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Early to Middle Variscan development of the West Sudetes

ABSTRACT: The Variscides overlying in the West Sudetes the Early Cadomide structure make up a continuation of the Caledonian series. They vary in structure and composition among the Kaczawa Mts, Świebodzice, Kłodzko, and Bardo structures as well as the Intra-Sudetic synclinorium and the Lower Carboniferous of the Owl Mts block. The Kłodzko structure is the only one folded during the Caledonian orogeny. The Świebodzice structure and the lower structural stage of the Bardo structure were folded during the Nassau phase. The Kłodzko structure was uplifted at that time. The Kaczawa nappes developed during the Sudetic phase. At the same time, the Bardo structure was ultimately formed, with molasse and Lower Carboniferous flysch series overlying the folds of Nassau age. Pebbles of epimetamorphic rocks found in the Devonian to Lower Carboniferous strata south of the Kaczawa Mts derived from the Proterozoic basement of the Kaczawa Mts structure. As shown by the palinspastic reconstructions, the coefficient of tectonic shortening ranges from 0.36 up to 0.80. Two distinct developmental stages are recognized in the history of the Struga and Domanów dislocations; the tectonic displacements were opposite at the two stages.

INTRODUCTION

Early Variscan development of the West Sudetes was discussed by the present author in a recent paper (Oberc 1977a). However, new and important data were discovered since the time that paper had been sent in its final version to the editor. The discoveries include recognition of the upper Lower Carboniferous and deep-water Upper Devonian deposits in the Kaczawa Mts (Urbanek 1975; Chorowska 1977, 1978), and finding of deep-water, non-flysch lower Lower Carboniferous deposits in the Bardo structure (J. Haydukiewicz 1977). Because of the appearance of these new data, one has to reconsider the age of the Early Variscan movements in the West Sudetes. There are also some implications for the position of the Świebodzice structure relative to the folds of the Kaczawa Mts.

The West Sudetes are here meant in the structural-geological sense, that is as the area west of the Ramzova overthrust. The neighboring area of the Fore-Sudetic block is also discussed in the present paper, as it bears a prolongation of some Variscan units of the West Sudetes. The tectonic structure of the Variscan units of the area under discussion is out of the scope of the present paper because it was presented separately (Oberc 1977a).

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PRE-VARISCAN BASEMENT

In general, the Variscan cycle comprises post-Silurian Paleozoic sequences. The Paleozoic sequences start with Cambrian, Ordovician, Silurian, Devonian, or even Carboniferous strata in various structural units of the Sudetes. Aside of the South Karkonosze Mts, which are out of the scope of the present paper, and possibly also the Kłodzko structure, Caledonian tectonics did not affect the Sudetes (Oberc 1977b). Hence, the Caledonian sequences (Cambrian to Silurian) are here considered within the framework of the Variscan cycle because they underwent deformations along with the Variscan ones.

The term pre-Variscan basement is meant in the present paper as the basement of the Variscan sequences instead of the Variscan structural units. The point is that the basement of Proterozoic age has become involved in some Variscan structures (Kaczawa Mts, Kłodzko structure, Bardo structure).

The pre-Variscan basement of the Sudetes crops out in the Kaczawa Mts, Kłodzko structure, Bardo structure, Owl Mts by Nowa Ruda, Karkonosze-Izera block, and Fore-Sudetic block (Fig. 1). Its structure was already discussed by the present author (Oberc 1965, 1966a, 1977a). The nucleus of the basement consists in the Moldanubian block of the Owl Mts built up by gneisses of probably Late Proterozoic age. The block is triangular in shape and its western angle separates two branches of the Early Cadomide tectogen. The southwest, that is Orlica-Izera branch of the Early Cadomides includes the Karkonosze-Izera block, old metamorphic rocks of Kłodzko and Nowa Ruda areas, metamorphics of Bystrzyca Mts and Orlica Mts, and a part of Śnieżnik metamorphics; the branch shows a southwesterly vergency. The north branch of the Early Cadomides includes the Radzimowice slates of the Bolków unit of the Kaczawa Mts and the metamorphic rocks of Wądroże and Imbramowice; this branch shows more or less southerly vergencies. The east branch shows easterly vergencies and borders the Owl Mts block from the east. Its prolongation to the south is represented by the rest of Śnieżnik metamorphics and the metamorphic rocks of Biała Mts and Gold Mts. The Early Cadomide tectogen is built up of gneisses, mezozonal schist series,

serpentinites, and gabbros. The schists are but weakly metamorphosed here and there, as *e.g.* in Przybkowice and Radzimowice areas or in the Pre-Sudetic block.

In turn, the Late Cadomide tectogen is very poorly represented in the Polish Sudetes. Actually, it occurs in Poland in form of the Kamień beds (Kamenzer Schichten *in* Brause & Hirschmann 1964) pressed inbetween the structure of Kaczawa Mts and the Izera block.

VARISCAN STRUCTURES

Variscan structures of the West Sudetes and the neighboring part of the Fore-Sudetic occur south, west, and north of the Owl Mts block covered in places with minute patches of Lower Carboniferous deposits. The West-Sudetic Variscides (Fig. 2) are briefly described below.

KACZAWA MTS

The structure of Kaczawa Mts (Figs 2-3) was for long assigned to Caledonides (Bederke 1924, Block 1938, Schwarzbach 1939, H. Teisseyre *in* Smulikowski & Teisseyre 1953). However, Oberc (1967) recognized Lower to Middle Devonian rocks in the Kaczawa Mts and concluded that the epimetamorphic Paleozoic rocks of that area had underwent Early Variscan folding prior to the Late Devonian sedimentation evidenced in the Świebodzice structure. A similar conclusion was also reached by H. Teisseyre (1975) who cited the Bretonian phase in this context. Later on, Lower Carboniferous strata were documented in the Kaczawa Mts (Chorowska & Ozonkowa 1975; Chorowska & Sawicki 1975; Chorowska 1977, 1978), which made the basis to a claim that the main folding phase had been the Sudetic phase (Chorowska 1977, 1978). The latter opinion was also

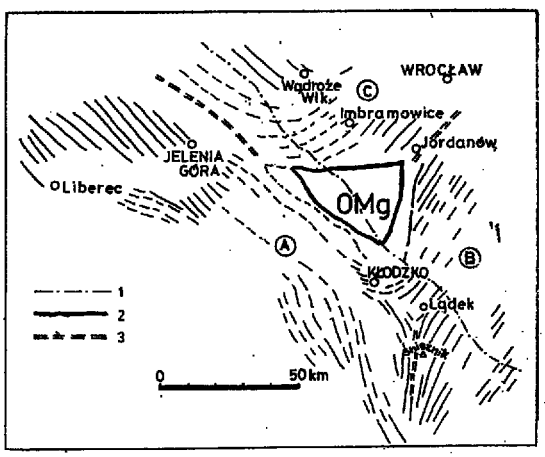


Fig. 1

Early Cadomide structure in Lower Silesia (*after* Oberc 1966)

1 Sudetic Marginal fault, 2 range of the Owl Mts block, 3 boundaries between distinct branches of the Early Cadomide tectogen

A Orlica-Izera branch, B eastern branch, C northern branch, OMg Owl Mts gneisses

followed by Oberc (1978). By the way, deep-water Upper Devonian sedimentary rocks were recognized in the Kaczawa Mts by Urbanek (1975).

Modern work on the tectonic structure of the Kaczawa Mts started with Schwarzbach (1939) who recognized the so-called Bolków-Wojcieszów anticline for a „Decksattel". The latter idea was followed and developed by H. Teisseyre (*in* Smulikowski & Teisseyre 1953) who demonstrated the nappe structure of the south Kaczawa Mts. Accordingly to that author, the Bolków-Wojcieszów anticline

