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A structural model for the western-central Sudetes: a deformed stack of Variscan thrust sheets

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Abstract: A model based on new structural and geochemical data is presented. It unifies the structural history of the Izera, Rudawy Janowickie and Kaczawa complexes with the Fore Sudetic block, despite their current separation by the Intra-Sudetic and Marginal Sudetic faults.

Above the granitoid Izera, Kowary and Wądroże gneisses, at the base of the structural sequence, the ductile Kowary shear zone marks the basal decollement of the Świerzawa thrust sheet, comprising often highly strained metasediments associated with enriched tholeiitic and alkaline metabasites. Above it, the ductile Kaczorów shear zone, corresponding to the main mylonitic zone within the Leszczyniec shear zone in the Rudawy Janowickie Complex, marks the base of the Dobromierz thrust sheet, characterized by voluminous MORB-like meta-tholeiites and minor metasediments in the higher parts of the Rudawy Janowickie and Kaczawa complexes and the Pyszczyńska Hill area of the Fore-Sudetic Block. In the east the Ślęza ophiolite and the Góry Sowie Block override the entire nappe stack.

Kinematic fabrics in the major and related shear zones indicate D_1 compressional transport towards the northwest, followed by minor D_2 extensional movements. The thrust stack was deformed during D_3 by southwest verging folds, was subsequently intruded by post-orogenic granites, and later disrupted by the Intra-Sudetic, Marginal Sudetic and associated faults.

Keywords: Bohemian Massif, Sudete Mountains, thrust sheets, shear zones.

The Bohemian Massif, exposed in adjacent parts of Poland, the Czech Republic, Austria and Germany, is an important part of the Variscides of Central Europe and comprises major structural zones, which from NW to SE are respectively the Saxothuringian, Teplá-Barrandian, Moldanubian and Moravo-Silesian (Fig. 1). In the NE of the massif are the Sudete Mountains of SW Poland, where the structural zones are disrupted by major NW–SE-trending dislocations that complicate correlations with the rest of the Bohemian Massif. In this area blueschist-facies metamorphic rocks are preserved, thought to be a product of high-*P* metamorphism close to the suture marking closure of the Saxothuringian Seaway (see below). These rocks were thought (Franke 1989; Don & Żelaźniewicz 1990; Franke *et al.* 1993, 1995) to correlate with the Saxothuringian zone farther to the west, although they are separated from the rest of the massif by these dislocations. In particular the Intra-Sudetic Fault (Fig. 2) has caused the most controversy.

Don & Żelaźniewicz (1990) described the Intra-Sudetic Fault as a major pre-Mesozoic feature controlling sedimentation, tectonism and metamorphism in the adjacent geological blocks. Don (1990) suggested that it separates units of different metamorphic facies and structural development, with end-Silurian 'Caledonian' deformation to the south and Devono-Carboniferous 'Variscan' deformation to the north. Oliver *et al.* (1993) proposed that the fault was one of many faults between a collage of suspect terranes in the Sudetes marking a suture zone dividing Baltica from either Gondwana itself or from Gondwanan derivatives, and that while both Caledonian and Variscan structures were present to the south of the Intra-Sudetic Fault, only Variscan structures occur to the north.

In contrast, Cymerman & Piasecki (1994) and Cymerman *et al.* (1997) placed little importance on the Intra-Sudetic Fault and showed terrane boundaries crossing it with only a small displacement. Cymerman *et al.* (1997) recognized seven symmetrically distributed terranes, their boundaries being ductile shear zones or zones of faulting which have experienced ductile shearing at an early stage of their evolution. Their model showed a 'Central Sudetic terrane' formed of basinal/oceanic and ophiolitic rocks at the centre of the Polish Sudetes, structurally overlain by a klippe of granulite-facies gneisses, the 'Góry Sowie terrane', and bordered, respectively to the NW and SE, by sialic 'Saxothuringian' and 'Moldanubian' terranes, both characterized by Palaeozoic plutonism. These are in turn flanked to the NW and SE by the sialic 'Lusatian' and 'Moravian' terranes with end-Precambrian 'Cadomian' granitoids. Their model separated the Central Sudetic terrane from the sialic rocks of the Saxothuringian terrane by the Leszczyniec shear zone in the Rudawy Janowickie Complex and its continuation in the Kaczawa mountains, which they termed the 'Kaczawa line' (Cymerman & Piasecki 1994; Cymerman *et al.* 1997).

Our integrated structural–geochemical–petrological study of the area has combined comparative geochemical studies aimed at extending the geochemical data of Furnes *et al.* (1994) with regional structural analysis in the Kaczawa Complex and selected areas in the Izera and Rudawy Janowickie complexes. Whilst petrochemical details are presented elsewhere (Seston 1999; Floyd *et al.* 2000) and are summarized in Table 1, this paper re-examines the structural relationships between the rocks of the Saxothuringian and Central Sudetic terranes (*sensu* Cymerman & Piasecki 1994) in the light of these new

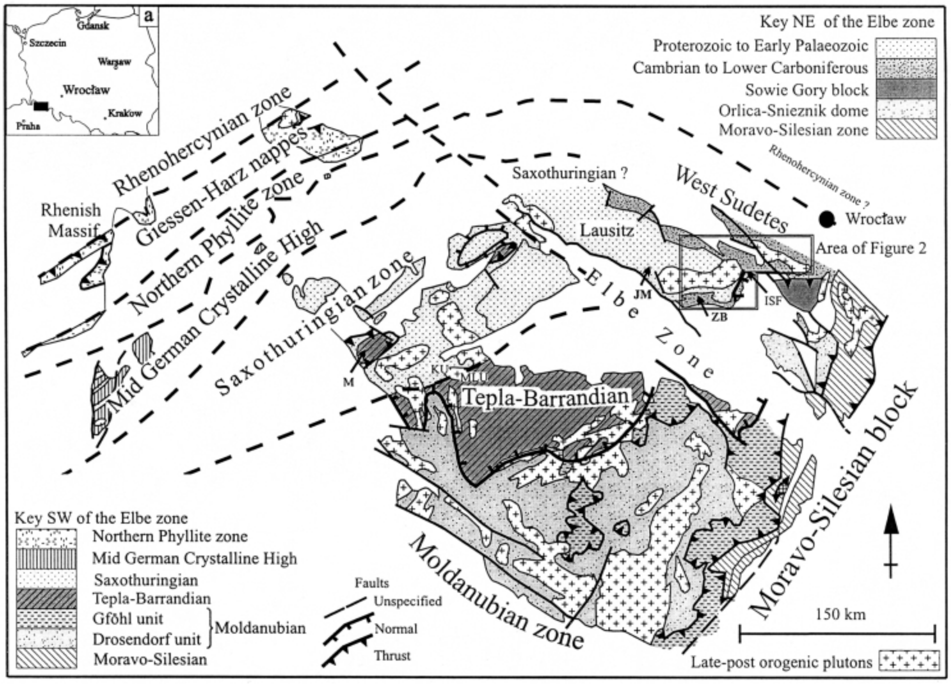

Fig. 1. Sketch map showing the principal structural divisions of the Bohemian Massif and adjacent inliers of Variscan rocks to the NW. Abbreviations: ISF, Intra-Sudetic Fault; JM, Ještěd Mts; KU, Kladská Unit; M, Münchberg Complex; MLC, Mariánské Lažně Complex; SO, Sleža Ophiolite; ZB, Železný Brod. Inset: area location in Poland.

