavily block faulted) and contains in its lowermost part the well developed Upper Permian salt-bearing formation. In the Middle Triassic, when a sufficient load of overlying sediments was attained in the central part of the basin, the salts of this formation were being mobilized, thus causing their cover to be deformed. The further towards the margins of the basin, the later commenced the movements of salt – in extreme cases they began to flow as late as the Late Cretaceous. Yet in the central part, where halokinesis began at the earliest, it acted repeatedly during the Late Triassic, Jurassic and

Cretaceous transforming the initial non-piercement anticlines into the piercement diapirs. In the latest Cretaceous an epoch of inversion began which continued till the earliest Tertiary and affected the tectonic units of different orders both in the areas of salt- and non-salt deformations.

The vertical movements of the basement blocks which triggered the salt flowage were evidently active also beyond the extent of salts. In these marginal parts of the basin it resulted in the formation of non-salt anticlines. The characteristic time-space wandering of the „deformation front” manifested itself in a zonal pattern of various kinds of anticlines, with a passage from the strongly deformed salt diapirs in the centre of the basin through the non-piercement anticlines in the transitional zone to the non-salt anticlines along the margins. The boundaries of particular zones are not clear-cut, e.g. small non-salt anticlines do occur also in the area of salt tectonics as well as single piercement salt anticlines do exist in such zones beyond the regional limit of salt tectonics where faults were extremely active.

The combination of various tectogenetic agents resulted in a wide array of platform anticlines observed in the Polish Lowlands. Their classification, proposed here, has been outlined by the author in his earlier papers (5, 6). It does not pretend to consider the problems of tectogenesis except for distinguishing between salt anticlines

and non-salt anticlines. It seems to be useful rather in the first stages of the subsurface exploration when only seismic reflection profiles and scarce boreholes are available. The examples given in figures are much simplified although they refer to the specific cases recorded in the area of study. The scale of cross-sections is not exaggerated.

All platform anticlines have been divided into two major groups according to two quite different mechanisms of their origin. Salt anticlines have been formed more „actively” due to the horizontal or vertical flowage of plastic rocks from the zones of higher pressure to those of lower pressure. Non-salt anticlines are the result of deformation of rigid rocks either in a „passive” way due to differential vertical movements during the period of basinal subsidence or due to active uplift during the inversion stage.

Salt anticlines have been investigated in a number of the world basins since many decades and have been classified in different manners. Some of these classifications are very sophisticated and of local significance (e.g. 1, 2, 9, 13). Apart from the degree of piercement, also the size and shape of salt bodies, their development stages, the age of overlying rocks, the depth to cap rock etc., are being used as the criteria of subdivision, and the names of classes and groups are derived from localities of the type diapirs.

The classification proposed here refers rather to simpler subdivisions (12, 16, 17). Salt anticlines have been divided into two sub-groups: non-piercement (Figs. 1 and 2) and piercement (Figs. 3 and 4) anticlines. The former are products of the first phase of salt flowage, predominantly horizontal. The strata above the crestal parts of non-piercement bulges are characterized by thickness reductions which may result either from uniform decrease in subsidence rates and sediment supply or – more often – from periodic breaks in sedimentation and erosional gaps. During the second phase of salt flowage its vertical motion prevailed. Salt began to intrude into the overlying rocks, thus causing the numerous stratigraphic gaps and/or

angular unconformities, and faulted contacts to appear above the top and around the salt core.

Both types of salt anticlines may be either elongated or more isometric. Their contours on the maps are being outlined according to various principles. Very steep or even vertical walls of piercement domes are rather easy to identify in seismic profiles and to project on a map. In case of non-piercement anticlines, however, there are two ways of defining their outlines. The first is to use the structure contours of top salt horizon, the second is to use the isopachs either of the evaporitic sequence as a whole or of the thickest salt layer involved in the halokinesis. The latter principle is preferred here because it reflects better the conditions of primary accumulation of salt. A map of the present thickness of salt records not only the places of salt accumulation, but also that ones which are of at least the same significance, namely the places out of which the salt was squeezed at the time of incipient mobilization. Another advantage of this method is that the structure contours are not always applicable. As exemplified in Fig. 2, some non-piercement anticlines, after having been formed upon the flat basement, were later tilted during the inversion stage; in this case only the isopachs can properly outline the anticline while the structure contours cannot.