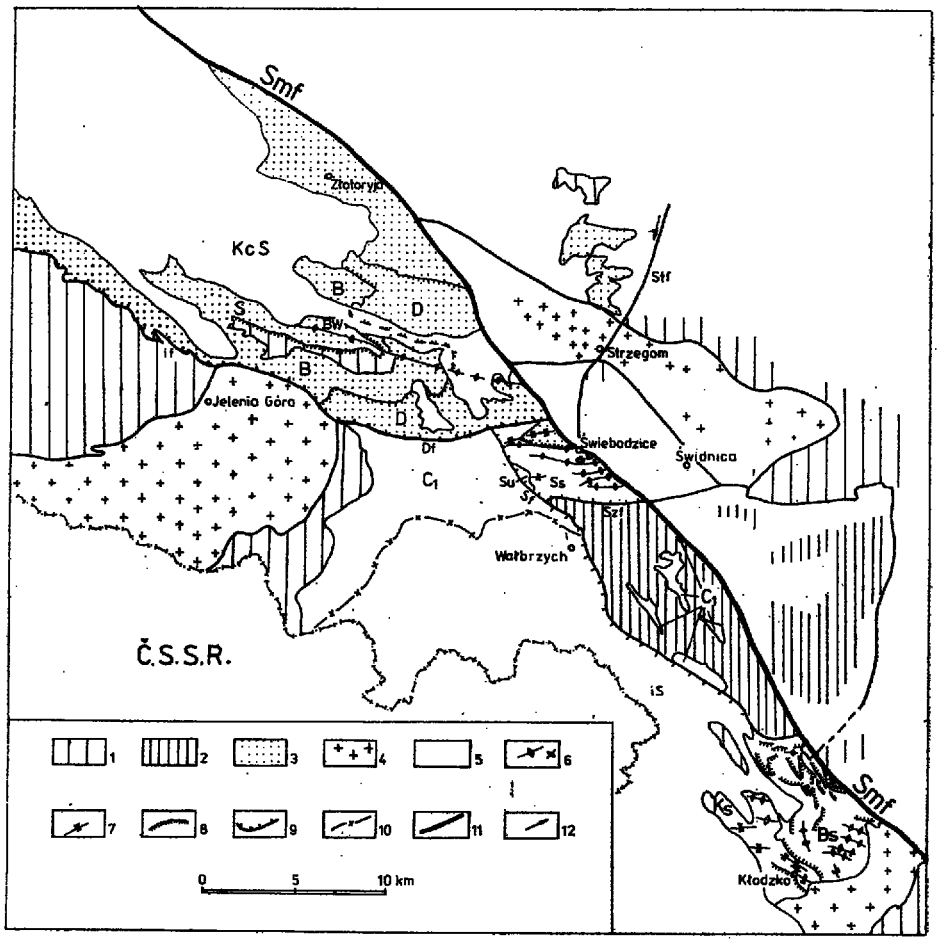


Fig. 2. West-Sudetic Variscides

1 Early Cadomide structures, *2* Moldanubian structures, *3* Paleozoic strata of the Kaczawa Mts, *4* Asturian granitoid intrusions, *5* post-Lower Carboniferous series, *6* anticline axes, *7* syncline axes, *8* overthrusts, *9* Variscan faults, *10* Lower/Upper Carboniferous boundary in the Intra-Sudetic synclinorium, *11* major tectonic boundaries, *12* displacements along the Strzegom fault

Tectonic units: *Kc* Kaczawa Mts structure (*S* Świerzawa unit, *D* Dobromierz unit, *B* Bolków unit, *BW* Bolków-Wojcieszów anticline), *KcS* North-Sudetic synclinorium, *Ss* Świebodzice structure, *Su* Struga diapiric fold, *iS* Intra-Sudetic synclinorium, *Ks* Kłodzko structure, *Bs* Bardo structure, O_1 Lower Carboniferous of the Owl Mts block and Intra-Sudetic synclinorium

Faults: *if* Intra-Sudetic Main fault, *Df* Domanów fault, *Sf* Struga fault, *Szf* Szczawienko fault, *Smf* Sudetic Marginal fault, *Stf* Strzegom fault

consists of the Świerzawa, Bolków, and Dobromierz units lying successively one over another. The highest tectonic unit of that structure (that is the Cieszów unit) has persisted up to date exclusively in the Świebodzice structure. The Bolków and Dobromierz units are actually nappes thrown south-southwestwards. It is to be noted that both the latter units may also continue north of the Świerzawa graben (Oberc 1967, A. Haydukiewicz 1977).

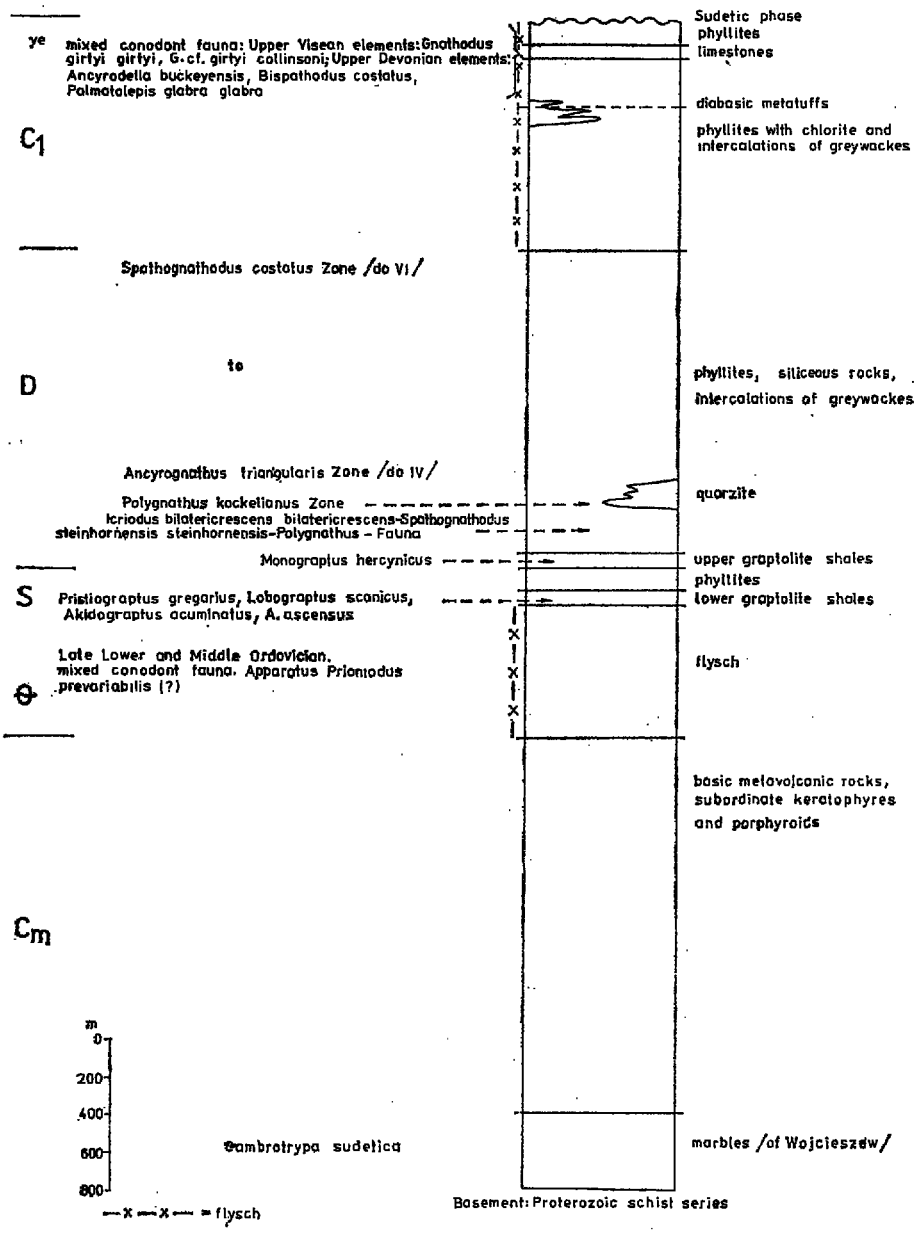


Fig. 3. Rock sequence in the Kaczawa Mts (*after* Schwarzbach 1939; H. Teisseyre 1953, 1963; Jaeger 1964; Gunia 1967; Baranowski & Urbanek 1972; Kornaś 1974; Urbanek 1975; Chorowska 1978)

ŚWIEBODZICE STRUCTURE

The Świebodzice structure (Figs 2 and 4) was for long interpreted as a part of the Intra-Sudetic synclinorium. H. Teisseyre (1956) was the first who recognized it for a distinct structural unit because of a difference from the synclinorium in the tectonic style as well as the age of sedimentation and main folding. The Świebodzice structure comprises mostly molasse deposits assigned to the Upper Devonian (Pavlik 1939; Gunia 1966, 1968) to lowermost Carboniferous. The folding of Świebodzice structure is to be assigned to the Nassau phase (Oberc 1967) followed in that area by erosion (Oberc 1972). The overthrust of sequences typical of the Kaczawa Mts (H. Teisseyre *in* Smulikowski & Teisseyre 1953) is to be related to a later tectonic phase. Relatively old rocks similar to the Paleozoic of the Kaczawa Mts appear also in the diapiric fold of Struga, squeezed out from beneath that unit (J. Teisseyre 1962).

The diastrophic deposits found in the Świebodzice structure were commonly assigned to erosion of the presumed Kaczawa elevation. This argument followed from the close geographic relationship between the two structures, and the assumption of Early Paleozoic to Middle Devonian age of the rocks found in the Kaczawa Mts. The Carboniferous age of the Kaczawa structure requires therefore a reconsideration of the Świebodzice structure. The present author is of the opinion that the pebbles of epimetamorphic Precambrian rocks and Devonian to Lower Carboniferous sedimentary rocks that occur in the Świebodzice structure derived from a cordillera risen from a part of the Kaczawa basin, whereas sedimentation persisted in the rest of the basin.

KŁODZKO STRUCTURE

The Kłodzko structure (Figs 2 and 5-6) appears at the surface in form of pre-Carboniferous patches scattered over the outcrops of younger deposits, mainly in the Intra-Sudetic synclinorium. The metamorphic rocks of the Kłodzko structure (Fischer *in* Finckh & *al.* 1942, Wojciechowska 1966) were attributed to the Ordovician to Devonian (Bederke 1924, Fischer *in* Finckh & *al.* 1942, Oberc 1957) but finally, some Ludlovian corals have been found to occur in limestone intercalations in the phyllites (Gunia & Wojciechowska 1964, 1971). The phyllites are overlain by epizonally metamorphosed geosynclinal volcanics lacking in their turn any cover of younger geosynclinal deposits. The age of folding cannot therefore be precisely determined but accordingly to the present author, it is to be assigned to the Early Devonian (Oberc 1972). The deformations consist in an intense folding of southern vergency which embraced the Silurian rocks and the volcanics as well as the Proterozoic basement metamorphosed mezozonally during the Early Cadomide movements. The Silurian rocks have underwent merely an epizonal metamorphism. Prior to the Late Devonian, the entire structure was eroded down to the pre-Silurian basement (amphibolites and gneisses). Thereafter, shallow-water limestones accumulated, attributed to the Upper Devonian and up to the Gattendorfia Stage (Tietze 1867, Gürich 1902, Schindewolf 1937, Chorowska 1974); this is so-called Kłodzko Devonian (Fig. 6). The shallow-water nature of the Kłodzko Devonian contrasts with the adjacent deep-water Upper Devonian of the Bardo structure (Oberc 1977a). Furthermore, deep-water Lower Carboniferous rocks (upper Mikołajów shales) occur at Gołogłowy, thrust over the Devonian limestones. Accordingly to Chorowska (1974), the Gattendorfia Stage is absent from the Gołogłowy section.

