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Structural analysis of the Devonian exposures within the middle part of the Bodzentyn syncline in the Holy Cross Mts

ABSTRACT: Structural analysis of the middle part of the Bodzentyn syncline in the Holy Cross Mts proves that during formation of the syncline at Variscan orogeny, the vertically displaced transverse faults as well as reverse longitudinal faults and joint originated; the syncline itself displays rather a simple tectonic structure, with secondary disharmonic minor faults. The Laramide rejuvenation caused formation of some other minor faults, shears, and cleavage. The Laramide movements effected also in gravitational longitudinal faults at southern limb of the syncline and in small drag folds at northern limb, being a result of more intensive uplift of the limbs in relation to the axial zone of the syncline.

INTRODUCTION

In spite of many studies, the age of main tectonic deformations of Paleozoic rocks in the Holy Cross Mts is still uncertain (*see* Czarnocki 1919, 1957; Kutek & Głazek 1972; Mariańczyk 1973; Znosko 1974; Kowalczewski 1976; Mizerski 1979a; Racki & Zapaśnik 1979). As there is no direct evidence in some regions, an attempt to apply the indirect data seems to be interesting, based e.g. on the analysis of palaeomagnetism (*see* Lewandowski 1980) or on the structural analysis. The most favorable area for the latter is, if taking a number of exposures into account, the middle part of the Bodzentyn syncline, the area recently investigated by the author. For this reason the paper continues the author's studies in the south-adjacent region, namely in the Łysogóry unit (Mizerski 1979a, b; Mizerski & Ozimkowski 1978).

The author is grateful to Professor A. Radwański for his help in final composition of the manuscript.

GENERAL SETTING OF THE AREA

The Bodzentyn syncline, located north off the Łysogóry unit, is a vast structure with its axis close to W-E direction. In the north it contacts, along the Świślina dislocation, with the Bronkowice-Wydrzyszów anticlinorium whereas in the south it gradually passes into the Łysogóry unit (Text-fig. 1). It is composed of the Devonian rocks: Lower Devonian is represented by fine-grained clastics, and Middle trough Upper Devonian by carbonates.