The choice of the boundary isopachs delimiting the zones of maximum outflow and maximum accumulation of salt depends on the regional conditions. In the area of study the isopachs of 300 m and 800 m interval between the supra- and sub-salt seismic reflectors have been chosen (in case of time sections, the isochrons of 130 ms and 450 ms of two travel time, respectively). The former represents the thickness which is smaller than the primary mean thickness of Stassfurt salt and the latter – the greater thickness.

An arbitrary limit value of the length to width ratio = 3:1 has been used while subdividing the salt anticlines into more elongated and more isometric ones. Elongated non-piercement anticlines have been called **salt swells**, more isometric ones – **salt pillows**; for piercement anticlines the respective terms of **salt crests** and **salt plugs** have been adapted. It is worth noting that both the salt pillows and the piercement domes are often superimposed upon the less arched salt swells. Diapirs pierced up to

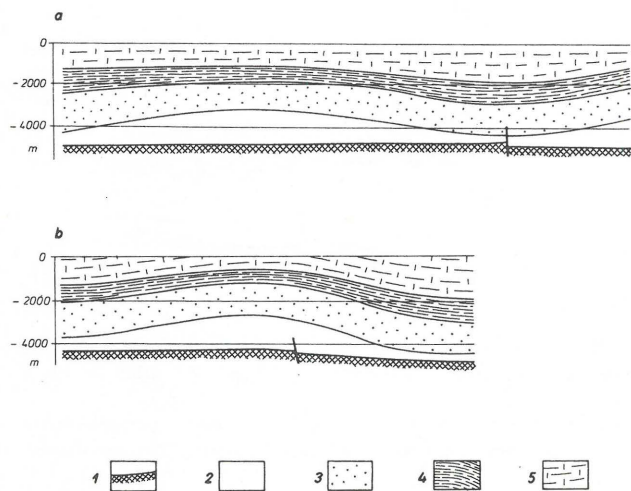


Fig. 1. Salt pillows: (a) active during Triassic and Jurassic, (b) active during Jurassic (and Cretaceous?).

Key to ornament in all Figures: 1 – sub-Zechstein basement, 2 – Zechstein, 3 – Triassic, 4 – Jurassic, 5 – Cretaceous.

Ryc. 1. Poduszki solne: (a) czynna w czasie triasu i jury, (b) czynna w czasie jury (i kredy?).

Objaśnienia, szrafury na wszystkich rysunkach: 1 – podłoże podcechsztyńskie, 2 – cechsztyń, 3 – trias, 4 – jura, 5 – kreda.

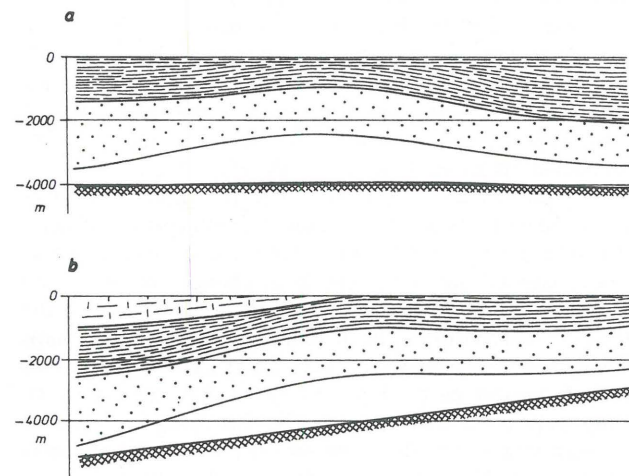


Fig. 2. Salt pillow formed upon the flat basement (a) and tilted during the inversion stage (b).

Ryc. 2. Poduszka solna utworzona na płaskim podłożu (a) i przechylona w stadium inwersyjnym (b).