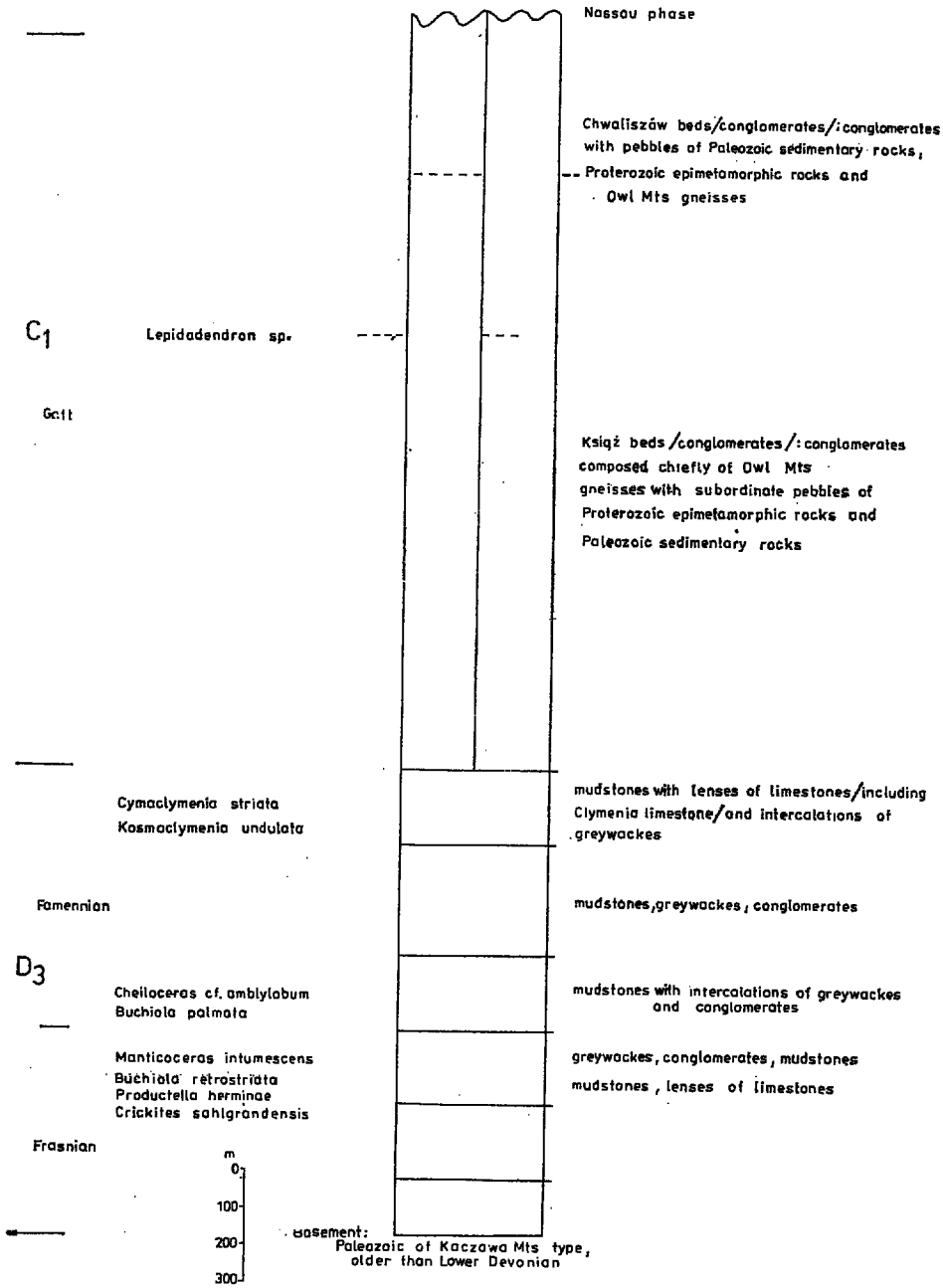


Fig. 4. Rock sequence in the Świebodzice structure (*after* Pavlik 1939, H. Teisseyre 1957, Gunia 1968)

BARDO STRUCTURE

The Bardo structure (Figs 2 and 7—8) comprises non-metamorphosed sedimentary rocks of Ordovician to Early Carboniferous age (Beyrich 1844, Krug von Nidda 1853, Dathe 1904), including a thick shale series (Herzogswalder Schichten *in* Dathe 1904) interpreted initially as Ordovician or Silurian (Bederke 1924, Dahlgrün & Finckh 1924) but attributed finally to the Lower Devonian to Lower Carboniferous (Oberc 1953, 1957; Kuchciński 1964; J. Haydukiewicz 1977). The controversy on age attribution of the shale series resulted also in a hot dispute focused at the age of folding preceding sedimentation of the Carboniferous molasse and flysch. In fact, the Early Caledonian (Bederke 1924, Teller 1959), Orcadian (Oberc 1957), and Early Bretonian movements (Oberc 1966b) were referred to in this context. Finally, Oberc (1978) assigned this folding to the Nassau phase basing upon an analogy to the Kłodzko Devonian (*cf.* Schindewolf 1937, Oberc 1957). The Lower Carboniferous molasse and flysch deposits had in their turn been folded during the Sudetic phase (Bederke 1929), the age of which was determined by Oberc (1957) as prior to the Goniatites granosus Zone because of the occurrence of lowermost Upper Carboniferous strata directly at the eroded Bardo structure.

The tectonic structure of Bardo structure (Beyrich 1844, Dathe 1904, Bederke 1929) is now regarded as a fairly complex one. In fact, Oberc (1957) recognized in that area some 50 folds, thrust slices and overthrusts including, related to the Sudetic (northerly and southwesterly vergencies) and Asturian phases (westerly vergency). The Asturian folds make up a prolongation of the Niemcza lineament southwards and split the structure developed during the Sudetic phase into its eastern and western parts.

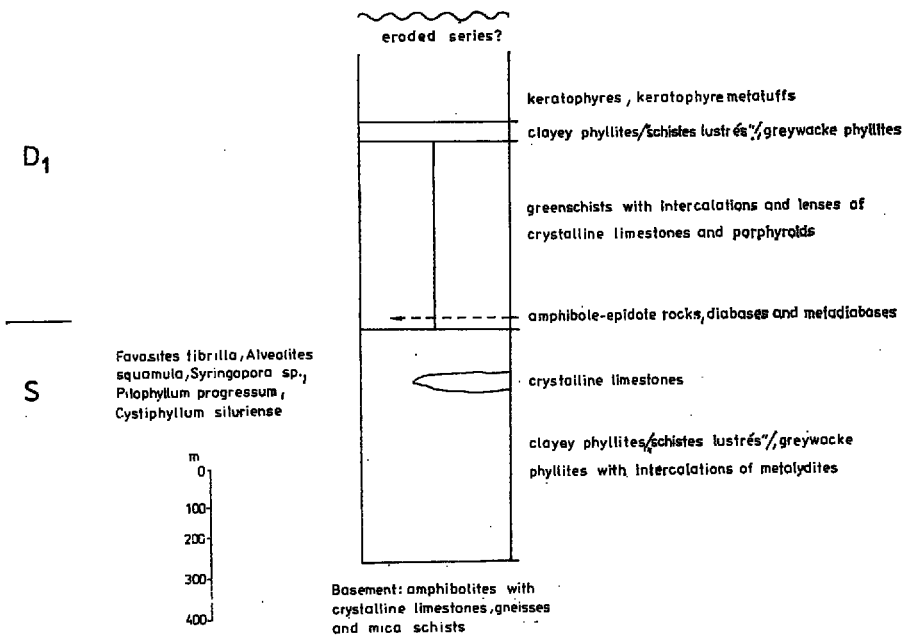


Fig. 5. Rock sequence in the Kłodzko structure (*after* Fischer *in* Finckh & *al.* 1942, Wojciechowska 1966, Gunia & Wojciechowska 1971, Oberc 1972)

INTRA-SUDETIC SYNCLINORIUM AND OWL MTS BLOCK

Sedimentary series building up the Intra-Sudetic synclinorium (Figs 2 and 9) cover the boundaries between various tectonic units comprising older rocks. Their equivalents, and those of the Carboniferous structural stage of the Bardo structure as well, covered also the Owl Mts block (Figs 2 and 10) but they have persisted merely in a part of the Fore-Sudetic portion of the eroded Owl Mts block.