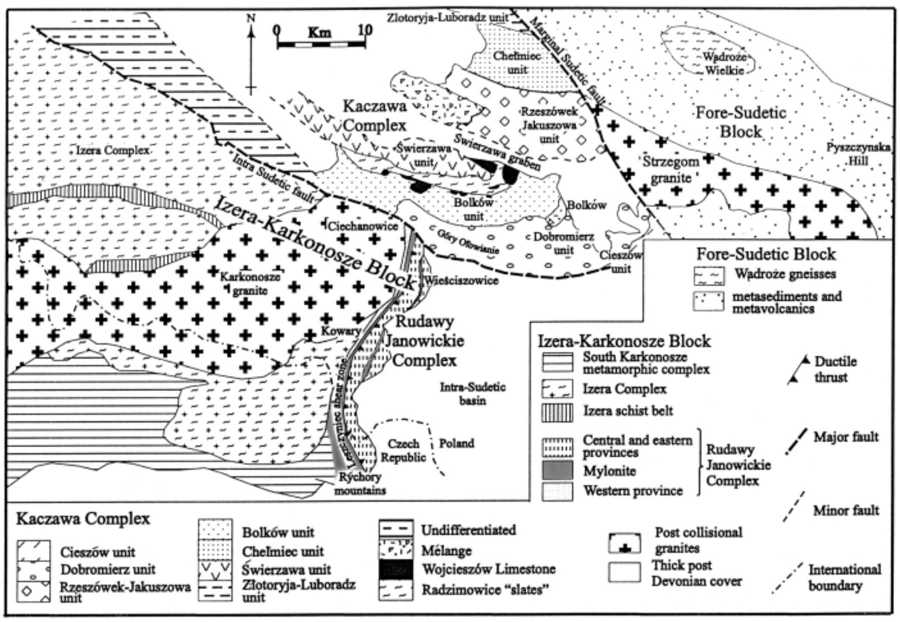

Fig. 2. Currently used structural subdivisions of the Kaczawa and Rudawy Janowickie complexes, the Izera–Karkonosze and Fore-Sudetic blocks. and the Rýchory Mts.

results, and presents a new model to illustrate the structural relationship between the different terranes in the Sudetes of southern Poland. The key elements in the regional structural analysis are as follows.

(1) The identification of ductile shear zones using the criteria for recognizing the fabrics of non-coaxial simple shear (see Passchier & Trouw 1996). This is aided by new criteria for identifying the products of strain-induced metamorphism in shear zones, most notably the formation of swarms of concordant quartz veinlets in mylonites at the time of shearing (Hyslop & Piasecki, 1999).

(2) The identification and use of small-scale, asymmetric, 'kinematic' fabrics, such as deformed porphyroclasts with or without 'tails', and S–C and shear band foliations that can be used to derive the sense of tectonic transport in shear zones (Cymerman 1994; Passchier & Trouw 1996; Barker 1998).

Table 1. *New analytical data obtained by X-ray fluorescence spectrometry (XRF) at Keele University and (REE, Cs, Hf, Ta, U) by inductively coupled plasma–mass spectrometry (ICP–MS) and instrumental neutron activation analysis (INAA) at Activation Laboratories, Canada*

	Kaczawa Complex				Fore-Sudetic Block		Izera Complex						
	Alkali metabasic rock		Enriched tholeiitic metabasic rock		Enriched tholeiite mapped as sediment		Tholeiitic metabasic rock		Tholeiitic metabasic rock	Wądroże gneiss		Izera gneiss	
	Mean	stdev	Mean	stdev	Mean	stdev	Mean	stdev		Mean	stdev	Mean	stdev
SiO_2	46.03	2.69	48.23	2.17	50.39	3.17	46.92	6.05	46.25	76.78	0.75	73.86	2.75
TiO_2	3.74	0.95	2.01	0.45	1.73	0.29	1.59	0.45	1.22	0.20	0.02	0.26	0.07
Al_2O_3	13.77	0.88	15.55	1.36	14.71	2.35	15.35	1.28	17.94	12.75	0.32	13.05	1.79
Fe_2O_3	14.16	2.91	12.08	1.85	14.22	2.02	11.38	2.30	10.13	1.47	0.21	2.77	1.99
MnO	0.17	0.02	0.15	0.03	0.14	0.01	0.17	0.04	0.15	0.02	0.01	0.02	0.01
MgO	6.11	1.31	6.30	1.98	4.02	0.95	7.38	2.35	7.80	0.19	0.06	0.54	0.22
CaO	7.92	0.38	7.19	2.23	5.93	4.06	9.56	3.07	11.82	0.33	0.22	0.58	0.38
Na_2O	3.50	0.82	4.10	1.19	3.89	1.77	2.89	1.05	2.62	3.03	0.22	2.96	1.06
K_2O	0.50	0.22	0.59	0.60	0.70	0.47	0.43	0.67	0.07	5.04	0.17	4.47	1.39
P_2O_5	0.58	0.18	0.31	0.18	0.59	0.32	0.16	0.06	0.09	0.11	0.01	0.12	0.05
S	0.02	0.01	0.01	0.02	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.00
LOI	4.16	1.42	3.75	1.21	3.66	1.20	4.08	1.53	2.82	0.63	0.07	1.22	0.37
Ba	670	749	126	89	203	108	88	134	11	225	78	407	196
Cl	31	20	45	123	28	13	24	30	37	92	21	47	22
Co	33	13	44	12	0	0	54	11	43	0	0	0	0
Cr	86	124	265	156	148	179	344	292	351	24	8	98	217
Cs	21.37	8.55	0.57	0.16	0.00	0.00	0.12	0.08	0.04	0.00	0.00	0.00	0.00
Cu	35	24	42	18	34	18	59	26	51	2	1	14	32
Ga	24	2	20	3	22	3	17	4	20	18	1	18	2
Hf	7.35	2.94	3.08	0.85	0.00	0.00	2.96	1.60	1.36	0.00	0.00	0.00	0.00
Nb	48	19	14	5	21	8	7	3	4	10	1	12	10
Ni	47	39	84	73	43	46	173	148	127	4	1	54	135
Pb	7	4	8	3	8	1	6	6	11	22	3	16	7
Rb	20	9	26	57	21	6	19	36	5	248	12	129	59
Sc	0	0	0	0	0	0	0	0	0	0	0	0	0
Sr	594	284	197	90	195	152	159	111	385	42	4	76	63
Ta	3.25	1.30	0.84	0.23	0.00	0.00	0.98	0.85	0.13	0.00	0.00	0.00	0.00
Th	1.80	1.17	1.71	2.39	5.67	4.03	1.56	3.64	0.00	10.17	1.77	11.33	6.91
U	4.64	1.86	0.94	0.26	0.00	0.00	1.16	0.96	0.20	0.00	0.00	0.00	0.00
V	378	91	286	56	184	31	274	79	213	15	4	53	68
Y	34	8	33	11	49	12	32	7	29	34	3	35	9
Zn	128	26	103	24	133	28	85	19	70	42	11	53	49
Zr	290	80	201	108	404	187	112	23	87	114	6	143	60
La	32.40	17.49	8.04	8.91	25.00	14.31	3.44	5.12	2.00	9.83	1.34	28.67	35.47
Ce	86.20	24.89	34.04	24.47	78.33	33.00	13.25	13.22	20.00	18.50	10.03	79.89	94.37
Pr	13.32	5.33	3.35	0.93	0.00	0.00	3.82	2.33	1.49	0.00	0.00	0.00	0.00
Nd	42.20	9.33	20.88	11.38	38.67	17.61	15.13	5.97	20.00	13.33	2.98	30.89	31.55
Sm	11.54	4.62	3.96	1.11	0.00	0.00	4.39	1.67	2.72	0.00	0.00	0.00	0.00
Eu	3.32	1.33	1.31	0.36	0.00	0.00	1.44	0.40	1.04	0.00	0.00	0.00	0.00
Gd	10.62	4.25	4.26	1.19	0.00	0.00	4.74	1.11	3.63	0.00	0.00	0.00	0.00
Tb	1.55	0.62	0.71	0.20	0.00	0.00	0.77	0.13	0.64	0.00	0.00	0.00	0.00
Dy	8.16	3.26	4.14	1.16	0.00	0.00	4.44	0.45	3.99	0.00	0.00	0.00	0.00
Ho	1.48	0.59	0.82	0.23	0.00	0.00	0.88	0.04	0.84	0.00	0.00	0.00	0.00
Er	3.72	1.49	2.17	0.61	0.00	0.00	2.36	0.00	2.35	0.00	0.00	0.00	0.00
Tm	0.55	0.22	0.35	0.10	0.00	0.00	0.37	0.00	0.37	0.00	0.00	0.00	0.00
Yb	3.13	1.25	2.03	0.57	0.00	0.00	2.09	0.06	2.15	0.00	0.00	0.00	0.00
Lu	0.44	0.18	0.31	0.09	0.00	0.00	0.32	0.02	0.33	0.00	0.00	0.00	0.00

Means and standard deviations are given for metabasic rock types from the Kaczawa Complex, and of granitoid gneisses from the Izera, Kowary and Wądroże gneisses.