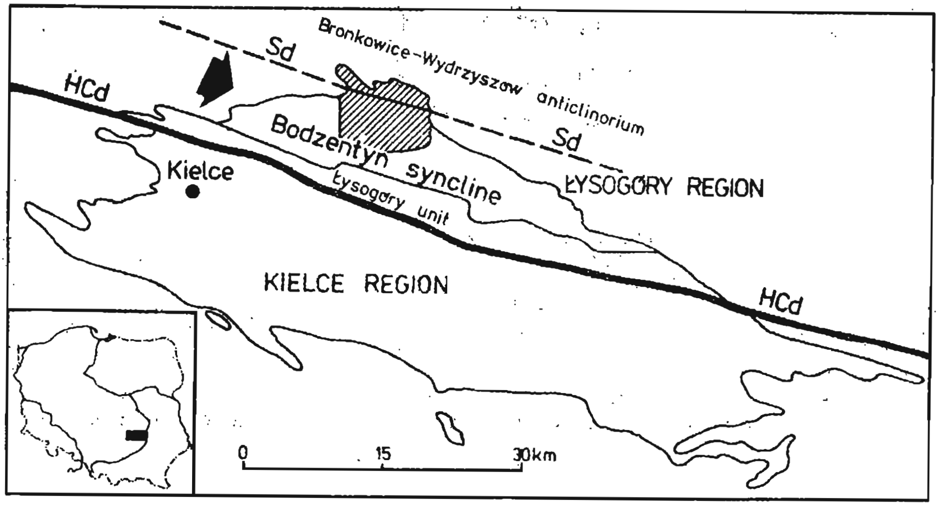


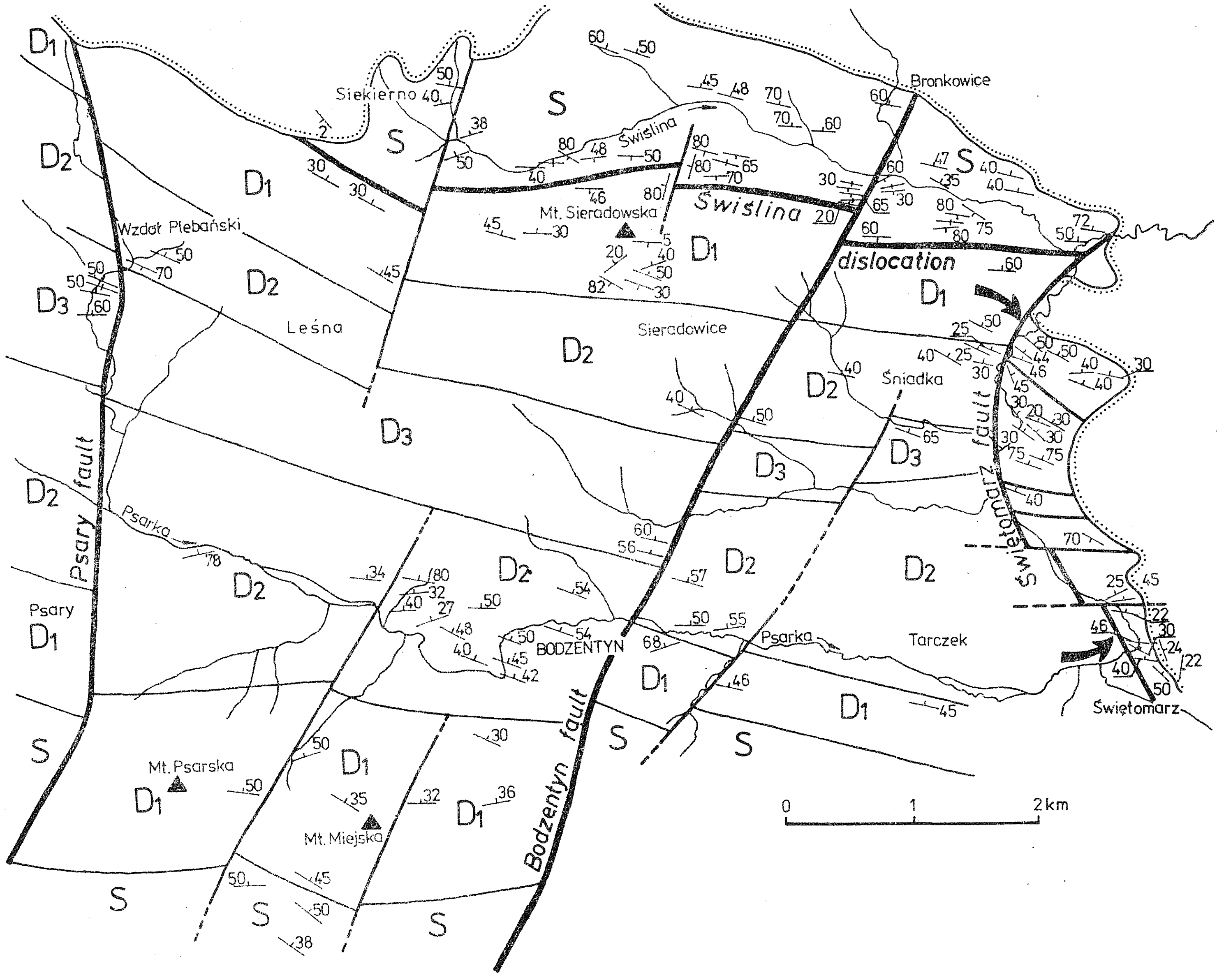
Fig. 1. General tectonic sketch of the Holy Cross Mts to show location of the Bodzentyn syncline (*arrowed*); inset indicates position of the region in Poland; investigated area is hachured (cf. Text-figs 2 and 11).

HCd Holy Cross dislocation, *Sd* Świślina dislocation

The investigated area comprises the middle part of the syncline, located in the Psarka river drainage basin (Text-fig. 2). The Bodzentyn syncline is overturned to the south and its axial plane dips from 60 to 30° northwards. The syncline axis emerges eastwards at an angle of about 10°. The whole syncline is cut by numerous transverse and longitudinal faults (*see* Text-figs 2 and 11).

Due to varying tectonic styles of separate parts of the Bodzentyn syncline and to obtain the comparable data in statistic analyses, the investigated area was divided into the three successive regions.

Tectonic map of the middle part of the Bodzentyn syncline



Bounded by arrows is the cross section along the Psarka river, presented in Text-fig. 7

STRUCTURAL ANALYSIS

SOUTHERN LIMB OF THE SYNCLINE

The Lower Devonian clastics that build the southern limb of the Bodzentyn syncline, have a stable attitude of the strata (diagram *a* in Text-fig. 3). Their average attitude is about 100/50N, with small variations only; the strike is generally equal 90—120° and the dips 45—60° northerly. A position of the strata is normal in every exposure. The attitude of the strata in this part of the syncline is very similar to that of the Łysogóry unit (*cf.* Mizerski 1979a).

In spite of a gentle occurrence of the Lower Devonian rocks, they comprise such discontinuous deformations as minor faults, shears, and cleavage. The faults noted in the exposures display their northern sides vertically displaced, usually at a distance of a few centimetres. The shear planes at which slickenside striae were noted several times, dip northerly (Text-fig. 4) and the strata that overlie a shear plane are displaced to the north, i.e. towards the syncline axis.

In some exposures a cleavage was noted, the planes of which dipped southerly. In a small rural quarry at the northern slope of Mt. Miejska (*see* Text-fig. 2), a sigmoidal cleavage was stated (Text-fig. 4); it proves a sliding of the strata towards the axial zone of the syncline (*cf.* Jaroszewski 1972).