The section of the Intra-Sudetic synclinorium starts with Lower Carboniferous diastrophic deposits. Accordingly to H. Teisseyre (1975), the material derived

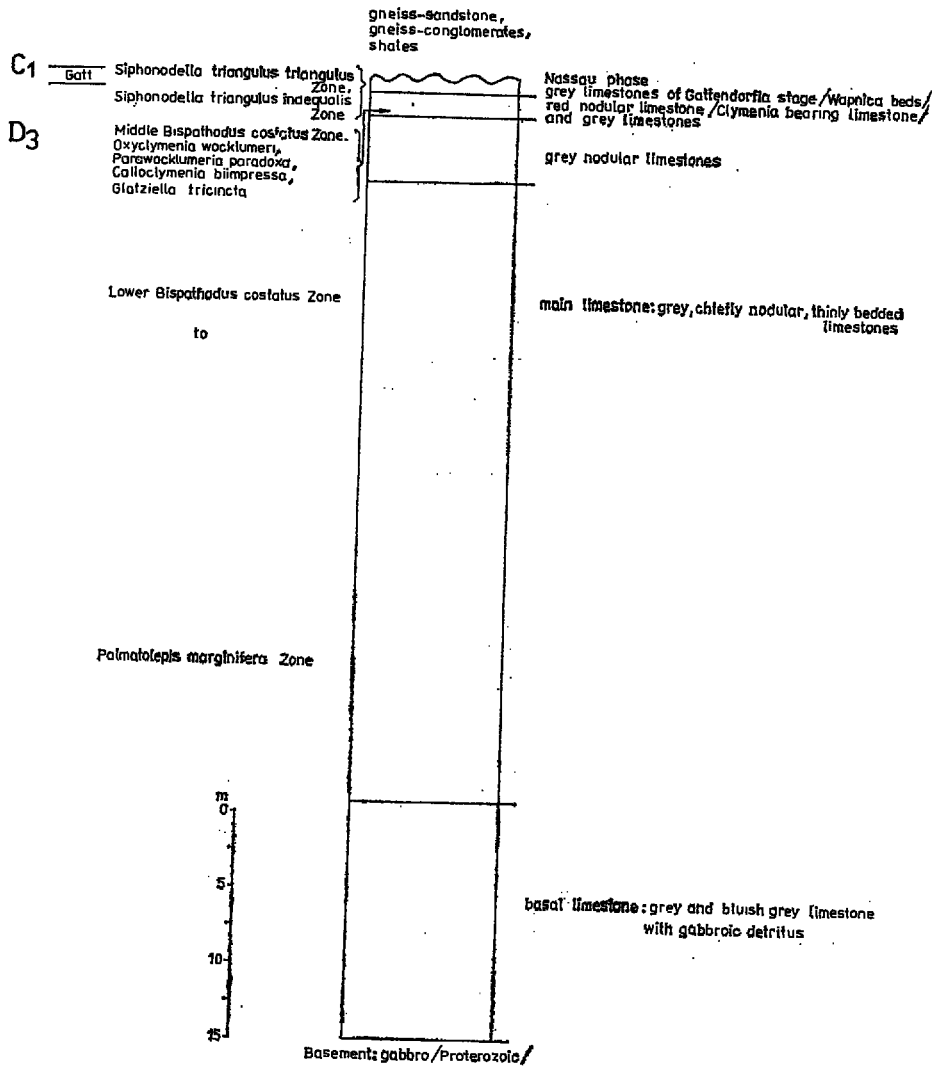


Fig. 6. Rock sequence in the Kłodzko Devonian, Wapnica Hill at Dzikowiec (*after* Schindewolf 1937, Chorowska 1974)

from the folded and weakly metamorphosed sequences of the Kaczawa Mts. The Tournaisian is represented by molasse deposits (Oberc 1966b) attaining their maximum thickness in the west. The Visean sea persisted up to the Early/Late Carboniferous boundary. Bederke (1929) claimed that the sedimentary series had underwent some deformations during the Sudetic phase. However, a sedimentary continuity was recognized between the marine Visean and continental Namurian strata in the axial part of the synclinorium (H. Teisseyre 1959, Dziedzic 1960, Grocholski 1960). Thus, the tectonic structure was formed mostly during some later tectonic phases, in particular the Asturian and Laramian ones, discussion of which is out of the scope of the present paper.

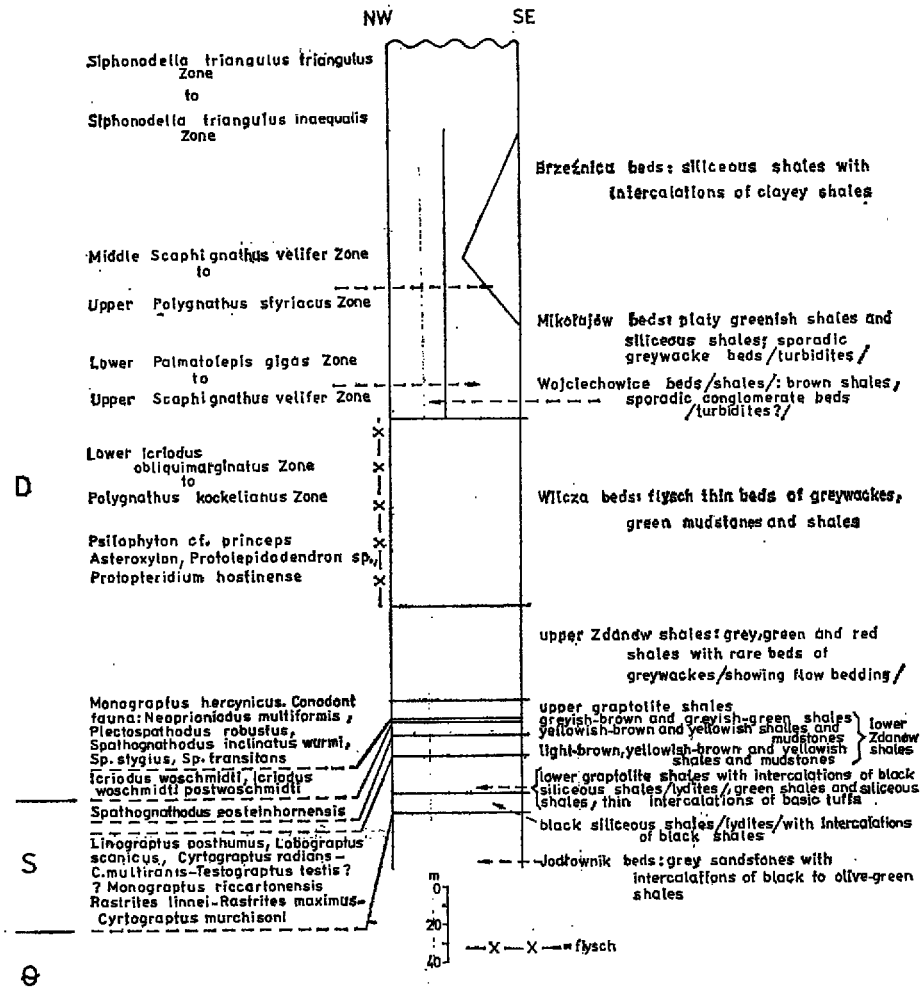


Fig. 7. Rock sequence in the lower structural stage of the Bardo structure (*after* Malinowska 1955, Teller 1960, Kuchciński 1964, Chorowska 1973, J. Haydukiewicz 1977, Chorowska & Oberc 1980)

VARISCAN SEQUENCES

The hitherto recognized thicknesses and spatial relationships in the West-Sudetic Variscan sequences (Figs 3—10) permit some general conclusions relevant to the topic under discussion.

The Variscan geosyncline expanded gradually with time. It embraced the Kaczawa Mts at the Early Cambrian, the South Karkonosze Mts (outside Poland) and Bardo structure at the Ordovician, the Kłodzko structure probably at the Silurian. At the moment, one can hardly determine precisely the time of the onset of pre-Late Devonian sedimentation in the Świebodzice structure. The deep-water nature of the pre-Late Devonian sediments in all the Variscan units, and the lack of

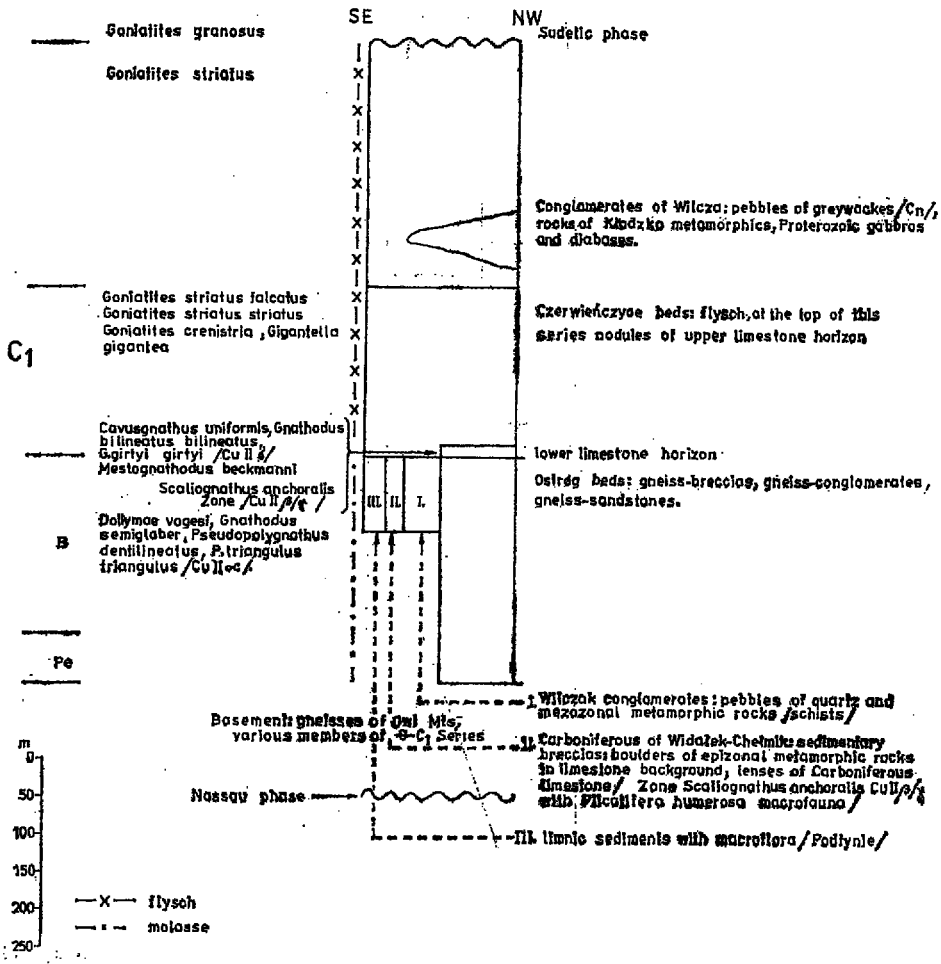


Fig. 8. Rock sequence in the upper structural stage of the Bardo structure (*after* Oberc 1957, Oberc & Górecka 1959, Żakowa 1963, Górecka & Gunia 1964, Chorowska 1973)