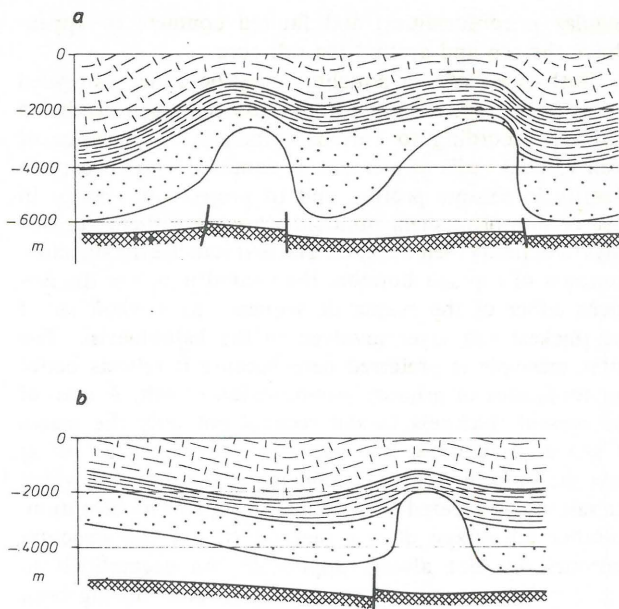


Fig. 3. Salt plugs partly pierced through the cover.

Ryc. 3. Słupy solne częściowo przebijające się przez nadkład.

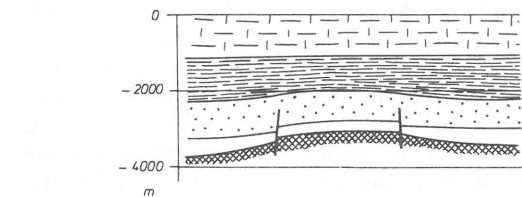


Fig. 5. Cryptomorphic anticline of the „buried hill” type.

Ryc. 5. Antyklina kryptomorficzna typu „pogrzebanego wzgórza”.

the earth's surface have not been distinguished as a separate category because such an approach seems to be somewhat anthropocentric: it favours one of the numberless moments in a long history of piercement processes. Nevertheless it is useful from the economic point of view.

Non-salt anticlines have also been known for a long time, particularly in the North American Mid-continent territories and in the East European platform. This group has been classified mainly on tectogenetic principles. It includes, among others: plains-type folds and placanticlines, reflected and superficial folds, stamp folds, buried folds, supratenuous, compaction and drape folds, finally „unrooted” folds (4, 7, 8, 10, 11, 14, 15).

The classification proposed here is again purely geometric because the determination of tectogenetic character of a fold is not possible unless the more detailed exploration is carried out. Frequent local changes of formation thickness, which affected the final shape of folds, are the basis of subdivision. The height of **cryptomorphic anticlines*** decreases upwards due to thickness reductions in their crestal parts (Figs. 5–7) — they may even be completely concealed beneath the flat lying or inclined younger strata. On the contrary, the height of **phaneromorphic anticlines** decreases downwards and they may even pass at depth into depressed structures (Figs. 8–10).

* Nomenclature refers to that of Belousov (3) who distinguished between the holomorphic and idiomorphic folds.

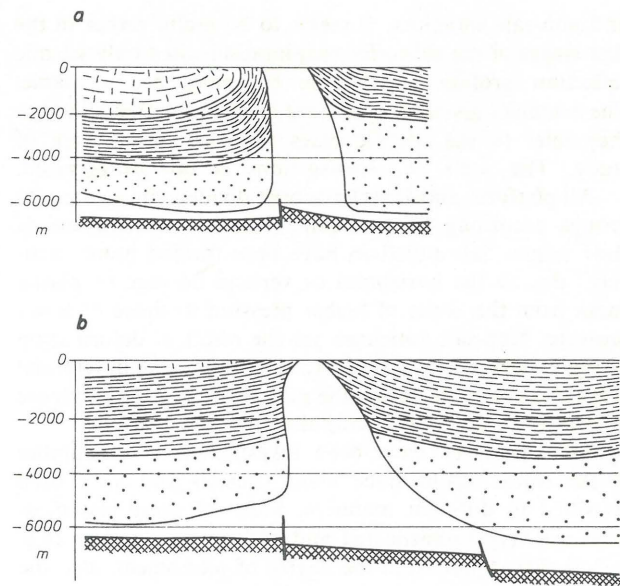


Fig. 4. Salt plugs pierced completely through the cover. Connection with growth faults suggested by thickness differences at both sides of diapirs.

Ryc. 4. Słupy solne całkowicie przebijające się przez nadkład. Związek z uskokami synsedymacyjnymi sugerowany przez różnice miąższości po obu stronach diapirów.