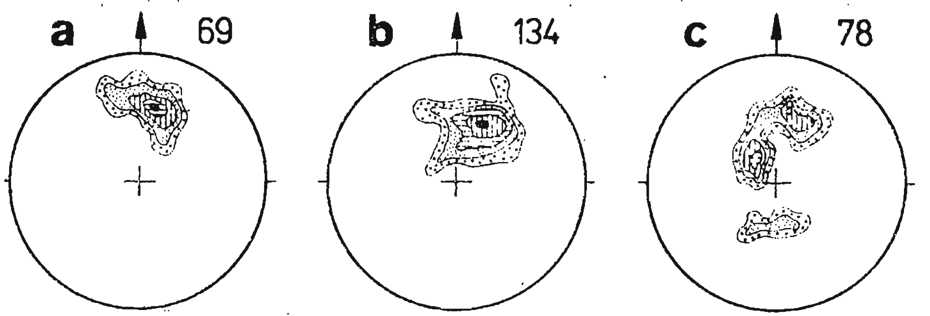


Fig. 3. Diagrams of the attitude of layers (contours of 2, 4, 6, 8, and 10%; numbers of measurements indicated at top right) for the southern limb (a), axial zone (b) and northern limb (c) of the investigated part of the Bodzentyn syncline

Faults and shear planes in the southern limb of the syncline possess the features of gravitational deformations as all of them prove a displacement of strata or, of strata sets, towards the syncline axis. It is also emphasized by sliding of the strata along their interbedding surfaces. Therefore, such deformations cannot be connected with the Variscan phase of evolution of the Bodzentyn syncline as in this case, the strata should have displaced southerly, outside the syncline axis. Thus, these deformations have been formed later.

AXIAL ZONE OF THE SYNCLINE

In the axial zone of the Bodzentyn syncline, to which an area of Middle and Upper Devonian outcrops was conventionally included, the exposures are very unevenly distributed. They occur mainly in the three regions: (*1*) near Bodzentyn where the exposures of Middle Devonian rocks predominante, (*2*) in the up-stream part of the Psarka valley where deposits of Middle and Upper Devonian are exposed, and (*3*) in the lower part of the Psarka valley, along the famous section of Świętomarz — Śniadka that yielded many Middle Devonian fossiliferous localities (*see* Gürich 1896, Sobolev 1909, Bednarczyk 1955).

Close to Bodzentyn the Middle Devonian deposits are slightly deformed. Their strike is about 120° and they dip northerly at an angle of about 40—50°. Sporadicly there occur small longitudinal faults dipping northerly and with northern sides vertically displaced of unsettled amplitude.

A considerably greater degree of deformations is noted within the deposits exposed in the upper part of the Psarka valley at Wzdół Plebański (*cf.* Text-fig. 2). At a distance of several hundred metres there are steeply arranged Middle and Upper Devonian deposits, among which there locally appear small folds which are closely connected with lon-

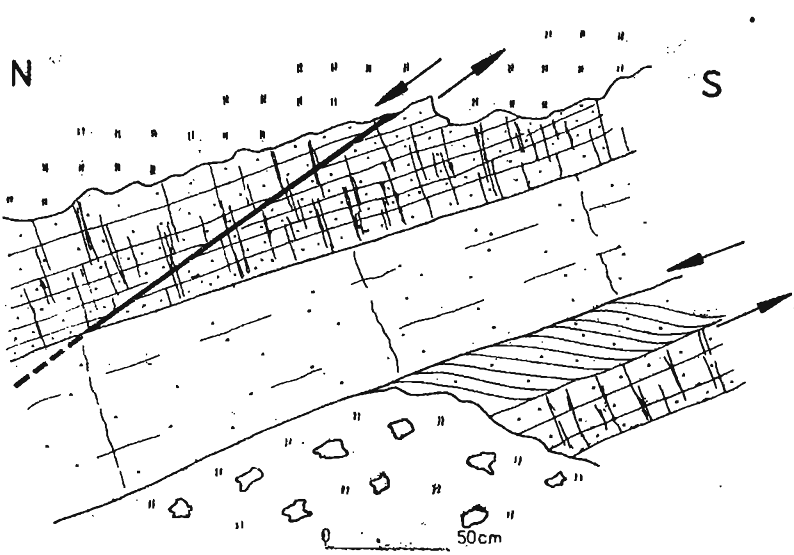


Fig. 4. Sigmoidal cleavage and shear plane in Lower Devonian clastics exposed on Mt. Miejska, southern limb of the Bodzentyn syncline

gitudinal faults of varying dips (Text-fig. 5). The fold axes are of varying directions, but generally, they are parallel to the syncline axis. Instead, dips of the fold axes are varying, and some of the folds are of a drag type, formed close to a fault surface. The northern sides of these faults are displaced upwards — to the south, evidencing their reverse nature. The faults that accompany the fine fold deformations possess the planes striking towards the axis of the syncline. But them, there are also some small faults of small vertical displacements, with strikes NNW-SSE and steep dips southerly. These faults displace upwards the southern sides, and they are therefore also reverse faults, although of the origin different that of the longitudinal faults, along which the tectonic transport was different. Probably the polished surfaces, steeply dipping south-westerly, are connected with these faults; the slickenside striae at the surfaces prove a displacement of the upper sides in a north--east direction. Along two fault surfaces of this kind a boudinage was noted (Text-fig. 6), and it proves a relatively great intensity of tectonic processes during a formation of the faults.