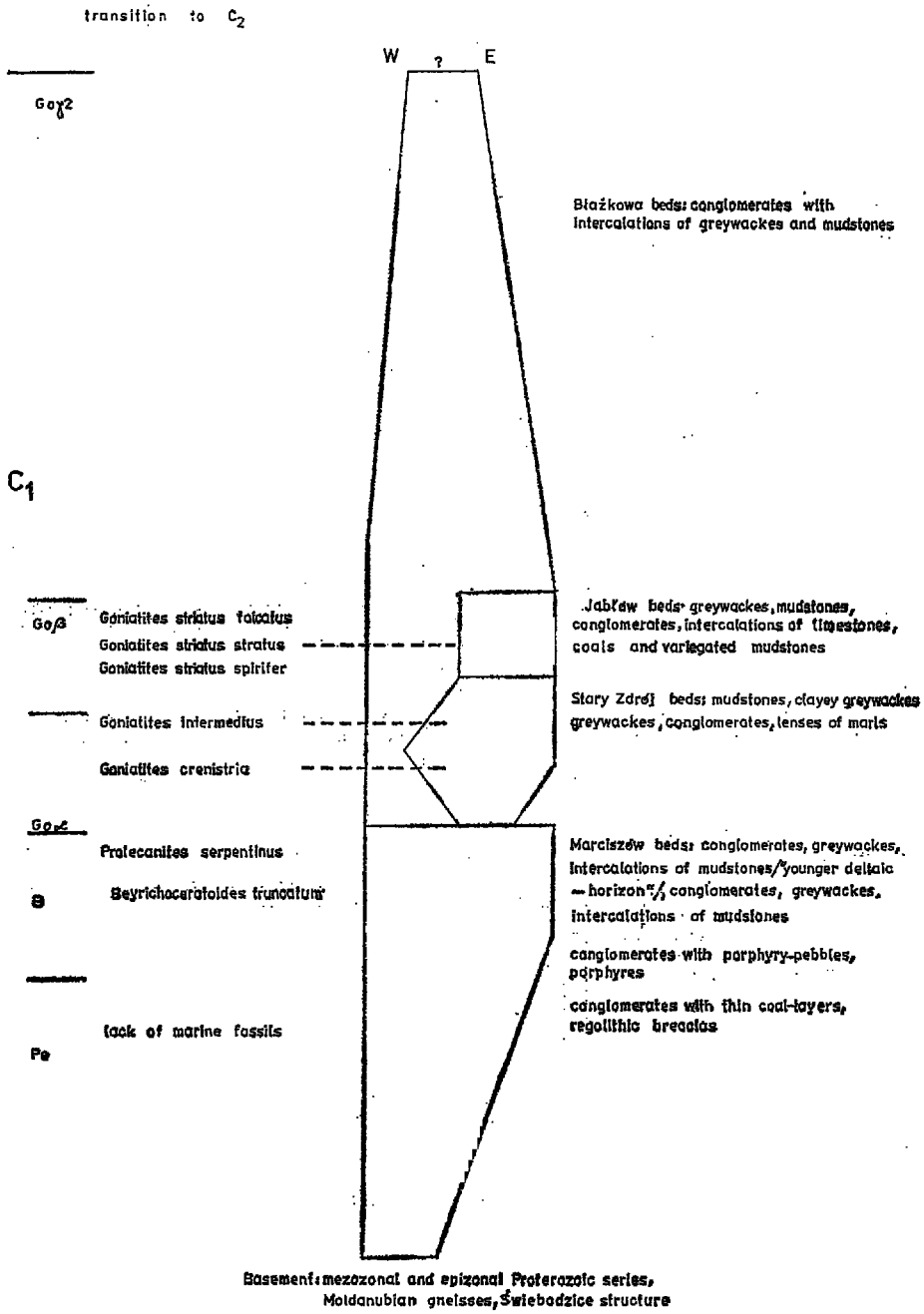


Fig. 9. Rock sequence in the Intra-Sudetic synclinorium (*after* Żakowa 1958, 1963)

any time equivalent shallow-water facies support a claim that one deals with a single Variscan geosyncline in the investigated area.

The geosynclinal volcanism did not accompany the expansion of the geosyncline. Prior to the Devonian, the Bardo basin was actually a miogeosyncline with poorly developed volcanism (*cf.* Malinowska 1955). At the Early Devonian, volcanic activity became more intense, as indicated by diabases present in the lower Zdanów shales (Dathe 1904, Chorowska & Oberc 1980). In the Kłodzko structure, geosynclinal volcanics overlie the Ludlovian and represent now the youngest member of the sequence (Oberc 1972). Volcanic activity started also during the Late Silurian in the South Karkonosze Mts (Chaloupský & *al.* 1968).

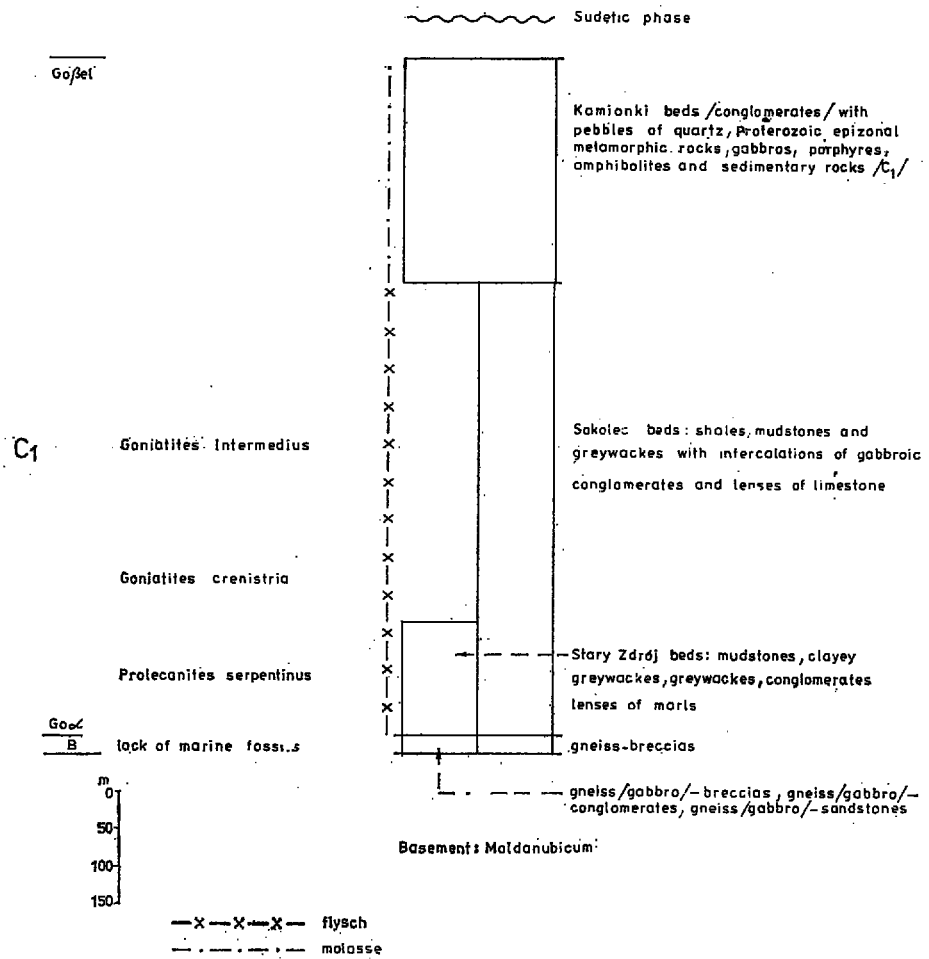


Fig. 10. Rock sequence in the Lower Carboniferous of the Owl Mts block (*after* Żakowa & Żak 1962, Żakowa 1963)

SYNSEDIMENTARY MOVEMENTS AND THEIR EFFECTS

Effects of the oldest synsedimentary movements in the West Sudetes are represented by the Ordovician (Baranowski & Urbanek 1972) flysch of the north Kaczawa Mts (Baranowski 1975). The flysch was probably related to erosion of the cordillera of the Izera Mts (Oberc 1966b) which supplied actually material to the Ordovician conglomerates of the South Karkonosze Mts (Chaloupský 1963).

Synsedimentary movements are also evidenced by the Middle Devonian (Kuchciński 1964) flysch Wilcza beds, Bardo structure, but one can hardly point to any source area in this case.

Prior to the Late Devonian, folding and subsequent epimetamorphism ended the geosynclinal development of the South Karkonosze Mts and Kłodzko structure.