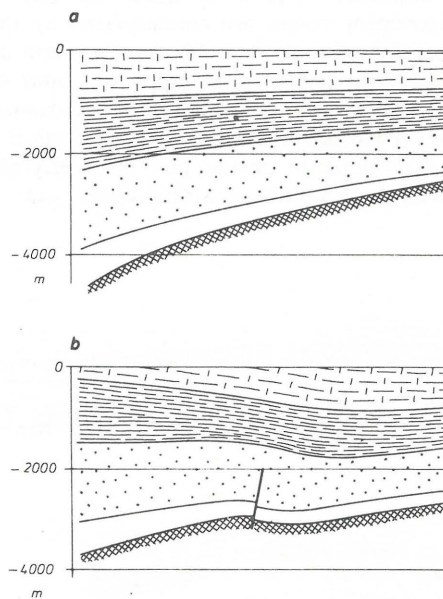


Fig. 6. Cryptomorphic anticline formed in the area of regional thickness increase: (a) before inversion, (b) after inversion.

Ryc. 6. Antyklina kryptomorficzna utworzona w obszarze regionalnego wzrostu miąższości: (a) przed inwersją, (b) po inwersji.

Finally, the height of **isomorphic anticlines** remains constant (Fig. 11).

The origin of cryptomorphic anticlines is variable. Some of them are related to the typical „buried hills” (Fig. 5). Since the inundation of more resistant basement blocks by the Zechstein sea was retarded, they were covered by sediments later than the adjacent blocks, and anhydrites and carbonates prevailed there in the Zechstein sequence. A rigid foundation of a more stable block thus formed above which an anticline of supratenuous or drape type

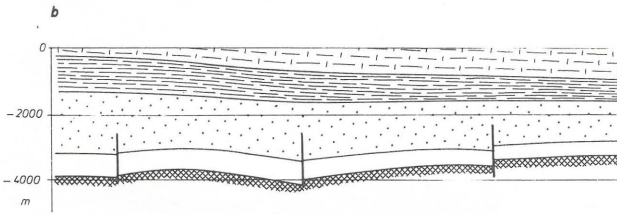
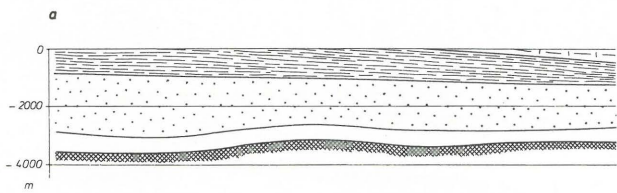


Fig. 7. Non-faulted (a) and faulted (b) cryptomorphous anticlines

Ryc. 7. Niezuskokowane (a) i zuskokowane (b) antykliny kryptomorficzne.

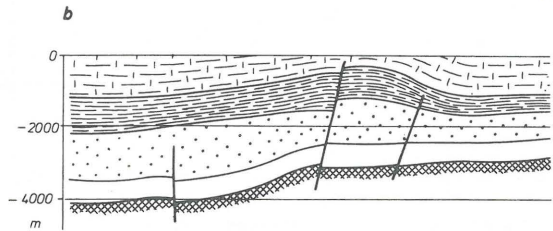
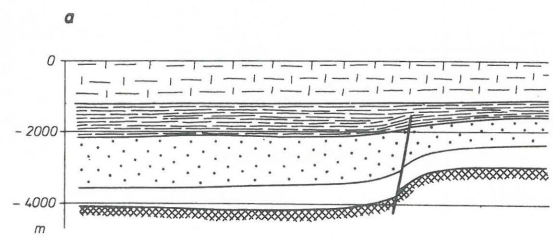


Fig. 8. Phaneromorphous anticline on the structural step: (a) before inversion, (b) after inversion.

Ryc. 8. Antyklina faneromorficzna na stopniu strukturalnym: (a) przed inwersją, (b) po inwersji.