Izera Complex

South of the Intra-Sudetic Fault, the Izera and the Rudawy Janowickie complexes form the Izera–Karkonosze Block (Fig. 2), intruded by the post-orogenic Karkonosze granite at 328 ± 12 Ma (Rb–Sr whole rock; Pin *et al.* 1987). Unlike the Kaczawa Complex, in which the earliest deformation is conventionally viewed as Variscan, the Izera–Karkonosze block has traditionally been considered to have a pre-Variscan history, with either Caledonian (Don 1990; Oliver *et al* 1993) or Cadomian deformation (Chaloupský 1988). The Lausitz (Fig. 1) is a northwesterly continuation of the Izera Complex and contains similar rocks, but with a much weaker Variscan overprint. In the Lausitz there is clear evidence of a Cadomian basement with folded and cleaved Neoproterozoic greywackes, intruded by post-tectonic granodiorites. This Cadomian basement is overlain by Tremadocian quartzites and intruded by Cambrian-Ordovician plutons.

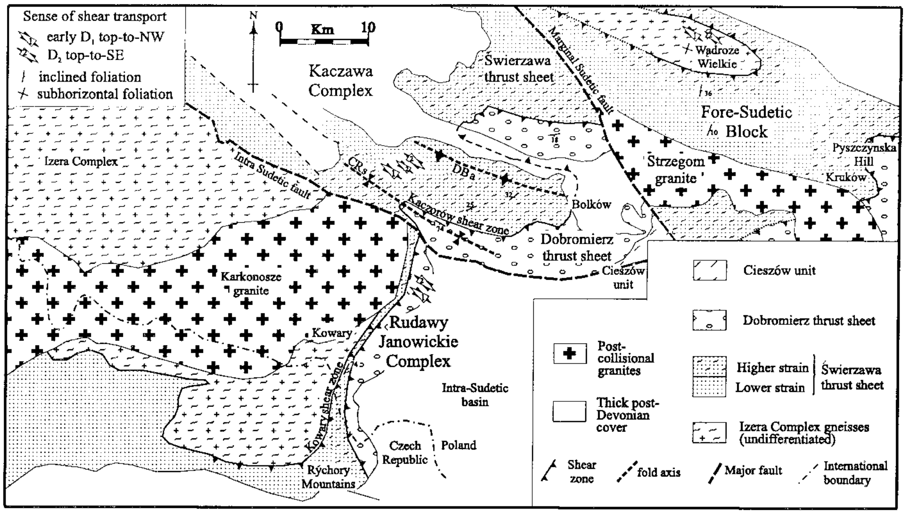

Fig. 3. A simplified geological interpretation of the western-central Sudete mountains, illustrating the major ductile thrust sheets and their bounding shear zones. Abbreviations: CRs, Chrosnica–Radomierz synform; DBa, Dobków–Bolków antiform.

The Izera Complex is dominated by variably-deformed granitoid rocks of Cambrian age (515 ± 8 Ma U–Pb zircon; Kröner *et al.* 1994), but includes several east–west-trending belts of mylonitic schists, metamorphosed in the staurolite–almandine subfacies of the almandine-amphibolite facies at 600°C ± 20°C; P_{H_2O}=6–8 kbar (Żaba 1984). Because the age of metamorphism is not clearly established, these metasedimentary rocks can be interpreted either as a previously metamorphosed (‘Cadomian’) envelope to the granitoid rocks, or as metasedimentary rocks metamorphosed and sheared at the same time as the granitoid rocks.

The granitoid rocks have been traditionally divided into foliated, commonly augen-bearing ‘Izera gneiss’ and relatively undeformed ‘Rumburk granite’, with gradational boundaries between them. The geochemical compositions of the Rumburk granite and Izera gneiss are virtually identical: either the granite crystallized from a total melt from the gneiss or, more probably, the gneiss was derived by deformation of the granite (Borkowska *et al.* 1980). Within the Izera Complex, the zones of sheared Rumburk granite, belts of mylonitic metasedimentary schist within the gneiss and numerous distinct mylonitic shear-zones in the gneiss exhibit kinematic fabrics indicating complex, transpressive ductile shear transport at first towards the west, followed by a reversal of these movements (Cymerman 1994; Aleksandrowski *et al.* 1997). Between these belts of mylonite and ultramylonite, zones ranging up to several hundred metres thick of less sheared, protomylonitic through blastomylonitic to mylonitic gneisses (for the nomenclature see Passchier & Trouw 1996, p.106), contain similar kinematic fabrics, indicating that the shear movements were not confined to the zones of highest shear-strain.

The Kowary gneiss, situated along the western margin of the Rudawy Janowickie Complex and structurally below its western province, is chemically and lithologically identical to the Izera gneiss, from which it is separated by the post-orogenic Karkonosze granite (Fig. 2).

Oliver *et al.* (1993) obtained a U–Pb zircon 493 ± 2 Ma age from the Rumburk granite and a 492–481 Ma age from the Kowary gneiss, as well as a range of ages from 504 to 480 Ma for the Izera gneiss (in which precise dating was not possible using U–Pb on zircon due to loss of lead), and interpreted these ages as indicating Cambro-Ordovician emplacement. This emplacement therefore postdated any Cadomian deformation that may have affected the rocks intruded by the granites. It also implies that the granite may have formed by melting of an older, possibly Cadomian, supracrustal basement sequence, a concept supported by the morphology of zircons in the gneisses and granites which reflect an earlier detrital stage in the protolith history (Klimas-August 1989). No clear ages at present define the age of deformation and metamorphism of the Izera gneiss, and therefore there is no direct evidence that it underwent an earlier ‘Caledonian’ metamorphism.

Kowary shear zone

South of Kowary (Fig. 2), mylonitic Kowary gneiss and adjacent mylonitized metasedimentary rocks mark the tectonic contact between the Kowary gneiss and the structurally lowest part of the overlying Rudawy Janowickie Complex. This tectonic contact is referred to below as the Kowary shear zone (Fig. 3). Mazur (1995) recognized early (D_1) WNW-directed ductile thrusting of the Rudawy Janowickie Complex over the Kowary gneiss, followed by a D_2 event which he interpreted as forming folds with WNW–ESE-trending axes associated with an axial planar cleavage in suitable lithologies and extensional movements with an eastward displacement of the upper tectonic units.

Rudawy Janowickie Complex

Winchester *et al.* (1995) divided the steeply east-dipping rocks of the Rudawy Janowickie Complex into three chemostratigraphic provinces (units), based on the locations of major ductile dislocations and contrasts of the geochemical composition of 117 metabasic rocks from throughout the complex. From west to east, in ascending structural order, these are the western, central and eastern provinces (Fig. 2), in which all of the metabasite compositions are chemically consistent with a magmatic origin in a tectonically extensional setting of an intracratonic rift or a rifted continental margin (Floyd *et al.* 2000). The highest structural levels of the complex are concealed beneath Upper Tournaisian–Lower Visean molasse conglomerates of the Intra-Sudetic Basin (Teisseyre 1973). Most of the complex now exhibits high greenschist- to low amphibolite-facies mineral assemblages; although isolated locations at the southern end of the complex, and its continuation in the Rýchory Mountains (Czech Republic) preserve relicts of an earlier high-*P*, low-*T* blueschist-facies metamorphism (360 Ma $^{40}Ar/^{39}Ar$; Maluski & Patočka 1997), subsequently overprinted by the greenschist- and low amphibolite-facies metamorphism (340 Ma $^{40}Ar/^{39}Ar$; Maluski & Patočka 1997) that largely obliterated evidence of the earlier event (Kryza & Mazur 1995; Smulikowski 1995).

Rudawy Janowickie Complex: western province

The western province, roughly equivalent to Teisseyre's (1971, 1973) Kowary group and some of the Czarnów schist formation, comprises mainly mylonitic metabasites of both alkali basaltic and enriched tholeiitic composition (Winchester *et al.* 1995; Floyd *et al.* 2000), associated with varied metasediments including limestones. Most rocks of this province are highly shear-strained.

Leszczyniec shear zone

In the Rudawy Janowickie Complex, the steeply dipping Leszczyniec shear zone (Fig. 2), interpreted as a suture separating the Saxothuringian terrane from the Central Sudetic terrane (Cymerman & Piasecki 1994; Cymerman *et al.* 1997), includes two major zones of particularly high ductile shear strain within a belt of anastomosing shears up to 4 km wide. We interpret this as the result of the southward convergence of the Kowary and Kaczorów shear zones (Fig. 3) with the result that the rocks of the western province sandwiched between the two shear zones are highly strained. The dominant kinematics in these zones are top to the NW, but in some places these have widely been overprinted by top to the east extensional kinematics, associated with an extensional phase after the initial top to the northwest thrusting and later amplified by the intrusion of the Karkonosze granite.