In many exposures near Wzdół Plebański a cleavage is observed, with is inclination almost independent on the dip of layers, and with its planes inclined southerly. The origin of this cleavage is regarded by Jaroszewski (1972) as a result of the post-Variscan disjunctive rejuvenation, taking its place probably during the Laramide movements.

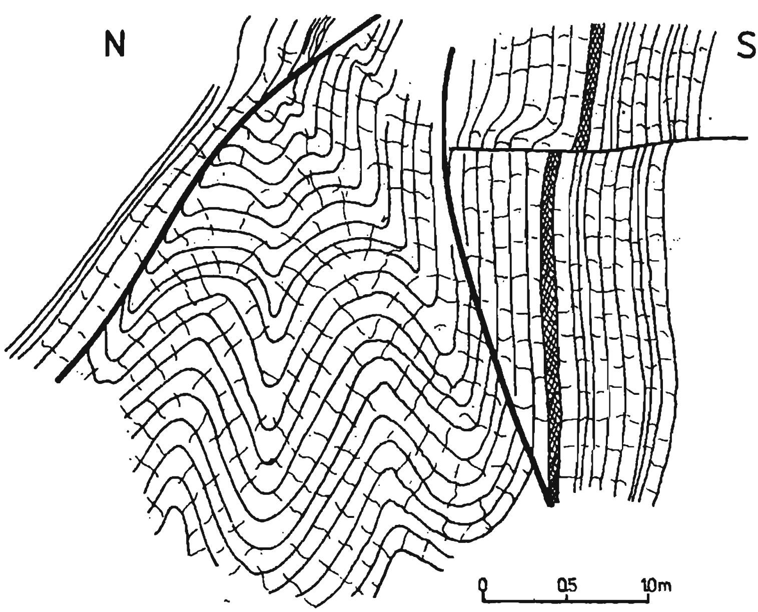


Fig. 5. Small-sized fold deformations associated to the faults in the axial zone of the Bodzentyn syncline, exposed near Wzdół Plebański

A local occurrence of minor fold structures and their connection with longitudinal faults in the axial zone of the Bodzentyn syncline that has generally a simple tectonic structure, allow to consider these deformations as originated due to disharmonic folding during formation of the syncline in the Variscan movements. Instead, the faults of NNW-SSE directions as well as the polished surfaces and the cleavage, are connected with the post-Variscan rejuvenation of the area (Jaroszewski 1972). This rejuvenation could result, after Jaroszewski (1972), in a local reversal of the vergence of Variscan folds and, as suggested from the collected data, has resulted not in a change of general inclination of the Bodzentyn syncline axial plane but in the increase of its steepness.

The geologic structure of the section Świętomarz — Śniadka has long been recognized (Sobolev 1909, Bednarczyk 1955, Czarnodcki 1957) as displaying several fold structures with their axial planes dipping to the north. It was first Kłossowski (1976) who found a single synclinal structure to occur there, cut by reverse faults that caused a repeated sequence of sediments of the same age (Text-fig. 7).

In the section Świętomarz — Śniadka the Bodzentyn syncline is overturned southerly; an attitude of its axial is 110/10W and the axial surface is inclined about 30—40° northerly. The southern part of the core, located south off the syncline bend, is dissected by numerous reverse faults, with amplitude from several to several hundred meters (Text-fig. 7). These faults are accompanied by smaller deformations; either folds or faults (Text-figs 7 and 9). As these deformations do not occur chaoticly in the section and they accompany the longitudinal dislocations, their genetic connections seem obvious.

The northern part of the core of the Bodzentyn syncline in the section Świętomarz — Śniadka displays much smaller tectonic complications. Larger longitudinal faults are almost completely absent as well as fine tectonic deformations. Instead, there are relatively numerous drag folds (Text-fig. 8), a majority of which prove a southward displa-

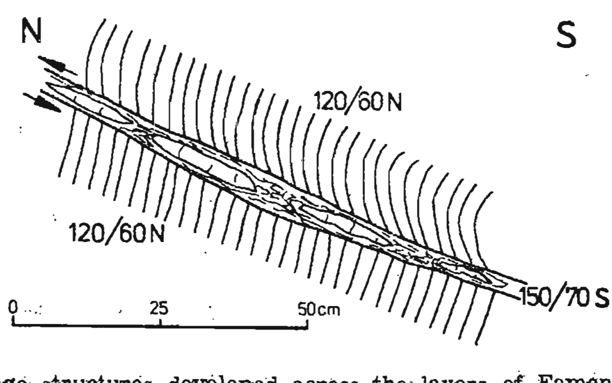


Fig. 6. Boudinage structures developed across the layers of Famennian limestones in the axial zone of the Bodzentyn syncline, exposed near Wzdół Plebański