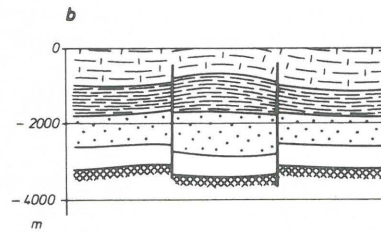
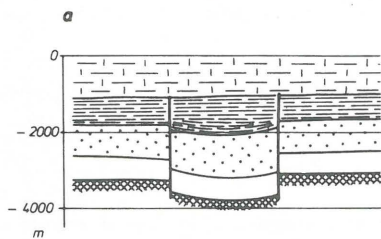


Fig. 9. Phaneromorphous anticline in the graben: (a) before inversion, (b) after inversion.

Ryc. 9. Antyklina faneromorficzna w rowie: (a) przed inwersją, (b) po inwersji.

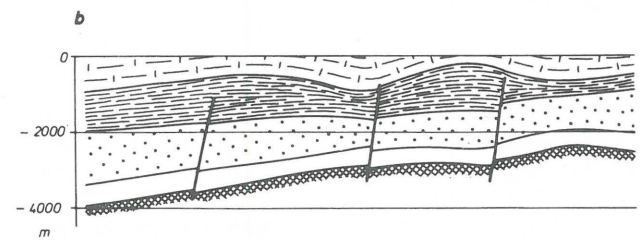
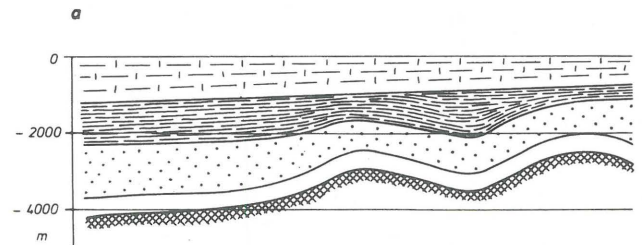


Fig. 10. A couple of phaneromorphous anticlines: (a) before inversion, (b) after inversion.

Ryc. 10. Zespół antyklin faneromorficznych: (a) przed inwersją, (b) po inwersji.

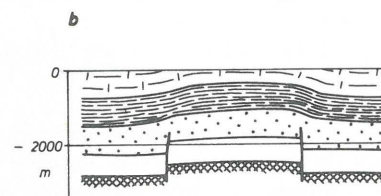
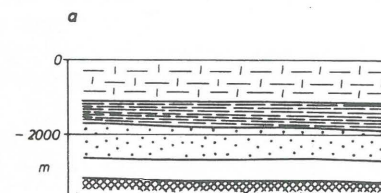


Fig. 11. Isomorphous anticline: (a) before inversion, (b) after inversion.

Ryc. 11. Antyklina izomorficzna: (a) przed inwersją, (b) po inwersji.

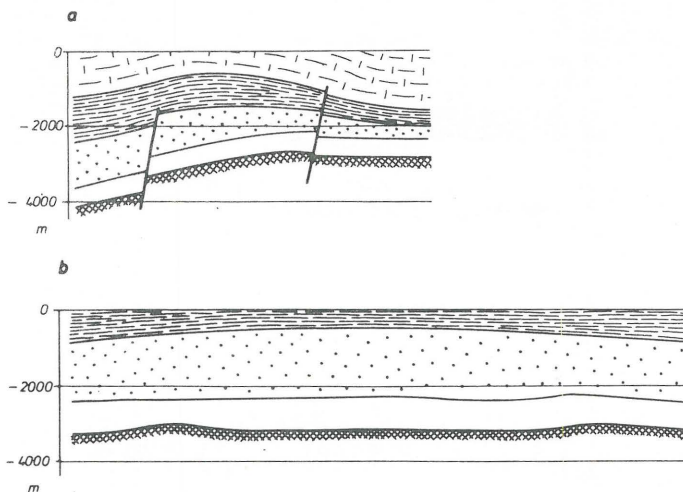


Fig. 12. (a) Phaneromorphic anticline (left) accompanied by cryptomorphic anticline (right), (b) Two small cryptomorphic anticlines beneath the broad phaneromorphic anticline.

Ryc. 12. (a) Antyklina faneromorficzna (po lewej) i towarzysząca jej antyklina kryptomorficzna (po prawej), (b) Dwie małe antykliny kryptomorficzne pod rozległą antyklina faneromorficzną.

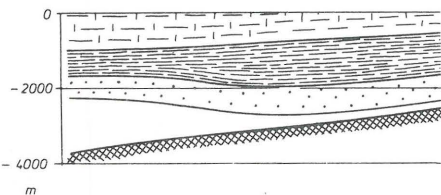


Fig. 13. Cryptomorphic syncline.