Central and eastern provinces

East of the Leszczyniec shear zone, the central and eastern provinces of the Rudawy Janowickie Complex are separated by another broad mylonite zone (Winchester *et al.* 1995), the Wieściszowice shear zone, well-exposed in a pyrite quarry near Wieściszowice (Fig. 2). Both provinces contain voluminous tholeiitic metabasites of MORB-like composition (including both metabasaltic lavas and high-level metadoleritic sills) consistent with magmatism in an extensional setting (Winchester *et al.* 1995), subordinate meta-trondhjemites, and rare metasediments.

The central province (Winchester *et al.* 1995) comprises the bulk of the 'Leszczyniec meta-igneous complex' of Kryza & Mazur (1995) and some of the Niedamirów formation. Its meta-trondhjemitic rocks yielded a Cambro-Ordovician U–Pb zircon protolith age of 500 ± 5 Ma (Oliver *et al.* 1993).

The eastern province includes the eastern part of the Leszczyniec meta-igneous complex and the Paczyń gneiss group, comprising both felsic and metagabbroic rocks. A U–Pb zircon age of 494 ± 2 Ma obtained from a metagabbro in the latter rocks (Oliver *et al.* 1993) again indicates their early Ordovician age, despite their high level in the structural sequence of the Rudawy Janowickie Complex. This implies tectonic repetition of the stratigraphy, and argues against Teisseyre's (1971, 1973) belief that the Rudawy Janowickie Complex could be interpreted as a complete stratigraphic sequence. In the eastern parts of the Rudawy Janowickie Complex the rocks are highly faulted with numerous normal faults marking the boundary of the Intra-Sudetic Basin.

Kaczawa Complex

The Kaczawa Complex, situated north of the Intra-Sudetic Fault, and separated into northern and southern parts by the Świerzawa graben (Fig. 2), comprises metabasites of alkali basaltic, enriched tholeiitic and MORB-like tholeiitic compositions, with associated clastic sediments and rarer limestones, interpreted to have been emplaced in an evolving rift basin (Furnes *et al.* 1994). These rocks were affected by greenschist-facies metamorphism overprinting an earlier blueschist facies metamorphism, revealed by locally preserved relicts of a glaucophane–jadeite mineral assemblage (Smulikowski 1990; Kryza & Mazur 1995).

The age of the rocks in the Kaczawa Complex are not well constrained. Suggested ages range from Cambrian (Gunia 1967) to Carboniferous based on poorly constrained fossil and isotopic data (Kozdroj & Skowronek 1999). However, Silurian graptolitic slates, Devonian slates and meta-cherts with a radiolarian and conodont fauna, and Carboniferous limestones are present (Baranowski *et al.* 1990). A meta-trachyte associated with alkaline metabasalts yielded a U–Pb zircon age of 511 ± 39 Ma (Furnes *et al.* 1989), indicating that the age of both basic and felsic magmatism is comparable to that in the Izera and Rudawy Janowickie complexes.

The Kaczawa Complex (Fig. 2) has been divided into seven fault-bounded tectonic units (Jerzmański 1965; Baranowski *et al.* 1990). North of the Świerzawa graben these units are, in structurally rising sequence from north to south, the Złotoryja–Luboradz, Chełmiec and Rzeszówek–Jakuszowa units. South of the graben, the units are, again in ascending order from north to south, respectively the Świerzawa, Bolków, and Dobromierz units, with the Cieszów unit at the top (Baranowski *et al.* 1990). Furnes *et al.* (1994) analysed metabasic rocks over a wide region, and observed that chemically different types of metabasite occur in different structural units of the Kaczawa Complex. Our study confirms that alkali metabasalt dominated volcanic rocks in the west of the area, mainly in the Świerzawa unit, and MORB-like metabasalts in the east, mainly in the Dobromierz unit (Table 1; Fig. 2; Floyd *et al.* 1997, 2000). A similar distribution is seen in the units north of the Świerzawa graben.

Świerzawa thrust sheet

Recent field studies and additional geochemical work (Seston 1999; Floyd *et al.* 2000) indicate that the structurally lower Świerzawa and Złotoryja–Luboradz units and the structurally overlying Bolków and Chełmiec units (Fig. 2) are all comparable in that they contain similar alkaline- and enriched tholeiitic metabasalts in a metasediment-dominated sequence. We therefore allocate all these four units to a single, geochemically consistent structural unit, the *Świerzawa thrust sheet* (Fig. 3). Within this thrust sheet the higher (Bolków and Chełmiec) units and the mylonitic Radzimowice 'slates' (hitherto separated on textural grounds, e.g. Baranowski 1988), contain similar lithologies and differ from their underlying equivalents (Świerzawa and Złotoryja-Luboradz units) only by being more

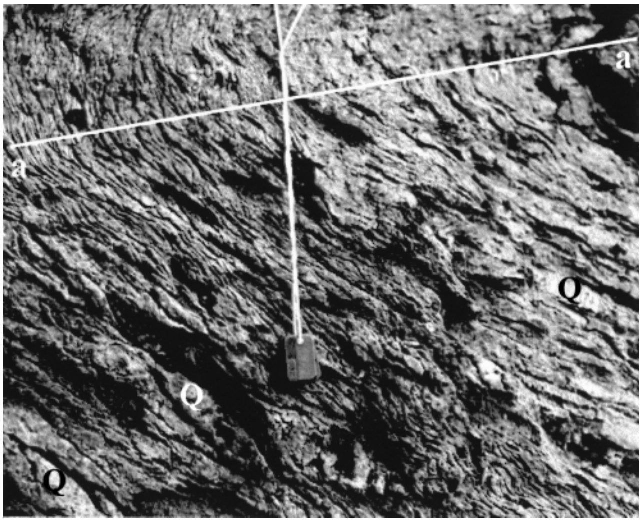

Fig. 4. S1 mylonite fabric in the Kaczorów shear zone defined by long lenticular chloritic units and a swarm of concordant quartz veinlets (Q), folded by an F_3 fold, with the trace of its axial surface (a–a). View is towards the east.

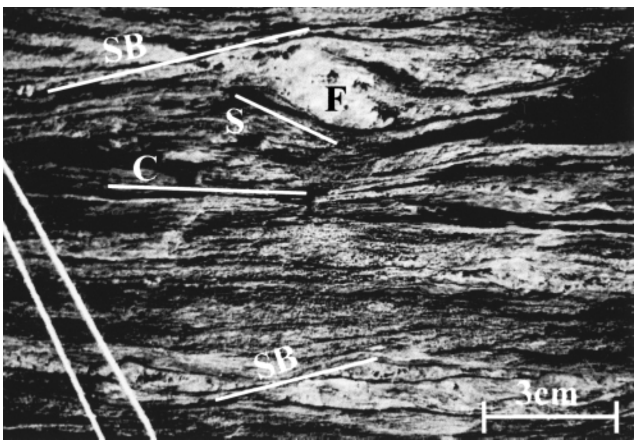

Fig. 5. D_1 fabrics in the Świerzawa thrust sheet, showing penetrative development of mylonitic fabric. SC foliations (S, C), shear bands (SB) and a σ-type feldspar porphyroblast (F) with asymmetric 'tails' (details in Barker 1998), all indicate a sinistral (top-to-NW) sense of shear movement. View is to the NE.

highly shear-strained (Figs. 2 & 3). This Bolków–Chełmiec high strain zone approximates to the 'Kaczawa Line' of Cymerman *et al.* (1997). This zone of enhanced shear-strain is not a simple mylonitic zone, but incorporates lower-strain lenses in between anastomosing zones of higher shear-strain, implying that this upper portion of the Świerzawa thrust sheet may have undergone a degree of imbrication. The relatively low-strain lenses are particularly well displayed by the limestone masses west of Wojcieszów and the pillowed metabasalts on which Bolków Castle stands. Least deformed volcaniclastic and phyllitic rocks commonly display a bedding-parallel foliation, S_1, which is occasionally a pressure-solution cleavage spaced at approximately 10 mm. Approaching a zone of high-shear strain, this pressure-solution cleavage becomes progressively more closely spaced, until it reaches a spacing of *c.* 1 to 2 mm: at which stage it passes imperceptibly into a bedding-parallel mylonitic foliation characterized by swarms of oblate-shaped concordant quartz veinlets (e.g. Figs 4 & 5), or more