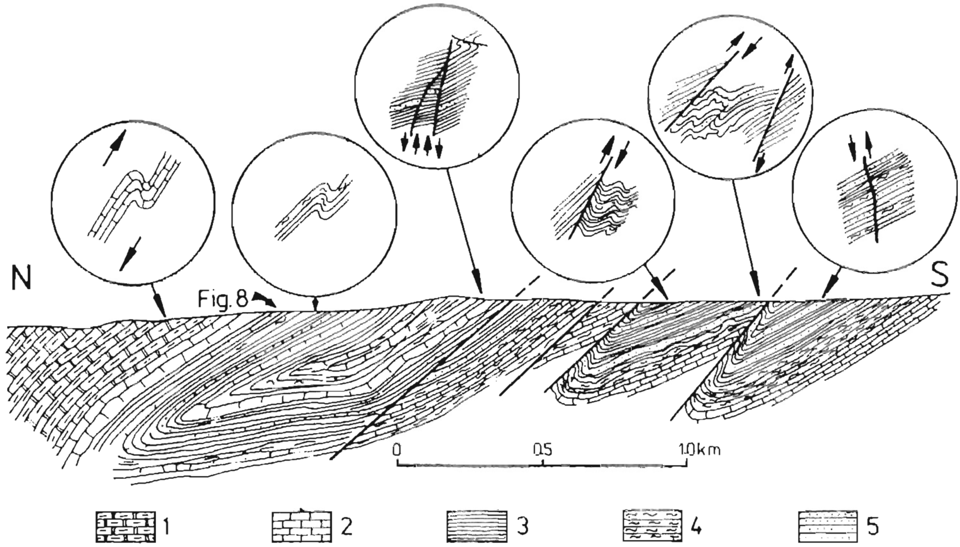


Fig. 7. Cross section through the Bodzentyn syncline, between Świętomarz and Śniadka as exposed along the Psarka river (see Text-fig. 2), and location of small-sized tectonic deformations (section *taken from* Kłossowski, 1976; simplified)
Lithology: 1 marly dolomites, 2 limestones, 3 shales, 4 siltstones, 5 sandstones

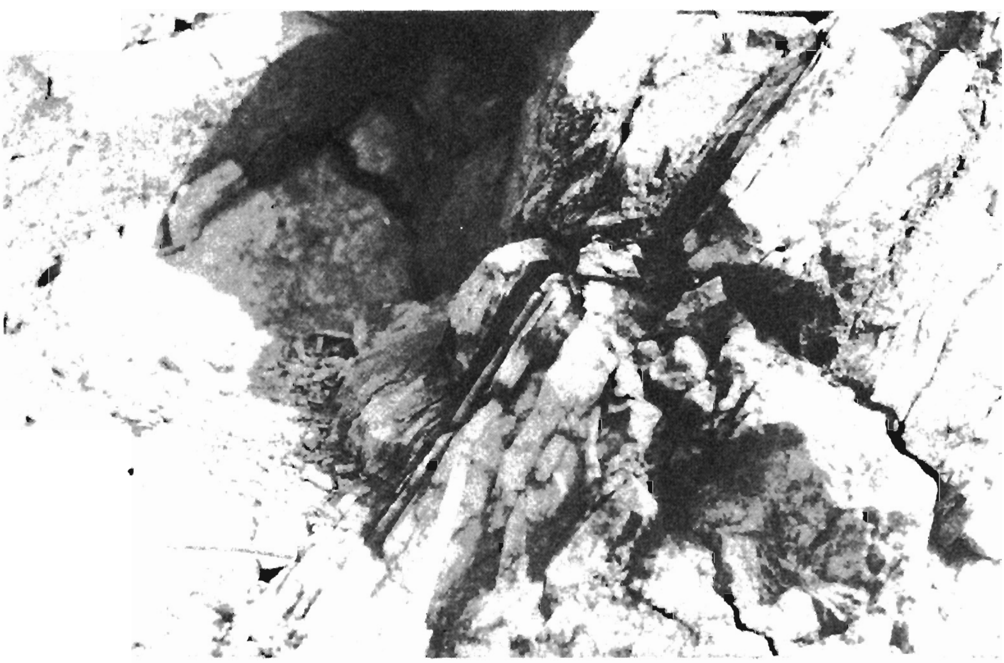


Fig. 8. Drag fold within Middle Devonian limestones exposed near Śniadka; axial zone of the Bodzentyn syncline (for location see Text-fig. 7)

Small-sized fault within Middle Devonian sandstones and shales exposed near Świętomarz: axial zone of the Bodzentyn syncline ement of the strata sets located in the noth in relation to the southern trata sets (Text-fig. 7). These folds seem to have been formed either after the Bodzentyn syncline was created, due to uplifting of its northern limb, or the uplifting was synchronous with a formation of the syncline. As apparent from the tectonic events noted in the exposures at Wzdół Plebański, the first contingency should be rather accepted, and thus the drag folds are to be connected with the Laramide activisation of the area. Such a post-Variscan activisation is also proved by a local deformation of the Zechstein deposits along the fault exposed at Świętomarz. Also the shears of southerly or south-westerly oriented dips are, according to Jaroszewski (1972), a result of the Laramide tectonic transport of the north-east direction.