Ryc. 13. Synklina kryptomorficzna.

developed (with or without influence of compaction processes). Other cryptomorphic anticlines originated only during the inversion stage when some local blocks were uplifted along faults, and the regional unidirectional increase in thickness of the younger formations was great enough to mask the effects of uplift (Fig. 6).

Phaneromorphic anticlines appeared mostly during the inversion stage at the sites of formerly downfaulted blocks which might be either structural steps in a tilted block-faulted basement (Fig. 8), or small troughs or grabens (Figs 9 and 10). However, the well-known turtle anticlines, occurring among salt diapirs in the areas of salt tectonics, belong also to this sub-group. Replacing the earlier primary depressions between salt pillows or salt swells, they formed passively during the piercement stage due to subsidence of the adjacent secondary rim synclines.

Isomorphic anticlines are products of a single, relatively short-lasting event of block uplift. It took place in the areas which had not been subjected earlier to the differential subsidence.

Occasionally, in view of lateral shifting of the zones of increased subsidence, non-salt anticlines of different sub-groups are closely spaced and partly overlap each other (Fig. 12).

All three sub-groups of non-salt anticlines have their counterparts in the depressed structures. Thus, the depth

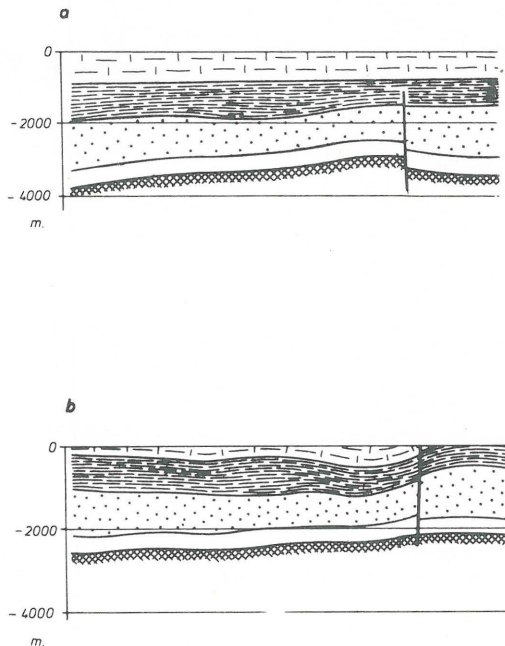


Fig. 14. Phaneromorphic syncline: (a) before inversion, (b) after inversion.

Ryc. 14. Synklina faneromorficzna: (a) przed inwersją, (b) po inwersji.

of **cryptomorphic syncline** (Fig. 13) increases downwards and that of **phaneromorphic syncline** (Fig. 14) decreases downwards. The former are common in the areas of immature salt tectonics, where the natural response to the gradual growth of salt pillows was the greater subsidence of the surrounding synclines.

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STRESZCZENIE

Synsedymacyjny charakter deformacji tektonicznych jest pospolitą cechą pokryw platformowych. Jest on spowodowany zarówno przez zróżnicowane ruchy pionowe bloków podłoża, jak i przez poziome przemieszczenia serii solonośnych, często występujących w epikontynentalnych środowiskach platformowych. Te synsedymacyjne procesy ujawniały się w lokalnych zmianach miąższości, które mogły być albo stopniowe, albo — w poprzek uskoków synsedymacyjnych — bardziej gwałtowne. Zmiany te z kolei spowodowały, że ostateczny kształt fałdów platformowych jest zmienny w różnych płaszczyznach ich pionowych i poziomych przekrojów.

Proponowana klasyfikacja jest oparta na analizie materiału z Niziu Polskiego. Jest to klasyfikacja geometryczna, uproszczona. Nie rości sobie ona pretensji do podejścia genetycznego, które wymaga znacznie obfitszego materiału analitycznego, i jest raczej użyteczna w pierwszych fazach badań wgłębnych, gdy dysponuje się tylko profilami sejsmicznymi i pojedynczymi wierceniami.