The Middle/Late Devonian boundary appears as a critical moment in the Variscan development of the West Sudetes. At that time, rapid subsidence started in Świebodzice area. The sedimentary basin developed at rocks typical of the Kaczawa structure, as evidenced by the rocks squeezed out from beneath the Świebodzice structure in the Struga unit (J. Teisseyre 1962). The basin received mudstones and limestones associated with molasse-type deposits. The molasse material derived mostly from the south (Pavlik 1939, H. Teisseyre *in* Smulikowski & Teisseyre 1953, Gunia 1968) but also from the north (H. Teisseyre 1968b, Gunia 1968). The nature of the Late Devonian sedimentation in the Świebodzice structure can be explained exclusively by appearance of a cordillera in that part of the Kaczawa basin that corresponds more or less to the later developed (namely, during the Sudetic phase) anticlinal elevation of Bolków-Wojcieszów. The cordillera should have comprised Paleozoic rocks overlying weakly metamorphosed Proterozoic schists. In fact, having demonstrated the occurrence of geosynclinal Lower Carboniferous sequence in the Kaczawa Mts (Chorowska 1978), one can hardly claim that the epimetamorphic detrital material found in the Devonian of the Świebodzice structure derived from the Kaczawa structure. The material must have derived from the above proposed cordillera overridden by the nappe units of the south Kaczawa Mts during the Sudetic phase.

The extent of the cordillera can hardly be determined. In the west, the Świebodzice basin terminated at the slopes of the East Karkonosze Mts (Oberc 1966b). Eastwards, the basin extended over the Fore-Sudetic block where it has thus far been but poorly recognized close to the Sudetic Marginal fault. The effects of the cordillera on the Upper Devonian facies are so far known only at its southern side. One should however keep in mind that some greenschist pebbles found in conglomerates in the Świebodzice structure may have derived from the South Karkonosze Mts that may actually continue towards the Kłodzko structure. At the northern side of the cordillera, its effects upon the facies distribution are to be looked for in the deep structure of the Świerzawa unit. In fact, the Upper Devonian of the Rzeszówek unit, contacting with the Świerzawa unit from the north and making actually part of the Bolków structure (Oberc 1967, A. Haydukiewicz 1977), is represented by deep-water sediments (Urbanek 1975).

The sedimentary basin of Świebodzice has become extinct during the Nassau phase when a bundle of mediotype, latitudinally directed folds developed (Oberc 1966b, H. Teisseyre 1968b). These movements affected both the Kaczawa and Intra-Sudetic portions of the Variscan geosyncline. They are certainly responsible

for development of the Lower Carboniferous flysch recorded by Chorowska (1978) at Rząśny, north to Gryfów, in the Bolków unit close to the southern boundary of the Kaczawa structure. On the other side, the folds of the Świebodzice structure, cut across by the synsedimentary Domanów fault (A. K. Teisseyre 1966), supplied detrital material to the Intra-Sudetic synclinorium. Pebbles of epimetamorphic rocks found commonly in the synclinorium were thus far regarded as derived from the Lower Paleozoic of the Kaczawa Mts (Radwański 1954; H. Teisseyre 1958, 1975; A. K. Teisseyre 1971). It is however to be noted that the latter sequences were not folded and metamorphosed prior to the Sudetic phase; one may therefore claim that the source of the pebbles of epimetamorphic rocks was the Proterozoic of the South-Kaczawa cordillera.

The East Karkonosze Mts had also undergone uplift at the Nassau phase and supplied thereafter enormous amounts of detrital material to the Intra-Sudetic synclinorium. One may thus conclude that development of the thick molasse cover consisting mostly of continental conglomerates started with the Nassau phase in the Intra-Sudetic synclinorium.

The Devonian up to Gattendorfia Stage strata of the Kłodzko structure represent a shallow-water facies; whereas the Kłodzko metamorphics and Nowa Ruda gabbros made up a threshold setting the western limit to the deep-water Devonian facies of the Bardo structure. The present-day contact of both the facies along the boundary of the Bardo structure, in particular at Gołogłowy, is indicative of considerable overthrusts at a distance equal to at least that one usually separating shallow-water facies from typically geosynclinal ones. The most plausible hypothesis is that the sedimentation in the Kłodzko basin stopped coevally with the pre-flysch sedimentation in the Bardo basin. This hypothesis is in fact supported by the occurrence of Tournaisian conodonts in the Mikołajów shales at Gołogłowy (J. Haydukiewicz 1977). There is no sedimentary continuity between the Devonian of Gołogłowy and the overlying Mikołajów shales, as Chorowska (1974) demonstrated the lack of the Upper Bispathodus costatus to Siphonodella triangulus triangulus Zones at that section. There are no strata intermediate in facies between the shallow-water Devonian limestones and the deep-water Mikołajów shales, which indicates that the section does not reflect any Tournaisian transgression. One may therefore conclude that contrary to the opinion of J. Haydukiewicz (1977), there indeed exists the Gołogłowy fold of Asturian age (Oberc 1957). In theory at least, one may also put forth another hypothesis. The post-Nassau synclines of the south and central Bardo structure could actually receive detrital influx from the eroded anticlines; then, a sedimentary continuity from the Mikołajów shales to the Lower Carboniferous flysch is to be expected.

The sedimentary cover of the Nassau folds is indicative of a fundamental paleogeographic reorganization. In the north Bardo Mts, the cover starts with molasse deposits passing upwards into a flysch sequence; in the south and east Bardo Mts, the flysch accumulated directly at various members of the Silurian to lowermost Carboniferous sequence. A cordillera developed at the Goniatites crenistria/Goniatites striatus Zone boundary, the effect of which are the Wilcza conglomerates composed mostly of pebbles of the Lower Carboniferous greywackes that accumulated in the Bardo basin (Oberc 1957, 1966b). The flysch sedimentation persisted up to the Sudetic phase; the latter happened however somewhat earlier than it is generally assumed.

The Sudetic and Asturian movements formed finally the fold structure of the Bardo structure. The Sudetic-Asturian structural plan embraced also the previously folded Ordovician to lowermost Carboniferous sequences. The latter strata appear

in the axial parts of anticlines and overthrusts attaining up to 4 km in distance even at the present-day intersection niveau (Oberc 1957, 1966b).

The complex tectonics of the Bardo structure was recently explained by Wajsprych (1978) by sliding of the pre-Carboniferous rocks from the Kaczawa structure down to the Bardo flysch basin. The present author is however of the opinion that the sliding model of tectogenesis of the Bardo structure is to be refuted (Oberc 1979).

The Sudetic movements stopped also the flysch sedimentation in the Kaczawa basin (Chorowska 1977, 1978) and the Lower Carboniferous sedimentation at the Owl Mts block.

One may thus conclude that the West-Sudetic Paleozoic sequences underwent folding during several successive phases, Late Caledonian through Asturian (Table 1). All the fold bundles show more or less southerly vergency.

Table 1
Main folding phases in the West-Sudetic Variscan structures

Tectonic structure	Folding phase
South Karkonosze Mts	Late Caledonian
Kłodzko structure	Early Devonian
Świebodzice structure	Nassau phase*
Kłodzko Devonian	Nassau phase*
Lower stage of Bardo structure	Nassau phase*
Kaczawa Mts structure	Sudetic phase
Bardo structure	Sudetic phase
Owl Mts block	Sudetic phase
Intra-Sudetic synclinorium	Asturian phase (and Laramide phase)

* The Nassau phase may vary in timing among the units.

PALINSPASTIC RECONSTRUCTIONS

Palinspastic reconstructions of the West-Sudetic Variscan structures (Figs 11—12) cannot for the moment be precise because the structures are fairly poorly exposed, often deeply buried under the overlying strata, sometimes considerably degraded and hence with unrecognizable original spatial distribution. The present reconstructions are therefore to be regarded as preliminary ones. Much bias is introduced to the reconstructions by longitudinal discontinuous deformations associated with folds, the vertical separation of which can hardly be determined. In such a case, the minimum value was assumed. One can also hardly estimate intensity of stretching of the strata that underwent tension, as *e.g.* in limbs of overturned folds.

ŚWIEBODZICE STRUCTURE

The present reconstruction is based upon the geological section given by H. Teisseyre (1968b, Text-fig. 2, section *E*). It is concerned only with a part of the original basin because the fold bundle of Świebodzice is cut down by the

Struga and Szczawienko dislocations in the south, and by the Domanów fault in the north. The reference point of the reconstruction is at the western angle of the Owl Mts block. Of the numerical results (Table 2), one may conclude that the investigated part of the Świebodzice basin extended northwards further than to the Bolków-Wojcieszów structure.

KACZAWA MTS

When dealing with the Kaczawa portion of the Variscan geosyncline, one has to take into account the palinspastic reconstruction of the Świebodzice structure because the deposits of Kaczawa geosyncline were partly involved in folding of the Świebodzice structure. However, the present paper is aimed to reconstruct the tectonic units themselves rather than the original geosynclinal basin and hence, the reference point chosen for the present reconstruction of the Kaczawa Mts is the southernmost range of the Świerzawa unit, that is the lowermost tectonic unit of that part of the Kaczawa structure. The basic assumption is here that the Świerzawa unit is autochthonous which may actually be disputable.

The palinspastic reconstructions are based upon the geological sections given by H. Teisseyre (1963) supplemented here and there with hypothetical data. The original sections range only up to the Świerzawa graben, whereas the investigated tectonic units extend actually much northwards. Accordingly to Oberc (1967) and A. Haydukiewicz (1977), the Rzeszówek and Jakuszowa units distinguished by Jerzmański (1965) are to be ascribed to the Bolków and Dobromierz units, respectively. There are no reliable data on the Rzeszówek and Jakuszowa units and hence, the average coefficient of tectonic shortening is extrapolated. The reconstructed units include decollement and shear nappes. Therefore a distance of 2 km is here recognized for a distance of facies transition from one tectonic unit to another.