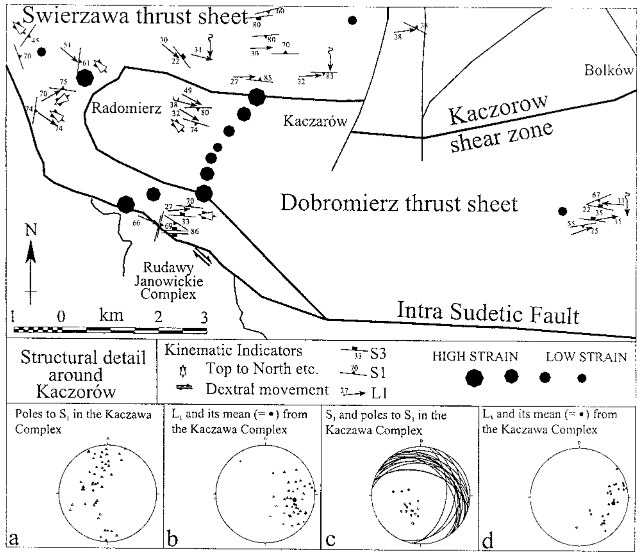

Fig. 6. Structural detail around Kaczorów, including kinematic indicators and relative states of strain. Stereograms illustrating poles to S_1, L_1, S_3 and L_3 and great circles of S_3 are included as insets.

rarely prolate-shaped quartz ribbons, and by asymmetric kinematic fabrics.

The entire thrust sheet is chemically and structurally comparable with the western province of the Rudawy Janowickie Complex, but has a higher proportion of metavolcanic rocks.

Kaczorów shear zone

The degree of shear strain within the Świerzawa thrust sheet progressively increases structurally upwards, ultimately passing into a zone of ultramylonite which characterizes the top of the sheet. This is best exposed in roadside cuttings at Kaczorów and in a small marble quarry NW of Ciechanowice (Figs 2, 3, 6). The ultramylonite zone marks an important major shear zone, which we name the Kaczorów shear zone (Figs 3 & 6). South of the Świerzawa graben this ductile shear zone marks the base of the Dobromierz unit, and north of the graben, the base of the Rzeszówek-Jakuszowa unit (see Figs 2 & 3). In this ultramylonite zone, original lavas and metasediments are reduced to fine-grained rocks, with a pervasive bedding-parallel foliation (S_1) that may easily be mistaken for bedding in metasediments. This mylonite foliation, the significance of which appears not to have been recognized by earlier workers, is accompanied by small intrafolial folds and a mineral lineation, L_1, which plunges gently towards the ESE; a direction broadly concordant with the direction of pillow and vesicle elongation in associated metabasalts. S–C and shear band foliations and asymmetric porphyroblasts mostly indicate a top-to-NW movement (Figs 5 & 6), although they are frequently overprinted by later (S_2), larger and less penetrative S–C and shear band foliations that mostly show a reversal of this motion. The S_1 asymmetric fabrics are interpreted as indicating the main direction of transport in the Kaczorów shear zone, which is similar to that in the Leszczyniec shear zone in the Rudawy Janowickie Complex.

Some of the early Carboniferous mélanges (Borkowska *et al.* 1980; Haydukiewicz 1987; Collins *et al.* 2000) are situated below the Dobromierz and Rzeszówek–Jakuszowa units. They therefore lie within the continuation of the Kaczorów shear zone (Figs 2 & 3) and were produced by Carboniferous high-level reactivation of movement on it.

Dobromierz thrust sheet

Rocks of the Dobromierz structural unit, well exposed in the Góry Ołowiane (Fig. 2), lie directly above the Kaczorów shear zone. The unit comprises dominantly pillowed, MORB-like tholeiitic metabasalts which, some way above the thrust, exhibit relatively low levels of strain (Fig. 3). Together with geochemically similar rocks from the Rzeszówek–Jakuszowa unit in the northern Kaczawa Complex, they comprise the upper structural unit of the complex, named the Dobromierz thrust sheet (Figs 2 & 3). These tholeiites, which share the same metamorphic history as the Świerzawa thrust sheet, are chemically comparable (Table 1) to those in the central and eastern provinces of the Rudawy Janowickie Complex, although isotopic proof of their full age equivalence has yet to be obtained.

Cieszów unit

Basalts assigned to the Cieszów unit (Figs 2 & 3), unlike those in the underlying Dobromierz thrust sheet, are virtually unmetamorphosed and relatively undeformed. Compositionally, they are highly-evolved, locally silicified tholeiitic basalts, with markedly low TiO_2, MgO, Cr and Ni, which distinguishes them from the underlying metabasites (Floyd *et al.* 2000). A reported association of these basalts with conodont-bearing upper Devonian sediments (Kryza pers. comm. 1998) suggests that they represent a brief late Devonian magmatic event in the area, possibly coeval with volcanism in the Münchberg area (Gandl 1981). The Cieszów unit now appears to be tectonically emplaced, as it is structurally underlain by a mylonite zone developed in the top of the Dobromierz thrust sheet, with kinematic fabrics indicating transport towards the south. As the Cieszów basalts appear to be unaffected by the Devonian metamorphism associated with northwest-directed ductile thrusting, it may be surmised that their south-directed tectonic emplacement was associated with late, SSW-verging (D_3) folds in the area, and that they were structurally high enough to be little affected by the greenschist-facies metamorphism associated with this event elsewhere in the Kaczawa Complex.

Structural history of the Kaczawa Complex

Detailed structural analysis reveals three deformation events in the Kaczawa Complex.

D_1, the first deformation event, caused a pervasive bed-parallel foliation, S_1 occasionally a pressure-solution cleavage, which intensifies into a mylonitic schistosity in zones of high shear-strain (Figs 3 & 6), such as the upper parts of the Świerzawa thrust sheet. It is associated with a stretching lineation, L_1, plunging to the southeast, and subsequently dispersed by non-cylindrical F_3 folds to a range of trends from 85° to 180°. Related ductile kinematic fabrics, such as S–C and shear band foliations and asymmetric porphyroblasts with 'tails' (Fig. 5) indicate that D_1 movements were compressional with consecutive upper tectonic units moving towards the northwest (top-to-NW). Much of the shear deformation was taken up by the less competent sedimentary rocks, most of which are now mylonitic.

By contrast the more competent basic rocks acted as low strain augen within the less competent, deforming matrix. Such metabasic low-strain augen exhibit almost perfect pillow structures in their centres. Traced towards the margins of the augen, these pillows become more progressively elongated in the direction of the main stretching lineation, until they can no longer be recognized and the metabasic material becomes mylonite or ultramylonite. Some metabasites, sheared to ultramylonite, were previously interpreted as interbasaltic intercalations of slate of sedimentary origin (Cymerman pers. comm. 1996), but our geochemical analysis (Table 1) has demonstrated that they have a basic composition identical to the recognizable pillows, and hence are sheared metabasite.

D_2 deformation largely took place in a relaxation phase after the main phase of thrusting and produced a new generation of S–C and shear band foliations within the main mylonitic fabric, indicating that this foliation became a composite of S_1 and S_2. The D_2 kinematic fabrics, which are non-pervasive and only seen in the mesoscopic scale, indicate top-to-SE movement and are less penetrative and commonly larger in size than the D_1 kinematic fabrics. Locally they modify the latter, re-orientating some of them from their original top-to-NW attitude, into a new top-to-the-SE attitude. Thus, the D_2 movements took the form of extensional reactivation of the earlier surfaces of shear. Locally, the top-to-the-SE fabrics are accompanied by weak shear bands showing top-to-NW motion, indicating a substantial component of flattening (pure shear) during the D_2 event.

D_3 deformation resulted in major and minor F_3 folds, that provide some of the most spectacular structures seen in the Kaczawa Complex, folding the earlier-established mylonitic fabrics, D_1 (Figs 3, 4 & 6) and D_2 structures. The F_3 folds are gently inclined, open, asymmetric structures, which trend WNW–ESE and verge towards the SW. Their axial planes have an average trend of 307° and dip at 32° towards the northeast. A north-eastward-dipping axial-planar crenulation cleavage, S_3 (Fig. 4) is best seen in the southern part of the complex, between the two major F_3 folds, the Dobków–Bolków antiform and the Chrosnica–Radomierz synform (Fig. 6). Minor F_3 folds abound as crenulations on steep, south-dipping limbs of larger F_3 folds, but are scarce on the gently-dipping, North-facing limbs. L_3, lineations are all crenulation lineations, plunging SE at approximately 26°. F_3 folds in the vicinity of the Intra-Sudetic Fault are drawn into parallelism with it, indicating that the main movement on the Intra-Sudetic Fault was later, although some of the earlier ductile movement on the fault may have been syn-D_3.