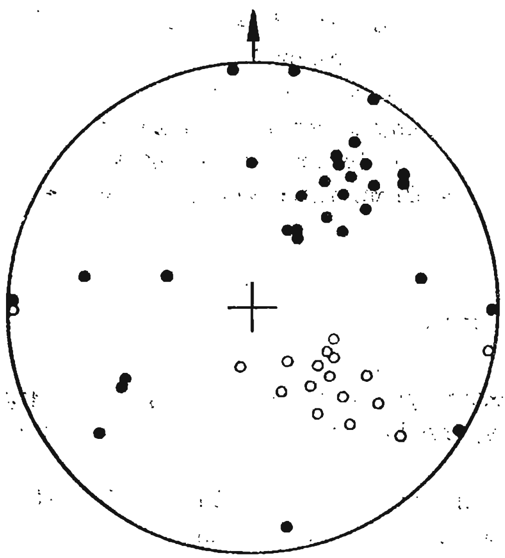


Fig. 10. Diagram of faults (*haevy dots*), and of fold axes (*quadrangles*) in the axial zone of the Bodzentyn syncline; projection on the upper hemisphere

An analysis of minor faults and folds in the Świętomarz — Śniadka section shows that their arrangement is relatively high (Text-fig. 10): the fold axes run in NW-SE direction and dip 60—40° northerly, and the minor faults run in a similar direction and dip also northerly at 70—40°. Vertical displacements noted in several cases are the evidence for a gravitational type of these faults. The other directions of fold axes and fault planes are sporadic.

Because the directions of minor faults at Wzdół Plebański and in the section Świętomarz — Śniadka are similar, they are supposed to have been formed in the same time as an effect of the Laramide movements, although the type of these faults remained different.

In spite of an apparent great deformations within the core of the Bodzentyn syncline, the attitude of the strata is highly arranged (diagram *b* in Text-fig. 3). Majority of the collected data prove that the layers dip northerly and the main maximum of the diagram is equal 110/50N. There are only some southerly dips and they are mainly a result of fine tectonic deformations. Therefore, the Laramide rejuvenation has not played a more significant part in a general structure of the axial zone of the Bodzentyn syncline.

NORTHERN LIMB OF THE SYNCLINE

An arrangement of the strata in the Lower Devonian rocks of the northern limb of the Bodzentyn syncline is differentiated (diagram c in Text-fig. 3) what makes it dissimilar to the remaining part of the syncline. The strata strikes are varying, from 10 to 120°. Most observations of the strata attitude proved the northerly dips; among them two distinct maxima can be distinguished (110/60N and 30/30N). Besides, there is a smaller maximum of southerly directed attitude of the strata (80—120/30—40S). Such a diagram is an effect of the occurrence of small folds as well as of flexural layer bends. The maximum 30/30N is, on the other hand, an effect of the deviation of strata strikes close to the transverse faults. In some exposures a close to the transverse faults. In some exposures a cleavage was observed, with southerly strikes and easterly dips, which accompanies the minor faults.

An attitude of the strata in the northern limb of the syncline, different than in the remaining regions, seems to result from an occurrence of a large dislocation zone, the Świślina dislocation, along which the Bodzentyn syncline contacts with the Bronkowice-Wydrzyszów anticlinorium (*cf.* Text-figs 1—2).

FAULTS

The investigated part of the Bodzentyn syncline is cut by three large transverse pivotal faults: the Psary, the Bodzentyn, and the Świętomarz fault (*see* Text-fig. 2).

The Psary fault throws down its eastern side in the south and its western side in the north. A displacement in the south ranges several hundred metres, and the fault extends farther to the south, cutting the Łysogóry unit. Probably, the fault had been developing before the Variscan movements, and it even influenced the sedimentation of Cambrian deposits (Mizerski 1979a, b).

The Bodzentyn fault throws down its western side in the south. The fault extends to the south and passes into the Kakonin fault that cuts the Łysogóry unit.

The above two pivotal faults result in a interesting situation south of Bodzentyn. There, the strata sets have been thrown down at a distance of several hundred metres so that the Lower Devonian outcrops of Mt. Miejska and Mt. Psarska were displaced southwards (*see* Text-figs 2 and 11). Anyway, no data are available for a wrench type of these two faults, suggested previously by Czarnocki (1957).

The Świętomarz fault, being also of a pivotal type, displays its general dip-slip character by an absence of Upper Devonian strata at its eastern side. A continuity of this fault south-wards is uncertain.

The other transverse faults are considerably smaller and of different type but the main component of a movement along their planes is the vertically displaced component.

All the investigated transverse faults do not continue within the Mesozoic sediments (*see* Text-fig. 11), and therefore they are of the Variscan age, synchronous with the fold tectonics.

The noted longitudinal faults are usually the reverse ones that throw down their southern sides, what proves their compressive origin and the Variscan age.