There is a large variability in coefficient of tectonic shortening among the units (Table 2), which is due mostly to the competency of large amounts of greenschists of the Dobromierz unit as well as to a variation in folding intensity in the Bolków unit. The reconstructions are strongly biased by erosion of the Kaczawa units thrust over the Izera block, East Karkonosze Mts, and Intra-Sudetic synclinorium. This erosion was due to the upthrow of all the three structures along the Intra-Sudetic Main fault and Domanów dislocation, both of them longitudinal relative to the Kaczawa folds.

H. Teisseyre (1963) claims that the overthrusts of the Kaczawa units attain some 10 km in distance. To estimate the horizontal displacement of an overthrust

Table 2

Tectonic shortening in the West-Sudetic Variscan structures

Tectonic structure	Fold-bundle width *Sf*	Tectonic shortening *Sr*	Coefficient of tectonic shortening *Sf/Sr*
Świebodzice structure	8,700 m	13,860 m	0.63
Kaczawa Mts structure:			
Świerzawa unit	2,300 m	4,600 m	0.50
Bolków unit (Pławna section)	12,400 m	32,600 m	0.38
Bolków unit (Wojcieszów section)	15,000 m	25,000 m*	0.60
Dobromierz unit	15,800 m	19,750 m	0.80
Bardo structure	14,000 m	28,000 m	0.50
Kłodzko structure (Silurian sequence)	8,800 m	24,300 m	0.36

* The value used for palinspastic map and sections (Figs 11—12).

unit one has however to add the overthrust distances of all the underlying units. The present palinspastic reconstructions indicate then horizontal displacement of 45 km for the Dobromierz unit, and 25 km for the Bolków unit. It is to be noted that these values refer to the marginal portions of the units, while the range of the nappes over the Intra-Sudetic synclinorium can hardly be recognized.

The Bolków unit includes two distinct structural stages, the lower of which comprises the Radzimowice slates of Proterozoic age (Oberc-Dziedzic & Oberc 1972). As indicated by the palinspastic map (Fig. 11), the Bolków unit displays an Early Cadomide basement. The lack of sialic crust can thus be claimed

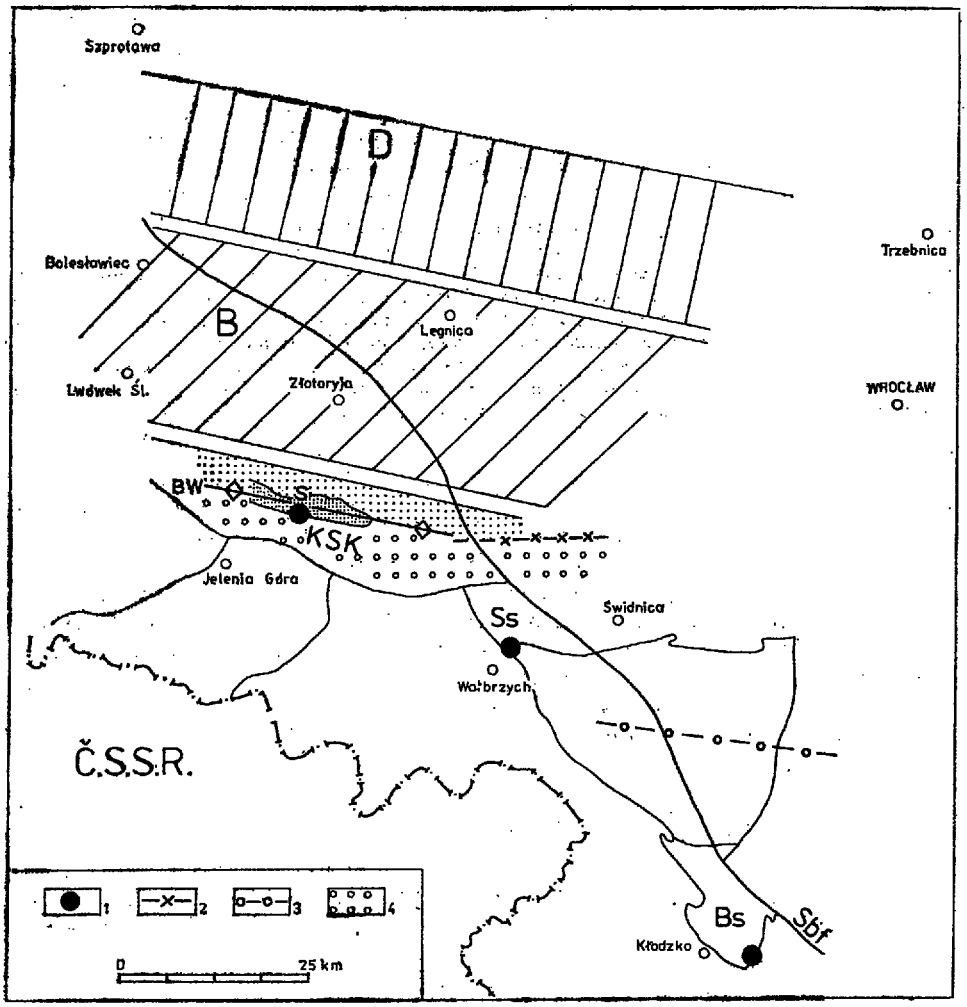
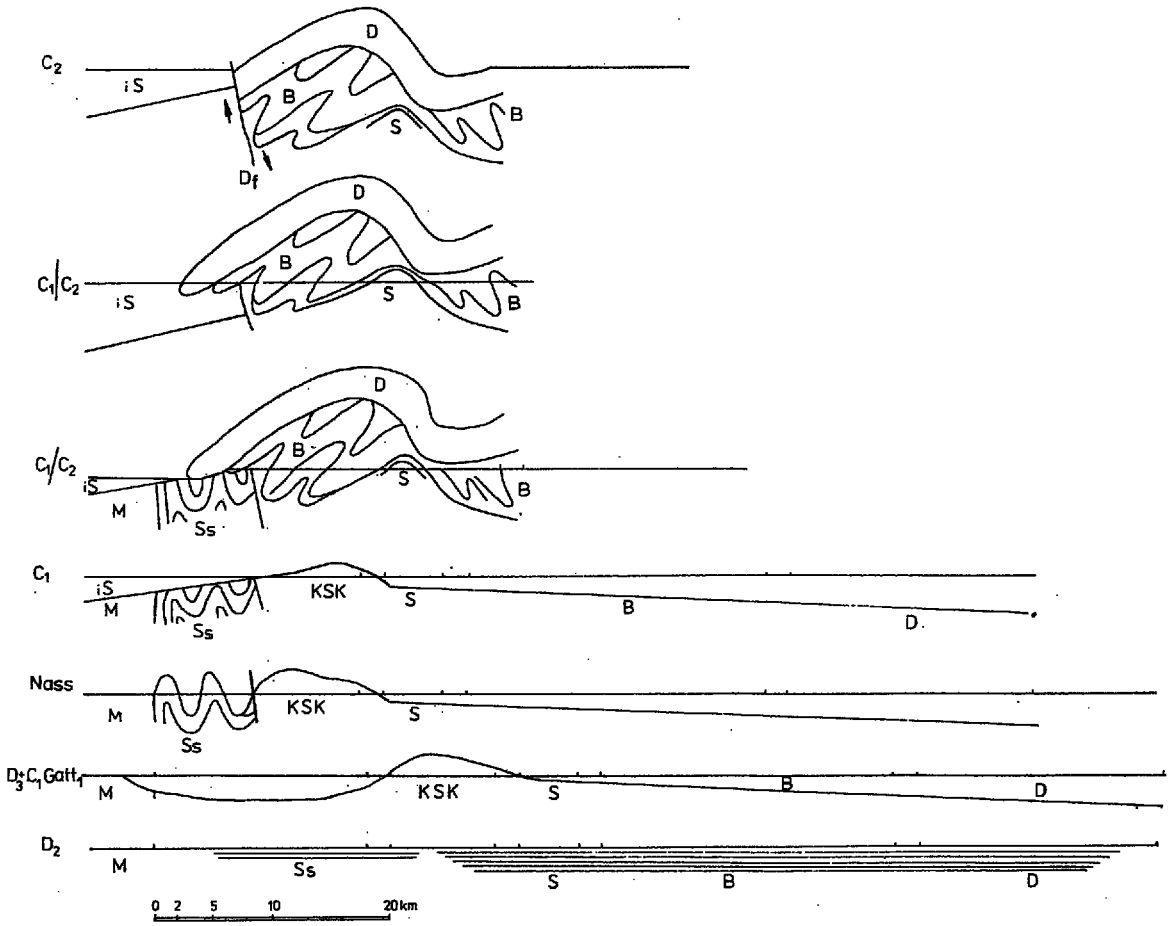


Fig. 11. Palinspastic reconstruction of the Kaczawa, Bardo, and Świebodzice depositional basins (*cf.* Table 2)

1 reference point, *2* northern range of the Świebodzice basin, *3* northern range of the Lower Carboniferous Bardo basin, *4* South-Kaczawa cordillera

S Świerzawa unit, *B* Bolków unit, *D* Dobromierz unit, *BW* Bolków-Wojcieszów anticline, *Ksk* South-Kaczawa cordillera, *Bs* Bardo structure, *Ss* Świebodzice structure, *Sbf* Sudetic Marginal fault



Palinspastic reconstruction of the tectonic development of the Kaczawa Mts and Świebodzice structures; reference points are located at the southern margin of the Świerzawa unit and at the western angle of the Moldanubicum

W Wojcieszów geological section (*after* H. Teisseyre 1963), **E** geological section *E* of H. Teisseyre (1968); **Nass** — Nassau phase, **Gatt** — Gattendorfia Stage

B Bolków unit, **D** Dobromierz unit, **S** Świerzawa unit, **Ss** Świebodzice structure, **iS** Intra-Sudetic synclinorium, **M** Moldanubicum, **KSK** South-Kaczawa cordillera, **Df** Domanów fault

merely for the source area of the Dobromierz unit, which hypothesis is indeed supported by the preponderance of volcanics in the latter unit.