The structural history of the Kaczawa Complex can be summarized in terms of an earliest, D_1, compression directed towards the NW, resulting in the superimposition (stacking) upon the Izera gneiss parautochthon of the following thrust sheets (Figs 7, 8a–c & 9):

(1) the Świerzawa thrust sheet of alkaline and peralkaline metabasic rocks associated with more abundant clastic sediments and limestones, along the Kowary shear zone onto the parautochthon of the Izera–Kowary–Wądroże gneisses (Figs 7 & 8a & b);
(2) the Dobromierz thrust sheet, consisting mainly of tholeiitic MORB-like metabasites, with minor associated deep water sediments along the Kaczorów shear zone, over the Świerzawa thrust sheet (Figs 7 & 8a & b).

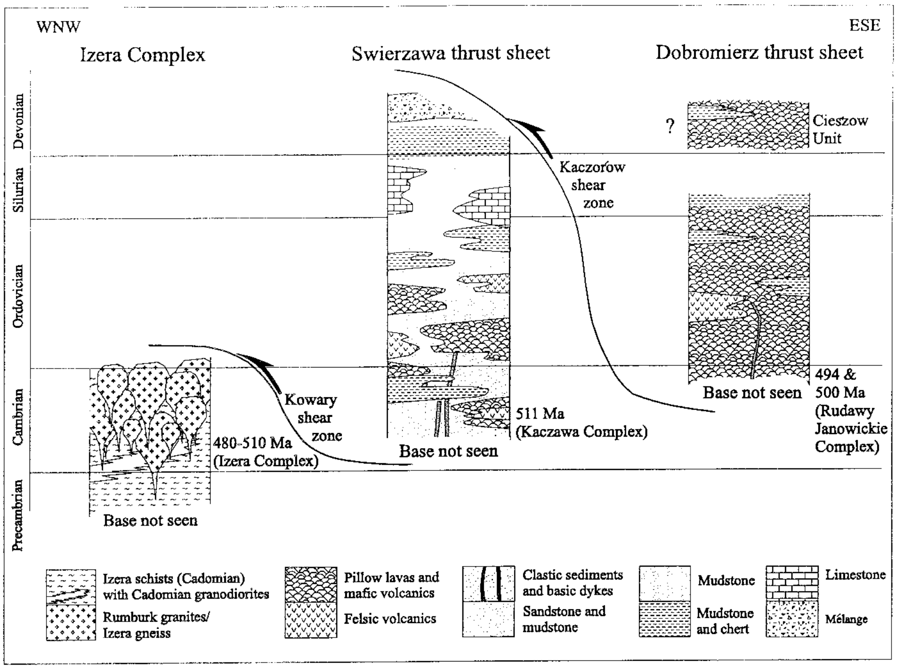

Fig. 7. Schematic stratigraphic sections of the principal thrust sheets in the western-central Sudete Mountains, Poland.

This compressional event was followed by a D_2 'relaxation' phase, marked by mainly southeast-directed, extensional movements, indicating some pure shear. The last penetrative regional deformation, D_3, was marked by gently inclined, asymmetric folding, which may be associated with a southwest-directed compressional event (Fig. 8c).

Our interpretation of the structural relationship between the units of the Kaczawa Complex is supported by borehole data (Kryza pers. comm. 1997) which shows that a series of low-strain metasediments with peralkaline mafic sills very similar to those found in the Świerzawa and Złotoryja–Luboradz units, underlies the Chełmiec unit.

The Kaczawa Complex is crossed by numerous brittle faults, in addition to those that bound it (Figs 2, 4 & 8d). Most were generated in the Carboniferous or later periods (Cymerman pers. comm. 1997), and some were reactivated during the Tertiary giving rise to the present elevation of the Kaczawa Mountains (Baranowski *et al.* 1990) as part of a regional-scale deformation of the entire Bohemian Massif in response to Alpine movements.

Fore-Sudetic block

The Fore-Sudetic block (Figs 2, 3 & 8d), situated NE of the Kaczawa mountains and separated from them by the Marginal Sudetic Fault, is considered by most workers, on lithological and metamorphic grounds, to be a continuation of the Kaczawa Complex. Owing to Tertiary dip-slip movement on the Marginal Sudetic Fault, thin Mesozoic and Tertiary cover is widely preserved throughout the Fore-Sudetic block. It obscures the underlying Palaeozoic rocks, which are revealed in poorly exposed, isolated inliers in the southern and western parts of the area, and elsewhere in borehole cores. The lack of good exposure makes detailed structural assessment almost impossible, but a broad structural overview can be obtained by combining chemical correlation with observed locations of zones of high ductile shear-strain. Fore-Sudetic block metasediments all show similar bed-parallel foliation to that in the Kaczawa Complex. The foliation is subhorizontal to gently dipping, with the average plunge of the L_1 lineation being 7° to the SE. The shallower dips reflect less intense F_3 folding, which, in the Fore-Sudetic block, is characterized by open folds with only local development of associated S_3 crenulation cleavage in metasedimentary rocks.

Within the Fore-Sudetic block, three principal structural units may be recognized, in ascending structural sequence. These are: (1) the Wądroże gneiss; (2) phyllonitic schists with scarce alkali basaltic greenschists; (3) the MORB-like tholeiitic schists of Pyszczyńska Hill (Figs 2 & 3). Major mylonitic zones separate each of these units and kinematics within each of these zones show a top to the NW movement.

Wądroże gneiss

Best exposed in a disused quarry in Wądroże Wielkie village in an open antiformal structure (Fig. 2), the protolith of the Wądroże gneiss is a porphyritic granitoid, variably deformed to a subhorizontally foliated augen-gneiss, locally containing concordant bands of ultramylonite up to 20 cm thick derived from the augen gneiss. The stretching lineation in the augen-gneiss and the ultramylonites plunges towards the NW or SE at low angles, and asymmetric kinematic fabrics (rotated porphyroclasts and S–C and shear band foliations) indicate tectonic transport directed towards the northwest (top-to-NW). The Wądroże gneiss, exhibiting highest greenschist-facies/lowest amphibolite-facies metamorphism (Cymerman pers. comm. 1996), is lithologically and geochemically identical to the granitoids and granitoid gneisses of the Izera Complex (Table 1), and both share a broadly similar kinematic geometry. Adjacent to, and structurally overlying the Wądroże gneiss, metasedimentary rocks of the Fore-Sudetic block are highly strained, marking the *Wądroże shear zone*, with kinematic indicators showing that they were transported towards the WNW.