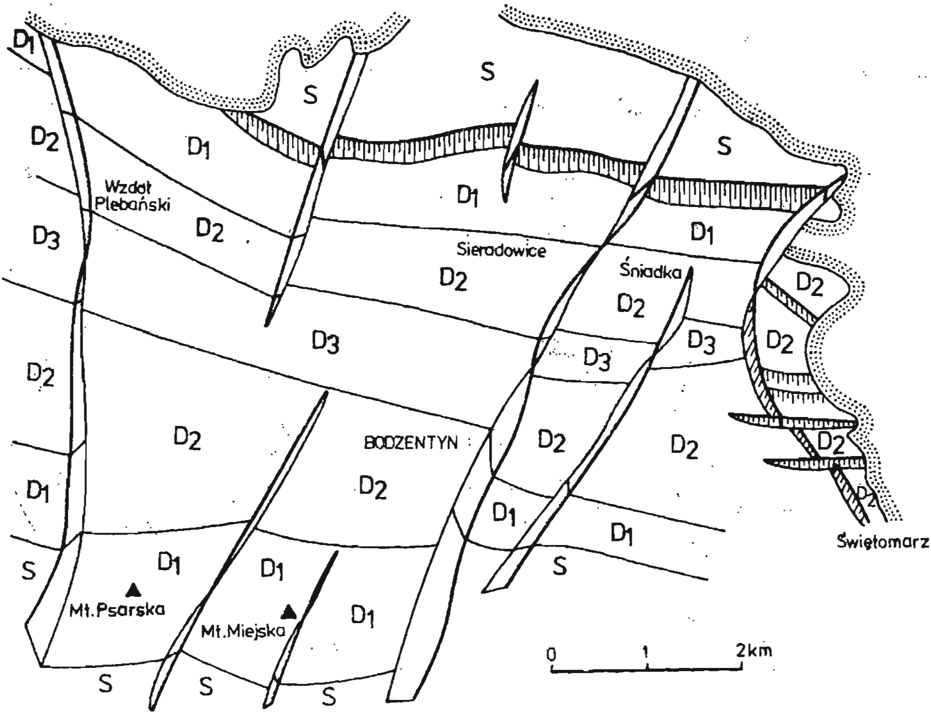


Fig. 11. Blockdiagram to illustrate the nature of faults in the investigated part of the Bodzentyn syncline (*cf.* Text-fig. 2)

JOINT SYSTEM

In this area there is generally a single fracture system of a kathetal trend what speaks for the Variscan age of the joint system (Jaroszewski 1972). In this system the fractures of the both sets are developed in different ways (Text-fig. 12).

A longitudinal set is the best developed in the southern limb and in the axial zone of the Bodzentyn syncline (diagram *a* and *b* in Text-fig. 12). The fractures of this set prove a strong trend of a perpendicular position to bed surfaces, and they are represented at the diagrams by the maxima with dips of 40—60°. An occurrence of several such maxima at the diagrams results from changes of the strata strikes (*see* Text-fig. 2). All the joint fractures are locally mineralized with calcite, and usually open.

A transverse set is well developed in the whole area and it is usually vertical, being perpendicular to the strata strikes. Therefore, the changes of the strata strikes are illustrated at a diagram by two or three maxima. But the field observations demonstrate that all these maxima represent a single joint set. Features of the fracture surfaces of the both sets and their mutual perpendicularity speak for their extensive origin, in agreement with the interpretation offered by Jaroszewski (1972).

Locally, there are extra sets of joint fractures (in the diagrams resulting in badly marked maxima) or single fractures of varying directions. As they are rare, their interpretation is difficult and needs further investigations.

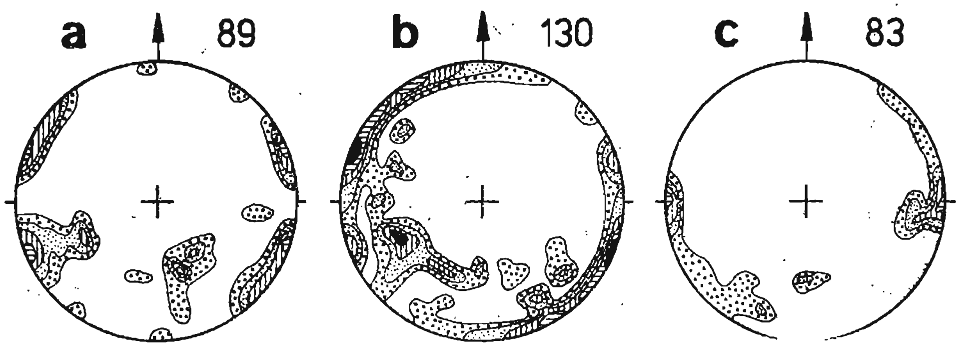


Fig. 12. Diagrams of joints (contours of 2, 4, 6, 8, and 10%; numbers of measurements indicated at top right) for the southern limb (**a**), axial zone (**b**), and northern limb (**c**) of the investigated part of the Bodzentyn syncline

Directions of joint fractures in this area prove a relatively great agreement with directions of joint fractures within the Silurian strata of the Bronkowice-Wydrzyszów anticlinorium in the north (*cf.* Text-fig. 2), noted by Mariańczyk (1973) and also by the author. A conclusion presented by Mariańczyk (1973) that a joint within the Silurian deposits should be connected with the Caledonian phase, seems however doubtful, and this joint is regarded as of the same age as that within the Devonian strata of the Bodzentyn syncline.

The measurements of density of joint fractures were done, accepting for simplification that in the investigated area there are only two joint sets. A calculation of a fracture density was based on measurements of a mean distance between the fractures of every set. A generally known regularity was found that the thicker the beds are the greater the distances between them appear. In the investigated area an interdependence of a fracture distance (*Rs*) on the bed thickness (*M*) is varying and equal (*see* Text-fig. 13): for the southern limb of the syncline Rs = 5/4M, for the axial zone Rs = M, and for the northern limb of the syncline Rs = 4/5M.