One can hardly consider any tectonic units higher than the Dobromierz unit because the relationships between the south and north Kaczawa Mts appear disputable. Were the greenschists thrust over the Świebodzice unit to be assigned to a nappe higher than the Dobromierz unit, as it is claimed by H. Teisseyre (1956), their minimum horizontal displacement would be some 60 km; Teisseyre's argument seems however to be questionable because the Świebodzice structure is certainly older than the Kaczawa nappes.

BARDO STRUCTURE

In the Bardo structure, there is a tectonic shortening normally to both the Sudetic-phase fold axes and the Asturian-phase ones. The problem of the Asturian folds is out of the scope of the present paper because of considerable difficulties making unreliable any attempt to solve it.

The Bardo structure is so complex that one can hardly trace any single section through all the tectonic units. The most adequate data derive from a joint consideration upon the sections *3* and *7* of Oberc (1957), as the former section ends and the latter starts within the same tectonic zone (eventhough one far away from the other).

The Sudetic-phase folds show a south-southwesterly vergency and hence, the reference point chosen for the palinspastic reconstruction is at the southern edge of the outlier of Podzamecka Kopa built up by Lower Carboniferous deposits embedded within the Kłodzko-Złoty Stok intrusion. One may then conclude that the Bardo basin extended at a distance of at least 14 km over the present-day Owl Mts block (*cf.* Table 2). This would imply that the Owl Mts block was considerably displaced southwards during the Sudetic phase. One may however also suppose that the basement of the Bardo structure was underthrust northwards, which hypothesis implies that only the northernmost fold of the Bardo structure (namely, the thrust slice of Grzepa and Orzech) has actually been thrust over the gneiss block (Oberc 1953).

There are no geological data sufficient to permit a palinspastic reconstruction of the Nassau structural stage of the Bardo structure.

KŁODZKO STRUCTURE

The Kłodzko structure is older and more southwards located than the Nassau stage of the Bardo structure. The available data allow merely to recognize the coefficient of tectonic shortening for the space covered with the Silurian sequence. To this end, the sections *1* and *3* of Oberc (1972) are analysed; only a part of the latter section is considered because the units southwest of the Jaszkowa overthrust may actually lack any Paleozoic strata. When the reference point is placed at the root zone of the Jaszkowa Dln. overthrust, the results of palinspastic reconstruction (Table 2) indicate that the northern boundary of the basin was close to the outcrops of the Szklary serpentinites north of Ząbkowice. These results are however insignificant because the pre-Nassau Bardo basin remains unreconstructed.

STRUGA AND DOMANÓW DISLOCATIONS

The Domanów dislocation (Fig. 2) separates the Kaczawa nappes from the Intra-Sudetic synclinorium and Świebodzice structure (H. Teisseyre 1963). The Kaczawa nappes are cut down by this longitudinal fault which implies that their absence from the area covered by the Intra-Sudetic synclinorium is due to erosion. At the present-day intersection niveau, the synclinorium occurs at the upthrown side of the Domanów fault. In contrast, that side was downthrown during the Tournaisian when the fault started to develop (A. K. Teisseyre 1966), as it is indicated by the detrital influx to the synclinorium from the Kaczawa structure.

Some fragments of the Kaczawa nappes are preserved over the Świebodzice structure which implies that the latter structure is upthrown relative to the Kaczawa structure but downthrown relative to the Intra-Sudetic synclinorium. This is also confirmed by the appearance of the pre-Devonian basement squeezed out from beneath the Świebodzice structure along the Struga dislocation. Again, the Świebodzice structure must have been upthrown relative to the Intra-Sudetic synclinorium during the Tournaisian, as the former supplied considerable amounts of detrital material to the latter (*cf.* H. Teisseyre 1956).

The Świebodzice structure is also downthrown relative to the Owl Mts block along the Szczawienko dislocation (H. Teisseyre *in* Smulikowski & Teisseyre 1953), whereas the block is upthrown relative to the Intra-Sudetic synclinorium along the Struga dislocation of Asturian age (Oberc 1972). Despite the contrasting displacements in the Owl Mts and Świebodzice portions of the Struga dislocation, this is not a pivotal fault. One may rather suppose that the Owl Mts portion of the dislocation maintained its original nature, while the Świebodzice portion remained active later on. The Struga dislocation becomes extinct at the Domanów fault. The westerly vergency of displacement along the Struga dislocation implies that the eastern portion of the Domanów dislocation acted as a horizontal fault (its southern side was moving westwards).

IMPLICATIONS FOR ADJACENT STRUCTURES

The above discussed time attribution of the strata building up the Kaczawa structure and their main folding has much significance for interpretation of the East Karkonosze Mts contacting with the Kaczawa Mts along the Intra-Sudetic Main fault. Thus far, the northern part of the East Karkonosze Mts was regarded as either built up of mezozonally metamorphosed Proterozoic rocks making part of the Cadomide tectogen (Oberc 1960, 1966a); or composed entirely or partly of Lower Paleozoic rocks making a prolongation of the sequences found in the South Karkonosze Mts (Szałamacha & Szałamacha 1967) or Kaczawa Mts (H. Teisseyre 1968a, J. Teisseyre 1971, A. K. Teisseyre 1971). The strata under discussion (along with the Przybkowice unit making part of the Bolków unit; Oberc 1961) decline eastwards and become overlain by the Tournaisian, which indicates that they underwent folding and metamorphism prior to the Tournaisian. In turn, the Upper Visean strata

were folded during the main orogenic phase and underwent epizonal metamorphism in the Kaczawa structure. This demonstrates clearly that there is no reason to claim that there exists any structural relationship between the Kaczawa and East Karkonosze Mts.

The Early Cadomide tectogen was recognized in the West Sudetes mainly after the metamorphic facies (Oberc 1965, 1966a) but also after the orientation of fold axes. Basing upon the latter criterion, some phyllitic complexes were assigned to the Early Cadomide tectogen (namely, the Radzimowice slates, Kąty Wrocławskie phyllites, and a part of Imbramowice metamorphics; Oberc 1972); while in general, phyllites were interpreted as related to the Paleozoic metamorphism. Having now documented the effects of epizonal metamorphism related to the Sudetic phase in the Kaczawa Mts, pebbles of greenschists and phyllites found in Devonian to Lower Carboniferous sedimentary rocks are to be regarded as derived from strata involved in the Early Cadomide tectogen. The latter category includes the Radzimowice slates, and contributes also to the south Kaczawa cordillera, Rudawy Janowickie Mts, and basement of the Intra-Sudetic synclinorium (*cf.* Oberc-Dziedzic & Oberc 1972). The epimetamorphic facies appears then restricted to depressions in the Early Cadomide tectogen. Its occurrence in the basement of large Paleozoic synclinoria points to a persistence of these depressions since the Early Cadomide tectogenesis.

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ROZWÓJ WARYSCYDÓW SUDETÓW ZACHODNICH

(Streszczenie)

W podłożu waryscydów Sudetów Zachodnich znajduje się tektogen kadomski zbudowany ze skał górnego proterozoiku, które w formie trzech wiązek obrzeżają wkomponowany w nie fragment podłoża moldanubskiego, reprezentowanego przez dolnoproterozoiczne gnejsy sowiogórskie (fig. 1). Waryscydy tworzą kilka jednostek (fig. 2), różniących się między sobą wiekiem i charakterem serii skalnych oraz wiekiem fałdowania (fig. 3—10). Geosynklina rozwijała się stopniowo, w związku z czym wulkanizm geosynklinalny i główne fałdowanie mają odmienne pozycje stratygraficzne w rozmaitych jednostkach tektonicznych (tab. 1). Rolę kordyliery grał najpierw blok izerski, potem obszar późniejszej antykliny Bolków-Wojcieszów (dewon górny aż po piętro Gattendorfia), a wreszcie południowozachodnią część struktury bardzkiej (wizen). Deformacje kaledońskie zaznaczyły się jedynie w strukturze kłodzkiej i w południowych Karkonoszach. W fazie nassauskiej sfałdowany został dewon kłodzki, dolne piętro strukturalne struktury bardzkiej i struktura Świebodzic. Podczas fazy sudeckiej rozwinęły się płaszczowiny kaczawskie, fałdy w dolnym karbonie bloku sowiogórskiego i mediotypne deformacje struktury bardzkiej. Otoczaki skał facji zieleńcowej, spotykane w dewonie i dolnym karbonie wzdłuż południowego brzegu struktury kaczawskiej, nie mogą zatem pochodzić z paleozoiku Gór Kaczawskich, lecz z jego proterozoicznego podłoża.

W pracy przedstawiono również rekonstrukcje palinspastyczne południowej części struktury kaczawskiej oraz struktury Świebodzic, bardzkiej i kłodzkiej (tab. 2 oraz fig. 11—12).