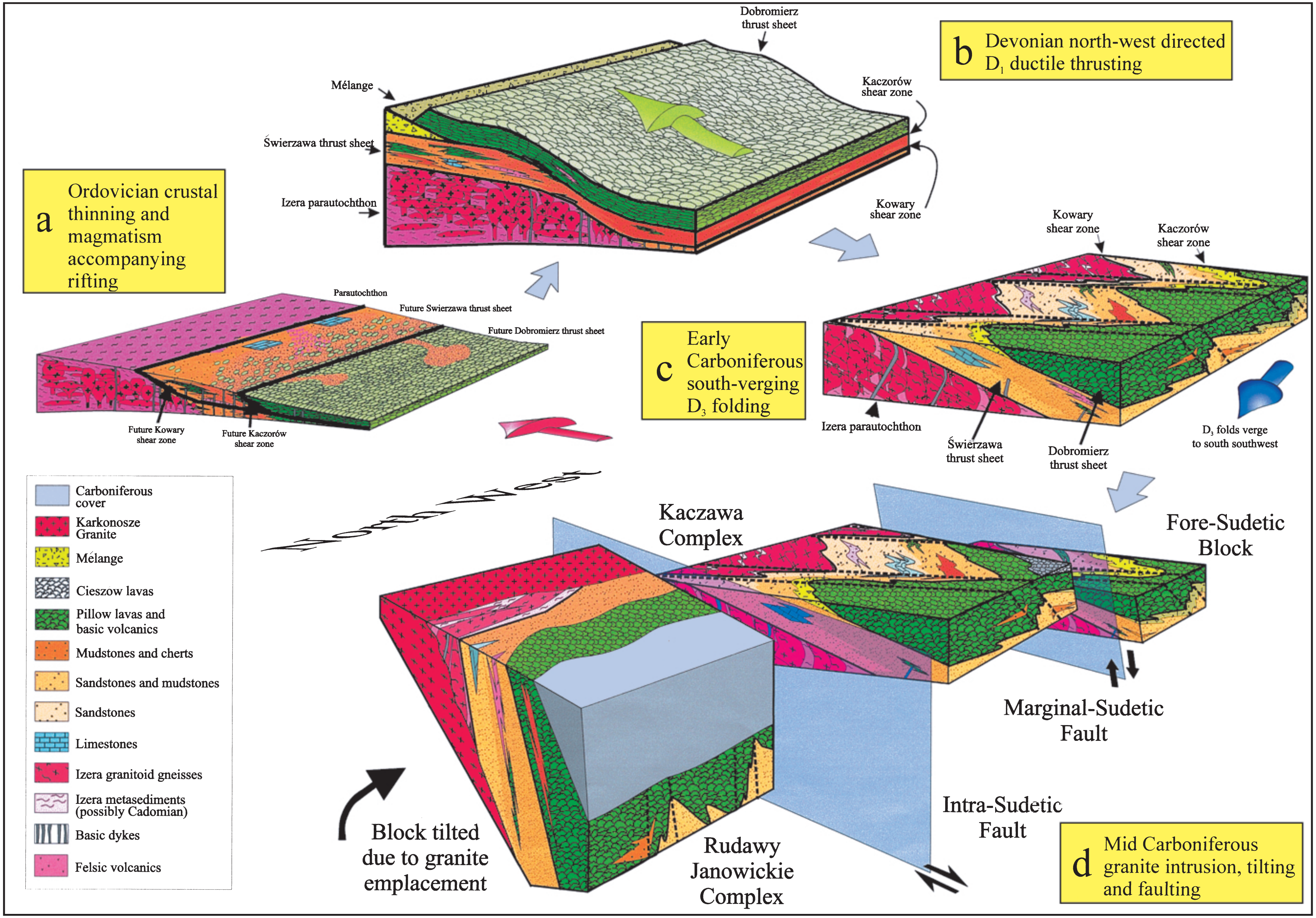

Fig. 8. Block diagrams illustrating major stages in the development of the Izera, Kaczawa and Rudawy Janowickie complexes and the Fore Sudetic Block: (**a**) volcanism associated with extension, *c.* 480 Ma; (**b**) NW-directed D_1 ductile thrusting initiating the Kaczorów and Kowary shear zones associated with early metamorphism, *c.* 360 Ma; (**c**) southward verging F_3 folding, *c.* 340 Ma; (**d**) post-metamorphic forceful intrusion of the Karkonosze granite (*c.* 328 Ma), steepening the Rudawy Janowickie Complex, and coeval formation of the Intra Sudetic and Marginal Sudetic faults.

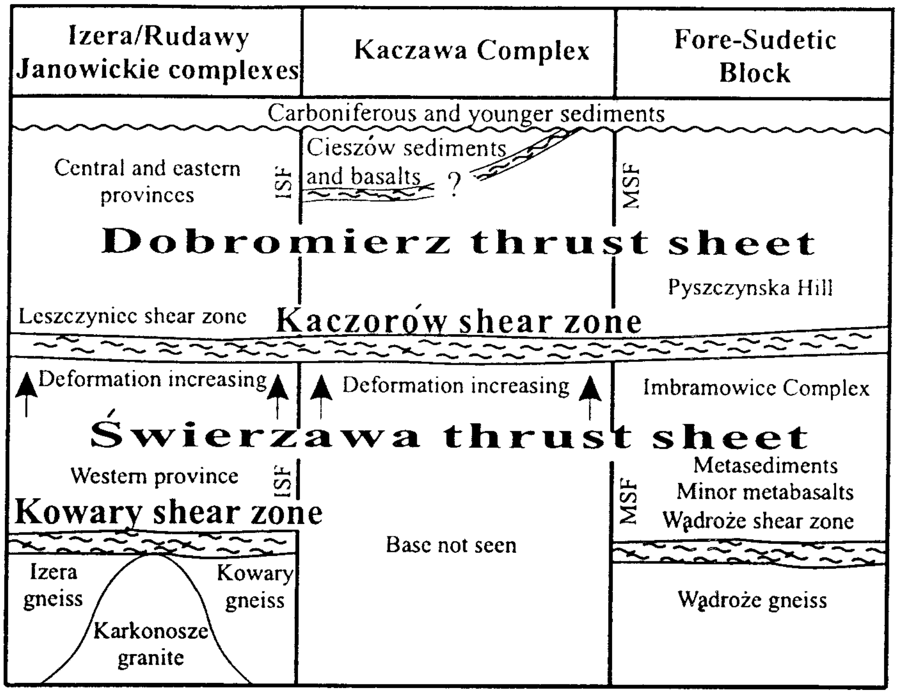

Fig. 9. Schematic extent of the thrust sheets and their bounding ductile shear zones throughout the metamorphic complexes of the western-central Sudetes of Poland. Abbreviations; ISF, Intra-Sudetic Fault; MSF, Marginal Sudetic Fault.

Fore-Sudetic block metasedimentary and metavolcanic rocks

These widely distributed, but poorly exposed rocks crop out on both sides of the post-orogenic Strzegom granite, where they are dominated by grey phyllites. In samples recovered from borehole sections, grey phyllites are associated with chloritic schists of metabasaltic origin which tend to have an alkali-basaltic composition.

Pyszczyńska Hill metabasalts

Best exposed on Pyszczyńska Hill (Figs 2 & 3), these metabasalts consist of highly-strained pillow-lavas, of MORB-like tholeiitic composition (Table 1), within foliated high greenschist-facies actinolite–chlorite–epidote schists. They structurally overlie amphibolites of enriched tholeiitic composition and serpentinitic rocks of the Imbramowice metamorphic complex (Majerowicz & Mierzejewski 1995) which are in turn separated from the structurally underlying metasedimentary phyllites by a broad mylonitic zone exposed in quarries south of Kruków village (Fig. 3).

Summary of correlations

On the basis of integrated studies of comparative lithologies, geochemical signatures, structural and kinematic histories in combination with the identification of ductile shear zones in the rocks of the Rudawy Janowickie, Izera, Kaczawa and the Fore-Sudetic complexes, we recognize regions of parautochthonous rocks, and we equate numerous spatially separated rock units and numerous ductile shear zones into two major, regional-scale thrust sheets, separated by two zones of major, regional-scale ductile shear (Figs 3, 7, 8 & 9). All these rocks appear to have been formerly connected but subsequently the various aforementioned complexes have experienced subtly differing metamorphic histories, and were also separated by the major Intra-Sudetic and Marginal Sudetic faults.

Our model proposes the following links (Figs 3, 7, 8 & 9).

(1) The Kowary gneiss in the Rudawy Janowickie mountains, the Izera Complex, and the Wądroże gneiss, all form a probably parautochthonous floor to the structurally higher complexes of the Rudawy Janowickie, Kaczawa and the Fore-Sudetic block.

(2) The Kowary shear zone, developed along the structural top of the Kowary gneiss, and the Wądroże shear zone along the top of the Wądroże gneiss, are interpreted as the basal zone of ductile decollement below the Rudawy Janowickie, Kaczawa and the Fore-Sudetic complexes. Because this zone is best exposed near Kowary, we propose for it the term *Kowary shear zone*.

(3) Resting on the decollement surface of this Kowary shear zone, we identify a major thrust sheet, the *Świerzawa thrust sheet*. The name Świerzawa has been retained for this thrust sheet, (despite convention which might require it to be named the Kowary thrust sheet) because it has been most closely associated with the rocks named thus in previous papers. It embraces the following tectonostratigraphic units: the western province of the Rudawy Janowickie Complex, the Świerzawa, Bolków, Złotoryja–Luboradz, and Chełmiec units in the Kaczawa Complex; and the metasediments resting tectonically on the Wądroże gneiss in the Fore-Sudetic block (Figs 2, 3, 8 & 9). We view these as disrupted parts of a single large thrust sheet, comprising a thick, mainly clastic metasedimentary sequence with subordinate alkali basaltic, enriched tholeiitic and felsic volcanic rocks (Fig. 8). Lateral variations within this extensive sheet include the abundance of volcanic rocks in the Kaczawa Complex and their relative scarcity in the Fore-Sudetic block.