Odstępstwem od zasady geometrycznej jest jedynie podział antyklin platformowych na dwie główne grupy: antyklin solnych i niesolnych. W obu przypadkach czynniki tektogeniczne były odmienne. Antykliny solne powstały w wyniku aktywnego przepływu skał plastycznych, antykliny niesolne — w wyniku deformacji skał bardziej sztywnych, albo na drodze „pasywnej” dzięki zróżnicowanej subsydencji albo wskutek aktywnego wypiętrzenia w stadium inwersyjnym.

Antykliny solne mogą być typu nie przebijającego bądź przebijającego się przez nadkład. Pierwsze powstały w stadium przeważnie poziomego przepływu soli i charakteryzują się redukcjami miąższości w partiach przegubowych, na ogół będącymi rezultatem licznych luk stratygraficznych. Drugie utworzyły się w fazie pionowego przebijania się soli przez skały nadległe, wynikiem czego są pospolite niezgodności kątowe i kontakty tektoniczne. Oba typy antyklin solnych mogą być wydłużone lub bardziej izometryczne w planie, przy czym umowną granicą

między tymi podgrupami jest stosunek długości do szerokości równy 3:1. Zarys w planie antyklin nie przebijających się przez nadkład określono drogą analizy miąższości serii solnej, zawartej między pod- a nadsolnym poziomem sejsmicznym — zarys ten wyznacza izopachyta 800 m. Wydłużone antykliny nie przebijające się nazwano wałami solnymi, bardziej izometryczne — poduszkami solnymi (ryc. 1 i 2); antykliny przebijające się, odpowiednio: grzebieniami solnymi i słupami solnymi (ryc. 3 i 4).

Antykliny niesolne podzielone zostały na trzy podgrupy, zależnie od zmian kształtu w przekroju pionowym, spowodowanych zmianami miąższości. Wysokość antyklin kryptomorficznych (ryc. 5–7) maleje ku górze dzięki redukcjom miąższości w partiach przegubowych — mogą one być nawet całkowicie ukryte pod warstwami młodszymi. Antykliny te mogą mieć charakter fałdów oblekających lub kompakcyjnych, ale mogły też powstać w stadium inwersji. Przeciwnie, wysokość antyklin faneromorficznych (ryc. 8–10) maleje ku dołowi — utworzyły się one na miejscu stopni strukturalnych lub rowów o pierwotnie zwiększonej miąższości osadów. Wreszcie wysokość antyklin izomorficznych (ryc. 11) pozostaje stała na różnych poziomach ich przekroju. Obie ostatnie podgrupy zawdzięczają swe powstanie wyłącznie ruchom inwersyjnym.

Odpowiednikiem form wypiętrzonych są formy obniżone: kryptomorficzne synkliny o głębokości wzrastającej ku dołowi i faneromorficzne synkliny o głębokości malejącej ku dołowi (ryc. 13 i 14).

РЕЗЮМЕ

Синседиментационный характер тектонических деформаций является распространенным свойством платформенных покровов. Он вызван как разными вертикальными движениями блоков фундамента, так и горизонтальными перемещениями соленосных серий находящихся часто в эпиконтинентальных платформенных средах. Эти синседиментационные процессы проявились в местных изменениях мощности, которые могли быть постепенными, или более резкими — поперечно к синседиментационным сбросам. Эти изменения стали причиной того, что окончательная форма платформенных складок является изменчивой в разных плоскостях их вертикальных и горизонтальных разрезов.

Предлагаемая классификация основана на анализе материала из Польской низменности. Это геометрическая, упрощенная классификация. Она не имеет генетического характера, так как это требует гораздо больше аналитического материала, и является пригодной в первых фазах глубинных исследований, когда имеем только сейсмические разрезы и единичные буровые скважины.

Отказом от геометрического правила является разделение платформенных антиклиналей на две группы: соляных и несоляных антиклиналей отличающихся генетическими факторами. Соляные антиклинали образовались вследствие активного протекания пластических пород, несоляные — в результате деформации более жестких пород, или „пассивным” путем — благодаря дифференцированной субсиденции или вследствие активного поднятия в инверсивной стадии.

Можно выделить два типа соляных антиклиналей: не пробивающиеся и пробивающиеся через вскрышу. Первые образовались в стадии преимущественного горизонтального протекания соли и они характеризуются уменьшением мощности в сочлененных партиях,