A comparability of the collected data in beds of varying thickness was received with a use of a thickness index of a fracture density, calculated after the formula given by Mastella (1972). The following values

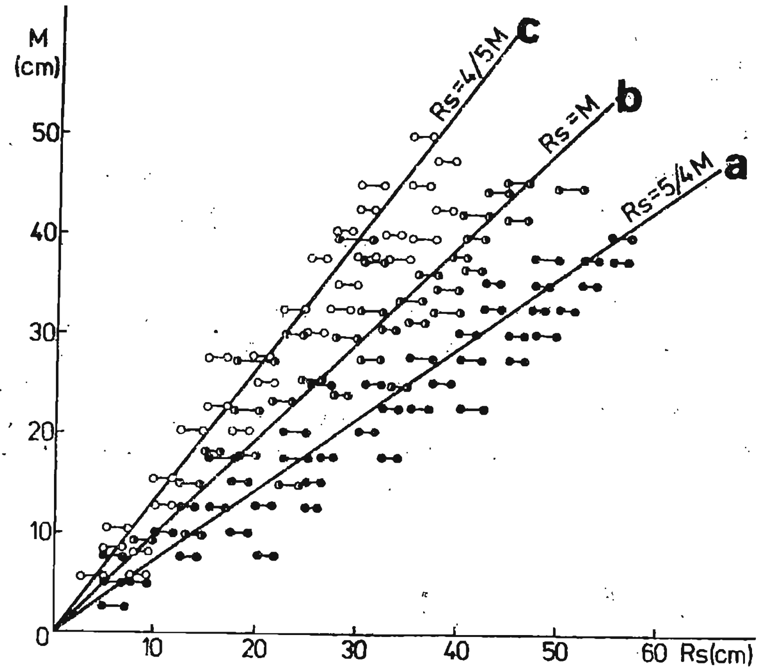


Fig. 13. Thickness of layers plotted against the joint density for the southern limb (**a**), axial zone (**b**), and northern limb (**c** of the ivestigated part of the Bodzentyn syncline; detailed explanation in the text

of the index were obtained: 0.6 for the southern limb of the syncline, 0.5 for the syncline core, and 0.4 for the northern limb. Thus, the fracture density evidently increases to the north, being probable a result of decreasing joint-creative stresses to to south. An increasing joint density in the northern limb of the Bodzentyn syncline is probably also coused by the Świślina dislocation.

REGIONAL INTERPRETATION

The Bodzentyn syncline in the investigated area displays a relatively simple tectonic structure. It is overturned southerly, its axial plane is inclined at 60—30° northerly and the axis runs in W-E direction dipping westerly at about 10°. The smaller fold deformations are caused by disharmonic folding and formed simultaneously with a development of the general structure of the syncline during the Variscan orogeny. The fold processes were accompanied by the formation of faults, transverse ones with a predominant component of vertical displacement as well as longitudinal ones of a reverse type. These processes were also associated by the formation of joint fractures that can be considered as the extensive ones. The joint density decreases systematicly southwards.

During the Laramide rejuventation of the syncline, the minor faults of NW-SE and NNW-SSE directions, as well as the shears and cleavage were formed. These minor faults are of the reverse type in the west and of the normal type in the east. During the Laramide movements the northern and southern limbs of the syncline were uplifted; at that time the longitudinal faults were also formed and they caused a vertical displacement of northern sides and shears of similar transport directions. The uplifting of the northern syncline limb resulted in a formation of drag folds there. This phenomenon is probably an effect of activisation of the Świślina dislocation as well as of uplifting (*cf.* Kutek & Głazek 1972) of the Łysogóry unit in the south. The deformation within the Devonian strata and a completely different tectonic pattern of the overlying Permo-Mesozoic cover prove that the Laramide rejuvenation of this Variscan structure was insignificant.

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ANALIZA STRUKTURALNA UTWORÓW DEWOŃSKICH ŚRODKOWEGO ODCINKA SYNKLINY BODZENTYŃSKIEJ

(Streszczenie)

Przedmiotem pracy jest analiza strukturalna środkowego odcinka synkliny bodzentyńskiej (*patrz* fig. 1—13). Synklina cechuje się stosunkowo prostą budową tektoniczną z podrzędnymi drobnymi fałdami dysharmonijnymi. W czasie jej tworzenia podczas ruchów waryscyjskich powstały również uskoki zrzutowe poprzeczne i odwrócone podłużne oraz spękania ciosowe, których gęstość zmniejsza się systematycznie w kierunku południowym. W trakcie przebudowy laramijskiej doszło tutaj do powstania drobnych uskoków oraz ścięć i kliważu. Z przebudową laramijską związane są również grawitacyjne uskoki podłużne w południowym skrzydle synkliny oraz część fałdków ciągnionych w skrzydle północnym, będące wynikiem silniejszego wypiętrzania skrzydeł w stosunku do strefy osiowej tej synkliny.