(4) We equate part of the Leszczyniec shear zone, which marks the top of the western province in the Rudawy Janowickie Complex, with the Kaczorów shear zone, which

marks the basal zone of decollement for the structurally higher Dobromierz thrust sheet in the Kaczawa Complex. Although the Leszczyniec shear zone was recognized first in the Rudawy Janowickie Complex (Cymerman & Piasecki 1994; Winchester *et al*. 1995; Cymerman *et al*. 1997), it is a very broad shear zone which is in places continuous with the Kowary shear zone, so, to avoid confusion between these structures, and because it is so well exposed at Kaczorów, we propose the term *Kaczorów shear zone* for this major boundary.

(5) The Kaczorów shear zone marks the base of the upper tectonic sheet, for which we suggest the term *Dobromierz thrust sheet*. As with the Świerzawa thrust sheet, the name Dobromierz has been retained, because it has commonly been used for these rocks in previous literature. This thrust sheet is dominated by MORB-like mainly pillowed meta-tholeiites (Fig. 7); it is represented by the central and eastern provinces of the Rudawy Janowickie Complex, the Dobromierz and Rzeszówek–Jakuszowa units in the Kaczawa Complex and the meta-tholeiites of Pyszczyńska Hill in the Fore-Sudetic block.

The presence of Cambro-Ordovician volcanic rocks in this upper thrust sheet overlying the Silurian Wojcieszów limestones in the Świerzawa thrust sheet argues for structural repetition of the local stratigraphy (Fig. 7).

Both major thrust sheets appear to contain internal zones of imbrication, indicated by the presence of numerous broad zones in which belts of high shear-strain anastomose between augen-shaped lower-strained units of all sizes. Such are, for example, the structurally higher levels of the Świerzawa thrust sheet; and many parts of the Rudawy Janowickie Complex, particularly the rocks of its western province and those adjacent to the Wieściesowice mylonite zone, which separates the central and eastern provinces.

Discussion

Tectonostratigraphic interpretations and timing of events

The emplacement of the Rumburk granite in the Izera Complex at *c*. 493 ± 2 Ma, is broadly contemporary with magma generation at 505 ± 5 Ma and 494 ± 2 Ma (U–Pb zircon) from felsic and metabasite components of the Leszczyniec meta-igneous complex in the Rudawy Janowickie Complex (Oliver *et al*. 1993) and with the times of emplacement of trachyte in the Świerzawa thrust sheet in the Kaczawa Complex (511 ± 39 Ma). This suggests that the rocks in all these complexes are broadly contemporaneous, and makes it unlikely that the Izera Complex acted as the original basement to the structurally higher rocks of the Rudawy Janowickie and the Kaczawa complexes.

Furthermore, the continuity across the Intra Sudetic Fault of the Świerzawa and Dobromierz thrust sheets and of their bounding shear zones (Figs 4, 8d & 9), is incompatible with the Intra-Sudetic Fault being a terrane boundary.

$^{40}Ar/^{39}Ar$ dating of phengites from blueschist-facies metabasites overprinted by greenschist-facies metamorphism in the Rýchory mountains, a lithological continuation of the Rudawy Janowickie Complex south of the Polish–Czech border (Figs 2 & 3), yielded ages of 360 Ma and 340 Ma, interpreted respectively as the end of the blueschist-facies metamorphic event and the succeeding greenschist facies overprint (Maluski & Patočka 1997).

In the Kaczawa Complex, in which relics of an early blueschist-facies metamorphism overprinted by a regional greenschist-facies event are widely recognized (Smulikowski 1990; Kryza *et al*. 1990) the relict blueschist mineral assemblages are intimately associated with the S_1 bed-parallel cleavage. If broadly coeval with the similar metamorphism in the Rýchory mountains, this early metamorphism occurred around 360 Ma, which sets a possible maximum age for the formation of the major thrust sheets. The greenschist overprint appears to be coeval with D_3, and, if contemporary with that in the Rýchory mountains, occurred around 340 Ma.

Apparent differences between interpretation of the structural evolution of the Rudawy Janowickie Complex and that of the Kaczawa Complex can be resolved, as the effect of regional tilting of rocks attributable to the intrusion of the Karkonosze granite at *c*. 328 ± 12 Ma (Pin *et al*. 1987) is not seen in the Kaczawa Complex (left and centre of Fig. 8d). Thus in the Rudawy Janowickie Complex, Mazur's (1995) D_2 folding event is equivalent to D_3 folding within the Kaczawa Complex, and a 'D_3'event recorded by Mazur (1995, pers. comm. 1998) postdating the emplacement of the Karkonosze granite, and folding the entire Rudawy Janowickie Complex as well as the Carboniferous molasse-conglomerate into a regional monocline, is therefore younger than the D_3 deformation we recognize in the Kaczawa Complex.

The presence of major dislocations, such as the Kaczorów shear zone, casts doubt on previous stratigraphic reconstructions, in which correlation ignored ductile faults. The thrust sheets above and below the Kaczorów shear zone probably both contain a stratigraphic range similar to that suggested by Furnes *et al*. (1994), with most of the volcanic rocks predating metasediments of Siluro-Devonian age (Figs 7 & 8). However, deformation and metamorphism may have rendered some biostratigraphic data unreliable in this region: for example Baronowski *et al*. (1990) commented that the evidence for the existence of the Silurian rocks in the Kaczawa Complex was based on 'conodonts of poor stratigraphic value'. Since then, however, recent microfossil discoveries in the Wojcieszow limestones indicate a Silurian age (Kozdroj & Skowronek 1999), despite their position near the structural base of the exposed rocks in the Kaczawa Complex.

Regional comparisons

Cambro-Ordovician rocks, similar in composition to those in the Kaczawa and Rudawy Janowickie complexes, are recorded from the Czech side of the Karkonosze granite in the Železný Brod area and the Ještěd Mts (Fig. 1). Further west, alkali basaltic metabasites from the Kladská unit, compositionally similar to those in the Świerzawa thrust sheet, are overthrust by the high-grade rocks with MORB-like tholeiitic compositions from the Mariánské Lažně Complex (Kachlík pers. comm. 1998). Still further west, some of the thrust sheets forming part of the Münchberg Complex in Germany, also contain Cambro-Ordovician rocks chemically similar to those in the western-central Sudetes. Other similarities with the Münchberg Complex include in the latter the presence of early Ordovician MORB-like mafic rocks, emplaced high in the nappe edifice, subjected to Devonian high-P metamorphism (Franke & Żelaźniewicz 2000; Franke *et al*. 1993).

While it is difficult to demonstrate that all these rocks, spread over such a large area, belonged to the same two thrust sheets, it does suggest that the tectonic movements of which those in the western-central Sudetes form a part, were of regional rather than local importance. In the Fore-Sudetic block itself, lack of exposure precludes clear establishment of the relationship between the thrust sheet containing the Pyszczyńska Hill metabasites and the nearby Ślęża Ophiolite. Local structural geometry suggests that the former could have been tectonically overthrust by the latter, which we speculate could be an even higher thrust sheet in the structural sequence. The presence of these thrust sheets in this area may have originally provided the additional loading needed to explain the higher metamorphic grade of the Izera Complex compared to the Lausitz area further west (Franke & Żelaźniewicz 2000).

Geotectonic significance

Persistent evidence of compression directed towards the NW to WNW from both the Kowary and the Kaczorów shear zones and within internal zones of high shear-strain in the Świerzawa and Dobromierz thrust sheets is inconsistent with a model for the collision of Gondwana-derived Variscide blocks with the margin of the East European Craton to the northeast. Instead, it suggests that the accretion of Variscide Europe to the East European Craton was a complex process which began with the amalgamation of various independently moving blocks. The age of the HP–LT metamorphism in the area shows that closure of the Saxothuringian Seaway, now represented by the ophiolitic material in the Central Sudetes of Poland and the Mariánské Lázně complex of the Czech Republic (Kastl & Tonika 1984), predated collision of the Bohemian Massif with the Moravo-Silesian Block (Fig. 1) and the Avalonian microcontinent, both of which had already docked with the East European Craton. Only when NE–SW compression initiated the later F_3 folding, well-displayed in the Kaczawa Complex, is there indication of oblique convergence between the now-amalgamated Bohemian Massif along its eastern and northern margins with the blocks already accreted to the East European Craton. Renewed compression reactivated existing ductile thrusts, deforming originally sedimentary mélanges (Collins *et al*. 2000) and initiated further, largely post-metamorphic thrusting such as the emplacement of the low-grade Ślęża Ophiolite and high-grade gneisses of the Góry Sowie Block at the top of the nappe pile. Final docking was marked by the development of major northwest-southeast trending dextral strike-slip faults.

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